Determination of some Physical Properties of African Yam Beans.

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ABSTRACT

Various post-harvest physical properties of African yam beans (*Sphenostylis stenocarpa*) as well as their application were investigated and reported. The major diameter, intermediate diameter, minor diameter, and geometric mean diameter were determined as 8.1778 cm, 6.712 cm, 6.3025 cm and 7.0128 cm, respectively. The sphericity indicated that the bean shape (0.85933) is close to a sphere. The surface area and specific surface area were 77.404 cm^2 and 169.709 cm^2 cm^{-3}, respectively. The static coefficient of friction on three different material surfaces varied from 0.114 to 0.196 on asbestos, from 0.097 to 0.1997 on aluminum, and from 0.1534 to 0.2049 on plywood. The angle of repose which was by the emptying method was 23.775^0. The solid volume, bulk volume, solid density, bulk density, seed mass and porosity were 0.2387 cm^3, 7.6552 cm^3, 1.0179 gcm^{-3}, 1.0036 gcm^{-3}, 0.2362 g and 1.6805%, respectively. The moisture content varies from the range of 2.84% wb to 3.13% wb or a range of 2.93% d.b to 3.23% d.b.

(Keywords: *Sphenostylis stenocarpa*, post harvest physical prosperities, diameter, sphericity, surface area, static coefficient of friction, angle of resose, solid volume, bulk volume, solid density, bulk density, seed mass, porosity, moisture content)

INTRODUCTION

African yam bean (Uzaaku or Ijiriji as it is named among the Igbos in Enugu State, South Eastern Nigeria) is a leguminous crop and is bean-shaped and black, brown, white, grey or speckled in appearance. The bean seeds are normally contained in a pod just like cowpea. Each pod contains between ten and thirty seeds that may be of more than one color. The pods are usually borne on a climbing stem, with wide heart-shaped leaves; one at each node spaced apart along the stem.

The African yam bean plant is an annual crop, whose pods could be harvested green when mature, but mostly when the color of the mature pods are just beginning to change to brown signifying the onset of drying.

The seed is high priced food very rich in protein (and other food components) and it is generally consumed in the entire southeastern Nigeria and beyond. African yam beans can be consumed in various forms. They can be fried and eaten with or without the seed coat just like fried groundnut. In some villages the fried beans are eaten with palm kernel or coconut. It could be cooked like cowpea (even though it takes longer to cook) and eaten as beans pottage or in combination with yam, "jigbu" or "abacha" (i.e. tapioca). Despite the high consumption rate of African yam bean and its potential as a good source of foreign earnings, the traditional method of processing provides a poor-quality product with low nutrient content. This limits it utilization both locally and internationally.

In Nigeria, there is scarcely any large-scale producer of African yam bean (who has machinery for its harvesting, handling or processing). Many small-scale producers carry out these operations manually. The physical properties of African yam bean, like those of other grains are essential for the design and construction of equipment systems and controls for handling, harvesting, processing, transportation, and storing the grains.

The physical properties of numerous grains, nuts and seeds have been determined by other researchers such as cocoa beans (Bart-Plange and Baryeh, 2003); pistachio nuts (Kashaninejad et al., 2006); green soybean (Sirisomboon et al., 2007); gorgon nut (Jha and Prasad, 1993); neem nut (Visvanathan et al., 1996); cashew nut (Balasubramanian, 2001); bambara groundnut (Baryeh 2001); arecanut (Kaleemulah and Gunasekar, 2002); macadamia nut (Braga et al., 1999); walnut (koyuncu et al., 2004); shea nut (Olaniyan and Oje,2002), and filbert nut (Pliestic et al., 2006). Despite all of these research accounts, there is very little information on the physical properties of African yam beans.

The aim of this work is to determine some post harvest physical properties such as moisture content, 1000 unit mass, linear dimension, geometric mean diameter, sphericity, bulk density, solid density, porosity, surface area, specific surface area, coefficient of static friction on various surfaces and angle of repose. These will be useful parameters in designing of handling and processing equipment.

MATERIALS AND METHODS

Sample

The mature seeds of African yam bean were bought from the market at Nsukka, Enugu State of Nigeria. The seeds were cleaned manually by hand to remove all foreign matter such as dirt, pieces of stones, and broken seeds. Measurement of the physical properties was thereafter carried out. Figure 1 shows the seed of African yam beans.

Figure 1: African Yam Beans with a Measuring Instrument.

Physical Properties

Moisture Content Determination: The method of moisture measurement of peanut (ASAE 5410.1 DEC. 97) (ASAE, 1998) was modified for determining the moisture content of African yam bean. Samples were randomly selected from 20kg to determine the moisture content according to ASAE standard 5410 (ASAE, 1983) by oven-drying 100g of each sample at 130° C for 6 hours. The samples were then cooled in a dessicator and weighed using an electronic balance (Yamato, model HB 3000, Japan) reading to 0.01g in order to determine the moisture loss. The measurement on each sample were replicated three times and the average moisture content taken. The moisture content of the seed in % (dry basis) was calculated with the following formula:

$$M_s = \frac{100(M_{si} - M_{sf})}{M_{sf}} \quad \textbf{(1)}$$

Where M_s is moisture content in % dry basis, M is mass in g, and subscripts s, i and f are seeds, initial and final, respectively.

Bulk Density, Solid Density, and Porosity: Bulk density of the seed (ratio of bulk weight to bulk volume) was determined. The bulk seed was put into a container whose weight and volume were known (1000 cm^3) and was weighed. Bulk density ℓ_b in g/cm^3 was calculated for three samples.

The solid density ℓ_S (g/cm^3) is calculated by dividing the mass of the individual seed by its volume. The mass of the individual seed (20 unit sampling from 20 kg bulk seed) was measured and recorded.

The volume of the individual seeds was determined by water displacement method:

$$V = \frac{M_w}{\ell_t} \quad \textbf{(2)}$$

Where: M_w is the mass weighed in water in g and ℓ_t is the density of water (1.0g/cm^3)

Porosity ε , in % shows the amount of pore spaces in the bulk material. Mohsenin (1980) presents a formula for its calculation as shown below:

$$\varepsilon = 100\left(1 - \frac{\ell_b}{\ell_S}\right) \quad \textbf{(3)}$$

Size and Shape of Seeds: Each unit seed from 20 kg sampling were weighed and measured for major diameter, intermediate diameter and minor diameter. This was done with 100 units of seeds and by using a Vernier caliper (Mitutoyo, model Absolute Digimatic, Japan) reading to 0.01 mm. Mohsenin (1980) presented an expression for calculation of geometric mean diameter D_g in mm as:

$$D_g=(abc)^{1/3} \quad \textbf{(4)}$$

and also for calculating sphericity ϕ as:

$$\phi = \frac{(abc)^{1/3}}{a} = \frac{D_g}{a} \quad \textbf{(5)}$$

Where: a is the major diameter, b is intermediate diameter and c is minor diameter (all in mm).

Surface Area and Specific Surface Area: Surface area S in mm^2 and specific surface area S_s in mm^2/cm^3 were estimated by the relationship given by McCabe et al. (1986) and which is given as:

$$S = \bar{\Lambda} D_g^2 \quad \textbf{(6)}$$

Where: S is surface area in mm^2 and Dg is geometric mean diameter in mm.

And the specific surface area S_s given as:

$$S_s = \frac{S\ell_b}{M_s} \quad \textbf{(7)}$$

Where S_s is specific surface area in mm^2/cm^3, S is the surface area mm, M_s is mass of unit seed in grams and ℓ_b is the bulk density of seeds in g/cm^3.

Coefficient of Static Friction on Various Surfaces: The coefficient of static friction of the seeds was determined against three structural materials: aluminum, asbestos, and plywood. A wooden box measuring 450 mm X 300 mm X 120 mm was constructed without a base (Olajide et al., 2000) and placed on an adjustable tilting plate, faced the test surface. There were two pieces of plastic between the box and the plate placed under the sides of the walls of the box oppositely to raise the box up and not to touch the plate surface. Then the box was filled with the sample, the two pieces of plastic removed which made the box to remain above the plate, but the sample touched the plate. The inclination of the plate was increased gradually by a screw device until the box just starts to slide down. The angle of tilt ϕ in degree was read from a graduated scale. This was done three times and the coefficient of static friction μ calculated from the expression (Fraser et al., 1987; Shepherd and Bhardwaj, 1986; Joshi et al., 1993; and Pliestic et al., 2006) below:

$$\mu = \text{Tan}\,\phi \quad \textbf{(6)}$$

Angle of Repose: The angle of repose of the bulk material was measured by emptying method as prescribed by Bart-plange and Baryeh (2003). This was conducted in five samples.

Thousand Unit Mass of Seeds: One hundred units of bean seeds were weighed (in 3 replicates) and recorded. 1000-unit mass was calculated by multiplying the mass (g) of 100-unit of the bean seed by 10.

RESULTS AND DISCUSSION

Table 1 shows the summary results of the physical properties of African yam beans.

Moisture Content: Moisture content value wet basis varied from 2.84% to 3.13% with a mean value of 3.00033%. For dry basis the moisture content mean value was slightly higher than the value for wet basis with a value of 3.10% and had a minimum value of 2.93% and a maximum value of 3.23%. As seen from the result, African yam bean has a low moisture content value.

Table 1: Summary of the Physical Properties of African Yam Bean.

Properties	N	Mean	S.D	Min. Val.	Max. Val.
Major diameter, a (cm)	100	8.1778	$\pm$ 0.6048	6.700	10.320
Intermediate diameter, b (cm)	100	6.712	$\pm$ 0.5656	5.000	7.700
Minor diameter, c (cm)	100	6.3025	$\pm$ 0.43365	5.17	7.44
Geometric Mean Diameter, G.M.D. (cm)	100	7.0128	$\pm$ 0.42946	5.91033	8.05721
Sphericity	100	0.85933	$\pm$ 0.04348	0.7781	1.01485
Surface Area (cm^2)	100	77.40427	$\pm$ 4.8939	27.4391	47.7309
Specific surf. Area (cm^2/cm^3)	100	169.7089	$\pm$ 42.4481	104.6362	388.3746
Coefficient of static friction on various surface					
Asbestos	4	0.1545	$\pm$ 0.041	0.114	0.196
Aluminium	4	0.1471	$\pm$ 0.0513	0.097	0.1996
Plywood	4	0.1694	$\pm$ 0.0264	0.1534	0.2049
Angle of Repose					
Emptying Method (^{o})	4	23.775	$\pm$ 0.1899	23.00	24.50
Kernel Mass, g	100	0.2362	$\pm$ 0.0528	0.1294	0.3839
Solid Volume, V_S (cm^3)	100	0.2387	$\pm$ 0.0524	0.1313	0.3858
Bulk Volume, V_b (cm^3)	3	7.6552	$\pm$ 0.06623	7.4576	7.8372
Solid Density, ℓ_S (gcm^{-3})	100	1.0179	$\pm$ 0.2530	0.3354	2.1059
Bulk Density ℓ_b (gcm^{-3})	3	1.0036	$\pm$ 0.06623	0.9991	1.116
Porosity, ε (%)	3	1.6805	$\pm$ 1.0325	0.6206	2.6854
Moisture Content, (%)					
Wet Basis (w.b)	3	3.0033	$\pm$ 0.1454	2.84	3.13
Dry Basis (d.b)	3	3.10	$\pm$ 0.6411	2.93	3.23

Where N is the number of replications

Bulk Density, Solid Density and Porosity: The kernel and bulk densities are more than the density of water. The mean bulk density and mean solid density are 1.0036 gcm^{-3} and 1.0179 gcm^{-3}, respectively. This implies that the seeds will sink in water. This makes it possible to separate them from materials that are less dense than water (Sirisomboon et al., 2007; Pliestic et al., 2006; and Cevat & Ozcan, 2002). The solid density for African yam beans vary from 0.3354gcm^{-3} to 2.1059gcm^{-3} while that of bulk density vary from 0.9991 to 1.0116 gcm^{-3}. The pore spaces in African yam bean in bulk loading are very few. The porosity ranges from 0.6206% to 2.6854% with a mean value of 1.6805% with small pore spaces. This property is required in air and heat flow in agricultural material. This shows how easily a stream of heated air for drying will pass through a pack of material and thus affect the rate of drying of the material. This seed with low porosity will dry very slowly. The aeration of this bean seed will be difficult. Natural aeration is impossible. High power fans and motors should be employed for effective aeration.

Size and Shape of Seeds: The major diameter range from 6.7 cm to 10.32 cm with mean value of 8.1778 cm. The intermediate diameter range from 5.0 cm to 7.7 cm with mean value of 6.712 cm. Minor diameter has a range of 5.17 to 7.44 cm with mean value of 6.3025 cm. The geometric mean diameter ranged from 5.910 cm to 8.057 cm with mean value of 7.013cm.

The shape of the bean was close to sphere with a range of 0.778 to 1.015 and a mean value of 0.859 (Afonso et al., 2007). This shows that the material will always tend to roll when it is on a particular orientation. These properties are always considered when designing hopper and dehulling equipment for seeds.

Surface Area and Specific Surface Area: The surface area of African yam beans ranges from 27.439 cm^2 to 47.7309 cm^2 with a mean value of 77.4043 cm^2. The surface area affects the velocity of air stream that can be used in other to separate the seed from unwanted material in pneumatic separator or to convey seed in pneumatic conveying. The mean specific surface area is very high (169.709 cm^2/cm^3). This value is higher than the values for *Jatropha curcas* l. nut (1.91 $\pm$ 0.12 cm^2/cm^3) and kernel (2.12 $\pm$ 0.08 cm^2/cm^3). This means that the mass or energy transfer rate through the surface of the beans might be higher than that for *Jatropha curcas* l nut and kernel.

Solid Volume/Bulk Volume: The bean solid volume ranged from 0.1313 cm^3 to 0.3858 cm^3 with weighed mean of 0.2387 cm^3. The bulk volume ranged from 7.458 cm^3 to 7.8372 cm^3 with weighed mean value of 7.6552 cm^3. The seed has a mean mass value of 0.236 g, with ranges between 0.1294 g to 0.3839 g.

Coefficient of Static Friction on Various Surfaces and Angle of Repose: Of the three surfaces tested, plywood had the highest coefficient of static friction (0.1694) followed by asbestos (0.1545), and aluminum 0.1471. This is due to variation in roughness of the surfaces. This value is needed in the design of agricultural machine hoppers and other conveying equipment. It determine how a pack of grain or seed will flow in these systems

The angles of repose is 23.78^0, using the emptying method this property determine the minimum slope of flow in self emptying bin or minimum slope of flow in a hopper. This value is 43% and 81% less than that of shea kernel and *Jatropha curcas* l. kernel, respectively. The reasons for this could be due to the hardness and less-viscous nature of the bean seeds compared to shea kernel and *Jatropha curcas* l. kernel.

Moisture Content: The moisture content of African yam beans ranged from 2.84% to 3.13% with mean value of 3.0033% wet basis or 2.93% to 3.23% with mean value of 3.10% dry basis. The moisture content of harvested African yam beans is very low.

CONCLUSIONS

The following conclusions can be drawn from the results of this study:

1. The mean values for major diameter, intermediate diameter, minor diameter, and geometric mean diameter were determined as 8.1778 cm, 6.712 cm, and 6.3025cm.

2. The mean sphericity indicated that the bean shape (0.85933) is close to a sphere. The material will always tend to roll when placed on a particular orientation. This property is useful in the design of hopper and dehulling equipment for seeds.

3. The mean surface area and specific surface area were 77.404 cm^2 and 169.709 cm^2cm^{-3}, respectively. The surface area affects the velocity of air stream that can be used in other to separate seed from unwanted material in pneumatic separator or to separate seed in pneumatic conveying. Specific surface area is considered during mass and energy transfer through the surface of seeds.

4. The static coefficient of friction on three different material surfaces varied from 0.114 to 0.196 on asbestos, from 0.097 to 0.1997 on aluminum, and from 0.1534 to 0.2049 on plywood. This value is used in the design of agricultural machine hopper and other conveying equipment.

5. The angle of repose which was by the emptying method was 23.775^0. This property is needed in determining the minimum slope of flow in self emptying bin or hoppers.

6. Mean values for the solid volume, bulk volume, solid density, bulk density, seed mass, and porosity were 0.2387 cm^3, 7.6552 cm^3, 1.0179 gcm^{-3}, 1.0036 gcm^{-3}, 0.2362 g, and 1.6805% respectively. The bulk and solid densities shows that the seed will sink in water. This makes it possible to separate from materials that are less dense than water.

7. High power motors and fans would be needed in aerating the bulk material due to its low porosity value.

REFERENCES

1. Afonso, P.C J., P.C. Correa, F.A.C. Pinto, and D.M. Queiroz. 2007. "Aerodynamic Properties of Coffee Cherries and Beans". *Biosystems Engineering.* 98:39-46.

2. ASAE. 1998. “ASAE 5410.1 DEC 97. Moisture Measurement of Peanut”. In: *ASAE Standards 1998. 45th edition*. 560-561. ASAE, the Society for Engineering in Agricultural, Food, and Biological Systems: St. Joseph, MI.

3. Bar yeh, E.A. 2001. “Physical Properties of Bambara Groundnuts”. *Journal of Food Engineering*. 47:321-326.

4. Balasubramanian, D. 2001. “Physical Properties of Raw Cashew Nut”. *Journal of Agricultural Engineering Research*. 78:291-297.

5. Bart-Plandge, A. and E.A. Baryeh. 2003. “The Physical Properties of Category B Cocoa Beans”. *Journal of Food Engineering*, 60(3): 219-227.

6. Braga, G.C., S.M. Couto, T. Hara, and J.Y.P. Almeida Neto. 1999. “Mechanical Behaviour of Macademia Nut under Compression Loading”. *Journal of Agricultural Engineering Research*, 39: 259-268.

7. Cevat, A. and M. Ozcan. 2002. “Some Physico-Mechanic Properties of Terebinth (*Pistacia terebinthus* L) Fruits”. *Journal of Food Engineering*. 52:97-101.

8. Jha, S.N. and S. Prasad. 1993. “Physical and Thermal Properties of Gorgon Nut”. *Journal of Food Process Engineering.* 16:237–245.

9. Joshi, D.C., S.K. Das, and R.K. Mukherjee. 1993. “Physical Properties of Pumpkin Seeds”. *Journal of Agricultural Engineering Research*. 54:219–229.

10. Kaleemullah, S. and J.J. Gunasekar. 2002. “Moisture-Depended Physical Properties of Arecanut Kernels”. *Biosystems Engineering*. 82:331-338.

11. Kashaninejad, M., A. Amortazavi, A. Safefekordi, and L.G. Tabil. 2006. “Some Physical Properties of Pistachio (*Pistacia vera* l.) Nut and its Kernel”. *J. Food Engr.* 72(1):30-38.

12. Kuyuncu, M.A., K. Ekinci, and E. Savran. 2004. “Cracking Characteristic of Walnut”. *Biosystems Engineering*. 87:305-311.

13. Mohsenin, N.N. 1980. *Physical Properties of Plant and Animal Material*. Gordon and Breach Science Publishers: New York, NY.

14. Olajide, J.O, B.I.O. Adepomowaye, and E.Y Otunola. 2000. “Some Physical Properties of Shea Kernel”. *Journal of Agric, Engr. Res.* 76:419-421.

15. Olaniyan, A.M. and K, Oje. 2002. “Some Aspects of the Mechanical Properties of Shea Nut”. *Biosystems Engineering*. 81:413–420.

16. Pliestic, S., N. Dobricevic, D. Filipovic, and Z. Gospodaric. 2006. “Physical Properties of Filbert Nut and Kernel”. *Journal of Biosystems Engineering*. 93(2):173-178.

17. Shepherd, H., and R.K. Bhardwaj. 1986. “Moisture-Dependent Physical Properties of Pigeon Pea”. *Journal of Agricultural Engineering Research*. 35:227–234.

18. Sirisomboon, P., P. Pornchaloeampong, and T. Romphophak. 2007. “Physical Properties of Green Soybean: Criteria for Sorting”. Journal of Food Engineering. 79:18–22.

19. Visbanthan, R., P.T. Palanisamyi, L. Gothandapany, and V.V. Sreenarayanan. 1996. “Physical Properties of Neem Nut”. *Journal of Agricultural Engineering Research*. 63:19-26.

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