Physical Properties of African Oil Bean Seed (*Pentaclethra macrophylla*)

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ABSTRACT

Some physical properties of African oil bean seeds at 8.73 ± 0.09% moisture content (db) were measured using standard methods as a prelude to obtaining relevant data for the design of tools, equipment, machines and systems for their processing. At the above moisture content, the major, intermediate and minor diameters of the seeds averaged 56.18mm, 37.89mm, 12.01m with standard deviations 8.46, 3.82 and 1.66 mm respectively. Of 100 seeds, the average values of seed weight, seed volume and seed particle density were 13.19 ± 3.28 g, 11.61 ± 3.02 cm^3 and 1.15 ± 0.18 g/cm^3. Using appropriate expressions, the arithmetic, geometric and square mean diameters were obtained as 35.36 ± 3.42, 29.28 ± 2.21, and 32.88 ± 2.87 mm respectively, while the equivalent diameter and sphericity were 32.51 ± 2.82 mm and 0.523 ± 0.065, and the seed surface area = 37.16 ± 2.96 cm^2. The bulk density was 0.588 ± 0.019 g/cm^3 and porosity was 51.56 ± 3.43%. The volume coefficient was found to be 0.464 and all parameters were positively skewed. These physical parameters were evaluated as functions of seed weight and linearity was established amongst some of them. However, sphericity and minor diameter had low correlation coefficients of -0.2280 and 0.2858 respectively and thus did not have a linear relationship with seed weight..

Keywords: Physical properties, oil bean, density, sphericity, equivalent diameter surface area

1. INTRODUCTION

The African oil bean (*Pentaclethra macrophylla* Benth) is a tropical tree crop found mostly in the Southern and Middle Belt Regions of Nigeria and in other coastal parts of West and Central Africa. It belongs to the *Leguminosae* family and the sub-family of *Mimosoideae* (Keay, 1989) with no known varietal characterization. The tree is recognized by peasant farmers in these parts of the country for its soil improvement properties and as a component of an agro-forestry system (Okafor and Fernandez, 1987). It has been cultivated since 1937 (Ladipo, 1984). Okafor (1982) recognized *P. macrophylla* as a food tree specie for outlying farms in the forest zone. Presently, they grow either wild or semi-wild with no organized cultivation in plantations or orchards in Nigeria. Okafor (1991) had reported suitable techniques for the vegetative propagation of the plant with buds and stem cuttings resulting in drastically reduces fruiting age of 2 – 4 years and fruiting at breast height. Their edible seeds require tedious but careful processing and fermentation before they can be eaten as food supplement. Some parts of the plant have medicinal values as shown in Table 1. The seed, when crushed and eaten with red ants, can induce abortion (Abbiw, 1990; Isawumi, 1993; Tico, 2005).The seed is also used to poison fish and arrows. Ashes of the pods are used as salt. The anthelmintic bark is pounded and applied to leprosy sores (Tico, 2005). In agro-forestry they supply wood and farming materials (stakes and mulch). Its trunk provides timber used for structural work. The tree yields forest products for making wooden household utensils (Okafor, 1987). The flat glossy brown edible seeds, averaging 8 (6-10) in number, are contained in a brownish flattened pod (Enujiugha, 2003), which explodes at maturity and disperses the seeds. The number of seeds in the pod depends on the length of the pod and the size of the seeds. The mature dispersed seeds are harvested by gathering them manually from around the tree. The kernel (a dicotyledon), which is gray in color, is embedded in a glossy brownish seed coat. The seeds may be said to be irregular and oval as shown in Plate 1 and lies flat in its natural position.

Table 1. Medicinal uses of *Pentaclethra macrophylla*

Uses	Parts of Plant	Country
Infertility	Seed	Cameroon
Convulsion	Pod	Cameroon
Convulsion	Smoke of burnt leaf	Ghana
Abortion	Crushed seed	Ghana/Nigeria
Diarrhea	Leaf/stem bark	Ghana
Itch	Bark as ointment	Ghana
Lactogenicity	Bark decoction	Ghana
Wound treatment	Bark as lotion	Ghana

Culled from Abbiw, 1990; NFT, 1995; Zapfack et al., 1999; ICRAF, 2004

Okafor (1987) identified *Pentaclethra macrophylla* as a minor food supplement, while other workers (Oyenuga, 1968; Okigbo, 1977; Okafor, 1979) have investigated and found that this oil seed contains 23 – 28% protein. It also contains the twenty (20) essential amino acids and essential fatty acids that make up over 10% of the fatty acids in the oil (Enujiugha and Agbede, 2000; Ikediobi, 1981). The oil content and carbohydrate contained in raw African oil bean seeds are $53.98 \pm 0.99\%$ and $19.16 \pm 0.76\%$ dry wt, respectively (Enujiugha and Akanbi, 2005). The seed when cooked, processed and fermented is called ugba (in Igbo language of Nigeria) and used for the preparation of many delicious African delicacies including African salad, soups and sausages for eating with different staples (Enujiugha, 2003). It is rich in vitamins and minerals and in high demand for both local consumption and for export. It is a low-acid food which could be prepared into flour and explored in food fortification and confectionaries. The seed is a source of edible oil and is used for candle making, cooking and soap (Tico, 2005). The seed shells are decorative and are often used to craft beads which are worn as necklaces, rosaries and sometimes as local dancing apparels (NFT, 1995; ICRAF, 2004). It has been reported that the *P. macrophylla* seed phytase has comparatively higher activity with higher protein concentration in the enzyme molecule than *Parkia* and *Tetracarpidium* seeds (Enujiugha, 2005). Physical properties data of agricultural materials affect how they are to be processed, handled, stored and consumed and so are required in the design of planting, harvesting and post harvest operations such as cleaning, conveying and storage (Kotwaliwale et al., 2003; Masoumi and Tabil, 2003; Welhelm et al., 2004). Presently, all the post harvest handling and processing practices such as extraction, washing, slicing, crushing, shelling and shaping of the shells are done manually and it is necessary to design tools, equipment and machines for the above processes. However, before the design and fabrication of these machines, it is necessary to consider some physical and engineering properties of the seeds (Aremu and Fowowe, 2000). The physical properties are also required for the design and analysis of equipment and systems for their handling, processing and storage (Asoegwu, 1995; Asoegwu and Maduike, 1999; Aviara et al., 1999; Gupta and Nachiket, 1999). Processing techniques and proper handling of African oil bean seeds need accurate knowledge of the physical properties such as shape, size, porosity, surface area, bulk density, (Alabadan, 1996). Seed weight, seed volume, seed density, major, intermediate, minor and mean (arithmetic, geometric, square and equivalent) diameters could be used to characterize the oil bean seed. Other researchers (Carman, 1996; Dutta et al., 1988; Deshpande et al., 1993; Aviara et al., 1999; Suthar and Das, 1996) have used the above parameters to characterize other crops.

Tabatabaeefar, et al., (2002) found it necessary to study the physical properties (seed quality indicators) of Iranian pea in order to properly design and facilitate the construction of its sieving and grading machine. They found the arithmetic mean diameter to be 6.7 – 9.7mm with an average of 7.8mm. Information on size which is correlated to product weight is essential for grading, uniformity and packing in standard boxes or cartons (Singh et al., 2004) and in sieve separation and grinding operations (Welhelm et al., 2004). Nelson (2002) determined volume coefficient (ratio of the measured volume to the orthogonal-dimension product) and used it to estimate seed volume and seed density from seed dimensional data and seed weight. Bulk density, seed density and porosity are useful in storage, transport and separation systems (Kachru et al., 1994; Oh et al., 2001; Ureña et al., 2002). Density is useful in the mathematical conversion of seed mass to volume and influences its texture or mouth feel. It is also useful in heat transfer operations. Bulk density can indicate the degree of kernel filling during growth and therefore an indicator of quality and predicated in breakage susceptibility and hardness studies, milling and baking qualities (Chang, 1988). Kernel and bulk density data have been used in research on determining the dielectric properties of cereal grains (Nelson and You, 1989) and for determining volume fractions for use in dielectric mixture equations (Nelson 1992). Porosity, on the other hand, allows gases, such as air, and liquids to flow through a mass of particles in aeration, drying, heating, cooling and distillation operations. The size of grains is represented by their equivalent diameter and the sphericity is necessary to describe their shape. The surface area, related to size and porosity but also depends on seed shape, is useful in calculating the rate of heating, cooling, freezing and drying and in designing heat exchangers, evaporators and driers and filtration equipment. It is also used to estimate the amount of wax or wrapping paper applied to fruits. An attempt is hereby made to determine these properties for the African oil bean seeds which had a moisture content of 8.73 ± 0.09% (d.b) at the time of purchase. Further handling, processing and storage can only be done after purchase, so the determination of the physical properties at this moisture content. Some of the methods used by Oje and Ugbor (1991) were applied to determine some of the parameters (linear dimensions, seed weight, roundness, sphericity and surface area), while new and current methods were used for others (arithmetic, geometric and square mean and equivalent diameters and bulk density, skewness and kurtosis and volume). Oje and Ugbor (1991) had investigated some physical properties of oil bean seeds at 4.5% moisture content (d.b). In determining the moisture content of the batch, they did not use an established standard of measurement and did not indicate their sampling and identification methods.

Fig.1a Different sizes of African oil bean seeds

Fig.1b An array of African oil bean seeds

2. MATERIALS AND METHODS

2.1 Material

One hundred and twenty seeds (Fig. 1) were bought from an open market in Owerri, Imo State, Nigeria (since there are no organized plantations). Also, when obtained from the commercial channel, the cultivar or variety designation could not be determined (Nelson, 2002). They were put in a thick polyethylene bag and kept in cold storage at 5^{o}C for 72hrs. They were then removed and spread on a table at room temperature of 25 – 27^{o}C for 3hrs before making any measurements. Twenty of the seeds were used to determine the initial moisture content of the seeds using the ASAE Standards (1999). The moisture content at purchase was found to be 8.73 ± 0.09% (d.b.). The remaining 100 seeds were mixed thoroughly and randomly selected and labeled for easy identification, using a sampling method similar to that used by Dutta et al., (1988) and Joshi et al., (1993).

2.2 Size and Shape

For each individual seed the principal dimensions of major (L_1), intermediate (L_2) and minor (L_3) diameters were measured using a vernier caliper (to 0.01mm). Since seed size plays an important role in handling, processing and storage, under approximately the same operating conditions (Masoumi and Tabil, 2003), the bulk seed sample was classified into small (< 50mm), medium (50 – 65mm) and large (> 65mm) categories based on the major diameter and their frequency distribution by number determined and recorded as for their skewness and kurtosis. Using the measured dimensions, the following size descriptors were calculated.

Equivalent diameter $D_e = (F_1 + F_2 + F_3) / 3$ (Ciro,1997) ….1

where F_1 = Arithmetic mean diameter = $(L_1 + L_2 + L_3)/3$
F_2 = Geometric mean diameter = $(L_1L_2L_3)^{1/3}$
F_3 = Square mean diameter = $[(L_1L_2 + L_2L_3 + L_3L_1)/3]^{1/2}$

Its sphericity was calculated using the equation by Mohsenin (1986) and Gupta and Das (1997)..

$$S = F_2/L_1 \quad ......2$$

Even though the determination of the surface area of irregular seeds is difficult, the surface area (A_s) of oil bean seed was first obtained by tracing method (Oje and Ugbor, 1991) and calculated using the planimeter. The result was subjected to statistical analysis compared to results from the following equation 3 and Pabis et al., (1998) equation for specific area equation 4.

$$A_s = \pi D_e^2 \quad ....3$$

and $$A_{sp} = (k)6/D_e \quad \text{(Pabis et al., 1998)} \quad ......4$$

Where k = constant depending on seed shape, since the equation was developed for grains.

2.3 Seed Weight and Seed Volume

While the weight of each seed was determined using a precision electronic balance reading up to 0.0001g with an accuracy of ±0.2mg, the volume of the individual seeds was obtained by the liquid displacement method (Orji, 2000; Dutta, et al., 1988; Ma, et al., 1998) using a top loading balance.. The experiment was done at room temperature of 25 – 27°C and 53 - 58% RH in the Agricultural Engineering Laboratory, Federal University of Technology, Owerri. Though the seeds have thick, smooth shinny shell, they were rubbed with oil before immersion in the water in the beaker which lasted 3 – 5 sec. For the few seeds that floated in the water, a rod sinker was used to submerge them without the sinker displacing water. The mass of the displaced water is the balance reading with the seed submerged minus the mass of the beaker and water. The seed volume (V) is expressed as

$$V\ (cm^3) = \frac{\text{mass of displaced water (g)}}{\text{density of water (g/cm}^3)} \quad ...5.$$

The volume of the seed was then calculated using Miller's (1987) equation

$$V_c\ (cm^3) = \pi\ (L_1 L_2 L_3)/6 \quad ...6$$

and compared with the values obtained from Equation 5 using a regression equation. The volume coefficient which is the ratio of the measured volume to the product of the three principal dimensions, and the linear relationship between them were also determined.

2.4 Bulk and Seed Density

The seed density was determined by dividing the seed mass (measured directly from the balance) by the measured seed volume obtained from equation 4. The bulk density was determined by filling a standard hectoliter with as many of the seeds as possible from the sample (Joshi et al., 1993). The excess on the top of the container was removed by sliding a wooden stick along the top edge of the container. After the excess had been removed completely the bulk weight of the seeds in the container was measured. This was repeated 10 times. Bulk density was calculated as the ratio of the bulk weight and the volume of the container.

2.5 Porosity

The porosity (P) is determined as a function of the bulk density and seed density of the seed. The volume fraction occupied by the seeds is given by the ratio of the bulk density ρ_b to the seed density ρ_s of the seed.($f_v = \rho_b/\rho_s$). The porosity (void fraction) expressed in percent was calculated from average values of bulk and particle densities using equation 7 (Joshi et al., 1993; Deshpande et al., 1993; Suthar and Das, 1996; Jha, 1999; Nelson, 2002)

$$P = (1 - f_v) \times 100\% = (1 - \rho_b/\rho_s) \times 100\% \quad ....7$$

Where ρ_b = bulk density (g/cm^3) and ρ_s = seed density (g/cm^3)

Shape and thus linear dimensions are irregular. Size may be indicated by weight and weight easily determined by placing on the scale (Wilhelm, et al., 2004). Thus, all the parameters were regressed against seed weight, analyzed and reported.

3. **RESULTS AND DISCUSSION**.

4.

3.1 Size and Shape

The size distribution of the oil bean seeds is presented in Table 2. Based on the major diameter, about 59% of the seeds were of medium size of between 50 to 65 mm by number. The large size seeds were 14% by number. The small seeds were 27%. For the ungraded lot, the major diameter ranged from 39.20 to 76.85 mm, the intermediate diameter from 30.60 to 49.80 mm and the minor diameter from 6.50 to 17.20 mm. Their coefficients of variation were 15.14%, 10.08% and 13.91% respectively. As observed by Oje and Ugbor (1991), the seed with the largest major diameter did not have either the largest intermediate or minor diameter. This may be because of the irregular shape and size of the seeds. Generally, the small size seeds had the largest minor diameters with average dimension of 12.86 ± 1.27 mm. For oil bean seeds all the linear parameters have positive skewness (Table 3) with minor diameter most skewed (2.3170) followed by geometric mean diameter (2.2980). Also, these two parameters are the most peaked (leptokurtic) with values 5.0052 and 4.6278 respectively. For these linear dimensions only the major diameter is platykurtic (-0.2699). Table 3 shows that oil bean, as a biological material has non-normal frequency distribution (Wilhelm et al., 2004). The disparity between this result and that of Oje and Ugbor (1991) may be due to the fairly larger seeds they used at a lower moisture content of 4.5% d.b. Shape classifications such as sphericity has been developed by Mohsenin (1986), but the product of the three orthogonal dimensions seems more useful (Nelson, 2002).

The sphericity of the seeds ranged from 0.36 to 0.67, averaging 0.52 ± 0.07 for the ungraded lot (Table 4). It is observed that sphericity increased with decrease in seed size with the small sized seeds having the highest sphericity (0.61 ± 0.04).. The frequency distribution showed positive skewness (1.2656) and kurtosis (0.6026) with about 71% of the seeds having sphericity of between 0.456 and 0.570. It is lower than the value reported by Oje and Ugbor (1991), which ranged from 0.395 to 0.819 averaging 0.605 ± 0.277 and skewed to the left. The shape of the oil bean seed is irregular, elliptical and flattish with minor diameter about 20% of the major diameter and cannot roll. This is confirmed by the low values of sphericity (0.52 ± 0.07) and roundness of 0.40 (Oje and Ugbor (1991), However, their smoothness and flatness help them to slide, a property required in the design of hoppers and chutes and other storage facilities.

The seed surface area ranged from 29.36 to 44.56 cm^2 with about 79% having surface area between 33.00 and 40.00 cm^2. Only about 6% of the seeds have surface area greater than 40.00 cm^2, most of them from the small size category. The frequency distribution of the surface area, which averaged 37.16 ± 2.96 cm^2 can be said to have positive skewness (1.7834) and kurtosis (2.3084). Interestingly, the surface area is 20 times higher than the results obtained using Equation 4. This was due to the fact that the seeds are relatively larger than grain seeds for which the equation was developed. Also, the equation is for the specific area of grains.

Table 2**:** Size distribution of oil bean seeds at 8.73 ± 0.09% (m.c.d.b.).

		Graded size category		
Particulars	Ungraded	Large	Medium	Small
Length of seed				
L_1 mm		> 65	50 – 65	< 50
Per cent of Sample				
By number %	100	14	59	27
L_1 mm	39.20 – 76.85	65.80 – 76.85	50.10 – 64.60	39.20– 9.35
L_2 mm	30.60 – 49.80	37.30 – 49.80	30.75 – 46.60	30.60– 3.45
L_3 mm	6.50 – 17.20	6.50 – 14.65	8.20 – 17.20	9.50 – 15.45
W g	8.13 – 22.21	10.72 – 22.21	9.14 – 20.54	8.13 – 14.15
V cm^3	7.24 – 21.06	9.90 – 21.06	7.24 – 19.09	7.13 – 13.26
Average dimensions				
L_1 mm	56.18 ± 8.51	69.86 ± 3.94	57.67 ± 4.36	45.82 ± 2.87
L_2 mm	37.89 ± 3.78	42.35 ± 3.45	37.44 ± 3.53	36.57 ± 2.99
L_3 mm	12.01 ± 1.69	11.69 ± 3.74	11.70 ± 1.53	12.86 ± 1.27
W g	13.19 ± 3.28	18.08 ± 3.43	13.11 ± 2.55	10.84 ± 1.58
V cm^3	11.61 ± 3.02	16.06 ± 3.43	11.45 ± 2.31	9.64 ± 1.60

The area obtained using equation 3 generally over estimated the measured surface area for large and medium sized seeds, and under estimated it for small seeds. Values that were got are 43.47 ± 4.77 cm^2 (large seeds), 34.77 ± 5.83 cm^2 (medium seeds) and 28.17 ± 2.46 cm^2 (small seeds). This may be because of the method used for calculating the equivalent diameter and the irregular shape of the oil bean seed with low sphericity of 0.52 ± 0.07. The small size seeds seem to have the largest surface areas and surface area increased with decrease in seed size.

For the ungraded oil bean seeds, the arithmetic, geometric and square mean diameters (Table 4) ranged from 28.35 – 45.12, 25.08 – 36.19 and 27.13 – 41.25 mm respectively, averaging 35.36 ± 3.42, 29.28 ± 2.23 and 32.88 ± 2.80 mm respectively. The equivalent diameter, which is the mean of the above three diameters, ranged from 26.93 – 40.86 mm for the ungraded lot and averaged 32.50 ± 2.80 mm. It was observed that the equivalent diameter is similar in value to the square mean diameter. The frequency distributions of these parameters are positively skewed and leptokurtic (Table 3).

Table 3. Skewness and kurtosis tests for measured parameters

Parameters	Skewness (Γ^1)	Kurtosis (Γ^2)
Major diameter, mm	0.7855	-0.2699
Intermediate diameter, mm	1.6146	1.6718
Minor diameter, mm	2.3170	5.0052
Seed weight, g	0.2143	-0.6842
Seed volume, cm^3	1.1864	2.5905
Seed density, g/cm^3	2.0639	3.3116
Bulk density, g/cm^3	2.0530	2.9983
Surface area, cm^2	1.7834	2.3084
Sphericity	1.2656	0.6026
Arithmetic mean diameter, mm	1.6355	1.1972
Geometric mean diameter, mm	2.2980	4.6278
Square mean diameter, mm	1.9021	2.5687
Equivalent diameter, mm	1.9019	2.8570
Porosity, %	1.7419	1.8804

3.2 Seed Weight and Seed Volume

The average seed weight and seed volume of 13.19 ± 3.28 g and 11.61 ± 3.02 cm^3 respectively (Table 4) differ slightly with those (20.2 ± 2.82g and 18.1 ± 4.77 cm^3 respectively) reported by Oje and Ugbor (1991) due to seed sizes and seed moisture content used. The range of their values were 10.1 - 30.3g (weight) and 8.6 – 27.1 cm^3 (volume), while those obtained in this report are 8.13 – 22.21g (weight) and 7.24 – 21.06 cm^3 (volume). The skewness of weight is 0.2143 and its kurtosis is platykurtic (-0.6842) while the skewness and kurtosis of seed volume are positve, 1.1864 and 2.5905 respectively as observed by Oje and Ugbor (1991). The near symmetric and mesokurtic distribution of weight (Table 3) compared with all the parameters measured confirms its choice for the regression equations. The major diameter could also have been used even though the seed shape is irregular. The product of the three orthogonal dimensions ($L_1L_2L_3$) provides information about the volume of the seed but it is not the true volume of this irregular seed. Dividing the estimated average seed volume (11.61 cm^3) with the average of the orthogonal products (25.03 cm^3) gives the volume coefficient of 0.464 which can be used to estimate the seed volume. Dividing the seed weight by the estimated seed volume gives the estimate of the seed density of African oil bean seed. This volume coefficient is close to those of lentil (0.460) and rye (0.465) as reported by Nelson (2002). Again, a linear regression equation (Equation 8) was developed between seed volume and the product of the orthogonal dimensions.

$$V = 2.0515 + 0.3791(L_1L_2L_3) \quad (r = 0.8472) \quad \ldots.8$$

When the values of seed volume obtained using Equations 5 & 6 were regressed, a linear positive regression equation was obtained.

$$V = 1.0575 + 0.7975V_c \quad (r = 0.8449) \quad \ldots.9$$

Table 4: Calculated physical properties of oil bean seeds.

Particulars	Ungraded	Large	Medium	Small
		Graded size category		
S_d g/cm^3	0.89 – 1.39	1.04 – 1.24	0.96 – 1.39	0.89 – 1.28
A_s cm^2	29.34 – 44.56	29.36 – 37.04	32.18 – 40.12	36.84–44.56
S_p	0.36 - 0.67	0.36 – 0.52	0.43 – 0.65	0.52 – 0.67
F_1 mm	28.35 – 45.12	38.08 – 45.12	32.57 – 40.95	28.35– 4.43
F_2 mm	25.08 – 36.19	25.76 – 36.19	26.28 – 33.52	25.08–30.38
F_3 mm	27.13 – 41.28	33.32 – 41.28	30.17 – 37.96	27.13–32.82
De mm	26.93 – 40.86	32.39 – 40.86	29.91 – 37.29	26.93–32.57
P_o %	33.56 – 57.73	43.62 – 52.50	38.75 – 57.73	33.56 – 54.06
Average dimensions				
S_d g/cm^3	1.14 ± 0.08	1.13 ± 0.05	1.16 ± 0.12	1.13 ± 0.08
A_s cm^2	37.16 ± 2.96	32.42 ± 1.92	36.78 ± 2.02	40.22 ± 1.86
S_p	0.52 ± 0.07	0.46 ± 0.04	0.51 ± 0.04	0.61 ± 0.04
F_1 mm	35.36 ± 3.42	41.32 ± 1.93	35.60 ± 1.88	31.75 ± 1.50
F_2 mm	29.28 ± 2.23	32.41 ± 2.60	29.24 ± 1.62	27.76 ± 1.31
F_3 mm	32.88 ± 2.80	37.70 ± 1.99	32.98 ± 1.72	30.10 ± 1.55
D_e mm	32.51 ± 2.80	37.14 ± 2.08	32.61 ± 1.67	29.90 ± 1.36
P_o %	48.47 ± 3.59	47.95 ± 2.45	48.61 ± 3.66	47.75 ± 3.92

3.3 Seed Density and Bulk Density

The seed density of the ungraded African oil bean seeds ranged from 0.89 to 1.39 g/cm^3 and averaged 1.14 ± 0.08 g/cm^3. The medium sized seeds had the highest seed densities (Table 4) ranging from 0.96 to 1.39 g/cm^3 and averaging 1.16 ± 0.12 g/cm^3. The frequency distribution of the seed density showed positive skewness (2.0639) and leptokurtic (3.3116). A negligible 6% of the seeds had density below 1.0 g/cm^3, and about 90% have densities between 1.03 and 1.24

Table 5: Relationships of oil bean seeds with seed weight

Parameter	a	b	r	CV
Seed vol. cm^3	3.971	0.519	0.9875	3.460
Seed density g/cm^3	0.840	0.033	0.9707	0.218
Major diameter mm	37.372	1.359	0.8656	9.057
Intermediate diameter mm	27.782	0.795	0.9796	5.297
Minor diameter mm	10.797	0.093	0.2858	0.617
Arith. Mean diameter mm	25.895	0.717	0.9675	4.781
Geo. mean diameter mm	20.900	0.659	0.9371	4.396
Square mean diameter mm	24.488	0.644	0.9857	4.294
Equivalent diameter mm	23.338	0.710	0.9908	4.734
Surface area cm^2	48.240	-0.839	-0.9097	-6.925
Sphericity decimal	0.578	-0.003	-0.2280	-0.018
Porosity %	36.337	1.297	0.9694	3.185

g/cm^3, a property to be used in the separation process from lighter materials. Interestingly, these values are close to those (1.10 – 1.20 g/cm^3) obtained by Oje and Ugbor (1991). The values are similar to those of other oil seeds: peanut (1.102 g/cm^3); canola (1.111 g/cm^3) and sunflower (1.023 g/cm^3) (Nelson, 2002). Also, there seems to be no significant difference between the seed densities of the different size categories at p = 0.05. Bulk density of the seeds averaged 0.588 ± 0.019 g/cm^3. Because the seed is larger than some other seeds, its bulk density is lower than lentil seeds (Carman, 1966), beniseed, (Olayanju and Lucas, 2003), fababeans (Fraser et al., 1978), rice, millet and sorghum (Olaoye and Oni, 2001). However, the bulk density was found to be higher than for some *cucurbita* seeds (Dutta et al., 1988).

3.4 Porosity

The porosity of oil bean seeds, which ranged from 33.56 to 57.73% averaged 48.47 ± 3.59% is close to that of other flat seeds (Joshi et al., 1993). It is observed that about 82% of the time the porosity will be greater than 45%...Because biological materials have irregular shape; most of their physical properties have non-uniform frequency distribution. For oil bean seed, porosity is leptokurtic (1.8804) and positively skewed (1.7419). When regressed against surface area and seed volume, both parameters did not show any linear relationship with porosity, as shown in the equations below:

$$P_o = 0.4640 + 0.0006A_s \quad (r = 0.1300) \qquad .....10$$

$$P_o = 0.5171 - 0.0029V_c \quad (r = -0.2391) \qquad .....11$$

3.5 Relationships with Seed Weight

Table 5 shows the linear relationships between some of the physical parameters with seed weight. It is observed that minor diameter (r = 0.2858) and sphericity (r = -0.2280) did not have a linear relationship with seed weight. This may be due to the near flat nature of the seed with the minor diameter only 20% of the major diameter. The equivalent diameter showed the strongest linear relationship with seed weight (r = 0.9908), closely followed by seed volume (r = 0.9875) and square mean diameter (r = 0.9857). From this work, it is observed that the values of equivalent diameter (32.51 ± 2.80 mm) are about the same with square mean diameter.(32.88 ± 2.80 mm) and may be used to represent all the linear dimensions in engineering calculations. However, porosity showed strong linear relationship (r = 0.9694) with seed weight.. While the other parameters had positive linear relationships with seed weight, surface area decreased as seed weight increased. The product of equivalent diameter and surface area (Y) had a quadratic relationship with seed weight (W) as shown in Fig 2 The relationship is given in equation 12.

$$Y = 8.0119 - 0.3613W + 0.0153W^2 \qquad (R^2 = 0.9979) \qquad ....12$$

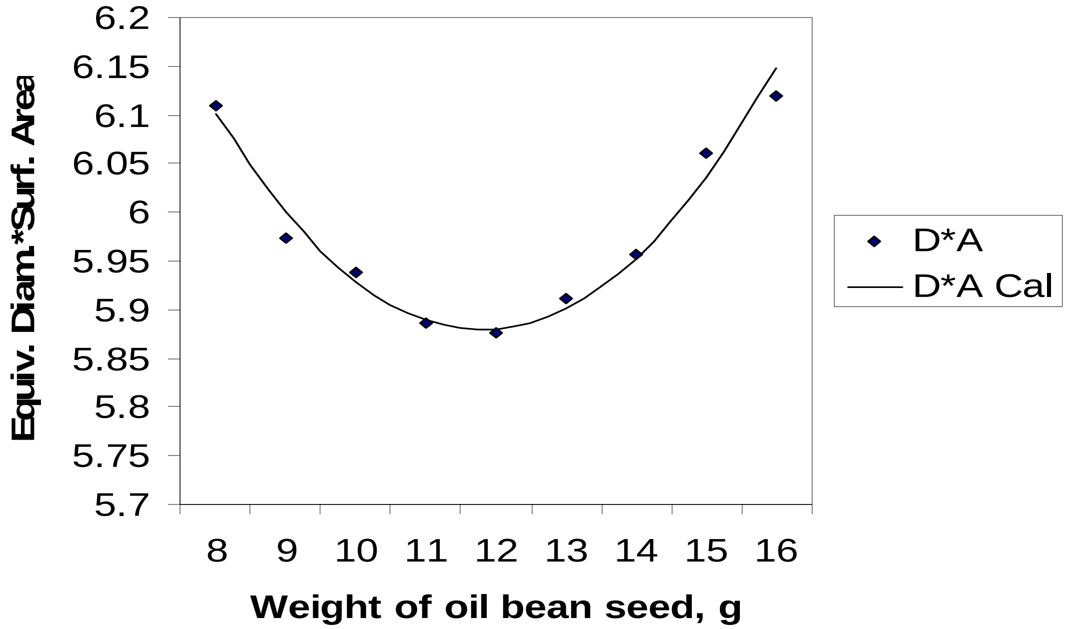

Fig. 2: Relationship between the product of equivalent diameter and surface area with seed weight

5. CONCLUSIONS

The following observations and conclusions may be deduced from the measurement of the physical properties of African oil bean seeds

1. The major, intermediate and minor diameters of African oil bean seed averaged 56.18, 37.89 and 12.01mm respectively and thus fairly larger than many other oil seeds.
2. Seed weight, seed volume and seed density were 13.19g, 11.61 cm^3 and 1.14 g/cm^3 respectively, showing that the seeds cannot float in water. A property needed in a separation process.
3. Arithmetic, geometric, square mean and equivalent diameters were found to be 35.36, 29.28, 32.88 and 32.51mm respectively, with the values for square mean and equivalent diameters almost equal.
4. The surface area, bulk density, porosity and sphericity were 37.16 cm^2, 0.588 g/cm^3, 51.56% and 0.523 respectively. The low sphericity makes the seeds difficult to roll.
5. The skewness of all the measured parameters of African oil bean seeds .showed non uniform distribution and are positive. The kurtosis of major diameter and seed weight are negative; other parameters are leptokurtic.
6. Most parameters had a linear relationship with seed weight. Minor diameter and sphericity had no linear relationship with seed weight. The product of equivalent diameter and surface area had a quadratic relationship with seed weight.

7. The volume coefficient was found to be 0.4610, and a linear relationship was established between measured volume and the product of the orthogonal dimensions.
8. Surface area and calculated volume showed no linear relationship with porosity.

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6. REFERENCES

Abbiw, D. 1990. *Useful Plants of Ghana*. Intermediate Technology Publications and the Royal Botanical Gardens, Kew

Alabadan, B.A. 1996. Physical properties of selected biomaterials as related to their postharvest handling. *Proc. Nigerian Society of Agric. Engineers* 18: 328 – 331

Aremu, A.K. and S.O**.** Fowowe, 2000. Development and performance evaluation of a manually operated plantain-slicing machine. *Proc. Nigerian Institution of Agric. Engineers* 22: 30 – 35.

ASAE Standards 46th Ed.1999. *Moisture measurement - unground grain and seeds*, .St Joseph, Mich. ASAE

Asoegwu, S.N**.** 1995. Some physical properties and cracking energy of conophor nuts at different moisture contents. *Int. Agrophysics* 9: 131 – 142.

Asoegwu, S.N. and J.O**.** Maduike. 1999. Some physical properties and cracking energy of *Irvingea gabonensis* (ogbono) nuts. *Proc. Nigerian Institution of Agric. Engineers* 21:131 – 137.

Aviara, N. A., M. I. Gwandzang, and M. A Haque,. 1999. Physical properties of guna seeds. *Journal of Agricultural Engineering Research*: 73(2): 105 – 111.

Carman, K.1996. Some physical properties of lentil seeds. *Journal of Agricultural Engineering Research:* 63: 89 – 98

Chang, C. S. 1988. Measuring density and porosity of grain kernels using a gas pycnometer. *Cereal Chemistry*. 65 (1): 13 – 15.

Ciro V., H. J. 1997. *Estudio Dinámico de la Café para el Desarrollo de la Cosecha Mecánica por Vibración* Thesis B. Sc. (Agricultural Engineering). Universidad Nacional de Colombia, Medellín, Colombia

Deshpande, S.O., S. Bal,. and T.P. Ojha, 1993. Physical properties of soybean. *Journal of Agricultural Engineering Research:* 56: 89 – 98.

Dutta, S.K., V.K Nema, and R.K Bhardwaji,. 1988. Physical properties of grain. *Journal of Agricultural Engineering Research:* 39: 2159 – 268.

Enujiugha, V.N. 2003, Nutrient changes during the fermentation of African oil bean (*Pentaclethra macophylla* Benth) seeds. *Pakistan Journal of Nutrition* 2(5):320–323.

Enujiugha, V. N. 2005. Preliminary characterization of phytase activity in African oil bean, locust bean and conophor nut. *Journal of Food Technology*. 3 (4): 475 - 478

Enujiugha, V.N. and J.O. Agbede,. 2000. Nutritional and anti-nutritional characteristics of African oil bean (*Pentaclethra macrophylla* Benth) seeds. *Applied Tropical Agriculture,* 5:11– 14.

Enujiugha, V. N. and C. T. Akanbi. 2005. Compositional changes of African oil bean (*Pentaclethra macrophylla* Benth) seeds during thermal processing. *Pakistan Journal of Nutrition.* 4 (1): 27 - 31

Fraser, B. M., S. S. Verma, and W. E Muir. 1978. Some physical properties of fababeans. *Journal of Agricultural Engineering Research:* 23: 53 – 57.

Gupta, R. K. and S. K. Das. 1997. Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research.* 56 (2): 89 – 98.

Gupta, R. K. and K Nachiket,. 1999. Bio engineering properties of oilseeds. In: *Processing and Storage of Oilseeds for Food Uses.* Central Institute of Agric. Engng (CIAE), Bhopal, India, C3-1 to C3-11.

ICRAF (International. Centre for Research In Agroforestry), 2004. Pentaclethra macrophylla. Agroforestree Database. World Agroforestry Centre .http://www.worldagroforestrycentre.org/Sites/TreeDBS/Aft/speciesinfo.cfm

Ikediobi, C.O. 1981. Amino and fatty acid composition of *Pentaclethra macrophylla* and *Treculia Africana. Journal of American Oil Chemists Society*: 58: 30 – 31.

Isawumi, M. A, 1993. The common edible fruits of Nigeria part ii. *The Nigerian Field* 58, Parts 3-4, 64pp

Jha, N. S. 1999. Physical and hygroscopic properties of makhana. *Journal of Agricultural Engineering Research:* 72: 145 – 150.

Joshi, D.C., S.K.Das and R.K Mukherjee. 1993. Physical properties of pumpkin seeds. *Journal of Agricultural Engineering Research:* 54:219 – 229.

Kachru, R. P., R. K. Gupta and A. Alam. 1994. *Physico-Chemical Constituents and Engineering Properties of Food Crops*. Jodhpur Scientific Publishers

Keay, R.W.J. 1989. *Nigerian Trees.* Claredon Press, UK. 281 pp.

Kotwaliwale, N., G. H. Brusewitz and P. R. Weckler. 2004. Physical characteristics of pecan components: effect of cultivar and relative humidity. *Trans. American Society of Agricultural Engineers.* 47 (1): 227 – 231.

Ladipo, D. O. 1984. Seed problems in fuelwood plantations in Nigeria. *Paper prepared for the International Symposium on Seed Quality of Tropical and Subtropical Species.* Bangkok. 12pp.

Ma, L., D. C. Davis, L. G. Obaldo, and G. V. Barbosa-Canovas, 1998. *Engineering Properties of Food and Other Biological Materials (A Laboratory Manual)* ASAE Publication No 14 – 98. ASAE St Joseph MI USA 198pp

Masoumi, A. A. and L. Tabil. 2003. Physical properties of chickpea (C. arientinum) cultivers. Paper No. 036058 for 2003 ASAE Annual Meeting, Las Vagas, Nevada, USA 27 – 30 July 2003. ASAE St Joseph MI USA

Miller, W. M. 1987. Physical properties data for post harvest handling of Florida citrus. *Applied Engineering in Agriculture.* 3(1): 123 – 128.

Mohsenin, N.N. 1986. *Physical Properties of Plant and Animal Materials. 2nd Edition.* Gordon and Breach Science Publishers. New York.N.Y.

Nelson, S. O. 1992. Correlating dielectric property of solids and particulate samples through mixture relationships. *Trans. American Society of Agricultural Engineers.* 35 (2): 625 – 629.

Nelson, S. O. 2002. Dimensional and density data for seeds of cereal grain and other crops. *Trans. American Society of Agricultural Engineers.* 45 (1): 165 – 170.

Nelson, S. O. and T. S. You. 1989. Microwave dielectric properties of corn and wheat kernels and soybeans at microwave frequencies. *Trans. American Society of Agricultural Engineers.* 32 (1): 242 – 249.

NFT (Nitrogen Fixing Trees) Highlights, 1995. *Pentaclethra macrophylla: a multipurpose tree from Africa with potential for agroforestry in the tropics.* NFTA 95-05, September 1995. www.winrock.org/forestry/factpub/pentamac.htm

Oh, I. H., S. H. Jo and K. S. Rhim. 2001. A new method for determining apparent density and void fraction in a tobacco column, *Trans. American Society of Agricultural Engineers.* 44 (3): 651 - 654

Oje, K. and E.C. Ugbor. 1991: Some physical properties of oilbean seed. *Journal of Agricultural Engineering Research:* 50:305 – 313

Okafor, J.C. 1979. Edible indigenous woody plants in the rural economy of the Nigerian forest zone. In D.U.U. Okali (ed):*The Nigerian Rainforest Ecosystem*.P.262– 300.

Okafor, J.C. 1987. Diversification of the Nigerian food basket through increased use of indigenous fruits and vegetables. *Paper presented at the Training Workshop on Massive Cultivation of Fruits and Vegetables in Anambra State*. July 21 –22, 1987 at Enugu Municipal Hall, Enugu.

Okafor, J. C. 1982. Promising trees of agroforestry in southern Nigeria. In *Agroforestry in the African Humid Tropics.* Ed. L. H. MacDonald (Proceeding of a Workshop held in Ibadan, Nigeria, 27th April – 1st May 1981). Published by The United Nations University Press. Tokyo, Japan.

Okafor, J. C. 1991. Improving edible species of forest products. In:*UNASYLVA (FAO 10th World Forestry Congress,17 – 26 September, 1991).* Paris, Edited by Stephen A. Dembner.

Okafor, J. C. and Fernandez, E. C. 1987. Compound farms of southeast Nigeria. A predominant agroforestry homegarden system with crops and small livestock. *Agroforestry Systems.* 5(2): 153 – 168.

Okigbo, B.N. 1977. Neglected plants of horticultural and nutritional importance in traditional farming systems of Tropical Africa. *Acta Horticulturae* 53: 131 – 150.

Olaoye, J. O. and oni, K. C. 2001. Some physical and mechanical properties of selected grain crops. *Proc. Nigerian Institution of Agric. Engineers* 23:315 – 329.

Olayanju, T. M. A and E. B**.** Lucas, 2003. Effect of moisture content on some gravimetric properties of two beniseed accessions. *Proc. Nigerian Institution of Agric. Engineers* 25: 274 - 279

Orji, C.U. 2000. Evaluation of the physical properties of breadfruit seeds *(Treculia Africana*) necessary for shelling. *Journal of Agricultural Engineering and Technolog* 8: 55 – 58.

Oyenuga, V.A. 1968. *Nigeria's Food and Feeding Stuffs: chemistry and nutritive value*. Ibadan Unversity Press, Ibadan

Pabis, S., S.D. Jayas. and S. Cenkowski. 1998. *Grain Drying Theory and Practice*. John Wiley and Sons, New York.

Sheperd, H. and R. K Bhardwaj,. 1986. Moisture dependent physical properties of pigeon pea. *Journal of Agricultural Engineering Research:* 35: 227 – 234.

Singh, K. K, B. S. Reddy, A. C. Varshney and S. Mangraj. 2004. Physical and functional properties of orange and sweet lemon. *Applied Engineering in Agriculture*. 26 (6): 821 – 823.

Suthar, S.H. and S.K. Das. 1996. Some physical properties of Karingda (*Citrullus lanatus* Thumb Mansf) seeds. *Journal of Agricultural Engineering Research:* 65:15 – 22.

Tabatabaeefar, A. H. Aghagoolzadeh and H. Mobli. 2002. The design and development of a chickpea second sieving and grading machine. *Paper No 021175. 2002 ASAE Annual International Meeting/CIGR XVth World Congress.* Chicago. Illinois, USA 28 = 31 July 2002.

Tico Etnobotanical Dictionary. 2005. *Pentaclethra macrophylla* (Benth) hhtp://www.ars-grin.gov/duke/dictionary/tico/p.html

Ureña, M. O., M. G. Galvån and A. A. Teixeira. 2002. Measurement of aggregate true particle density to estimate grain mixture composition. *Trans. American Society of Agricultural Engineers.* 45 (5): 1925 – 1928.

Wilheim, L. R., D. A. Suter and G. H. 2004. Physical Properties of Food Materials. Chapter 2. *In Food and Process Engineering Technology*. P. 23 – 52. St Joseph, Michigan. ASAE (Revised August 2005)..

Zapfack, L., M. Ngobo, N. Tchamon, S. Weise and A. Gallason. 1999. Plant diversity and non-timber forest products of short fallows in southern Cameroon. *In International Institute for Tropical Agriculture Project 1 1999. Shallow Fallow Systems*. P. 46 – 49.