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# MOISTURE DEPENDENT: PHYSICAL PROPERTIES OF BAOBAB SEEDS (*ADANSONIA DIGITATA* L.)

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ABSTRACT

The research investigated physical properties of baobab seeds to determine suitable equipment for the processing of its seeds. Pods of baobab used in the study were collected at a local farm in Ilorin, North Central Nigeria. Physical properties of the samples, such as moisture contents, mass, axial dimensions, shape indices, true and bulk densities, porosity, angle of repose and surface area were determined. The results showed that physical properties of baobab seeds were stable for moisture content, ranging between 12 to 18% dry mass (dm). The 100 seed mass (g) and geometric mean diameter increased from 0.60 g to 0.62 g and 10.12 to 10.27 mm respectively, in the moisture range of 12 to 18% dm. Other studied ranges of physical properties ranges included: average length (12.22 to 12.63 mm), width (10.10 to 10.28 mm), thickness (8.23 to 8.42 mm,), sphericity, (81.23 to 82.56 mm), surface area (319.42 to 332.53 mm$^2$), 50 seed mass (0.60 and 0.62 g), and 1000 seed mass (12 and 12.4 g) within the moisture content range of 12 to 18% dm. The angle of repose of baobab seeds decreased with an increase in moisture content. The maximum value of 29.18° was obtained at 14% moisture content while a minimum value of 24.42° was obtained at 18% moisture. Moisture content had a significant effect on coefficient of friction of baobab seeds on glass, stainless steel, plywood and rubber. In the same moisture range (12-18%), the static coefficient of friction for baobab seeds ranged from 0-739 to 0-905 on stainless steel, 0-960 to 1-190 on galvanized steel, 0-812 to 1-055 on plywood and 0-496 to 0-950 on glass. The least coefficient of friction values were recorded on stainless steel and glass which implies that baobab seeds will move with lower resistance on these surfaces in post-harvest handling. On the other hand, the resistance will be higher on plywood and glass. The data obtained will serve as guide for agricultural and food engineers, food processors and technicians involved in design and construction of post-harvest equipment used for separating, cleaning, milling and other production processes, to which baobab seeds are subjected.

## Introduction

Baobab (*Adansonia digitata* L.) belongs to the *Malvaceae* family, which includes approximately 20 genera and 180 species (Abdus-Salam and Adekola, 2018). The species is found throughout tropical Africa's hot, arid regions. It extends from the Northern Transvaal and Namibia to Ethiopia, Sudan, the southern fringes of the Sahara (Perissinotto and Šípek, 2019) and to West Africa. It is a majestic deciduous tree with thick, angular, wide-spreading branches and a short, strong trunk that is usually highly fluted. The leaves, fruit pulp, and seeds are used as the main ingredients in sauces, porridges, and beverages in some West African countries (Iswariya and Devi, 2021; Debelo et al., 2019; Hussain et al., 2019). Due to its nutritional profile (Anoh, 2021), baobab has recently been described as a super fruit (i.e., rich in vitamins, fatty acids and minerals). In the past, comprehensive studies on the nutritional properties of baobab fruit pulp and seed has previously been published (Karungamye and Murthy, 2017), the nutritional value of baobab was only briefly discussed with the focus on the mineral composition of baobab fruit pulp (Erwa et al., 2018; Acham et al., 2020). Baobab pulp has very little iron and is a poor source of manganese, but is rich in calcium (Deconinck, 2020). Therefore, baobab fruits are appealing as a natural source of calcium supplements for pregnant and nursing women, as well as young people and the elderly (Rahman and Sofyaningsih, 2020). Proteins, lipids (oils), fibre and the majority of minerals are abundant in the nutritious seeds of baobab (Barakat, 2021). Furthermore, they are are rich in lysine, thiamine, and iron (Ndjientcheu et al., 2020).

The information on surface area is important in handling and processing operations of food raw materials. It is especially used in calculating the terminal velocity of the material used in aerodynamic and hydrodynamic operations such as pneumatic conveying and separation processes. In these processes, the material is lifted only when the air velocity is greater than its terminal velocity (Chaudhary, 2015). According to Asoiro and Ani (2011) who determined some physical properties of baobab seeds, as their moisture content increased from 12 to 14%, their surface would exhibit lower mass or energy transfer rate than other seeds under higher moisture content.

Numerous studies on baobab seeds have been conducted in terms of its health properties and preservation. However, there is less research dedicated to the physical properties of baobab seeds. The available research is dedicated to the moisture content of baobab seeds, to determine suitable equipment for its processing. Furthermore, since seeds have high protein and oil content, the mechanization of these processes is worth exploring. As a result, it is critical to ensure that all possible sources of baobab seeds are efficiently explored and used. Physical properties of baobab seeds need to be studied to obtain a framework for mechanization of the processing operations. The purpose of this research, therefore, was to determine some physical properties of baobab seeds with different moisture contents, to determine the parameters needed for designing machines that would increase the value of the seeds by processing them. The purpose was also to investigate higher moisture content values on dry basis (dm) for mechanization of baobab seeds' processing.

## Materials and Methods

### Materials

Ten pods of baobab were plucked from a local farm in Ilorin, North Central Nigeria, on February 12, 2021. The location was selected due to the abundance of baobab trees in that part of the country. The pods (Fig. 1-3) were removed and the seeds were cleaned and separated from foreign materials. Other materials used in the study include: weighing balance (Model-Metra TL 5000 series, accurate to 0.001mg), vernier calipers (made in China, accurate to 0.01-150 mm), plywood, glass, stainless steel, galvanized steel, iron sheet, cotton wool, petri dish, distilled water, and THIES anemometer (MEASNET Calibrated, #9288; 0.3 to 75 $m \cdot s^{-1}$; 0.7 to 168 mph).

*Figure 1. Baobab fruit and its seed*

*Figure 2. Dried extracted baobab seeds*

*Figure 3. Baobab pods*

### Moisture contents determination

The initial moisture content of the seeds was determined by the oven-drying method. Known mass of baobab seeds was compared to constant mass (Ogunlade et al., 2019; Fadeyibi et al., 2021). For moisture adjustment, the seeds (not crushed in the process of moisture content determination) were divided into four samples. One was kept at the initial moisture level of 12% while the other three were adjusted to 14, 16 and 18% through rehydration and dehydration. This was done by adding a calculated amount of distilled water to the seeds (Equation 1). The seeds were put in polythene bags and kept in a refrigerator for one week to equilibrate. The samples were removed from the refrigerator 24 hours before use to allow thawing (Ogunlade et al., 2016). Afterwards, their respective actual moisture contents were determined.

$$Q = \frac{A(b-a)}{(100-a)} \tag{1}$$

where:

A – initial mass of the sample, g
A – initial moisture content of the sample,% wet basis (w.b.)
B – final (desired) moisture content of the sample, % w.b.
Q – mass of water added, g

### Unit mass determination

The mass of randomly selected hundred seeds was determined individually using electronic weighing balance.

### Axial dimensions and shape indices

A sample of 100 seeds was randomly selected from a pod containing approximately 2500 seeds. For each seed, the major axis (X-axis), length L, the intermediate axis (Y axis), width W, and the minor axis (Z-axis) and thickness T was measured (Fig. 4), using an aerospace digital vernier caliper. Values were reported as an average of 100 replications with their standard deviations. The ratios of various seed dimensions were established. The arithmetic mean diameter, $D_a$; geometric mean diameter, $D_g$; and sphericity, ϕ of the seeds were calculated as follows using Mohsenin (1986) and Arslan and Vursavus (2008) equations;

$$D_a = \frac{L+W+T}{3} \tag{2}$$

$$D_g = (LWT^{1/3}) \tag{3}$$

$$\phi = \left(\frac{D_g}{L}\right) \times 100\% \tag{4}$$

$$Volume(mm^3), V = \frac{\pi LWT}{6}$$

(5)

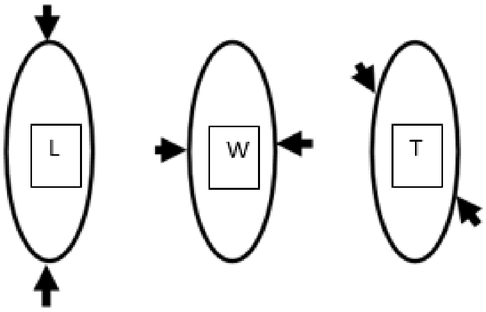

*Figure 4. Representation of three axes and three perpendicular dimension of baobab seed; X-axis (length, L), Y axis (width, W), Z-axis (thickness, T)*

### Determination of porosity and density (true and bulk)

Porosity was estimated using the bulk and true densities. The bulk density is obtained by dividing the dry mass of 100 seeds by their total volume in three replicates each. The equation for bulk density is as follows:

$$\gamma = \frac{Ms}{Vs} \tag{6}$$

where:

Ms – the mass of the dry seed,
Vs – the volume of the dry seed,
$\gamma$ – the bulk density of the dry seed.

The true density ($\rho_t$) was determined using the toluene displacement method in three replicates each (Bagherpour et al., 2010; Gharibzahedi et al., 2010). Porosity ($\varepsilon$) was calculated with the values of the bulk and true densities using the equation:

$$\text{Porosity} = 1 - \frac{bd}{td} \tag{7}$$

where:

bd – is the bulk density, $kg \cdot m^{-3}$
td – is the true density, $kg \cdot m^{-3}$

### Determination of the surface area of baobab seeds

The arithmetic surface area ($S_A$) and geometric mean diameter ($D_g$), sphericity ($\varphi$), surface area ($S$) of the baobab seed were calculated according to Milani et al. (2007). The mass of 1000 seeds ($m_{1000}$) was determined by means of an electronic balance with an accuracy of 0.001g, using the expression cited by Sacilik et al. (2003), as follows:

$$S_A = \pi {D_g}^2 \tag{8}$$

$S_A$ – Arithmetic surface area, $m^2$
$D_g$ – geometric mean diameter, m

### Determination of angle of repose

The angle of repose was determined using a hollow cylinder of known dimensions. It was placed on a wooden table, filled with the seeds and raised slowly until the bulk assumed its natural slope as a cone of seeds, and the angle made by the slope with the horizontal was obtained as the angle of repose (Ajav and Ogunlade, 2014). The angle of repose was calculated using Equation (9).

$$\theta = tan^{-1}\frac{2H}{D} \tag{9}$$

### Determination of coefficient of friction

This was determined with respect to four structural materials (stainless steel, galvanized steel, plywood and glass). The baobab seeds were placed parallel to the direction of motion and the table was gently raised. The angle at which the materials begin to slide (the angle of inclination) was read on a graduated scale. The coefficient of friction was taken as the tangent of this angle (Jaiyeoba et al., 2020) and calculated using the relationship given by Mohsenin (1986) as presented in Equation 10:

$$\mu = \tan\theta \tag{10}$$

where:

$\mu$ – the coefficient of friction (decimal) and $\theta$ is the angle of inclination (degrees).

### Statistical analysis

Data obtained from all experiments were subjected to analysis of variance (ANOVA) using a complete randomized block design using SAS 9.1 software. Duncan's multiple range test was used to separate the means at a significance level of 5%. The coefficient of variation (CV%) was used to analyze the range of the mean deviations and the least significant difference (LSD) was used for the mean values that too close.

## Results and Discussion

### Effect of moisture content on physical properties

Table 1 shows the size, shape, density, porosity, and unit mass of baobab seeds with four distinct moisture contents ranging from 12 to 18%. The moisture content is critical because it affects the size, shape, and angle of repose of the seeds, dictating the upper capacity and free flow. The average length of the varied moisture content ranged from 12.22 to 12.63 mm. Seeds with an 18% moisture content had the highest seed length (12.63 mm), whereas seeds with a 14% moisture content had the shortest seed length (12.22 mm). The study of the physical characteristics of the length, width and thickness of baobab seeds under the impact of different moisture levels revealed that baobab seeds with a moisture content of 18% promote greater seed length. This finding is in tandem with similar biomaterials such as Uyole-96 seeds (Addi et al., 2018), and larger than the common bean cultivars Elkoca-05 (Ozturk et al., 2008), barbunia bean seed (Ohaeri and Ohaeri, 2015).

Furthermore, the width of the seeds varied between 10.10 and 10.27 mm depending on the moisture content, also with statistical differences between the mean values in the width of the seeds, Table 1. It was discovered that seeds with a moisture content of 16% had the largest width (10.27 mm), while seeds with a moisture content of 14% had the smallest width (10.10 mm). Similarly, the thickness of a baobab seed was determined to be between 8.23 and 8.42 mm with statistical differences between mean values. It also increased linearly as the moisture content increased from 12% to 18%. Seeds with a moisture level of 18% had the highest thickness rate (8.42 mm), while seeds with a moisture content of 12% had the lowest thickness (8.23 mm) and moisture content have linear relationship with the thickness, as moisture content increases, the thickness of the seed increases.

The geometric mean diameter was discovered to be between 10.07 and 10.28 mm, also with statistical differences among the mean values. Baobab seeds with a moisture level of 18% had the largest geometric mean diameter (10.28 mm), whereas seeds with a moisture content of 14% had the lowest value for the same feature (10.07 mm), but it was a nonlinear increase when compared to moisture content variations with thickness of baobab seeds. The average geometric mean diameter of the physical characteristics of the baobab seeds was determined to be 10.17 and 10.19 mm, respectively, which was lower than the Filbert nut (Pliestic et al., 2006). Yildirim and Tarhan (2016) discovered that the geometric mean diameter of the seeds for the apricot seed (a Turkish variety "Hachaliloglu" ) was 14.59±1.11 mm. The mass of the baobab seeds was similar to that of red spruce seeds from Ontario (Mosseler et al., 2000), Schrenk spruce seeds from Tianshan Mountains (Gui-feng et al., 2012), white spruce seeds from the Great Lakes region (Pike et al., 2016) and Morinda spruce seeds from Garhwal Himalaya (Rawat and Uniyal, 2011).

Furthermore, the percentage of sphericity of baobab seeds was determined to be between 81.23 and 82.56% under various conditions of moisture content, with statistical differences between the mean values. Seeds with a moisture content of 16% had the lowest sphericity percentage (81.23%), while seeds with a moisture content of 14% had the highest value for the same character (82.56%), also the relationship between moisture content and sphericity is nonlinear. The of baobab seeds of sphericity percentage was found to be highest in seeds with less than 16% moisture content (82.56%), but lowest in seeds with 12% moisture content (81.50%). The values obtained are similar to those of African nutmeg (Burubai et al., 2007; Alonge and Udofot, 2012; Jaiyeoba et al., 2020) and African yam bean (Irtwange et al., 2002). The resulting sphericity values agree with those published by Simonyan et al. (2009) for Ronghai lablab and Highworth Ronghai seeds, and (Bande et al., 2012) for the egusi melon seed. The high value implies that baobab seeds would roll freely on any surface without necessarily being interrupted when placed in a particular orientation on processing equipment like design of hoppers where decisions are made based on the rolling or sliding properties of agricultural products and handling machinery (Olalusi and Bolaji, 2010)**.** A lower sphericity indicates that the seed cannot roll on its side but can slide when appropriately inclined. Idowu et al. (2012) reported this in their work on the measurement of various engineering characteristics of sandbox seeds.

The surface area of a baobab seed was non-linear with the moisture content and ranged between 319.42 and 328.07 mm$^2$. The mass was determined to be in the range of 0.60-0.62 g, with no significant differences, Table 1. Baobab seeds with an 18% moisture content had the highest value (0.62 g), while those with 12 and 14% moisture content levels had the lowest value (0.60 g). The mass of baobab seeds varies linearly with the moisture content of the seeds. The surface area of baobab seeds did not rise linearly from 12-18% moisture variations dm, this is in contrast to what Ünal et al. (2013) discovered on the surface area of bitter gourd seed, which rises linearly from 181.91 to 197.42 mm$^2$ when the moisture content rose from 9.3 to 32.1% dm. Thus, baobab has not behaved like bitter gourd seed,, millet, hemp seed and caper seed who have all shown similar tendency of increase moisture content dm with increase surface area (Baryeh, 2002; Sacilik et al., 2003; Dursun and Dursun, 2005). During deep bed drying, the moisture content of these seeds can be characterized by strong aeration and water vapour diffusion.

Table 1.

*Four levels of moisture contents percentage in seeds of selected baobab and results of statistical analysis by the least significant protected difference (p< 0.05).*

| Moisture content (%) | Length (mm) | | | | Width (mm) | | | | Thickness (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Mean | CV% | Max | Min | Mean | CV% | Max | Min | Mean | CV% |
| 12 | 14.42 | 11.01 | 12.44b | 5.98 | 11.75 | 8.27 | 10.14b | 6.46 | 9.86 | 7.19 | 8.23c | 5.71 |
| 14 | 14.56 | 9.81 | 12.22c | | 11.53 | 7.92 | 10.10b | | 9.39 | 6.80 | 8.30b | |
| 16 | 14.05 | 10.00 | 12.60a | | 12.17 | 7.97 | 10.27a | | 11.79 | 6.55 | 8.25c | |
| 18 | 15.88 | 10.59 | 12.63a | | 12.00 | 7.97 | 10.24a | | 10.16 | 7.04 | 8.42a | |

| Moisture content (%) | Geometric Mean Diameter (mm) | | | | Sphericity (%) | | | | Surface Area (mm$^2$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Mean | CV% | Max | Min | Mean | CV% | Max | Min | Mean | CV% |
| 12 | 11.08 | 8.91 | 10.12bc | 4.10 | 88.49 | 72.74 | 81.50b | 4.41 | 385.58 | 249.34 | 322.03bc | 8.14 |
| 14 | 11.14 | 8.08 | 10.07c | | 91.01 | 71.33 | 82.56a | | 389.47 | 205.34 | 319.42c | |
| 16 | 12.14 | 8.47 | 10.21b | | 97.35 | 67.45 | 81.23c | | 463.08 | 225.19 | 328.07a | |
| 18 | 11.51 | 9.29 | 10.28a | | 90.35 | 68.81 | 81.56b | | 416.94 | 271.55 | 322.53ab | |

| Moisture content (%) | Mass 100-seeds (g) | | | CV (%) |
|---|---|---|---|---|
| | Max | Min | Mean | |
| 12 | 0.77 | 0.33 | 0.60a | 13.98 |
| 14 | 0.74 | 0.25 | 0.60a | |
| 16 | 0.74 | 0.27 | 0.61a | |
| 18 | 0.72 | 0.28 | 0.62a | |

$^{abc}$Means in the same column followed by the same letter are not significantly different, based on the 5%

Information on seed characteristics acquired at a specific moisture content and its impact on seed particle size can be utilized to build an appropriate machine and create measuring devices. Physical properties such as 1000 seed weight, surface area, and sphericity are important criteria to consider when optimizing and designing an internal run roller plate seed metering system. However, seeds with a moisture level of 12% were shown to have the highest value of sphericity, 322.03 mm, while seeds with a moisture content of 16 % were shown to have the lowest sphericity (328.07 mm). This means that the higher the moisture content, the higher the sphericity. This is similar to some seeds, such as coriander (Coskuner and Karababa, 2007) and sesame, which showed increased sphericity when the moisture content increased, similar to baobab seeds (Darvishi, 2012). Finally, the mass of the seeds at 12, 18, 16, and 14% moisture content was found to be 0.62 g, 0.61 g, 0.60 g, and 0.60 g, respectively, showing no statistical differences between the values. In Table 1, the coefficient of variation (CV) ranged from length (4.10%) to mass (13.98%) and all their values were within the acceptable limit (less than 20%).

The true density of the baobab seeds ranged from 0.976 to 1.06, while the bulk density ranged from 0.52 to 0.60 kg m$^{-3}$) as shown in Table 2. Porosity also ranged between 0.406 and 0.469. The high true density value resulted in the high low porosity of the baobab seeds. When comparing this range of bulk density values with that of alfalfa (0.772) and maize (0.675), it has a low bulk density, but with oat (0.412), it is much more bulky than oat. Baobab seeds are less porous (57.70) than maize (30.37), rice (50.22), and wheat (42.80) according to the results obtained by Aremu et al. (2014). The mean values were the less significant at 16% moisture content, and this could be the right moisture content level for the handling processes of baobab seeds.

The angle of repose increased with an increase in moisture content up to a maximum value of 29.18° was obtained at 14% moisture content but was again decreasing as the moisture content increased from 16% to 18% with the least angle of repose of 24.42° obtained at 18% moisture content (Table 2). The decrease in the angle of repose with moisture content shows that the friction of the baobab seeds increases on their surface and the seeds will not flow easily when piled on each other at higher moisture content (Jaiyeoba et al., 2020) and the increase of the angle of repose at 14% moisture content will only show that the seeds will flow easily when piled on each other at lower 14% moisture content. This property is used in the design of agricultural machine hoppers and other conveying equipment (Aremu et al., 2016).

Table 2.
*Mean values of porosity, bulk density and angle of repose at four levels of moisture contents*

| Moisture content levels (%) | Porosity (%) | LSD | True Density (g·cm$^{-3}$) | LSD | Bulk Density (g·cm$^{-3}$) | LSD | Angle of Repose (°) | LSD |
|---|---|---|---|---|---|---|---|---|
| 12 | 43.4 | 0.51 | 1.060 | 0.55 | 0.600 | 0.61 | 25.41 | 0.31 |
| 14 | 41.9 | 0.66 | 1.011 | 0.53 | 0.587 | 1.29 | 29.18 | 0.28 |
| 16 | 40.6 | 0.48 | 0.976 | 1.33 | 0.580 | 0.43 | 26.48 | 0.27 |
| 18 | 46.9 | 4.24 | 0.980 | 0.43 | 0.520 | 0.66 | 24.42 | 0.24 |

The moisture content had a significant effect on the coefficient of the friction of baobab seeds on the four surfaces considered, as shown in the statistical differences between the mean values shown in Table 3. The effect of moisture content on stainless steel, galvanized steel, plywood and glass is presented in Table 3. The lowest coefficient of friction values were recorded on stainless steel and glass (Fig. 5) which implies that baobab seeds will move easily with less resistance on these material surfaces when used to produce post-harvest handling equipment while the seeds will have more resistance on plywood and rubber. This could be due to the smooth surface of glass and stainless steel. The coefficient of friction as a property is required in the choice for the materials of construction of processing machines. The regression equations representing the relationships between moisture content (x) and the coefficient of friction in stainless steel, plywood, galvanized steel and glass is presented in Equations 11-14, respectively. The high coefficient of determination of the models shows a good representation of the interactions between these variables.

Table 3.
*Mean values of coefficient of static friction of stainless steel, plywood, rubber and glass at four levels of moisture contents.*

| Moisture content levels (%) | Stainless steel | Galvanised steel | Plywood | Glass |
|---|---|---|---|---|
| 12 | 0.739± 0.035c | 1.190 ± 0.057a | 0.920± 0.707b | 0.496±0.028c |
| 14 | 0.774± 0.031b | 0.998± 0.000b | 0.812 ±0.082d | 0.508±0.018c |
| 16 | 0.750 ± 0.000c | 0.966 ±0.000c | 0.860 ± 0.156c | 0.950±0.071a |
| 18 | 0.905± 0.134a | 0.960± 0.325c | 1.055± 0.078a | 0.860±0.156b |

$^{abc}$Means in the same column followed by the same letter are not significantly different based on the 5%

$$\text{Coef. of Friction (stainless steel)} = 0.03x^2 - 0.1026x + 0.8235R^2 = 0.8397 \quad (11)$$

$$\text{Coef. of Friction (plywood)} = 0.0757x^2 - 0.3334x + 1.1773R^2 = 0.9999 \quad (12)$$

$$\text{Coef. of Friction (galvanized steel)} = 0.0465x^2 - 0.3047x + 1.4415R^2 = 0.9748 \quad (13)$$

$$\text{Coef. of Friction (glass)} = -0.0255x^2 + 0.2809x + 0.1925R^2 = 0.7221 \quad (14)$$

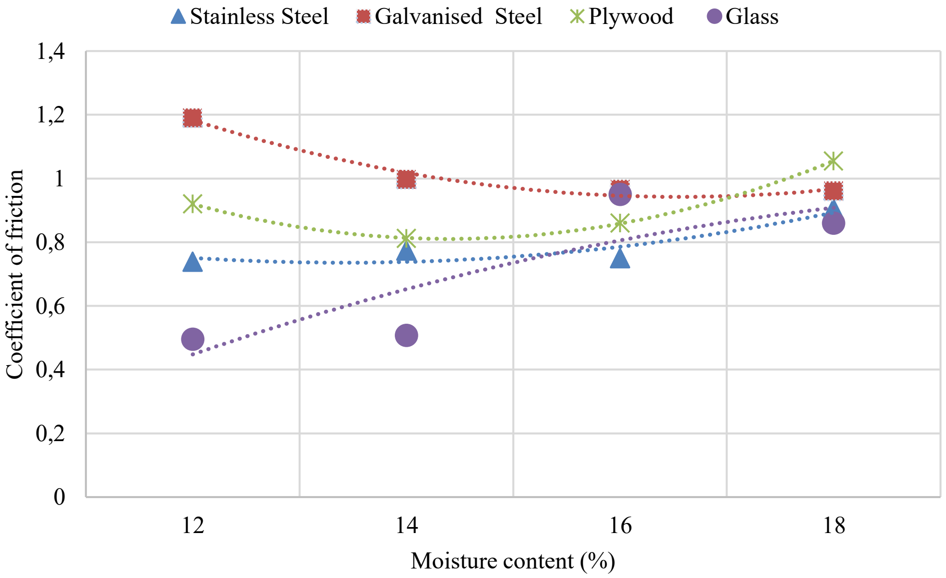

*Figure 5. Influence of moisture content on coefficient of friction of baobab seeds.*

## Conclusion

The physical properties of the baobab seeds were determined at varying moisture content. The properties determined include unit mass, axial dimensions, shape, porosity, surface area, and angle of repose. The moisture content had a significant impact on the physical properties of the baobab seeds considered. The data obtained will serve as guide for agricultural and food engineers, food processors, and technicians involved in design and construction of post-harvest equipment like sorting, separating, cleaning, milling, and other material handling machineries.

## References

Abdus-Salam, N., Adekola, S. (2018). Adsorption studies of zinc (II) on magnetite, baobab (*Adansonia digitata*) and magnetite–baobab composite. *Applied Water Science*, *8*(8), 1-11.

Acham, I., Eke, M., Edah J. (2020). Physicochemical, microbiological and sensory quality of juice mix produced from watermelon fruit pulp and baobab fruit pulp powder. *Croatian journal of food science and technology, 1*(12), 48-55.

Addi, A.S.P., Bashira, A.M., Baraka K. (2018). Physical and Mechanical Properties of Selected Common Beans (*Phaseolus vulgaris* L.) Cultivated in Tanzania. *Journal of Engineering*, *2018*, 8134975.

Ajav, E.A., Ogunlade, C.A. (2014). Physical Properties of Ginger (*Zingiber officinale). Global Journal of Science Frontier Research, 14*(8), 1-9.

Alonge, A.F., Udofot, E.J. (2012). Some Physical Properties of African Nutmeg (*Monodara myristica*) Seed Relevant to its Processing. In 2012 Dallas, Texas, July 29-August 1, 2012 (p. 1). American Society of Agricultural and Biological Engineers.

Anoh, K., (2021). Effect of baobab fruit pulp meal on testosterone concentration and gonadal and epididymal morphometry of rabbit bucks in a hot environment. *Nigerian Journal of Animal Production, 3*(44), 98-103.

Aremu, D.O., Babajide., N.A., Ogunlade C.A. (2014). Comparison of Some Engineering Properties of Common Cereal Grains In Nigeria. *International Journal of Engineering Science Invention, 3*(4), 10-14.

Aremu, D.O., Ogunlowo, Q.O., Babajide, N.A., Ogunlade, C.A., Makinde, O.O. (2016). Selected Engineering Properties of Fluted Pumpkin (*Telfaria occidentalis*) Seeds. *Journal of Multidiscpilinary Engineering Science and Technology, 3*(4), 4594-4598.

Arslan, S., Vursavus, K. (2008). Physico-Mechanical Properties of Almond Nut and Its Kernel as a Function of Variety and Moisture Content. *Philippine Agricultural Scientist, 91(2)*, 171-179.

Asoiro, F.U., Ani, A.O. (2011). Determination of some physical properties of African Yam beans. *The Pacific Journal of Science and Technology, 12*(1), 374-380.

Bagherpour, H., Minaei, S., Khoshtaghaza, M.H., (2010). Selected physico-mechanical properties of lentil seed. *International Agrophysics, 24,* 81-84.

Bande, Y.M., Adam, N.M., Azmi, Y., & Jamarei, O. (2012). Determination of Selected Physical Properties of Egusi Melon (*Citrullus colocynthis* lanatus) Seeds. *Journal of Basic & Applied Sciences, 8*, 257-265.

Barakat, H. (2021). Nutritional and Rheological Characteristics of Composite Flour Substituted with Baobab (*Adansonia digitata* L.) Pulp Flour for Cake Manufacturing and Organoleptic Properties of Their Prepared Cakes. *Foods. 4*(10):716.

Baryeh, E.A. (2002). Physical properties of millet. *Journal of Food Engineering, 51*, 39-46.

Burubai, W., Akor, A.J., Igoni, A.H., Puyate, Y.T. (2007). Some physical properties of African nutmeg (*Monodora myristica*). *International Agrophysics*, *21,* 123-126.

Chaudhary, D.A. (2015). Engineering properties of Biological materials. Retrieved August 20, 2022, https://www.academia.edu/3879560/Engineering_properties_of_biological_Materials

Coskuner, Y., Karababa, E. (2007). Physical properties of coriander seeds (*Coriandrum sativum* L.). *Journal of Food Engineering, 80*(2), 408-416.

Darvishi, H. (2012). Moisture-Dependent Physical and Mechanical Properties of White Sesame Seed. *American-Eurasian Journal of Agricultural and Environmental Sciences, 12*(2), 198-203.

Debelo, H., Ndiaye, C., Kruger, J., Hamaker, B., Ferruzzi, M. (2019). African Adansonia digitata fruit pulp (baobab) modifies provitamin A carotenoid bioaccessibility from composite pearl millet porridges. *Journal of Food Science and Technology. 4*(57), 1382-1392.

Deconinck, W. (2020). The science of the very small has enormous potential. Retrieved August 20, 2022, from https://futurumcareers.com/Wouter_Deconinck-The-science-of-the-very-small-has-enormous-potential.pdf

Dursun, E., Dursun, I. (2005). Some physical properties of caper seed. *Biosystems Engineering, 92*(2), 237-245.

Erwa, I., Shinger, M., Ishag, O. (2018). Background Correction Method for Determination of Ascorbic Acid in Baobab Fruit Pulp Using Direct UV Spectrophotometry. *Chemical Science International Journal. 2*(23), 1-6.

Fadeyibi, A., Lamidi, W.A., Ademola, S.M. (2021). Engineering and proximate properties of miracle berry fruit (*Synsepalum dulcificum* L.) essential for its processing equipment design. *Agricultural Engineering International: CIGR Journal, 23*(4), 227-235.

Gharibzahedi, S.M.T., Etemad, V., Mirarab-Razi, J., Fos'hat, M. (2010). Study on some engineering attributes of pinenut (*Pinus pinea*) to the design of processing equipment. *Research in Agricultural Engineering, 56*(3), 99-106.

Hussain, Z., Yagi, S., Mahomoodally, M., Mohammed, I., Zengin, G. (2019). A comparative study of different solvents and extraction techniques on the anti-oxidant and enzyme inhibitory activities of *Adansonia digitata* L. (Baobab) fruit pulp. *South African Journal of Botany. 126,* 207-213.

Idowu, D.O., Abegunrin, T.P., Ola, F.A., Adediran, A.A., Olaniran, J.A. (2012). Measurement of some engineering properties of sandbox seeds (*Hura crepitans*). *Agriculture and Biology Journal of North America, 3,* 318-325.

Irtwange, S.V., Igbeka, J.C. (2002). Some physical properties of two African yam bean (*Sphenostylis stenocarpa*) accessions and their interrelations with moisture content. *Applied Engineering in Agriculture,18*(5), 567-576.

Iswariya, V., Devi, A.G.S. (2021). Assessment of Potential Property of Baobab Fruit Pulp Derived Pectin as a Pharmaceutical Excipient. *International Journal of Pharmaceutical Sciences Review and Research, 1*(67), 91-96.

Jaiyeoba, K.F., Ogunlade, C.A., Kwanaki, O.S., Fadele, O.K. (2020). Moisture Dependent Physical Properties of Nutmeg (*Myristica fragrans*) Relevant for Design of Processing Machines. *Current Journal of Applied Science and Technology*, *39*(12), 74-85.

Karungamye, P., Murthy, H. (2017). Corrosion Inhibitive and Adsorption Behaviour of Methanolic Extracts of *Adansonia digitata* (Baobab) Fruit Pulp and Seeds for Mild Steel in 1.0 M $H_2SO_4$. *IOSR Journal of Applied Chemistry, 7*(10), 64-74.

Gui-feng, L., Run-guo, Z., Hua, L., Zhi-qiang, B., Zhong-jun, G., Yi, D. (2012). Geographic variation of seed morphological traits of Picea schrenkiana var. tianschanica in Tianshan Mountains, Xinjiang of Northwest China. *Yingyong Shengtai Xuebao, 23*(6), 1455-1461.

Milani, E., Razavi, S.M.A., Koocheki, A., Nikzadeh, V., VahediN., MoeinFard, M., GholamhosseinPour, A. (2007). Moisture dependent physical properties of cucurbit seeds. *International Agrophysics*, *21*, 157-168.

Mohsenin, N.N. (1986). *Engineering Properties of Plants and Animal Materials*. Gordon and Breach Science publishers, New York, London. 2nd Edition.

Mosseler, A., Major, J.E., Simpson, J.D., Daigle, B., Lange, K., Park, Y.-S., Johnsen, K.H., Rajora, O.P. (2000). Indicators of population viability in red spruce, Picea rubens. I. Reproductive traits and fecundity. *Canadian Journal of Botany, 78*, 928-940.

Ndjientcheu, L. Y., Ouiminga, S., Sidibe, S., Ouedraogo, I. (2020). Synthesis of a cleaner potassium hydroxide-activated carbon from baobab seeds hulls and investigation of adsorption mechanisms for diuron. *Scientific African, 9,* e00476.

Ogunlade, C.A., Aremu, A.K. (2019). Influence of Processing Conditions on Yield and Quality of Mechanically Expressed African Oil Bean (*Pentaclethra macrophylla* Benth) Kernels: A Response Surface Approach. *Journal of Food Process Engineering, 42*(2), 1-9.

Ogunlade, C.A., Alaka, A.C., Babajide, N.A., Aremu, D.O., Anjorin, S.E., Akinyele, O.A. (2016). Moisture-dependent physical properties of popcorn. *Journal of Multidisciplinary Engineering Science and Technology*, *3*(2), 4069-4073.

Ohaeri, O.H., Ohaeri, E.G. (2015). Some physical and frictional properties of Dikanut (*Irvingia wombolu*) as a function of moisture content. *British Journal of Earth Sciences Research 3(1)*, 16-29.

Olalusi, A.P., Bolaji, O.T. (2010). Some engineering properties of indigenous grown jatropha seeds ("Lapalapa"). Electronic Journal of Environmental, Agricultural and Food Chemistry*,* 9, 1760-1771.

Ozturk, M., Kara, Elkoca E., Ercisli S. (2008). Physico-chemical grain properties of new common bean cv. 'Elkoca-05'. *Scientifc Research and Essays, 4*(2), 88-93.

Perissinotto, R., Šípek, P. (2019). New species of Xiphoscelis Burmeister, 1842 (Coleoptera, Scarabaeidae, Cetoniinae) from arid regions of South Africa and Namibia. *ZooKeys, 879,* 57-89.

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

Rawat, B.S., Uniyal, A.K. (2011). Variability in cone and seed characteristics and seed testing in various provenances of Himalayan spruce (*Picea smithiana*). *Journal of Forestry Research, 22,* 603-610.

Sacilik, K., Ozturk, R., Keskin, R. (2003). Some physical properties of hemp seed. *Biosystems Engineering, 86*, 213-215.

Simonyan, K.J., Yiljep, Y.D., Oyatoyan, O.B., Bawa, G.S. (2009). Effects of Moisture Content on Some Physical Properties of *Lablab purpureus* (L.) Sweet Seeds. Agricultural Engineering International: CIGR Journal, 9, 1279.

Ünal, H., Alpsoy, H.C., Ayhan, A. (2013). Effect of the moisture content on the physical properties of bitter gourd seed. *International Agrophysics, 27*, 455-461.

## WŁAŚCIWOŚCI FIZYCZNE NASION BAOBABU (*ADANSONIA DIGITATA* L.) W ZALEŻNOŚCI OD ICH WILGOTNOŚCI

**Streszczenie.** W pracy zbadano właściwości fizyczne nasion baobabu w celu określenia parametrów urządzeń do ich przetwarzania. Strąki baobabu zostały zebrane w gospodarstwie w miejscowości Ilorin w północno-środkowej Nigerii. Właściwości fizyczne określone w pracy to zawartość wilgoci, masa, wymiary osiowe, wskaźniki kształtu, gęstość rzeczywistą i objętościową, porowatość, kąt usypu i powierzchnię. Wyniki wykazały, że właściwości fizyczne nasion baobabu są stabilne dla wilgotności pomiędzy 12 a 18% suchej masy (sm). W zakresie wilgotności od 12 do 18% sm stwierdzono wzrost masy 100 nasion (g) i średniej geometrycznej średnicy odpowiednio z 0,60 g do 0,62 g i 10,12 do 10,27 mm. Pozostałe zbadane zakresy właściwości fizycznych to: średnia długość (12,22 do 12,63 mm), szerokość (10,10 do 10,28 mm), grubość (8,23 do 8,42 mm), kulistość (81,23 do 82,56 mm), pole powierzchni (319,42 do 332,53 mm$^2$), masa 50 nasion (0,60 i 0,62 g) oraz masa 1000 nasion (12 i 12,4 g) w zakresie wilgotności od 12 do 18% sm. Kąt usypu zmniejszał się wraz ze wzrostem wilgotności, maksymalną wartość 29,18° uzyskano przy wilgotności 14%, natomiast minimalną 24,42° przy 18% sm. Wilgotność miała istotny wpływ na współczynnik tarcia nasion baobabu na szkle, stali nierdzewnej, sklejce i gumie. W tym samym zakresie wilgotności 12-18% współczynnik tarcia statycznego dla nasion baobabu wynosił od 0-739 do 0-905 na stali nierdzewnej, 0-960 do 1-190 na stali ocynkowanej, 0-812 do 1-055 na sklejce i 0-496 do 0-950 na szkle. Najmniejsze wartości współczynnika tarcia odnotowano na stali nierdzewnej i szkle. Sugeruje to, że nasiona baobabu będą się przesuwać z mniejszym oporem na powierzchniach z tych materiałów, jeżeli wykorzysta się je do produkcji urządzeń przetwórczych, podczas większy opór wystąpi na sklejce i szkle. Uzyskane dane mogą posłużyć technologom rolnictwa i żywności, zakładom przetwórstwa żywności i konstruktorom maszyn do przetwórstwa baobabu, np. urządzeń do sortowania, czyszczenia, mielenia itp.

**Słowa kluczowe**: gęstość nasypowa; średnia geometryczna średnica; białko surowe; włókno surowe; kulistość.