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RESEARCH ARTICLE

Moisture-Dependent Properties of Unshelled *Moringa oleifera* Seed

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ABSTRACT

This study was carried out to determine selected physical properties of *Moringa oleifera* seed for post-harvest equipment design. Four levels of moisture contents ranging from 10.250-32.343% dry basis were used in the study. The properties studied were: major (length), intermediate (width) and minor (thickness) dimensions, arithmetic, geometric and equivalent sphere diameters, surface area, sphericity, unit volume, unit mass, aspect ratio, true and bulk densities, porosity, dynamic angle of repose, angle of internal friction, angle of friction, coefficient of static friction, 1000 grain mass and initial moisture content. The effect of moisture content on the properties of unshelled *Moringa oleifera* seed was investigated and the mean values of the physical properties of the seeds were determined as length ranged from 11.964-12.813mm, width from 9.983-10.803mm, thickness 9.421-10.226mm, arithmetic mean diameter of 10.456-11.280mm, geometric mean diameter of 10.388-11.210 mm, equivalent mean diameter of 10.392-11.217 mm, sphericity of 0.872-0.880, aspect ratio of 84.013-84.987%, thousand grain mass 273.95-329.20g, bulk density 0.247-0.279 g/cm^3, particle density 0.594-0.658 g/cm^3, porosity 58.271-7.503%, surface area 342.528-397.397 mm^2, unit volume 604.734- 697.673 mm^3. The angle of internal friction measured on plywood was 42.374°-52.619°, mild steel 36.630°-48.514°, glass 33.619°-41.878°; angle of repose measured 17.643°-23.500°, coefficient of friction as measured on plywood was 0.570-0.749, mild steel 0.480-0.674, glass 0.436-0.562. Both linear and quadratic regression equations established had very high coefficients of determination (R^2>0.9), which indicates that they described the relationships reasonably. The coefficient of static friction of seed was higher on plywood surface and lowest on glass. This information will provide engineers and designers the relevant data for efficient process handling and equipment design.

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INTRODUCTION

Moringa oleifera (synonymously called *M. pterygosperma*) which belongs to the family Moringaceae and has fourteen species (Morton, 1991) is widespread throughout the tropics. It is a small graceful tree with sparse foliage, white flowers and long pods, widely cultivated in farms and compounds (mostly as fence) especially in the Northern part of Nigeria and many countries in tropical Africa (Anjorin *et al*., 2010). In Nigeria, the plant is popularly known as the “miracle tree” or “tree of life” and it is identified by various names, such as Drumstick tree or Horseradish plant in English, Zogale in Hausa, ‘Okwe oyibo’ or ‘Okwulu oyibo’ in Igbo, Ewe Ile in Yoruba and Gawara in Fulani. Although the tree is regarded as a local plant in Nigeria, it is in fact native to Arabia and India but widely distributed in Old World tropics, common in northern regions and cultivated in India in ancient times. In Nigeria, *Moringa* trees are distributed both in the South and North where it features as a multipurpose tree providing items of food, medicine, household water treatment, among other uses such as revenue generation through products formulation (Ozumba, 1996; Okafor, 2008). The tree is regarded as a miracle and life-saving resource with enormous nutritional and medicinal benefits readily providing the needs of local populace. Its choice as a national crop, worthy of intensive and widespread development, in order to enhance the realization of socio economic growth and development in Nigeria is therefore most timely.

Mature seeds yield 38-40% edible oil called ben oil from its high concentration of behenic acid. The refined oil is clear, odourless and resists rancidity. The seeds oil can also be used as a natural source of behenic acid, which has been used as an oil structuring and solidifying agent in margarine and foods containing semisolid and solid fats, eliminating the need to hydrogenate the oil (Foidl *et al*., 2001).The seed cake remaining after oil extraction may be used as a fertilizer (Rashid *et al*., 2008). In developing countries, *Moringa* have potentials to improve nutrition, boost food security, foster rural development, and support sustainable land care (National Research Council, 2006). *Moringa* seed had been known to combat malnutrition in infant and nursing mothers. Despite the usefulness and nutritional value, the seeds are still among the lesser known crop under-utilized and under-processed. Akani *et al.* (2000) reported that inadequate data on engineering properties of indigenous crops have greatly retarded the development of indigenous technologies for the processing of these crops. When these data are available, the design and development of machines for processing indigenous crops will receive the needed boost. The problems associated with local processing method, lack of processing machines, and inadequate preservation for *Moringa* seed, maybe due to the fact that the basic necessary data on the physical and mechanical properties are limited or not available.

MATERIALS AND METHODS

Sample preparation

Bulk quantity of *Moringa Oleifera* seeds were obtained from a large scale farmer at Monday market, Kakuri, Kaduna State, Nigeria. The quantity was tied and kept in a polyethylene bag for 78 hours to equilibrate the moisture throughout the whole bulk. Samples were randomly taken to determine the initial moisture content of the seed by drying seed samples in an air ventilated oven at 103ºC for 24 hours (Ozarslan, 2002) and the average values got was 10.246% d.b.

The remaining mass was divided into four groups. Three parts for the seed samples were reconstituted in addition to the initial moisture sample parts by adding a calculated amount of distilled water and sealing them in separate polyethylene bags and storing them in a refrigerator at 5ºC in a refrigerator for a week to enable the moisture to distribute uniformly throughout the sample (Sacilik, 2003; Garnayak *et al*., 2008).

The initial moisture contents (dry basis) of the seed samples were determined by the relationship (ASAE Standards, 1999):

$$\%\ \text{Moisture Content (d.b)} = \frac{\{M_i - M_f\}}{M_f} \times 100 \qquad (1)$$

Where, M_i = initial mass of the seeds/kernels in grams and M_f = final mass of the seeds in grams when constant mass is detected.

Also, the quantity of distilled water added to the samples, to obtain the required moisture content of study was calculated through the following equation (Tabatabaeefar, 2003):

$$W_2 = W_1 \times \left\{\frac{M_2 - M_1}{100 - M_2}\right\} \qquad (2)$$

Where, W_2= the mass of distilled water added in grams; W_1=the initial sample mass in grams; M_1 = the initial moisture content of sample in % dry basis, and M_2= the desired moisture content of the sample in % dry basis.

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 hours (Singh and Goswami, 1996; Coskun *et al.*, 2006) and after which the reconstituted samples were checked for the moisture content using the method described by ASAE, 1999 and values obtained were 10.246%, 17.303%, 24.063% and 32.246% (on dry basis). The sample was kept in the ambient environment in sealed conditions so there is no chance for changing moisture.

Dimensional property measurement

The physical dimensions of the seed was determined by taking 100 seeds randomly and measuring the length, width and thickness at the different moisture contents using a micrometer screw gauge (DIN 863I, Model No.03699 with 0.01mm accuracy and 0 – 25mm main reading).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 as shown in (Figure 1). The measurements were taken at room temperature of 28ºC. The arithmetic mean diameter, equivalent mean sphere diameter and geometric mean diameter were determined using the equations given by Joshi *et al*. (1993):

$$AMD = \frac{(L+W+T)}{3} \qquad (3)$$

$$EMD = \left\{\frac{L(W+T)^2}{4}\right\}^{1/3} \qquad (4)$$

$$GMD = \{L \times W \times T\}^{1/3} \qquad (5)$$

Where, L is the length in mm; W is the width in mm; T is the thickness in mm.

Sphericity (Ø) was calculated by using the following relationship given by (Koocheki *et al*., 2007; Milani *et al.*, 2007):

$$\emptyset = \left\{\frac{(LWT)^{1/3}}{L}\right\} \qquad (6)$$

The Surface area, S in mm^2 was determined by the relationship given by (McCabe *et al*., 1986; Asoegwu, 2006) as:

$$S = \pi (D_g)^2 \qquad (7)$$

The Aspect Ratio, R_a was calculated by applying the following relationships given by (Maduako and Faborode, 1990):

$$Ra = \left\{\frac{W}{L}\right\} \times 100 \qquad (8)$$

The Unit Volume, V, of 100 individual seed was calculated from values of L, W and T (Asoegwu, 2006) following the formula:

$$V = \pi\left\{\frac{L \times W \times T}{6}\right\} \qquad (9)$$

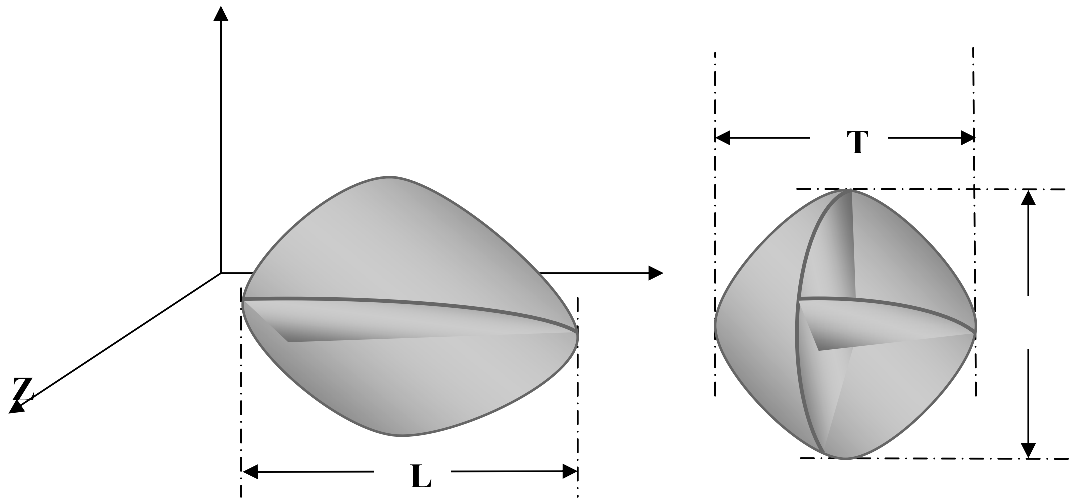

Fig. 1: Dimensions of *Moringa* seed (L, W, T is the length, width and Thickness respectively)

Gravimetric property measurement

Determination of one thousand seed mass

Mass of 1000 seeds of *Moringa* was determined by counting 100 seeds randomly and measuring its mass at different moisture contents using an electrical digital balance (G & G, Model No: JJ600 with maximum capacity of 600g and accuracy 0.01g) and then its mass was multiplied by10 to give the mass of 1000 seeds (Karababa, 2005). The measurements were taken at room temperature of 28 ºC.The mass of each test was done in twenty replicates.

Determination of moringa seed and kernel bulk density

Seeds were poured to a 500mL beaker in excess and with a constant rate from a height of about 150mm (Singh and Goswami, 1996). Dropping the seeds from a height of 150mm 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 0.01g. 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 four moisture levels, with 10 replications at each level of moisture. The bulk density was calculated from the mass of bulk seed divided by the volume containing the mass as:

$$\rho b = \frac{Mb}{Vb} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where, ρb = bulk density (g/cm^3); M_b= mass of seeds (g) V_b= volume of container (cm^3).

Determination of Moringa seed particle density

The particle density (ρ_t) was determined by the Toluene Displacement Method (Matouk, *et al*, 2004). Toluene (C_7H_8) was used in place of water because it is absorbed by seeds to a lesser extent. Also, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Mohsenin, 1986). The displacement method was the Archimedean Principle used in determining the density of bodies and liquids. The procedure for the displacement method entails determining the mass of the liquid displaced by the body as shown in (Fig. 2). A container of the liquid is placed directly on the weighing pan while the body is immersed. When the body is immersed in the liquid, it displaces a volume of liquid V_{fl} with density ρ_{fl} and mass m_{fl}. The buoyancy force exerted on the body is:

$$\mathbf{F_B = \rho_{fl} \times V_{fl} \times g = m_{fl} \times g} \quad \ldots\ldots\ldots\ldots \mathbf{(11)}$$

Because the weight of the body $W_s = m_s \times g$ is carried by the hanger assembly and the balance is not loaded, the balance readout directly indicates the mass of the liquid m_{fl} – assuming the weight of the container was tarred beforehand. The beaker was placed on the pan of the balance and the sample-holding device was immersed in the liquid, to the same depth that it shall later be immersed with the sample on it. With the weighing instrument tarred, the sample was placed next to the beaker on the weighing pan. The mass of the sample in air $\mathbf{M_a}$ was determined. The sample was placed in the holding device on the stand and immersed in the liquid. The weight readout shows the mass of the displaced liquid $\mathbf{M_{fl}}$. The particle density of the seed was calculated as:

$$\rho_t = \rho_{fl} \cdot \frac{M_a}{M_{fl}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where, ρ_t= particle density of the seed in (g/cm^3); ρ_{fl} = toluene density at room temperature = 0.867 g/cm^3; M_a = air mass of seed in (g) and M_{fl} = mass of submerged seed or mass of displaced liquid in (g).

Determination of seed porosity

Porosity (P) was determined in terms of bulk density (ρ_b) and particle density (ρ_t) of the seed or kernel. The porosity (P) of the bulk was computed from the values of the particle density and bulk density of the seeds by using the relationship given by Mohsenin, 1986.

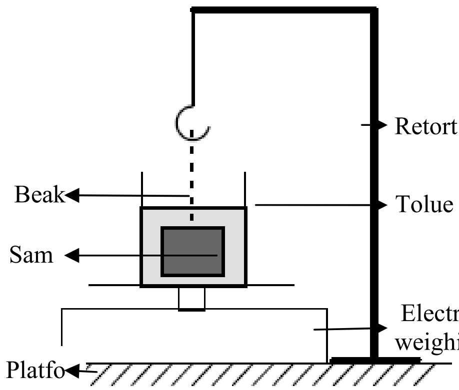

Fig. 2: Basic Procedure for the Displacement Method

$$P = \left\{1 - \frac{\rho_b}{\rho_t}\right\} \times 100 \quad \ldots\ldots (13)$$

Where, P = porosity in (%); ρb= bulk density (g/cm^3) and ρt= particle density (g/cm^3)

Frictional property measurement

Determination of seed angle of repose

The angle of repose indicates the cohesion among the individual units of a material. The higher the cohesion, higher is the angle of repose. The angle of repose of *Moringa* seeds was measured using the emptying method (platform method) to determine the dynamic angle of repose. The emptying method was conducted using a bottomless cylinder of 5cm diameter and 10cm height (Taser *et al*., 2005; Garnayak *et al*., 2008). The cylinder was placed over a plain surface and *Moringa* seeds were filled in. The cylinder was raised slowly allowing the sample to flow down and form a natural slope. The dynamic angle of repose was calculated from the height and diameter of the pile as:

$$\theta = \tan^{-1}\left\{\frac{2H}{D_p}\right\} \quad \ldots\ldots (14)$$

Where, θ = angle of repose (^{o}), H = height of pile (cm) and D_p = diameter of the pile (cm) Angle of repose measurements of *Moringa* seeds were replicated 5 times.

Determination of seed and kernel coefficient of static friction

The static coefficient of friction of *Moringa* seeds against three different surfaces namely plywood, mild steel, and glass were determined using a plastic cylinder of 100mm, diameter and 50mm height as described by (Karaj and Müller, 2010.). The cylinder filled with seed was placed on an adjustable inclined surface. The plastic cylinder was raised slightly so that its bottom edge cannot touch the inclined surface. All three surfaces were raised slowly with help of screw device until the cylinder filled with seeds/kernels started to slide down. At that point, the angle of tilt was recorded. The coefficient of friction was calculated using Equation (3.15):

$$\mu_s = \tan^{-1}(\Phi') \quad \ldots\ldots (15)$$

Where, μ_s is the coefficient of static friction and Φ' is the tilt angle or angle of friction in degree. Static coefficient of friction measurements of *Moringa* seeds at the moisture content of study were replicated 5 times.

Seed and kernel theoretical calculation of internal angle of friction

Abdel, Fattah *et al*, 2006 estimated the angle of internal friction using:

$$\Phi = \frac{\tan^{-1}(\mu_s)}{0.7} \quad \ldots\ldots (16)$$

Where, μ_s = Static coefficient of friction of seed on any material

Using the values of static coefficient of friction measurements of *Moringa* seeds at the moisture content of study observed in section 3.2, the angle of internal friction was estimated.

RESULTS AND DISCUSSION

Seed and kernel physical properties

The results of *Moringa Oleifera* seed size measured at different moisture content levels are presented in Table 2. The table shows that the three axial dimensions of the seed increased with moisture content in the moisture range of 10.246-32.246% (d.b.).

Seed axial dimension

From Table 2 above and Figure 1, the major axis (length) increased from (11.964±1.487) mm to (12.813±1.427)mm, the intermediate axis (width) from (9.983±1.064)mm to (10.803±0.922)mm, and the minor axis (thickness) from (9.421±1.018)mm to (10.226±0.950) mm. The increasing trend in axial dimensions, with gain in moisture content, was due to filling of voids upon absorption of moisture and subsequent swelling. Information of the length, width, thickness of the seeds was necessary in determining aperture sizes in the design of seed handling equipment. Thus the regression equation representing each axial dimension was deduced as shown below:

Seed mean diameter

The arithmetic mean of the three principal axes, their geometric mean and the equivalent sphere diameter of the seed at different moisture contents, also presented in Table 2, increased with moisture content. The arithmetic mean diameter had higher mean values of (10.456±1.059mm to 11.280±0.899 mm) than the geometric (10.388±1.047mm to 11.210±0.882mm) and equivalent sphere diameters (10.392±1.047 mm to 11.217±0.883 mm) of the seed. These could be of important consideration in the theoretical determination of the *Moringa* seed volume at different moisture contents. Moreover, assessment of the mean geometric diameter is useful in evaluation of the projected area of a particle moving in the turbulent or near-turbulent area of an air stream. Figure 2 revealed the relationship for seed mean diameter with moisture content.

Table 2: Mean values of the measured and calculated axial dimensions of the *Moringa* seed.

Seed property	Moisture content, % dry basis	N	Mean	SD	Minimum	Maximum
Seed Length	10.250	100	11.9640	1.48676	7.79	16.19
	17.329	100	12.5399	1.46284	9.30	16.08
	24.471	100	12.5785	1.38910	9.26	15.89
	32.343	100	12.8125	1.42670	9.78	16.07
	Total	400	12.4737	1.47002	7.79	16.19
Seed Width	10.250	100	9.9830	1.06393	7.38	12.48
	17.329	100	10.5366	0.90663	8.38	13.30
	24.471	100	10.6674	0.86058	7.93	12.47
	32.343	100	10.8029	0.92223	8.73	13.59
	Total	400	10.4975	0.98840	7.38	13.59
Seed Thickness	10.250	100	9.4206	1.01794	6.65	11.75
	17.329	100	10.0665	0.85903	8.06	12.28
	24.471	100	10.1884	0.91831	7.02	12.19
	32.343	100	10.2255	0.95003	8.32	12.89
	Total	400	9.9752	0.98977	6.65	12.89
Seed Arithmetic Diameter	10.250	100	10.4559	1.05878	7.59	12.80
	17.329	100	11.0477	0.89273	8.87	13.19
	24.471	100	11.1448	0.91625	8.55	13.30
	32.343	100	11.2803	0.89853	8.94	13.35
	Total	400	10.9822	0.99192	7.59	13.35
Seed Geometric Diameter	10.250	100	10.3876	1.04658	7.59	12.58
	17.329	100	10.9807	0.88222	8.85	13.17
	24.471	100	11.0861	0.90476	8.41	13.19
	32.343	100	11.2104	0.88223	8.92	13.34
	Total	400	10.9162	0.98037	7.59	13.34
Seed Equivalent Diameter	10.250	100	10.3923	1.04683	7.59	12.59
	17.329	100	10.9839	0.88206	8.86	13.18
	24.471	100	11.0896	0.90295	8.42	13.19
	32.343	100	11.2169	0.88323	8.92	13.35
	Total	400	10.9207	0.98026	7.59	13.35
Seed Sphericity	10.250	100	0.8723	0.05821	0.76	0.99
	17.329	100	0.8814	0.06748	0.75	1.09
	24.471	100	0.8854	0.05501	0.76	0.98
	32.343	100	0.8796	0.06051	0.75	1.01
	Total	400	0.8797	0.06044	0.75	1.09
Seed Aspect Ratio	10.250	100	84.0131	8.42444	66.96	99.84
	17.329	100	84.8841	10.10225	65.62	114.58
	24.471	100	85.4235	8.09763	66.55	99.57
	32.343	100	84.9872	8.87143	65.21	99.91
	Total	400	84.8270	8.88770	65.21	114.58
Seed Surface Area	10.250	100	342.528	68.07374	181.08	497.24
	17.329	100	381.373	60.84811	246.03	545.48
	24.471	100	388.806	61.83334	222.36	546.62
	32.343	100	397.397	62.29727	250.21	559.62
	Total	400	377.526	66.49520	181.08	559.62
Seed Unit Volume	10.250	100	604.734	178.47048	229.08	1042.41
	17.329	100	706.800	168.36821	362.80	1197.71
	24.471	100	727.602	169.98185	311.72	1201.48
	32.343	100	751.557	176.36932	372.09	1244.61
	Total	400	697.673	181.55388	229.08	1244.61

Table 4: Mean seed dimensional property.

Seed dimensional property	Moisture content (%, DRY BASIS)			
	10.250%	17.329%	24.471%	32.343%
Length (mm)	11.964 ± 0.984^{a}	12.540 ± 0.951^{b}	12.579 ± 0.930^{b}	12.813 ± 0.987^{b}
Width (mm)	9.983 ± 1.064^{c}	10.537 ± 0.907^{d}	10.667 ± 0.861^{d}	10.803 ± 0.922^{d}
Thickness (mm)	9.421 ± 1.018^{e}	10.067 ± 0.859^{f}	10.188 ± 0.918^{f}	10.226 ± 0.950^{f}
GMD (mm)	10.388 ± 1.05^{k}	10.981 ± 0.88^{l}	11.086 ± 0.90^{l}	11.210 ± 0.88^{l}
EMD (mm)	10.392 ± 1.04^{i}	10.984 ± 0.88^{j}	11.090 ± 0.90^{j}	11.217 ± 0.88^{j}
AMD (mm)	10.456 ± 1.06^{g}	11.048 ± 0.89^{h}	11.145 ± 0.92^{h}	11.280 ± 0.90^{h}
Sphericity	0.872 ± 0.058^{m}	0.881 ± 0.067^{m}	0.885 ± 0.055^{m}	0.880 ± 0.061^{m}
Aspect ratio (%)	84.013 ± 8.420^{n}	84.884 ± 10.10^{n}	85.424 ± 8.10^{n}	84.987 ± 8.87^{n}
Surface area (mm^2)	342.53 ± 68.07^{p}	381.37 ± 60.85^{q}	388.81 ± 61.83^{q}	397.40 ± 62.30^{q}
Unit volume (mm^3)	604.73 ± 178.47^{x}	706.80 ± 168.37^{y}	727.60 ± 169.98^{y}	751.56 ± 176.369^{y}

[*]Means in rows with the same superscript are not significantly different at $p \leq 0.05$ using Duncan's Multiple Range Test mean comparison technique.

Table 5: Mean seed gravimetric property

Seed gravimetric property	Moisture content (%, dry basis)			
	10.250%	17.329%	24.471%	32.343%
1000 Seed mass (g)	273.95 ± 15.48 ^{ab}	274.50 ± 9.85 ^{a}	291.40 ± 19.95 ^{b}	329.20 ± 12.84 ^{c}
Unit mass of seed (g)	0.3497±0.072 ^{a}	0.3657±0.059 ^{ab}	0.3657±0.077 ^{ab}	0.3990±0.068 ^{b}
Bulk density (g/cm^3)	0.247 ± 0.005 ^{a}	0.253 ± 0.005 ^{b}	0.262 ± 0.006 ^{c}	0.279 ± 0.008 ^{d}
Particle density (g/cm^3)	0.594 ± 0.032 ^{a}	0.596 ± 0.043 ^{a}	0.609 ± 0.069 ^{a}	0.658 ± 0.035 ^{b}
Porosity (%)	58.271 ± 2.785 ^{a}	57.352 ± 3.093 ^{a}	56.183 ± 7.134 ^{a}	57.503 ± 2.737 ^{a}

*Means in rows with the same superscript are not significantly different at P≤0.05

Table 6: Mean seed frictional property

Seed frictional Property	Moisture content (%, dry basis)			
	10.250%	17.329%	24.471%	32.343%
Angle of repose (°)	*17.643 ± 0.472 ^{A}	19.386 ± 0.474 ^{B}	21.271 ± 0.711 ^{C}	23.500 ± 0.432 ^{D}
Angle of internal friction (°)				
Plywood	42.374 ± 0.131 ^{A}	44.831 ± 0.844 ^{B}	48.402 ± 0.120 ^{C}	52.619 ± 0.074^{D}
Mild steel	36.630 ± 0.095 ^{A}	42.343 ± 0.087 ^{B}	46.366 ± 0.330 ^{C}	48.514 ± 0.279 ^{D}
Glass	33.619 ± 0.146 ^{A}	36.029 ± 0.095 ^{B}	38.145 ± 0.646 ^{C}	41.878 ± 0.132 ^{D}
Static coefficient of friction				
Plywood	0.570 ± 0.002^{A}	0.610 ± 0.014^{B}	0.672 ± 0.002^{C}	0.749 ± 0.001^{D}
Mild steel	0.480 ± 0.001^{E}	0.569 ± 0.001^{F}	0.636 ± 0.006^{G}	0.674 ± 0.005^{H}
Glass	0.436 ± 0.002^{I}	0.471 ± 0.001^{J}	0.503 ± 0.010^{K}	0.562 ± 0.002^{L}

*Means in rows with the same superscript are not significantly different at P≤0.05 using Duncan's Multiple Range Test mean comparison technique

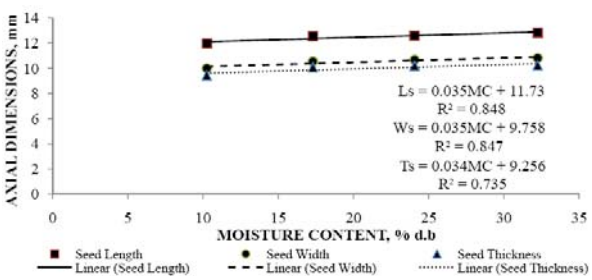

Fig. 1: Effect of moisture content on axial dimensions of *Moringa oleifera* seed.

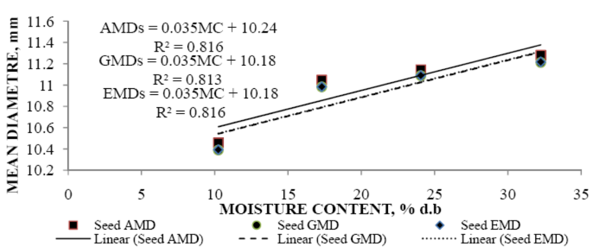

Fig. 2: Effect of moisture content on mean diameter of *Moringa oleifera* seed.

$$SPs = 0.845 + 0.003MC - 0.00007036MC^2 \quad R^2=0.992$$

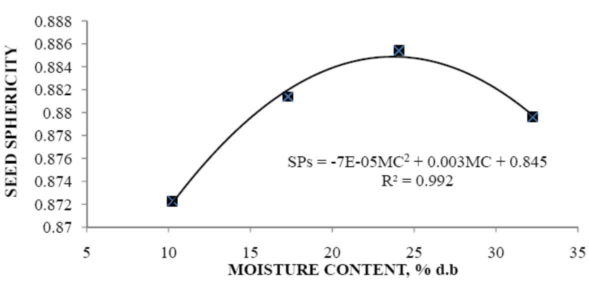

Fig. 3: Effect of moisture content on the Sphericity of *Moringa oleifera* seed.

Seed spericity (SPs)

From Table 2, seed sphericity was quadratically related with moisture content. A quadratic relationship was found for the sphericity and the quadratic increase was from 0.872±0.058 to 0.880±0.061. This shows that the seed is spherical but not oblong such that it can roll rather than slide. This property is essential in developing processing and handling machines for optimal quality with minimal physiological damage.Also, the results demonstrated that the *Moringa* seed is quite the shape of a sphere, and with that, consequently, a sieving or separating machine with circular holes will easily let seeds through. The regression equation in Figure 3 below shows the relationship between seed sphericity and moisture levels.

Seed aspect ratio (ARs)

Also, the aspect ratio of seed was quadratically related with moisture content.The seed aspect ratio was observed to increase quadratically from 84.013±8.424 to 84.987±8.871 as the moisture content increases. The aspect ratio relates the width to the length of the seed which is indicative of its tendency toward being oblong in shape (Omobuwajo *et al*., 1999).The high aspect ratio was found for the seed which shows that seeds are not oblong in shape and will roll easily. This information is important in the design of hoppers, separation and conveying equipment. The regressed equation below showed the relationship between aspect ratio and moisture levels.

Seed surface area (SAs)

As seen from Table 2, the surface area of *Moringa* seed increased linearly from 342.528±68.074 to 397.397±62.297 mm^2 when the moisture content increased from 10.246 to 32.246% d.b. The increase in the values might be attributed to its dependence on the three principal dimensions of seed. Similar results have been reported by Saçilik *et al*. (2003) for hemp seed, Paksoy and Aydin (2004) for squash seed, and Yalçin (2007) for

$ARs = 81.42 + 0.313MC - 0.006MC^2 \quad R^2=0.983$

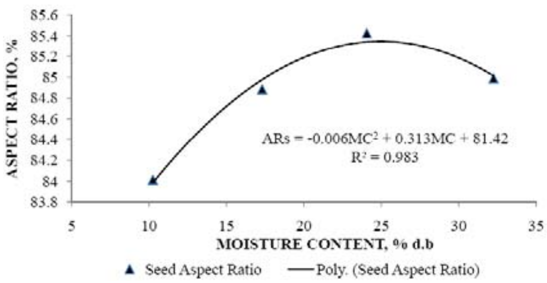

Fig. 4: Effect of moisture content on aspect ratio of *Moringa oleifera* seed.

$SAs = 2.338MC + 328.4$ $R^2=0.823$ ($SAs = 271.2 + 8.627MC - 0.147MC^2$ $R^2=0.971$)

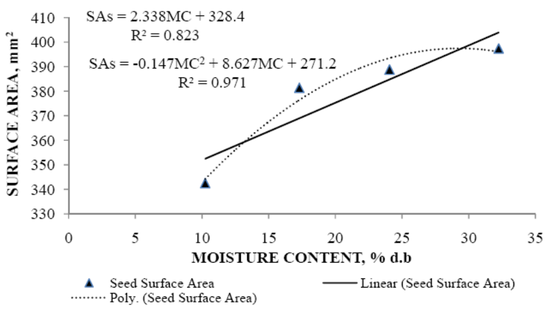

Fig. 5: Effect of moisture content on surface area of *Moringa oleifera* seed.

$Vs = 6.272MC + 566.1$ $R^2=0.833$ ($Vs = 417.9 + 22.56MC - 0.382MC^2$ $R^2=0.972$)

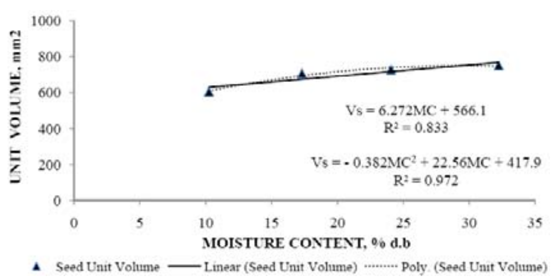

Fig. 6: Effect of moisture content on unit volume of *Moringa oleifera* seed.

$TWs = 2.546MC + 238.8 \quad R^2 = 0.853$

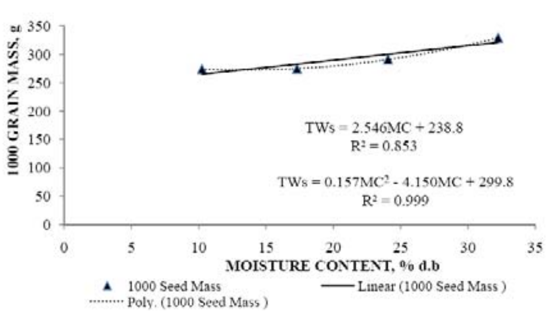

Fig. 7: Effect of moisture content on 1000 grain mass of *Moringa oleifera* seed.

cowpea seed. The variation of moisture content and surface area can be expressed graphically as represented in Figure 5:

Seed unit volume (Vs)

The seed volume was found to increase linearly with the increase of moisture content. The volume increased from 604.734±178.470 to 751.556±176.369 mm^3 (statistically significant at $P<0.05$) when moisture content increased from 10.246 to 32.246% (d.b). This volumetric expansion may be attributed to the expansion in the dimensions which contributed to weight increase of *Moringa* seed thereby resulting to the displacement of more liquid. Similar results have been reported by Karababa (2006) for popcorn kernels. The relationship between moisture content and seed volume can be expressed by the regression graph in Figure 6.

Thousand seed weight (TWs)

Table 5 shows the thousand seed weight variation with seed moisture content ($P<0.05$). The Figure indicates that the thousand seed mass increases linearly with increase in seed moisture content. The increase ranges from 273.950±15.478g to 329.200±12.836g as moisture content increases from 10.246% to 32.246%. The variation can be expressed graphically as follows with a coefficient of determination $R^2= 0.853$ as shown in Fig. 7.

Seed bulk density (bds) and particle density (TDs)

The bulk density of *Moringa* seed varied from 0.247g/cm^3 to 0.279g/cm^3 ($P<0.05$) and indicated increase in bulk density with an increase in moisture content from 10.246% to 32.246% d.b. This was due to the fact that a corresponding decrease in mass owing to moisture gain in the sample was lower than accompanying volumetric expansion of the bulk (Solomon and Zewdu, 2009). Similar results have been reported by Özarslan (2002) for cotton seed and Mwithiga and Sifuna (2006) for sorghum seeds. The linear relationship between the bulk density and moisture content in *Moringa* seed was found to be as presented in Figure 8.

The variation of particle density with moisture content for *Moringa* seed is shown in Table 5. The particle density of seed was found to increase from 0.594g/cm^3 to 0.658g/cm^3 ($P<0.05$) with moisture content. The increase in particle density with increase in moisture content might be attributed to the relatively lower true volume as compared to the corresponding mass of seed attained due to adsorption of water. The density values of *Moringa* seed was used in design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products (Solomon and Zewdu, 2009). A similar result was reported by Ghadge *et al*. (2008). The variation in particle density with moisture content of *Moringa* seed was described in Figure 9.

Seed porosity (Ps)

Table 5 shows the porosity variation with seed moisture content. This reveals that the porosity decreases from 58.27% at 10.246% d.b. moisture to 56.183% at 24.063% d.b and then increases with further increase in moisture content. The relationship existing between

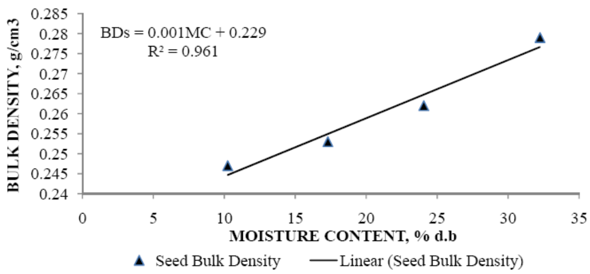

Fig. 8: Effect of moisture content on bulk density of *Moringa oleifera* seed.

TDs = 0.002MC + 0.554 R^2=0.813 (TDs = 0.632 – 0.005MC + 0.000MC^2 R^2=0.995)

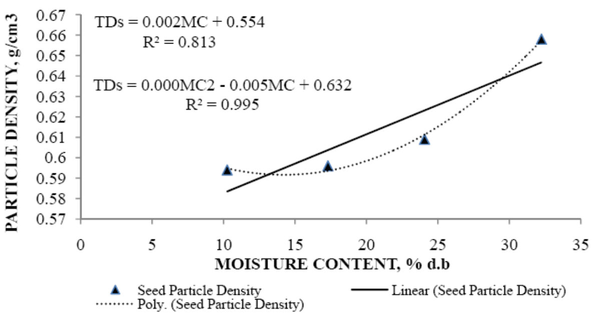

Fig. 9: Effect of moisture content on particle density of *Moringa oleifera* seed.

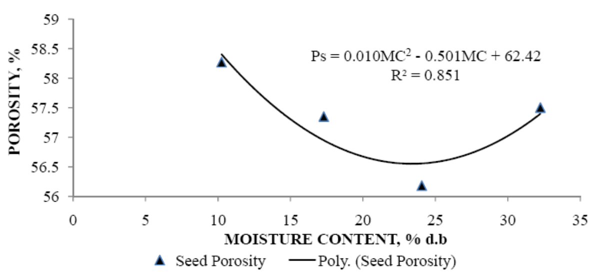

Fig. 10: Effect of moisture content on porosity of *Moringa oleifera* seed.

Rs = 14.84 + 0.267MC R^2=0.999

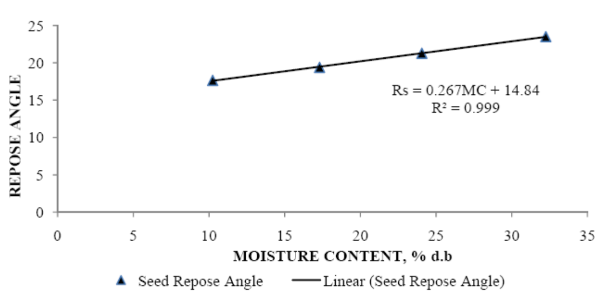

Fig. 11: Effect of moisture content on repose angle of *Moringa oleifera* seed.

porosity and seed moisture content was found to be polynomial as shown in Figure 10 with the coefficient of determination, R^2 = 0.851:

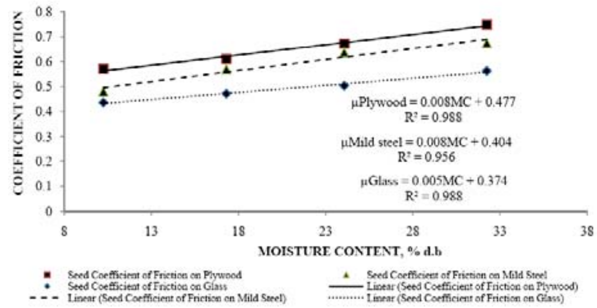

Fig. 12: Effect of moisture content on coefficient of friction of *Moringa oleifera* seed.

Seed angle of repose (Rs)

Table 6 shows the result of the angle of repose of *Moringa* seed at the study moisture content. From the mean values, it shows that the angle of repose increases as the moisture content increases. Thus, linear relationships exist between angle of repose and moisture content as shown in Figure 11.

Seed coefficient of friction (µ)

Table 6 shows the result of the frictional properties of the seed on three structural surfaces, that is plywood, mild steel and glass as the moisture increases. From the mean values, linear relationships exist between coefficient of friction, µ on these surfaces and moisture content as shown in the regression graph with high coefficient of determination. This shows that angle of repose is strongly in linear relationship with moisture content as seen in Figure 12.

Conclusion

The result obtained from *Moringa* seed size measured at different moisture content levels showed incremental relationships with moisture. From the ANOVA and mean comparison tables, the reconstituted fractions show no difference with each other except for the properties at the initial moisture level.

Also, the seed is spherical in shape but not oblong such that it can roll rather than slide. This property is essential in developing processing and handling machines for optimal quality with minimal physiological damage. Also, the results demonstrated that the *Moringa* seed is quite the shape of a sphere, and with that, consequently, a sieving or separating machine with circular holes will easily let seeds through. Thus circular sieve holes of 12mm in diameter for the seed can be used to sort out or clean husked seed pods during *Moringa* seed processing.

The aspect ratio relates the width to the length of the seed which is indicative of its tendency toward being oblong in shape. The high aspect ratio was found for the seed which shows that seeds are not oblong in shape and will roll easily. Also, the seed can be described as being spherical from the sphericity index which showed high value for the seed (0.87-0.88). This information is important in the design of hoppers, separation and conveying equipment.

The increase in particle density with increase in moisture content might be attributed to the relatively lower true volume as compared to the corresponding mass of seed attained due to adsorption of water. The density values of *Moringa* seed and kernel will be used in design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products. Also the angle of repose and surface frictional coefficient of the seed and kernel showed positive increase in relationship with moisture content but porosity did not rather it decreases with moisture increment

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