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Influence Of Moisture Content On Some Physical Properties Of Baobab Seeds (*Adansonia Digitata)* In Relation To Equipment Development For Postharvest Processing And Handling.

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Abstract

In this study, the effect of moisture content on the physical attributes of baobab seeds was examined, along with the implications for the design of machinery for postharvest handling and processing of the seeds. The seed's volume, sphericity, aspect ratio, axial dimensions, arithmetic, and geometric mean diameters were all determined. Gravimetric properties including porosity, bulk density, and thousand grain mass were measured. Additionally, the seeds' frictional characteristics on different surfaces for handling after harvest were established. The arithmetic and geometric mean diameters were found to be in a range of 8.00 and 9.64 mm and 7.86 and 9.50 mm, respectively, with moisture contents between 5.4 and 20.6% on a dry basis. The seed's sphericity ranged from 78.18 to 80.38 percent. Densities for the bulk and particle ranged from 740.77 to 763.40 kg/m^3 and 1155.22 to 1223 -29 kg/m^3, respectively. The study revealed that among the four frictional surfaces, plywood surface had the greatest resistance to the flow of the seeds, and the least was registered for the glass surface material. The effect of moisture content on the seed's physical properties were statistically significant ($p \le 0.05$). Regression equations for future predicting the various physical properties at different moisture contents were developed. The study has produced valuable information that will help with the design of machinery for handling and processing baobab seeds after harvest.

Keywords: gravimetric properties, frictional properties, baobab seed, sphericity, aspect ratio

1.0 Introduction

The search for food to feed the world's ever-growing human population has led to research into non-traditional plants that can provide an alternative food to well-known food substances like cereals, legumes, fruits, vegetables, root, and tuber crops to meet the sustainable development goal two (SDG 2). It is not enough having adequate food, but having healthy, high-quality, and nutritional food has prompted scientists to look into non-timber forest products (NTFPs). The baobab tree (*Adansonia digitata L.*), a Malvaceae family tree native to Sub-Saharan Africa, is one of these products. The baobab tree has been shown in studies to be a viable alternative for food, cosmetics, and nutraceutical products all over the world (Bremer *et al.,* 2003; Sabina *et al.,* 2020). It is seen as a multi-purpose tree that provides protection, food, clothing, medicine, and raw materials for industrial goods from the plant's roots, bark, leaves, pulp, and seeds (De Caluwé, *et al.,* 2010; Kamatou *et al.,* 2011). Gebauer *et al.* (2016) highlighted a number of research gaps that need to be filled. The impact of post-harvest handling, storage conditions, storage time, and processing procedures on the flavour and nutritional value of leaves, fruit pulp, and seeds.

Various studies on baobab seeds have revealed that they contain significant amounts of phosphorus, vitamin C, magnesium, zinc, sodium, iron, and manganese (Burlando *et al.,* 2010; Abubakar *et al.,* 2015), as well as high levels of lysine, thiamine, calcium, and iron (Phyto-trade, 2009). Baobab has antimicrobial, antimalarial, diarrhoea, anaemia, asthma, antiviral, anti-oxidant, and anti-inflammatory biological properties (Jackson, 2015; Rahul *et al.,* 2015). It is considered a "super food" in the United States and other European Union countries due to its extensive nutritional and biological properties (PhytoTrade, 2009; Sanchez *et al.,* 2010).

Baobab seeds can be roasted, dried, or ground for snacking or cooking (Nnam and Obiakor 2003). The seed has a higher energy value than the leaves, with 1803 kJ per 100 g, according to Diop *et al.* (1988). Seed oil from the baobab is a valuable resource for both industrial and medicinal uses (Nzikou *et al.,* 2010). Study by Edogbanya *et al.* (2016) confirm the potential of the baobab seed cake as a biosorbent to remove lead (Pb2+) from a concentrated aqueous. Notwithstanding the economic benefits derived from the baobab seeds, it is still underutilized due to its growing in the natural state. The Volta Region of Ghana is a typical agro-ecological setting, with plenty of baobab trees that can be domesticated (Egbadzor, 2020). Aside from the fruits harvested in the wild, research is underway to domesticate and propagate the baobab tree, which has significant economic value around the world. The baobab fruit must be processed in order to be preserved for future use as food and animal feed for man's continued survival.

Agricultural material is diverse and complex by nature, which means engineering and chemical characteristics can vary from one ecological zone to the next, but the extent of these differences requires empirical research. The physical property of any agricultural material must be considered when designing or selecting the appropriate equipment and system for processing. Engineers and scientists need to understand these properties in order to address a variety of issues in food processing unit operations. From pre-harvest to post-harvest processing, biological materials, particularly those used as food or feed, go through a series of unit operations. Understanding how these food materials react to physical, chemical, thermal, and mechanical treatment is critical for optimizing processing equipment design and selection, as well as ensuring that processed food is of high quality and safe to eat (Bamgboye and Adebayo, 2012).

According to Mungofa *et al.* (2018), cited by Darr *et al.* (2020), food products in African tradition are frequently poorly integrated into formal markets, supply chains, and retail outlets because many of these products are sold by street vendors or at fresh markets rather than supermarkets. This could be due to a scarcity of indigenous processing equipment, which is exacerbated by a scarcity of data on the engineering properties of these biological materials. Researchers have opined the practical usefulness of physical properties of a biological material in machine and process design (Waziri and Mittal, 1983).

Agriculture products from the harvesting time until consumption time undergo different processes and changing factors. These processes may be simple operations such as cleaning, separating, washing, size reduction and grading. Seed size distribution is important for equipment design for cleaning, grading and separation (Babić *et al.,* 2011; Al-Mahasneh and Rababah, 2007). The empirical data on the angle of repose, for example, is useful when determining grain flowability during threshing (Balasubramanian and Viswanathan 2010). The frictional coefficient existing between the seed and the structural surface in contact with the grain is valuable in estimating motor size and materials for grain transportation and storage from one level of the processing unit to the next (Karababa and Coşkuner, 2007). Bulk and true density, surface area, and porosity, according to Mohsenin (1980), determine the dryer's capacity, storage, and mode of transportation of material, as well as resistance to airflow during air circulation. The lateral and vertical loads in silos during stockpiling are affected by bulk density and porosity, and the angle of repose is essential in designing handling systems and accessories (Mohsenin, 1986). Data on the static coefficient of friction is always required when designing the angles at which chutes or hoppers must be positioned in order to achieve smooth flow. Bulk densities, coefficients of friction on some commonly used material surfaces (galvanized steel, plywood, glass, plastic, and concrete), and angles of repose of crops are all needed for the development of handling and storage machinery (Parde *et al.,* 2003). These properties are also necessary for predicting the load and pressure on storage structures, as well as designing grain hoppers for processing equipment (Asoiro *et al.,* 2020).

Consumers place a premium on safety and quality of processed food materials. Hence, processing equipment must be carefully chosen or designed to perform the task purposely designed for. The physical properties of the seed have a great influence on how processing equipment is designed. The performance and efficiency of processing facilities such as grading, conveyors, metering mechanism for planting, screeners and size reduction are dependent on the physical properties of the seed and data on its characterization must be done appropriately (Ofori *et al.,* 2020).

Moisture is crucial in seed drying, cleaning, size reduction, roasting, storage, and marketing. Though, moisture content is not a thermo-physical property, it has a significant impact on all engineering properties of food and biological materials (Bart-Plange, 2015; Stroshine and Hamann, 1995). The amount of moisture in agricultural materials and food product affects properties like size or shape, density, porosity, frictional parameters, and angle of repose, as well as having a significant impact on equipment design features. The effect of moisture content on the physical properties of African star apples (Onwe *et al.,* 2020), cocoa beans (Bart-Plange *et al.,* 2011), sunflower seed (Seifi and Alimardani, 2010), corn seed (Javad *et al.,* 2011), dry sweet corn kernels (Karababa and Coşkuner, 2007), maize (Sobukola *et al.,* 2013), and other biological materials have been studied.

Cracking, crushing or pounding, sieving, soaking, seed roasting, oil extraction, and size reduction are all part of the value-added processing of baobab fruit. These processes are time-consuming and labour-intensive, and they are still carried manually, with low output. Equipment development for processing is contingent on the baobab seed engineering properties. However, data on baobab seed as a function of moisture content, as well as the implications for equipment design and selection for processing Ghana baobab locally, is dearth. To reap the benefits of this African fruit enormous economic, nutritional, and culinary potential, systems and equipment for unit operations and handling that require knowledge of the seed engineering properties must be developed. Therefore, the goal of the study was to look into the postharvest physical properties of baobab seed as a function of moisture content in order to get a baseline for developing equipment for unit operations, handling, and storage.

2. Materials and Methods

The baobab pods were harvested in the Volta region of Ghana in the first week of March 2022. The pods were manually cracked and emptied into a container using a machete. Figures 1 and 2 depict the fruits and seeds of the baobab.

Figure 1. Fruits of baobab

Figure 2. Baobab seeds

A pestle and mortar were used to pound the seeds with the attached pulp to separate the pulp and fibre from the seeds. The pulp was separated from the seeds using a 710 mm wire mesh sieve. The seeds were then washed in clean water to remove any remaining pulp before being sun dried for 5 hours. The seeds initial moisture content (MC) was determined. To accomplish this, a known sample mass (M_i) of three replicates of baobab seeds were placed in crucibles and heated in a hot-air laboratory oven at 80 ℃ for 6 hours, with no change in seed mass (M_f) recorded. Equation 1 was used to determine the moisture content on a percentage dry basis (Bart-Plange, 2015).

$$MC_{db} = \frac{(M_i - M_f)}{M_f} \tag{1}$$

Where,

MC_{db} is the moisture content in dry basis, M_i is initial mass of sample and M_f is the final mass of the sample.

The initial moisture content of the baobab seed sample was 5.4 % dry basis (db). The seeds were conditioned to additional three levels of moisture content (10.2 %, 15.8 %, and 20.6 %) for this study. A known amount of distilled water differently was added to the seeds before they were sealed in a zip-lock polyethylene bag to achieve the desired moisture content levels. Equation 2 was used to calculate the desired moisture content levels of the seeds (Aviara *et al.,* 2013). Before performing the analysis, the seeds were checked again for the desired MC levels.

$$M_w = \frac{Mi(mf - mi)}{100 - mf} \tag{2}$$

Where, M_w = mass of distilled water (g)

M_i = initial mass of sample (g)

m_f = final moisture content of sample (%)

m_i = initial moisture content of sample (%)

2.1 Seed size determination

The seeds principal dimensions (major diameter 'L,' intermediate diameter 'W,' and minor diameter 'T') were calculated using a digital vernier calliper with a precision of 0.01 mm. From the seeds principal dimensions (L, W, and T), arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity (Ø), aspect ratio (R_a), volume (V) and surface area (S) were calculated using equations 3, 4, 5, 6, 7 and 8, respectively (*Aviara et al.,* 2013; Saraçoğlu and Özarslan, 2012).

[Equation] (3)

$$D_g = (LxWxT)^{1/3}, mm \tag{4}$$

$$Ø = \frac{(LxWxT)^{1/3}}{L} x100\% \tag{5}$$

$$R_a = \frac{W}{L} \tag{6}$$

$$V = \frac{\pi LWT}{6} \text{ , mm}^3 \tag{7}$$

$$S = \pi (D_g)^2, \text{mm}^2 \tag{8}$$

2.2 **Determination of thousand seed mass (TSM), bulk density, true density and porosity**

The thousand seed mass (TSM) of the baobab was determined by counting one hundred seeds and the mass was determined by using a digital balance with an accuracy of 0.01 g. The value obtained was multiply by 10 to get the thousand seed mass (Gharibzahedi *et al.,* 2010).

The bulk density was determined using the method described by Jan *et al.* (2019). With the use of a cylinder of known volume, baobab seeds were filled from a height of 15 cm to the brim of the cylinder. The additional seeds were carefully taken off using a flat rule, making sure that the seeds were not compacted. Using equation 9, the bulk density was calculated from the mass of the seeds (M_s) in the cylinder and the volume the seeds (Vs) occupied in the cylinder.

$$\rho_b = \frac{M_s}{V_s} \quad (\text{g cm}^{-3}) \tag{9}$$

Equation 10 was also used to calculate the particle density (true density) (Vengaiah *et al.,* 2015). A known sample mass was placed in the cylinder containing the liquid, which was filled with toluene as a liquid for displacement. The particle density was calculated as the ratio of the sample's mass to the solid volume it occupied.

$$\rho_t = \frac{M(g)}{V_2 - V_1 (cm^{-3})} \tag{10}$$

Porosity was essayed using the method described by Shallangwa *et al.* (2021) in equation 11.

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} x100 \tag{11}$$

2.3 Determination of static coefficient of friction

An open-ended PVC cylinder with dimensions of 110 mm diameter and 90 mm height was placed on an inclined plane and filled with baobab seeds to determine the coefficient of static friction. Four different surfaces (glass, plywood, plastic board, and galvanized steel) were used. To avoid contact with the inclined plane upper surface, the PVC cylinder containing the seeds was slightly raised. The adjustable inclined plane was gradually raised until the seeds in contact with the inclined plane slanted surface began to move. A protracted fitted to the side of the inclined plane was used to read the tilt angle. The procedure was replicated, with each time a new sample of seeds being used. The angle of tilt of the inclined plane determines the static coefficient of friction using equation 12 (Vengaiah *et al.,* 2015).

$$\mu = \tan\theta \tag{12}$$

The angle of repose was estimated from the height and diameter of the heap formed by the seeds using equation 13. This was achieved by using an open-ended cylinder having a radius of 5.5 cm and a height of 9 cm. The cylinder was placed on a circular plate of a known diameter (10 cm) and filled with seeds from a height of 15 cm. The cylinder was gradually raised for the seeds to form a heap, and the height formed by the heap was measured (Saraçoğlu and Özarslan, 2012).

$$\theta = \tan^{-1}\frac{2h}{D} \tag{13}$$

2.4 Data analysis

On R-Studio software, version 1.3.1073-1, a completely randomized design was used for statistical analysis. In order to create graphs and calculate the regression equations, Microsoft Excel 2013 was used. The test for Tukey's honestly significant difference (HSD) was employed to determine whether there were any significant differences between the sample means.

3.0 Results and Discussion

Table 1 shows the seed's mean axial dimensions (length, width and thickness), arithmetic and geometric mean diameters, volume, surface area, aspect ratio, and sphericity.

Table 1. Geometric properties of the baobab seed at varied moisture content

MC (% db)	Length (mm)	Width (mm)	Thickness (mm)	Arithmetic mean diameter (mm)	Geometric mean diameter (mm)	Aspect ratio	Sphericity (%)	Volume (mm^3)	Surface Area (mm^2)
20.6	11.82a	9.2a	7.89a	9.64a	9.49a	0.78b	80.38b	451.97a	898.04a
15.8	11.09b	8.92b	7.49b	9.17b	9.04b	0.81a	81.61a	388.43b	808.55b
10.2	11.04b	8.34c	7.29c	8.89c	8.75c	0.76c	79.39b	352.58c	757.36c
5.4	10.07c	7.52d	6.43d	8d	7.86d	0.75c	78.18c	255.27d	611.03d
MSD	0.19	0.19	0.14	0.13	0.13	0.02	1.15	16.73	22.95

* Means with common letter at the same column are not significantly different by Tukey's minimum difference test at $p \leq 0.05$.

From table 1, it is observed that the seeds axial dimensions increased with increasing moisture content (MC). The seed axial dimensions increased from 10.07 – 11.82 mm, 7.52 – 9.20 mm and 6.43 – 7.89 mm, respectively for length, width and thickness. Tukey's HSD test carried on the seed axial dimensions at varied moisture contents were found to be to significant at $p \leq 0.05$. The seeds axial dimensions is crucial when developing sieves for cleaning purposes. A study conducted by Ola *et al.* (2017) on baobab seeds found a similar trend for increase in length (11.65-14.26 mm), width (9.43-11.38 mm) and thickness (7.33-11.10 mm) as MC was increased from 8.38 – 52.26 % (db). The correlation between the seed's three axial dimensions and MC can be expressed in the following linear regression equations.

Length $= 0.1174MC + 9.3041$ ($R^2 = 0.969$)

Width $= 0.1097MC + 7.069$ ($R^2 = 0.9555$)

Thickness $= 0.0.888MC + 6.1201$ ($R^2 = 0.9094$)

The arithmetic mean diameter (AMD) and geometric mean diameter (GMD) were found to be in a range of 8.00 - 9.64 mm and 7.86 – 9.50 mm, respectively at the respective MC levels. The increase in MC had a corresponding increase in the AMD and GMD. These properties are relevant for design of equipment for cleaning and grading. Several authors, Seifi and Alimardani, (2010) for wheat; Aviara *et al.* (2013) for moringa oleifera also found an increase in MC for increased in AMD and GMD, respectively. The equation that correlates with the baobab seeds AMD and GMD and the MC is expressed linearly as:

AMD $= 0.101MC + 7.6123$ ($R^2 = 0.9367$)

GMD $= 0.1006MC + 7.4771$ ($R^2 = 0.936$)

The sphericity of a seed determines the seed's ability to roll on its axis. This property is of essence in selection of equipment for seed transport and cleaning. Muhammad *et al*. (2015) observed that seeds with sphericity range between 50 -100 % has the propensity of rolling on its axis. The baobab seeds were found to be in a range of 78.18 – 80.38 % in the respective MC range for the study. From Table 1, it is observed that at 20.6 % dry basis moisture content, the sphericity of the seeds declined from 81.61% to 80.38%. The regression equation for sphericity and the MC was non-linear and it is expressed as:

Sphericity = $-0.0244MC^2 + 0.8102MC + 74.289$ ($R^2 = 0.8628$)

The volume of the seed was found to increase from 255.27 – 457.98 m^3 with increasing moisture. An increased in the seed volume is due to moisture absorption. There was a percentage increase in volume of 74.41 %, when the seed MC was increased from 5.4 – 20.60 % db. This attribute is a determining factor for heat and mass transfer during cooling and heating of biological materials and is necessary for accurate modelling to estimate the amount of heat through a biological material. A similar trend was observed by Baümler *et al.* (2006) for safflower seeds. The model for correlation between the seed volume and MC is linearly expressed as:

Volume = $12.159MC + 203.99$ (R2 = 0.9568)

The aspect ratio and the surface area of the seed ranged from 0.75 – 0.78 and 611.04 – 893.05 m^2, respectively within the studied MC. All these attributes are essential for selection and design of processing equipment. Surface area predicts the flow of gas, water and heat transfer during processing. Bala (2017) posits that the greater to surface area of a material, the better the heat absorption and desorption during cooling and heating (roasting and drying). The relationship between the aspect ratio and the surface area at the studied MC were seen to be non-linear and linear, respectively.

Aspect ratio = $0.0004MC^2 + 0.0132MC + 0.684$ ($R^2 = 0.682$)

Surface area = $17.718MC + 538.41$ ($R^2 = 0.9511$)

3.1 Gravimetric properties

These properties involve the seeds' bulk density, particle density, porosity and the thousand grain mass (TGM) is shown in Table 2. The bulk and the particle densities were found to increase from 740.77-763. 40 (kg/m^3) and 1155.22-1223.29 (kg/m^3), respectively within the respective MC range of 5.4-20.6 % db. These attributes are valuable in the estimation of pressure imposed on design of silo bottom as well as separation of seeds from pulp with aerodynamic seed separators.

Table 2. Gravimetric properties of the baobab seed at varied moisture content

Gravimetric properties

MC (% db)	Bulk density (kg/m^3)	Particle density (kg/m^3)	Porosity (%)	Thousand grain mass (g)
20.6	763.4a	1297.48a	41.15a	44.66a
15.8	756.69ab	1246.84ab	39.25ab	41.95b
10.2	749.86b	1193.63bc	37.17ab	40.89b
5.4	740.77c	1155.22c	35.86b	37.95c
MSD	3.16	75.98	4.15	2.2

*Means with common letter at the same column are not significantly different by Tukey's Minimum Difference test at p≤0.05.

The seed porosity and the thousand grain mass (TGM) were found to range from of 35.86 - 41.15 and 37.95 - 44.66, respectively. A significant differences were observed in the seed's porosity and TGM at the respective MC content studied. Jan *et al.* (2019) also observed a similar trends for porosity and the TGM for quinoa seeds as MC was increased from 5 – 25% db. The size of grain holder units (hoppers) and shelling compartments of processing machinery are largely influenced by the thousand grain mass, and the knowledge of this property is crucial for its estimation. The thousand grain mass is a determinant property for predicting the stability of a machine during operations like size reduction and planting (Muhammad *et al.,* 2015). The porosity of the seed influences rate of movement of air during drying, storage, and aeration. In pneumatic conveyors, it is also a helpful determinant property for estimating material transport. According to Boukouvalas *et al.* (2006), porosity is one of the most important characteristics that can be used to describe the shape of food materials. Among other properties, porosity is a crucial characteristic for equipment design.

Frictional properties

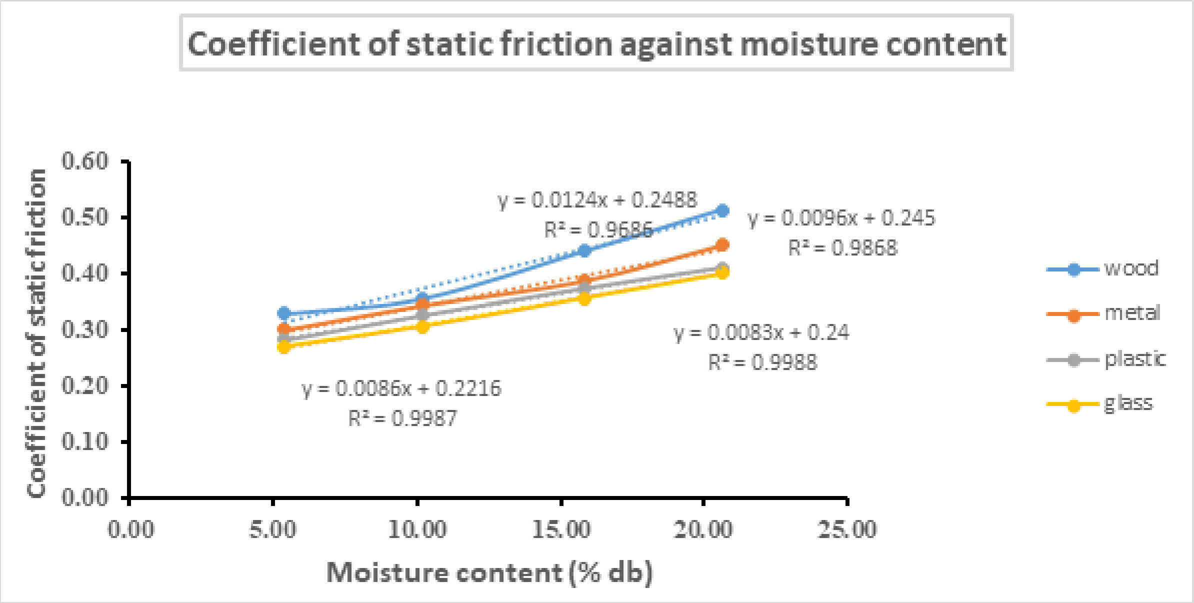

Figure 3. Effect of moisture content variation on coefficient of static friction on different surfaces.

This property provides a useful reference point for determining the angle of inclination in inclined grain transport machinery like chutes and hopper for flow with ease of resistance (Gharibzahedi *et al.,* 2010). When choosing materials for design and the amount of power needed to transport a specific biological material, coefficient of friction is an important dependent variable for consideration. For this study, the coefficient of static friction for different material handling surfaces at varied MC were found to be in a range of 0.33-0.51, 0.3-0.45, 0.28-0.41, and 0.27-0.4, respectively for wood, metal, plastic and glass material surfaces (fig. 3). These observation were in consonant with Alonge and Udofor (2012) for nutmeg and Sangamithra *et al.* (2016) for maize kernels. Linear regression equations were developed to predict the coefficient of static friction of the baobab seeds at the varied MC is shown Table 3.

Table 3. Regression equations for the coefficient of static friction

Surface	Regression equations
Wood	$y = 0.0124x + 0.2488$ ($R^2 = 0.9686$)
Metal	$y = 0.0096x + 0.245$ ($R^2 = 0.9868$)
Plastic	$y = 0.0083x + 0.24$ ($R^2 = 0.9988$)
Glass	$y = 0.0086x + 0.2216$ ($R^2 = 0.9987$)

The angle of repose is a property useful for determining the best sides for seed hoppers, silos, and storage containers to enable free flow of material (El-Fawal *et al.,* 2009). Moreso, it is an important property for storage equipment bottoms and conveyor width analysis (Galedar *et al.,* 2008). The angle of repose for the baobab seeds at the studied MC range of 5.4 – 20.6% db were in a range of 23.73 – 27.73°. Javad *et al.* (2011) found a similar trend of increasing MC for increase in angle of repose for corn, however, study by Bamgboye and Adebayo (2012) on jatropha seeds found a decrease in angle of repose with increasing MC.

4.0 Conclusion

Based on research into the influence of moisture content ranging from 5.4 to 20.6 % db on the physical characteristics of baobab seeds, the following conclusions have been made.

1. From the study, it was observed that moisture content has an influence on the properties studied. An increase in the MC had a corresponding increase in the seed length, width, thickness and the other properties studied.

2. The study have shown that there were significant differences ($p \leq 0.05$) between the ranges of moisture content and the physical properties studied.

3. The coefficient of static friction on the glass surface was lowest, and that of the plywood surface had the largest resistance to the flow of baobab seed.

4. To aid in the future prediction of these attributes tested for comparable work at various MC of the baobab seed, both linear and non-linear regression equations were developed.

Conflict of interest

For this study, the authors have no any conflict of interest to declare.

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