Some Moisture Dependent Physical Properties of Baobab Seeds (*Adansonia digitata* L.)

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ABSTRACT

Baobab seed is a good source of protein and oil, but its processing and handling has not been mechanized. Therefore, this study determines the moisture dependent physical properties of baobab seeds that can be useful for development and performance of baobab seed processing and handling machines within moisture level range of 8.38 to 52.26% dry basis (d.b). The properties (Major diameter, intermediate diameter and minor diameter, seed sphericity, bulk density, true density, porosity, geometric mean diameter, seed surface area and seed static coefficient of friction on different surfaces) were determined following ASAE 2005 Standard. The major diameter (D_1), intermediate diameter (D_2) and minor diameter (D_3) of seed increased from 11.65 to 14.26mm, 9.43 to 11.38mm and 7.33 to 11.10mm, respectively with increased in moisture content levels from 8.38 to 52.26% (d.b). Seed sphericity decreased linearly from 80 to 78% as moisture content levels increases, while bulk density, true density and porosity increases from 667.04 to 1128.07kg/m^3, 1196.79 to 1761.49 kg/cm3 and 36.09 to 44.66%, respectively as moisture content levels increases. Similarly, geometric mean diameter of the seed and seed surface area increases from 9.3 to 11.10 mm and 236.93 to 335.17mm^2, respectively with increased in moisture content levels. Also seed static coefficient of friction on different surfaces increased in the order of mild steel plate (0.404 to 0.507), galvanized steel plate (0.502 to 0.525) and stainless steel plate (0.598 to 0.638) as moisture content levels increases.

Keywords: Baobab seed, physical properties, moisture level.

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INTRODUCTION

Baobab (*Adansonia digitata* L.) belongs to the *Bombaceae* family and is known generally as the African baobab. The African baobab is a deciduous, tropical tree with a massive trunk supporting a tangled mass of small branches. It height ranges from 10 to 25 m and the trunk may be up to 6– 10 m in diameter. The leaves are palmate with five sessile leaflets. The bark is smooth, silver-grey, pinkish-purple or dark grey in colour and contains a yellow or green inner layer, which is composed of thick, tough, longitudinal fibres. It is a very long-lived, fast-growing tree (in its juvenile stage) and has a life span of hundreds of years. The flowers are large, up to 12– 15 cm in diameter (Saulawa*et al*., 2014).

In Africa, baobab plays an important role in human nutrition; the dried leaves are rich in ß carotene, a precursor to vitamin A which is important in the fight against cancer and heart disease and also necessary for good eyesight. The dried leaves are excellent source of several trace elements, which can combat micronutrient deficiency. The young tender leaves are rich in vitamin A and calcium and are used as a vegetable and in sauce preparation (Chadare *et al*., 2008). The fruit pulp are exceptionally high in vitamin C. Baobab, locally called kuka (Hausa) and luru (Yoruba), is another non-conventional feedstuff that is readily available and under-utilized but holds much agronomic potential (Saulawa *et al*.,2014). According to Chadare*et al*. (2008), about 23 g of baobab fruit powder provides the daily recommended amount of vitamin C for an average adult. Fruit powder contains vitamins and other valuable nutrients, essential for normal human growth while the seed contains edible oils and more protein than groundnuts and is rich in the amino acid lysine, vitamin B1 (thiamine), calcium and iron (Chadare *et al.,* 2008). The baobab tree is multipurpose, widely used for household, medicinal, and nutritional purposes and also provides additional income to farmers (Wickens, 2008).

The baobab fruit pulp contains ten times the Vitamin C of oranges, calcium, tartaric, malic and succinic acids, water soluble pectin, and a whole range of minerals and essential micro elements rarely found in regular foods (Besco *et al*., 2007; Bosch *et al*., 2009). Its leaves have a protein content of 4%, and are rich in calcium, iron, potassium, magnesium, molybdenum, zinc, phosphorus and vitamins A and C (De Caluwe *et al*., 2009). The traditional use of various parts of the baobab plant in the prevention and cure of ailments such as measles, small pox, dysentery, diarrhea and in the management of the sickle cell anaemia has been reported (De Caluwe and Damme, 2010). Cold and hot drinks have been prepared from the fruit pulp of the Baobab; the fruit pulp is also locally processed into sweets. The uses of the plant across the globe and its contribution to rural incomes in some parts of Africa has created a case for its domestication and promoted the call for further research to ensure that its potentials are maximized (De Caluwe and Damme, 2010).

The knowledge of physical properties of biomaterials are significant in various challenges that are identified with the design of particular machines or explanation of the behavior of products in storage, handling, planting, harvesting, threshing, separating, cleaning, sizing and grading (Olalusi *et al*., 2009). The answer to these problems demands the knowledge of information on physical characteristics. Over the years, numerous researchers Moshenin (1986), Aviara *et al*. (2005), Calisir *et al*. (2005), Faleye *et al.* (2013) and Ahmadi *et al*. (2012) have conducted investigations into diverse physical properties of biomaterials employing related techniques as reported in various research works. Among the physical properties examined were size and shape, true and bulk density, sphericity, surface area, porosity, arithmetic and geometric mean diameter as relating to design of machines. Most of these studies were conducted with respect to moisture contents because the functionality and efficiency of agro-processing machines is moisture dependent. Therefore, this study determined the moisture dependent physical properties of baobab seeds such as; size, shape, sphericity, bulk density, true density, porosity, thousand weight, coefficient of friction and surface area, for effective development and performance of baobab seed processing and handling machines.

MATERIALS AND METHODS

Material Collection and Preparation: Baobab fruit pods were obtained from Saki, Oyo State, Nigeria. The dried baobab fruit pods harvested were cracked and washed to separate the seeds from the white pulps covering the seeds (Figure 1). The collected seeds were then sun dried to storage moisture level and further oven dried in accordance with ASAE 2005 standard as described by Okoro and Osunade (2013).

a b c

Figure 1: Baobab Fruit: a) Dried Pods b) Split Pods and c) Baobab Seed

Oven drying of the seeds in triplicates were performed at 65 ^{0}C for 24 h until constant weight was. Weight measurements were determined using an MP 10001 Gallenhamp digital weighing balance of 0.001 kg accuracy. The moisture content, MC_1 of the oven dried seeds was computed from equation 1.

$$MC_1 = \frac{100(W_1 - W_2)}{W_2} \qquad 1$$

Where:

MC_1 = Moisture content of baobab seed (% db)
W_1 = Initial weight of the sample (kg)
W_2 = Final weight of the oven dried sample (kg)

Samples of the oven dried baobab seeds were conditioned by the method developed by Visvanathan (1998) by soaking in water for 2, 4, and 6 h to obtain seed samples of three more moisture content levels, MC_2, MC_3 and MC_4, respectively for the physical property experiments. The conditioned seed samples were then kept in polyethylene bags of 100 μm thickness and then stored in a refrigerator at 5^0C for two weeks for moisture distribution in each of the samples. The moisture contents, MC_2, MC_3 and MC_4 of the conditioned seed samples and weight of moisture absorbed were computed from equations 2 and 3 (De caluwe *et al*., 2009), respectively. The conditioned samples were therefore carefully packed separately in double layer, low density polyethylene bag and stored in the refrigerator for 72 h for proper moisture distribution. Before the experiment, required quantities of the dried and conditioned seeds were placed in the laboratory for 2 h and allowed to be in equilibrium with the ambient conditions.

$$Bf = \frac{Ai(100-a)}{100-b} \quad 2$$

$$Q = \frac{Ai(b-a)}{100-b} \quad 3$$

Where,

Bf = Final mass of the sample after drying (kg)
Ai = Initial mass of the sample (kg)
a = Initial moisture content of the sample (% d.b)
b = Final (desired) moisture content of the sample (% d.b)
Q = Mass of water adsorbed (kg)

Size, Shape, Sphericity and Surface Area of Seed

Ten seeds each from the dried and conditioned seeds were randomly selected. The three principal axes of the selected seeds namely: major (D_1), intermediate (D_2) and minor (D_3) diameters (Figure 2) were measured using a Neiko 01407A Electronic Digital Vanier Calliper of 0.01 mm degree accuracy. The shape of the seeds was compared with the chartered standards (Moshsenin, 1986) and the Geometric Mean Diameter, D_{gm}, Sphericity, Ø and Surface Area, S_a of each seed was determined from equations 3, 4 and 5, respectively (Kibar and Ozturk, 2008).

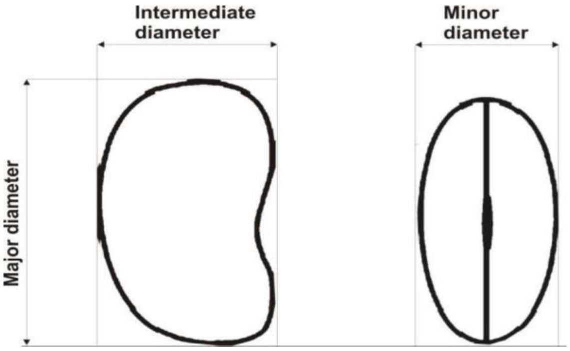

Figure 2: A sketch of baobab seed with measured principal axes

Geometric mean diameter, $D_{gm} = (D_1 D_2 D_3)^{\frac{1}{3}}$ 4

Sphericity, $\emptyset = \frac{(D_1 D_2 D_3)^{\frac{1}{3}}}{D_1}$ 5

and,

Surface Area $S_a = \frac{\pi D D_1^2}{(2D_1 - D)}$ 6

Where:

$D = (D_2 D_3)^{\frac{1}{2}}$

D_1= Major diameter (mm)

D_2 = Intermediate diameter (mm)

D_3 = Minor diameter (mm)

Bulk and True Density and Porosity: The bulk densities, ρ_b of baobab seeds at the different moisture levels was determined by filling an open top rectangular box of 200 x 100 x 100 mm of known self-weight to the brim with baobab seeds and weighed to determine the net weight of the seeds (Figure 3). The procedure was repeated ten times and the average taken as the bulk density of the seeds at the different moisture levels. Bulk density was calculated from equation 6 as:

$$BulkDensity(\rho_b) = \frac{weightofsample\ (kg)}{volumeoccupied\ (m^3)} \quad 7$$

The true or solid density, ρ_t of baobab seeds was determined by the water displacement method. Baobab seeds sample of known weight (50 g) was poured into a 100 cm^3 fractionally graduated cylinder containing 50 cm^3 distilled water. The volume of water displaced by the seeds was collected and measured. The true density, $\rho_t$was calculated from equation 7. The experiment was repeated ten times and the average was taken as true density of the seeds at different moisture contents.

$$True\ Density, \rho_t = \frac{Weigt\ of\ sample\ (g)}{Volume\ of\ distilled\ water\ displaced\ (cm^3)} \quad 8$$

Figure 3: Solid Density Apparatus: Fractional Cylinder and Weighing Balance

The Porosity, ρ_p of baobab seeds was determined theoretically from bulk and true densities of the seeds using the relationship presented by Mohsenin (1986) as expressed in equation 9. The density apparatus used during the experiment is as presented in Figure 3.

Porosity, $\rho_{p=1-(\frac{\rho_b}{\rho_t})}$ 9

Where;

ρ_p= porosity (%)

ρ_b= bulk density (g/cm^3)

ρ_t= true density (g/cm^3)

Coefficient of Friction: Coefficient of static friction of baobab seeds was determined on three surfaces namely stainless steel, galvanized steel and mild steel. Using the method described by Solomon and Zewdu (2009), about a handful of baobab seeds was placed on an inclined plane apparatus. The plane portion of the apparatus which is replaceable was raised gradually and the angle of inclination to the horizontal at which the baobab seeds begins to slide was measured from a protractor attached to the inclined plane (Figure 4). The tangent of the angle of the inclination measured gives the coefficient of static friction. The procedure was repeated ten times and the average gives the coefficient of static friction of baobab seeds. Coefficient of static friction was determined at varying moisture levels on the three surfaces.

Figure 4: Inclined Plane Apparatus

RESULTS

The obtained values for the moisture content levels determination, MC$_1$ of the dried seed and MC$_2$, MC$_3$ and MC$_4$ of the conditioned seeds were 8±0.38, 12.64±1.27, 40.70±0.92 and 52.26±1.05 % (d.b), respectively. The results of the physical properties: principal axial dimensions involving the major, intermediate and minor diameters, surface area, bulk and true density, porosity and coefficient of frictional properties of the seed on mild steel, galvanized steel and stainless steel plates surfaces at the four moisture levels were as presented in Table 1.

Table 1: Physical properties of baobab seeds with mean and standard deviation of the properties evaluated at the four moisture levels.

	MC1			MC2				MC3					MC4			
Property	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**	**Mean**	**SD**
D_1	10.08	13.10	11.65	0.56	10.17	13.83	11.90	0.73	11.08	15.28	13.39	0.81	12.23	16.12	14.26	0.78
D_2	8.13	10.33	9.43	0.45	7.90	11.25	9.62	0.67	8.47	11.70	10.60	0.63	9.78	19.55	11.38	0.99
D_3	6.30	8.56	7.33	0.40	6.07	8.75	7.50	0.52	6.14	9.03	7.88	0.48	7.01	9.47	8.44	0.49
GMD	8.14	10.01	9.30	0.32	8.24	10.76	9.50	0.50	8.71	11.45	10.37	0.49	9.90	13.65	11.10	0.46
Sphericity	0.72	0.87	0.80	0.28	0.73	0.87	0.80	0.03	0.72	0.86	0.78	0.03	0.70	0.91	0.78	0.03
Surface area	179.98	272.33	236.93	16.40	185.39	314.05	247.62	25.94	202.99	356.92	292.43	26.71	265.33	542.08	335.17	30.85
Porosity	36.02	36.16	36.09	0.057	40.50	40.72	40.62	0.084	42.68	42.84	42.75	0.068	44.56	44.72	44.66	0.063
Bulk density	654.62	678.31	667.04	9.18	688.47	706.69	697.85	6.87	932.22	998.02	963.05	24.02	1108.36	1142.90	1128.07	13.73
True density	1189.94	1202.35	1196.79	5.03	1199.80	1242.22	1221.21	17.17	1598.38	1642.62	1621.96	18.56	1704.66	1802.56	1761.49	39.75
$\mu_{Stainless\ steel}$	0.598	0.612	0.605	0.006	0.620	0.630	0.626	0.004	0.628	0.634	0.631	0.002	0.628	0.654	0.638	0.010
$\mu_{Galvernized\ steel}$	0.502	0.514	0.509	0.005	0.509	0.520	0.514	0.005	0.509	0.522	0.517	0.005	0.519	0.530	0.525	0.004
$\mu_{Mild\ steel}$	0.404	0.412	0.408	0.003	0.427	0.432	0.429	0.002	0.466	0.490	0.476	0.010	0.502	0.516	0.507	0.005

D_1-Major diameter D2-Intermediatediameter D_3-Minor diameter GMD-Geometric mean diameters

SD-Standard deviation Min.-Minimum Max.-Maximum

Also presented in Table 1 is the descriptive statistics of the evaluation showing the mean and standard deviation of the evaluation of the principal axial dimensions, sphericity, surface area, true density, bulk density, porosity and coefficient of static friction of the seed on various surfaces. The mean values of the coefficient of static friction, μ of baobab seed determined with respect to the mild steel, galvanized steel and stainless steel plate surfaces at the four different moisture levels were also presented in Table 1

DISCUSSION

Axial Dimensions: It can be observed from Table 1 that the axial dimensions (the three axes; major, intermediate and minor diameter) and the geometric mean diameter of baobab seed increased with increased in moisture content of the seed. The major, intermediate, minor and geometric mean diameters of the seed increased from 11.65 to 14.26, 9.43 to 11.38, 7.33 to 8.44 and 9.30 to 11.10 mm, respectively as the moisture content levels of the seed increased from 8.0 to 52.26% (d.b).Similar trends have been reported by Aviara *et al.* (2005) for *Brachystegiaeury coma* seeds and Sessiz*et al.* (2007) for caper fruit. The relationship between major (D_1), intermediate (D_2) and minor (D_3) diameters of the baobab seed and its moisture content (MC) were as presented in equations 10, 11 and 12, respectively. The R^2 values of the equations were observed to range between 52 and 58%, the equations however revealed that the diameters increased with increased in moisture levels.

$$D_1 = 0.883M_c + 10.593 \quad (R^2 = 0.582) \qquad 10$$

$$D_2 = 0.615M_c + 8.696 \quad (R^2 = 0.522) \qquad 11$$

$$D_3 = 0.344M_c + 6.952 \quad (R^2 = 0.553) \qquad 12$$

Where M_C = Moisture content of seed, % (db)

Sphericity: The sphericity of the baobab seed was observed to decrease from 80 % at 8.0 and 12.64 % (d.b) moisture content levels to 78 % at both 40.70 and 52.26 % (d.b) moisture content levels. The relationship between the sphericity, of the seed and moisture content of the seed is represented by equation 13:

$$\emptyset = 0.049M_c^2 - 1.137M_c + 81.242 \quad (R^2 = 0.105) \qquad 13$$

The R^2 value in equation 13 which is 0.105 is consider to be low, however the P value is zero which signifies a very strong relationship between sphericity and moisture content of the seed. The result of the sphericity of the baobab seeds was in agreement with those reported for soybean by Kibar and Ozturk (2008) and for cowpea by Faleye *et al.* (2013).

Surface area: The surface area of the baobab seed increased as the moisture content levels of the seed increased from 8.0 to 52.26 % (d.b.). The mean surface area of the seed was 236.93, 247.62, 292.43 and 335.17 mm^2 at 8.0, 12.64, 40.7 and 52.26 % (d,b) moisture content levels, respectively. The quadratic relationship between the surface area and moisture content of the seed is presented in equation 14 below.

$$S_a = 13.358M_c^2 - 34.987M_c + 265.200 \quad (R^2 = 0.666)$$

Kabas*et al.* (2006), Sessiz*et al.* (2007)and Razavi*et al.* (2007) obtained a similar results working with Cactus pear *(Opuntiaficusindia L.)*, Caper fruit (*Capparis spp.*)and pistachio, respectively.

Bulk and true density: Both the bulk and true densities of the seed were observed to increase with increased in moisture content levels. The bulk density increased from 667.04 to 963.05 kg/m^3, while the true density increased from1196.79 to 1621.96 kg/m^3 as the moisture levels increased from 8.0 to 52.26 % (d.b) (Table 1). The relationship between the bulk density and moisture content of baobab seed is represented in equation 15, while that of the true density with moisture content is given in equation 16.

$$\rho_b = 154.558M_c + 448.805 \ (R^2 = 0.929) \qquad 15$$

$$\rho_t = 208.500M_c + 925.285 \ (R^2 = 0.954) \qquad 16$$

From equations 15 and 16 with R^2 values o2f792.9 and 95.4%, respectively, the moisture content have a direct relationship with bulk and true densities, respectively. The results obtained agreed with the report of Kibar and Ozturk (2008) for soybean, Faleye*et al.*(2013) for cowpea, Kabas*etal*. (2006) for Cactus pear and Sessiz*et al*. (2007) for Caper fruit on bulk density, while the positive linear relationship of true density with moisture content was also observed by Aviara*et al.* (2005) for sheanut (*ButyrospernumParadoxum*) and Faleye*et al,* (2013) for cowpea.

Porosity: The mean values of the porosity of baobab seed at 8.0, 12.64, 40.70 and 52.26 % (d.b) moisture content levels were 36.09, 40.62, 42.75 and 44.66 %, respectively. The porosity increased with increased in moisture content of the seed. The relationship between the porosity and moisture content of the seed is as expressed by equation 17. The relationship is quadratic and as the moisture content increase the porosity also increases.

$$\rho_p = -0.655M_c^2 + 6.063M_c + 30.788 \qquad (R^2 = 0.994) \qquad 17$$

This result is in tandem with the reports of Aviara, *et al.*(2005) for sheanut (*ButyrospernumParadoxum)*, Kabas*et al*. (2006) for Cactus pear and Sessiz*et al*. (2007) for Caper fruit.

Coefficient of Frictional Properties: It was observed from Table 1 that the coefficient of static friction is different on different surfaces and it increases with increase in moisture content levels on the surfaces treated. The baobab seed coefficient of static friction on mild steel plate, galvanized steel plate and stainless steel plate surfaces increased in the order of: Mild steel plate < galvanized steel plate < stainless steel plate While the coefficient of static friction increases from 0.408 to 0.476, 0.509 to 0.517 and 0.605 to 0.631 on the mild steel plate, galvanized steel plate and stainless steel plate surfaces, respectively as moisture levels increased from 8.0 to 52.26 % (d.b). The relationship between the coefficient of static friction against the three surfaces and moisture content of baobab seeds are expressed by equations 18, 19 and 20.

$(R^2 = 0.968)$ 18

$(R^2 = 0.813)$ 19

(R^2=0.622) 20

$$\mu_{Mild\ steel} = 0.003M_c^2 + 0.021M_c + 0.382$$

$$\mu_{Stainless\ steel} = -0.003M_c^2 + 0.028M_c + 0.51$$

$$\mu_{Galvernized\ steel} = 0.001M_c^2 - 0.002M_c + 0.506$$

The increased in coefficient of static friction at higher moisture content levels is attributed to higher percentage of water present in the baobab seeds offering a higher cohesive force on the surface of contact. The increased coefficient of static friction with increasing moisture content have also been reported by Kheiralipour*et al.* (2008) for apple and Kabas*et al.* (2006) for Cactus pear.

CONCLUSION

The investigations of various physical properties of baobab seeds revealed the following:

- The major diameter, intermediate diameter, minor diameter and geometric mean diameter of baobab seeds increased linearly with increasing moisture content levels.
- The mean value of the baobab seeds sphericity decreased from 80 to 78 %, as the moisture content levels increased from 12.64 to 52.26 % (d.b).
- True and bulk density, porosity and surface area of baobab seeds increased with increase in moisture content levels
- The coefficient of static friction has the highest value on stainless steel surface followed by galvanized steel surface and the lowest was on mild steel surface.

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