Physical properties of *Irvingia gabonensis*, *Detarium microcapum*, *Mucuna pruriens* and *Brachystegia eurycoma* seeds

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A B S T R A C T

A culinary enhancer is a substance that enhances the flavor and other properties of soups, stews and foods. Normally in flour form, culinary enhancers are used to enhance the proximate composition, viscosity, flavor and some other rheological and functional properties of soups and convenience foods. Physical properties of culinary seeds are utilized in the development of their handling, storage and processing facilities. The unit operations in the process of converting culinary seeds into flour include handling or conveying, cleaning, drying, storage, cracking, and separation of chaffs and shells before milling of the kernels or endosperm into flour. The aim of this study was to determine some postharvest physical properties of four African culinary enhancers, namely *Irvingia gabonensis* (*Ogbono*), *Detarium microcapum* (*Ofor*), *Mucuna pruriens* (*Ukpo*) and *Brachystegia eurycoma* (*Achi*) seeds. *Ogbono* seed had the highest dimensions (Length, L = 3.91, Width, W = 3.13, Thickness, T = 2.34 cm, Geometric mean diameter, $D_g = 3.13$ cm, Equivalent mean diameter, $D_e = 2.87$ cm and Square mean diameter, $D_s = 1.02$ cm), followed by *Ukpo*, *Ofor* and *Achi* seeds. The average sphericity, surface area and 1000-unit mass were 0.6, 25.61 cm$^2$ and 11130 g; 0.95, 13.24 cm$^2$ and 4019 g; 0.94, 17.79 cm$^2$ and 7720 g and 0.48, 3.11 cm$^2$ and 8960 g for *Ogbono*, *Ofor*, *Ukpo* and *Achi* seeds respectively. These properties are useful baseline data required for further research studies on rational development of handling and processing systems for the products. The seeds’ dimensions, size, and shape will be useful in the design and development of their cleaning, sorting, and grading machines and in the analyses of their drying behavior. The seeds’ densities and porosity values will be used to develop their conveying and storage facilities. The angles of repose and coefficient of friction will be used to design their conveying chutes and hoppers of their cracking machines and storage facility outlets.

1. Introduction

*Irvingia gabonensis* (*Ogbonoin* Ibo language of Nigeria), *Detarium microcapum* (*Oforin* Ibo language), *Mucuna pruriens* (*Ukpo* in Ibo language) and *Brachystegia eurycoma* (*Achi* in Ibo language) are economic trees and leguminous plants that are traditionally found in the savannah and forest zones of Africa. Among the various crops used in Africa as culinary enhancing agents during soup making, *Irvingia gabonensis* (*Ogbono*), *Detarium microcapum* (*Ofor*), *Mucuna pruriens* (*Ukpo*) and *Brachystegia eurycoma* (*Achi*) are most profound due mainly to their thickening, emulsification, stabilization, drawability and spicing function in soups and stews (for eating *fufu* made from *gari*, cocoyam and pounded yam). The seeds when pulverized to flour can cause changes in viscosity of other foods by swelling in water. They also serve as food additives to create required changes in the texture and functional properties of convenience foods, due to their absorption capacity (Ajayi et al., 2006).

These seeds have excellent economic and nutritional advantages. They are good sources of bioactive compound especially saponins, alkaloids, tannins, and flavonoids. They also contain protein, minerals, vitamins, carbohydrate, fats and soluble fiber. The component vitamins are soluble in water, which also possess high nutritional importance (Uhegbu et al., 2009). The proteins of these crops are rich in lysine but deficient in sulfur containing amino acids particularly cysteine and methionine. Precisely, *Mucuna sloanei* (*Ukpo*) contains between 6-19% crude protein, 39.8–61.49% carbohydrate, 1.84–5.9% fat and 11.24–17.10% vitamins. *Brachystegia eurycoma* seed (*Achi*) contains 56% carbohydrate, 15% crude fat, 9% protein, 4.5% ash and 2.9% crude fibre (Uhegbu et al., 2009; Ene-Obong, 1992). *Detarium microcapum* (*Ofor*)
contains 12.0–15.6% protein, 0.79% vitamins, 6.0% fat and 35.4–68.2% carbohydrate (Ajayi et al., 2006; Eze-Obong, 1992). *Irvingia gabonensis* (Ogbono) seed consists of approximately 62.8% of fats and 19.7% of carbohydrates. Protein is about 8.9%, dietary fibre, 5.3% and ash, 3.2% (Ejiro, 1994). *Brachystegia eurycoma* and *Detarium microcarpum* are reported to be very effective in the lowering of blood glucose level and blood cholesterol content and help in stabilizing the body temperature (Onimawo and Egbekun, 1998). The seed gum from *Brachystegia eurycoma* can be used as a binding agent in tablet formulation and compares favourably with the industrial type (Olayemi and Jacob, 2011). The seed, stem bark and exudates have been reported to possess antioxidant, anti-inflammatory, antibacterial, antifungal activities as well as facilitating wound healing (Igwe and Echeme, 2013; Igwe and Okwu, 2013; Adekunle, 2000). *Irvingia gabonensis* seed has very huge amount of soluble fibre and therefore commonly used in Western countries as a supplement for weight loss. It is also widely used in West Africa as a binder in pharmaceutical industries and a very important ingredient in the production of confectionary, edible fats, soap and cosmetics (Ogunsina et al., 2003; Ugbor, 1991), karingda seed (Suthar and Das, 1996), cumin seed (Singh and Goswami, 1996), lentil seeds (Carman, 1996), sunflower seeds (Gupta and Das, 1997), green (Nimkar and Chattopadhyaya, 2001), chick pea seeds (Konak et al., 2002), neem nuts (Visvanathan et al., 1996), quinoa seeds (Vilche et al., 2003), hemp seed (Sacilik et al., 2001), faba bean (Haciseferogullaria et al., 2003), rapeseed (Calisir et al., 2005), African yam beans (Asirow and Ani, 2011) and coffee (Chandrasekar and Viswanathan, 1999) have all been investigated. The following researchers have also studied some physico-mechanical properties of other seeds and crops (Aydin, 2003; Baryeh and Mangoe, 2002; Gezer et al., 2002; Guner et al., 2003; Olajide et al., 2000; Olayo, 2000).

However, there is scarcity of information in literature on physical properties of *Irvingia gabonensis* (Ogbono), *Detarium microcarpum* (Ofor), *Mucuna pruriens* (Ukpo) and *Brachystegia eurycoma* (Achi). Seed dimensions are very necessary in their electrostatic separation from contaminants and in the design and fabrication of sizing, sorting, conveying and grading systems (Mohsenin, 1986). Shapes of seeds are vital in the analysis and prediction of their drying behavior (Esref and Halil, 2007). True density, bulk density, density ratio and porosity are needed in the development and sizing of grain hoppers and storage facilities. They also affect the rate of heat and mass transfer of moisture during drying, cooling and aeration processes. Low porosity seed bed will require a high powered fan during drying or aeration as occasioned by the resistance to water vapor escape. Seed densities are needed during hardness studies and breakage susceptibility tests. When designing the angles at which chutes or hoppers must be positioned in order to achieve smooth flow, data on the static coefficient of friction are always necessary. Such information is also vital in determining the size of motor needed during seed handling and transportation (Ghasemi et al., 2007). The development of handling and storage machinery requires data on bulk densities, coefficients of friction on some commonly used material surfaces (galvanized steel, plywood and concrete) and angles of repose of crops (Parde et al., 2003). The knowledge of these properties are also needed for predicting the load and pressure on storage structures as well as for design of grain hoppers for processing machinery. The maximum angle of a pile of grains with the horizontal axis is normally used in the measurement of angle of repose (Mohsenin, 1986).

The processing of *Irvingia gabonensis* (Ogbono), *Detarium microcarpum* (Ofor), *Mucuna pruriens* (Ukpo) and *Brachystegia eurycoma* (Achi) for value addition involves parboiling, soaking or roasting, frying, dehulling and size reduction. These processes are laborious and time consuming, and are still done manually across West Africa with low output. In order to take advantage of the huge economic, nutritional and culinary potentials of these African seeds, there is the need to develop machines, systems and equipment for carrying out the dehulling, processing, cooking and handling operations which require knowledge of the physical and mechanical properties. The aim of this study therefore, was to investigate

![Figure 1. Brachystegia eurycoma (Achi), Detarium microcarpum (Ofor), Irvingia gabonensis (Ogbono) and Mucuna pruriens (Ukpo).](image-url)
the postharvest physical properties of *Irvingia gabonensis* (Ogbono), *Detarium microcapum* (Ofor), *Mucuna pruriens* (Ukpo) and *Brachystegia eurycoma* (Achi) which will serve as baseline data for the development of their handling and processing facilities.

2. Materials and methods

2.1. Collection and preparation of sample

Matured, harvested and dried samples of *Irvingia gabonensis* (Ogbono), *Detarium microcapum* (Ofor), *Mucuna pruriens* (Ukpo) and *Brachystegia eurycoma* (Achi) were sourced from Afikpo market, Ebonyi State, Nigeria.

Manual cleaning was used to separate foreign materials and damaged seeds. Manual cracking was done, and the seeds were grouped and the physical properties measured. The physical properties were determined in the Food and Bioprocess Laboratory, University of Nigeria, Nsukka, Nigeria. Figure 1 shows the seeds of *Irvingia gabonensis* (Ogbono), *Detarium microcapum* (Ofor), *Mucuna pruriens* (Ukpo) and *Brachystegia eurycoma* (Achi).

2.2. Determination of physical properties

The dimensions of 100 randomly picked seeds—length, \( L \); width, \( W \) and thickness, \( T \) were measured using Electronic Digital Caliper Vernier-

### Table 1. Physical properties of *Irvingia gabonensis* (Ogbono) seeds.

| Property                        | No. of Samples | Range          | Mean Value | Standard Deviation | Coef. of Variability (%) |
|--------------------------------|----------------|----------------|-------------|--------------------|--------------------------|
| Length, \( L \) (cm)            | 100            | 2.85-4.58      | 3.91        | 0.38               | 9.72                     |
| Width, \( W \) (cm)             | 100            | 2.34-4.10      | 3.13        | 0.33               | 10.54                    |
| Thickness, \( T \) (cm)         | 100            | 1.76-2.86      | 2.34        | 0.23               | 9.83                     |
| Geometric mean diameter, \( D_g \) (cm) | 100        | 2.32-3.50      | 3.06        | 0.25               | 8.17                     |
| Arithmetic mean diameter, \( D_a \) (cm) | 100         | 2.37-3.61      | 3.13        | 0.26               | 8.31                     |
| Equivalent mean diameter, \( D_e \) (cm) | 100         | 2.21-3.37      | 2.87        | 0.24               | 8.36                     |
| Solid volume, \( V_s \) (cm³)   | 100            | 6.56-22.44     | 15.25       | 3.58               | 23.48                    |
| Bulk volume, \( V_b \) (cm³)    | 100            | 398.8-400.3    | 399.95      | 0.5                | 3.28                     |
| Solid mass, \( M_s \) (g)       | 100            | 6.4-16.7       | 11.08       | 2.78               | 25.09                    |
| Bulk mass, \( M_b \) (g)        | 100            | 118-136        | 129.5       | 5.55               | 4.29                     |
| 1000-unit mass, \( M_{1000} \) (g) | 100        | 8720-13200     | 11130       | 80.67              | 7.79                     |
| Solid density, \( \rho_s \) (g cm⁻³) | 100         | 0.33-1.73      | 0.78        | 0.30               | 28.46                    |
| Bulk density, \( \rho_b \) (g cm⁻³) | 100         | 0.3-0.34       | 0.33        | 0.01               | 3.03                     |
| Density ratio (%)               | 100            | 101.74-525.85  | 241.66      | 89.95              | 37.51                    |
| Sphericity, \( Sp \)            | 100            | 0.81-81.34     | 52.81       | 17.63              | 34.14                    |
| Angle of repose, \( \phi \) (°) | 100            | 28.11-55.30    | 37.88       | 6.88               | 18.16                    |

### Table 2. Physical properties of *Detarium microcapum* (Ofor).

| Property                        | No. of Samples | Range          | Mean Value | Standard Deviation | Coef. of Variability (%) |
|--------------------------------|----------------|----------------|-------------|--------------------|--------------------------|
| Length, \( L \) (cm)            | 100            | 2.76-3.76      | 3.41        | 0.24               | 7.04                     |
| Width, \( W \) (cm)             | 100            | 2.22-2.88      | 2.61        | 0.16               | 6.13                     |
| Thickness, \( T \) (cm)         | 100            | 1.04-1.87      | 1.26        | 0.14               | 11.11                    |
| Geometric mean diameter, \( D_g \) (cm) | 100        | 1.98-2.43      | 2.23        | 0.11               | 4.93                     |
| Arithmetic mean diameter, \( D_a \) (cm) | 100         | 2.08-2.65      | 2.43        | 0.13               | 5.35                     |
| Equivalent mean diameter, \( D_e \) (cm) | 100         | 1.86-2.27      | 2.10        | 0.10               | 4.76                     |
| Square mean diameter, \( D_s \) (cm) | 100        | 0.66-0.81      | 0.74        | 0.04               | 5.41                     |
| Sphericity, \( Sp \)            | 100            | 0.88-0.98      | 0.96        | 0.05               | 5.05                     |
| Aspect ratio, \( Ra \)          | 100            | 0.71-0.83      | 0.77        | 0.03               | 3.90                     |
| Surface area, \( A \) (cm²)     | 100            | 10.46-15.65    | 13.24       | 1.29               | 9.74                     |
| Specific surface area, \( S_s \) cm² cm⁻³ | 100       | 2.07-2.57      | 2.27        | 0.12               | 5.29                     |
| Solid volume, \( V_s \) (cm³)   | 100            | 4.07-7.56      | 5.89        | 0.85               | 14.43                    |
| Bulk volume, \( V_b \) (cm³)    | 100            | 300-300.6      | 300.31      | 0.17               | 2.89                     |
| Solid mass, \( M_s \) (g)       | 100            | 2.10-5.40      | 4.11        | 0.89               | 21.65                    |
| Bulk mass, \( M_b \) (g)        | 100            | 160-192        | 177.3       | 9.34               | 5.27                     |
| 1000-unit mass, \( M_{1000} \) (g) | 100        | 3900-4780      | 4019        | 32.1               | 0.99                     |
| Solid density, \( \rho_s \) (g cm⁻³) | 100         | 0.38-1.20      | 0.72        | 0.20               | 27.78                    |
| Bulk density, \( \rho_b \) (g cm⁻³) | 100         | 0.53-0.64      | 0.59        | 0.03               | 5.09                     |
| Density ratio (%)               | 100            | 101.29-216.37  | 140.15      | 27.91              | 29.25                    |
| Sphericity, \( Sp \)            | 100            | 1.28-53.78     | 26.03       | 13.72              | 36.84                    |
| Angle of repose, \( \phi \) (°) | 100            | 19.98-34.18    | 27.49       | 3.87               | 14.08                    |
150MM LCD: Konga Product code: 3003530 (0–150, 0.01 mm). Geometric mean diameter ($D_g$) Arithmetic mean diameter ($D_a$), Equivalent mean diameter ($D_e$) and Square mean diameter ($D_s$) were calculated from length, $L$; width, $W$ and thickness, $T$ according to Eqs. (1), (2), (3), and (4)

$$D_e = \left(\frac{LW}{C_0}\right)^{1/3}$$

$$D_s = \frac{L + W + T}{3}$$

$$D_a = \frac{D_e + D_s + D_t}{3}$$

$$D_v = \left[\frac{2W + TL_1}{3}\right]^{1/2}$$

where, $L$, $W$, $T$, $D_g$, $D_a$, $D_e$ and $D_s$ are all in cm.

Sphericity ($S_p$) and aspect ratio ($R_a$) of the seeds were also calculated from the $L$, $W$ and $T$ using the expressions by Mohsenin (1986) and Asoiro et al. (2017) in Eqs. (5) and (6).

$$S_p = \frac{\left(\frac{L}{C_0}\right)^{1/3}}{L}$$

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

Specific surface area ($S_s$) and Surface area ($S$) were evaluated using the expression by Haciseferogullari et al. (2007) and Subukola and Onwuka (2011), given in Eqs. (7) and (8) respectively.

$$S_s = \frac{S_p}{M_b}$$

$$S = \frac{\pi BL^2}{2L - B}$$

where, $B$ is (LT)$^{1/2}$ (cm), $M_b$ and $\ell_s$ are solid mass (g) and bulk mass (g cm$^{-3}$) of seed respectively.

Solid volume ($V_s$) and bulk volume ($V_b$) (cm$^3$) were determined by water displacement method (Asoiro et al., 2017). The solid density, Bulk density, Density ratio and Porosity of Irvingia gabonensis (Ogbono), Detarium microcarpum (Ofor), Mucuna pruriens (Ukpo) and Brachystegia eurycoma (Achi) seeds were calculated using Eqs. (9), (10), (11), and (12) respectively, according to Asoiro et al. (2017):

$$\ell_s = \frac{M_s}{V_s}$$

$$\ell_b = \frac{M_b}{V_b}$$

$$\ell_s = \frac{\ell_s - \ell_b}{\ell_s} \times 100$$

$$\phi = Tan^{-1}\left[\frac{2H}{D}\right]$$

where, $M_s$ and $M_b$ are solid mass (g) and bulk mass (g) of seeds respectively.

A digital weight balance (Metler Digital Electric Weighing Balance (Range: 0–30,000 g) 0.01 g; Model: ME-702718) was used to measure and record 1,000-unit-mass, bulk mass for randomly selected samples from a mass of 50 kg. The method by Heidarbeigi et al. (2008) was used in the determination of angle of repose by employing a trigonometry rules and hollow cylinder. The seeds were placed into a hollow cylinder of known diameter ($D$) and known height ($H$) above a table top. The cylinder was gradually pulled off to allow the seeds flow out to form a conic shape. Angle of repose of a seed is the angle with the horizontal at which the seed will stand when piled (Paksy and Aydin, 2004). This was calculated using the expression in Eq. (13).

Table 3. Physical properties of Mucuna pruriens (Ukpo) Seed.

| Property                      | No. of Samples | Range       | Mean        | Standard Deviation | Coeft. of Variability(%) |
|-------------------------------|----------------|-------------|-------------|--------------------|--------------------------|
| Length, $L$ (cm)              | 100            | 2.23–3.22   | 2.84        | 0.16               | 5.63                     |
| Width, $W$ (cm)               | 100            | 2.06–3.09   | 2.81        | 0.18               | 6.41                     |
| Thickness, $T$ (cm)           | 100            | 1.23–2.22   | 1.94        | 0.18               | 9.28                     |
| Geometric mean diameter, $D_g$ (cm) | 100            | 1.89–2.70   | 2.49        | 0.15               | 6.02                     |
| Arithmetic mean diameter, $D_a$ (cm) | 100            | 1.94–2.73   | 2.53        | 0.15               | 5.93                     |
| Equivalent mean diameter, $D_e$ (cm) | 100            | 1.84–2.64   | 2.43        | 0.15               | 6.17                     |
| Square mean diameter, $D_s$ (cm) | 100            | 0.63–0.90   | 0.83        | 0.06               | 6.02                     |
| Sphericity, $S_p$             | 100            | 0.84–0.98   | 0.94        | 0.06               | 6.31                     |
| Aspect ratio, $R_a$           | 100            | 0.83–1.08   | 0.99        | 0.05               | 5.05                     |
| Surface area, $S$ (cm$^2$)    | 100            | 9.95–21.16  | 17.79       | 2.13               | 11.97                    |
| Specific surface area, $S_s$ (cm$^2$cm$^{-3}$) | 100            | 1.98–2.83   | 2.19        | 0.14               | 6.39                     |
| Solid volume, $V_s$ (cm$^3$)  | 100            | 3.52–10.31  | 8.19        | 1.30               | 15.87                    |
| Bulk volume, $V_b$ (cm$^3$)   | 100            | 699.1–700.4 | 700.11      | 0.36               | 4.39                     |
| Solid mass, $M_s$ (g)         | 100            | 4.0–9.3     | 7.62        | 1.03               | 13.52                    |
| Bulk mass, $M_b$ (g)          | 100            | 300–581     | 344.4       | 22.03              | 6.40                     |
| 1000-unit-mass, $M_0$ (g)     | 100            | 7050–8440   | 7720        | 33.0               | 4.27                     |
| Solid density, $\rho_s$ (g cm$^{-3}$) | 100            | 0.39–2.45   | 0.97        | 0.30               | 30.93                    |
| Bulk density, $\rho_b$ (g cm$^{-3}$) | 100            | 0.42–0.54   | 0.49        | 0.03               | 6.12                     |
| Density ratio, $\rho_r$ (%)   | 100            | 125.4–489.4 | 197.96      | 56.89              | 29.68                    |
| Porosity, $\varepsilon$ (%)  | 100            | 20.27–79.57 | 46.64       | 11.24              | 34.42                    |
| Angle of repose, $\phi$ (°)  | 100            | 17.06–30.86 | 24.61       | 2.94               | 11.95                    |
Table 4. Physical properties of Brachystegia eurycoma (Achi) seed.

| Property                        | No. of Samples | Range   | Mean Value | Standard Deviation | Coeft. of Variability (%) |
|---------------------------------|----------------|---------|------------|--------------------|---------------------------|
| Length, L (cm)                  | 100            | 1.46-2.66 | 2.11       | 0.23               | 10.90                     |
| Width, W (cm)                   | 100            | 1.04-2.0  | 1.62       | 0.23               | 14.20                     |
| Thickness, T (cm)               | 100            | 0.24-0.45 | 0.36       | 0.05               | 13.89                     |
| Geometric mean diameter, Dg (cm)| 100            | 0.72-1.29 | 1.07       | 0.12               | 11.22                     |
| Arithmetic mean diameter, Da (cm)| 100            | 0.92-1.62 | 1.36       | 0.15               | 11.03                     |
| Equivalent mean diameter, De (cm)| 100            | 0.74-1.33 | 1.11       | 0.13               | 11.71                     |
| Square mean diameter, Ds (cm)   | 100            | 0.24-0.43 | 0.36       | 0.04               | 11.11                     |
| Sphericity, Sp                  | 100            | 0.32-0.57 | 0.48       | 0.05               | 10.42                     |
| Aspect ratio, Ra                | 100            | 0.62-0.91 | 0.77       | 0.07               | 9.09                      |
| Surface area, S (cm²)           | 100            | 1.39-4.45 | 3.11       | 0.63               | 20.26                     |
| Specific surface area, St (cm² cm⁻³)| 100        | 3.99-7.22 | 4.88       | 0.64               | 13.12                     |
| Solid volume, Vs (cm³)          | 100            | 0.19-1.11 | 0.66       | 0.19               | 28.79                     |
| Bulk volume, Vb (cm³)           | 100            | 297.5-300.6 | 299.78   | 0.97               | 19.89                     |
| Solid mass, M_s (g)             | 100            | 0.5-1.4   | 0.86       | 0.20               | 23.26                     |
| Bulk mass, M_b (g)              | 100            | 197-217   | 207.4      | 6.71               | 3.23                      |
| 1000-unit mass, M_u (g)         | 100            | 7400-9900 | 8960      | 5.4                | 6.03                      |
| Solid density, ρ_s (g cm⁻³)     | 100            | 0.66-4.67 | 1.47       | 0.77               | 52.38                     |
| Bulk density, ρ_b (g cm⁻³)      | 100            | 0.66-0.72 | 0.69       | 0.02               | 2.90                      |
| Density ratio, ρ_r (%)          | 100            | 102.31-699.52 | 216.57 | 113.96             | 52.89                     |
| Porosity, ϕ (%)                 | 100            | 2.26-85.70 | 44.47     | 21.68              | 50.79                     |
| Angle of repose, ψ (°)          | 100            | 14.83-27.46 | 20.63     | 3.35               | 16.24                     |

Table 5. Comparative average value of some physical properties of the four African culinary enhancers at a glance.

| Seed                     | L (cm) | W (cm) | T (cm) | D_s (cm) | S_p | ρ_s (g cm⁻³) | ρ_b (g cm⁻³) | R_a (cm) | ϕ (%) | M_u (kg) | S (cm²) |
|--------------------------|--------|--------|--------|----------|-----|--------------|--------------|----------|-------|----------|---------|
| Ogbono                   | 3.91   | 3.13   | 2.34   | 3.13     | 0.64| 0.78         | 0.33         | 0.8      | 37.88 | 11.1     | 25.61   |
| Ofor                     | 3.41   | 2.61   | 1.26   | 2.43     | 0.96| 0.72         | 0.59         | 0.77     | 27.49 | 4.0      | 13.24   |
| Ukpo                     | 2.84   | 2.81   | 1.94   | 2.53     | 0.94| 0.97         | 0.49         | 0.99     | 24.61 | 7.7      | 17.79   |
| Achi                     | 2.11   | 1.62   | 0.36   | 1.36     | 0.48| 1.47         | 0.69         | 0.77     | 20.63 | 9.0      | 3.11    |

The moisture content MCₐb, % and (MCₐwb) of the seeds was evaluated according to ASAE (1983) recommended methods. The sample seeds were weighed (M_initial) and then oven-dried at 105 °C to a constant weight (M_final). The moisture content of the seeds (%) dry basis (wb) and wet basis (db) were calculated using the expressions in Eqs. (14) and (15) respectively.

\[
MC_{db} = \frac{M_{initial} - M_{final}}{M_{final}} \times 100 \quad (14)
\]

\[
MC_{wb} = \frac{M_{initial} - M_{final}}{M_{initial}} \times 100 \quad (15)
\]

where, M_initial and M_final are initial and final mass of seeds (g) respectively.

The method used by Asoro et al. (2017) and Pliestic et al. (2006) was employed to determine the coefficient of static friction of the seeds on surfaces of plywood, corrugated metal sheet, aluminum, asbestos, glass and plastic. An open-ended hollow metal cube was filled with the seeds and put on adjustable tilting surface. The surface was gradually tilted to angle θ at which the cube began to slide down the surface. The expression in Eq. (16) was used to determine the coefficient of static friction, μ.

\[
\mu = \tan \theta \quad (16)
\]

3. Results and discussion

Table 1 presents some physical properties of Irvingia gabonensis (Ogbono) seeds. At a MC. of 8.27 ± 1.05 % db, Ogbono seed had a mean length, L of 39.1 ± 3.8 mm; a width, W of 31.3 ± 3.3 mm; and a thickness, T of 23.4 ± 2.3 mm Ohaeri and Ohaeri (2015) had earlier reported a slightly higher dimension of 44.00-47.73 mm, 33.50–34.89 mm, 20.60–21.79 mm and 32.20–33.73 mm for major, intermediate, minor and equivalent diameters respectively as moisture content (MC) rose from 7.02% to 15.04% db. Aviara et al. (2012) had earlier reported a slight increase in the average, L, W, T, D_s, D_a and geometric mean diameter by 2.7, 1.0, 0.4, 1.6, 1.4 and 1.3% for Irvingia gabonensis and 4.1, 0.1, 0.6, 2.2, 1.6 and 1.6% for Irvingia wombolu with increasing moisture content, respectively. At moisture content values of 10.6, 21, 32.54 and 43.14% db, Nwigbo et al. (2013) reported slightly different values of solid density, bulk density and porosity...
75.51% respectively. The variation in values may be as a result of the grinding of the sample. Aviara et al. (2015), however, reported average values of 17.3 mm, 1316 kg m\(^{-3}\), 3.184 kg, 35%, and 58% for arithmetic mean diameter, particle density, bulk density, 1000-unit mass, porosity, and sphericity at a MC of 8.2% db. The differences are likely because of different moisture contents and different size composition of the experimental samples.

Table 3 shows the measured physical properties of *Mucuna pruriens* (*Ukpo*) seed at average moisture content of 11.39 ± 0.82% db. *Ukpo* seed has a mean length, width, and thickness of 28.4 ± 1.6 mm, 28.1 ± 1.8 mm, and 19.4 ± 1.8 respectively. Other average physical properties of *Ukpo* seed include sphericity (1.11 ± 0.05), aspect ratio (0.99 ± 0.03), surface area (1779 ± 213 mm\(^2\)), and specific surface area (21.9 ± 1.4 mm\(^2\)/mm\(^3\)). The solid volume, solid mass, and 1000-unit mass of *Ukpo* seed is 819 ± 13.0 mm\(^3\), 7.62 ± 1.03 g, and 7720 ± 33 g respectively. Its solid density, bulk density, density ratio, porosity, and angle of repose are 0.97 ± 0.30 g cm\(^{-3}\), 0.49 ± 0.03 g cm\(^{-3}\), 19.83 ± 5.89%, 45.82 ± 15.77%, and 24.61 ± 2.94° respectively.

Physical properties of *Brachystegia eurycoma* (*Achi*) seeds at an average MC of 12.64 ± 0.27% db are shown in Table 4. The average length, width, and thickness of *Achi* seed is 21.10 ± 0.23 mm, 16.2 ± 0.23 mm, and 3.6 ± 0.5 mm respectively. Its average solid volume, solid mass, and 1000-unit mass are 660 ± 190 mm\(^3\), 0.86 ± 0.20 g, and 8960 ± 5.4 g respectively. However, Aviara et al. (2014) had reported that the axial dimensional length, width and thickness increased from 2.29 mm to 2.45 mm, 1.65 mm–1.91 mm and 0.34 mm–0.52 mm respectively, as moisture content, MC increased from 2.79% to 27.13% d.b. In the same MC range, one thousand seed weight, particle density, porosity, roundness, angle of repose, surface area and sphericity also increased linearly from 0.901 kg to 1.252 kg, 2270 kg m\(^{-3}\) to 2520 kg m\(^{-3}\), 11.23%–15.46%, 35%–47%, 16.8°–29.2°, 7.67 cm\(^2\)–8.48 cm\(^2\) and 67% to 82% respectively, while bulk density decreased from 745.4 kg m\(^{-3}\) to 613.6 kg m\(^{-3}\).

Table 5 shows comparative average values of some physical properties of the four African culinary enhancers at a glance. Obviously, based on the arithmetic mean diameter (D\(_a\)), *Ogbono* seed is larger than *Ukpo*,

![Figure 2](https://example.com/figure2.png)
Ofor, and Achi seeds in that order; but less spherical (Sₚ) than Ofor and Ukpo. The average solid density was higher than the average bulk density for all the seeds. Similar findings had earlier been documented for Jamin Syzygium cuminii seeds (Bajpai et al., 2019). The average solid and bulk densities (ρₛ and ρₜₚₑ) of Achi seeds were higher than that of Ukpo, Ofor, and Ogbono seeds. The solid density values showed that Ogbono (0.78 g cm⁻³), Ukpo (0.97 g cm⁻³) and Ofor (0.72 g cm⁻³) seeds are lighter and will most likely float in water except for Achi (1.47 g cm⁻³). This makes them easily separated from the mixture with one another or other biomaterials in water. The aspect ratio (Rₐ) of Ukpo is more than that of Ogbono, Ofor, and Achi seeds. The angle of repose (φ) of Ogbono seed is greater than that of Ofor, Ukpo, and Achi seeds. This indicates that Ogbono (37.88°) seeds aggregate and stick more closely together, followed by Ofor (27.49°), Ukpo (24.61°) and Achi (20.63°). The angle of repose values for Ogbono, Ukpo and Achi were clearly within the range of values (27.37–33.53°) for Jamun Syzygium cuminii) seeds as MC increased from 11.54 to 26% (db) (Bajpai et al., 2019). Equally, Ogbono seed has the highest 1000-unit mass (Mu), followed by Achi, Ukpo, and then Ofor. Again, Ogbono seed had a larger surface area (S), followed by Ukpo, Ofor, and then Achi seeds.

Based on the shape and size differences, Ukpo and Ofor seeds would flow or roll down chutes and hoppers more readily than Achi and Ogbono seeds. On the average, it will be more economical to package and transport Achi seeds than Ogbono and Ukpo seeds because of its higher bulk density. Based on the Aspect ratio value, Ukpo seeds would sort better than Ogbono, Ofor, and Achi seeds in that order. The porosity values indicate that it would cost more to aerate or dry Achi seeds in storage than Ukpo, Ofor, and Ogbono seeds in that order due to higher pressure requirement.

Figure 2 presents the comparative porosity, density ratio, coefficient of static friction and moisture content (% db). The porosity (ε) of Ogbono seed (52.81%) is greater than that of Ukpo (46.64%), Achi (44.47%) and Ofor (26.03%) seeds, with similar trend also observed for density ratio. The increase in porosity is dependent upon the cellular arrangement of the seeds, bulk and solid densities (Bajpai et al., 2019).

The coefficient of static friction values for Ogbono seeds on surfaces of aluminum, plastic and corrugated metal falls within the range of values of 0.37–0.7, 0.3–0.64 and 0.5–0.82 respectively, reported by Ohaeri and Ohaeri (2015) over a moisture content range (7.02–26%) (Bajpai et al., 2019). Equally, Ogbono seed has the highest 1000-unit mass (Mu), followed by Achi, Ukpo, and then Ofor. Again, Ogbono seed had a larger surface area (S), followed by Ukpo, Ofor, and then Achi seeds.

From Figure 2, the nature of material surface used for design of the conveying material significantly affected the coefficient of static friction. Similar findings had earlier been reported by Bajpai et al. (2019) for Jamun Syzygium cuminii seeds. The trend may be as a result of differences in surface roughness and the force of cohesion between the seeds and the material surfaces. Coefficient of static friction gives information about the friction which the food material has with respect to the material surfaces in contact with the material. It is an important property in the design of conveyors. The entire seeds offered maximum static friction on corrugated metal sheet and minimum on glass surface, except for Achi where plastic surface was the minimum. This is likely due to the force of adhesion and roughness between the contacting surfaces (Singh and Meghwal, 2019). Ogbono seed with MC of 8.27% db suggests better storage stability than Ofor (10.96% db), Ukpo (11.39% db) and Achi (12.64% db).

4. Conclusions

Based on arithmetic mean diameter, Irvingia gabonensis (Ogbono) seed was larger (31 mm) than Ofor seed (24 mm), Ukpo seed (25 mm), and Achi seed (14 mm). Ofor seed (0.96) is more spherical than Achi seed (0.48); Ofor seed therefore has more tendency to roll down a surface than Achi seed. The mean surface area of Ogbono seed was larger (2561 ± 413 mm²) than Ofor seed (1324 ± 129 mm²), Ukpo seed (1779 ± 213 mm²), and Achi seed (311 ± 63 mm²). Achi seed (0.69 ± 0.02 gcm⁻³) has more bulk weight than Ogbono seed (0.33 ± 0.01 gcm⁻³), Ofor seed (0.59 ± 0.03 gcm⁻³), and Ukpo seed (0.49 ± 0.03 gcm⁻³). Based on surface of plywood, the static coefficient of friction of Ogbono seed (0.52 ± 0.04) is higher than that of Ofor seed (0.33 ± 0.01), Ukpo seed (0.30 ± 0.02) and Achi seed (0.41 ± 0.02). Ukpo seed with the smallest static coefficient of friction would therefore flow more easily down a plywood surface than the other seeds. The high coefficient of variability for properties of Ogbono seed (3.03–34.42), Ofor seed (2.53–27.78), Ukpo seed (2.97–34.42), and Achi seed (1.87–52.87) indicates the need to classify the seeds into large, medium, and small before carrying out any process operations based on their size. This study has generated baseline data for the development of processing, handling, storage, packaging and transportation facilities for the seeds studied.

Declarations

Author contribution statement

Felix Uzochukwu Asoiro: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sunday Louis Ezeoha: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Cosmas Ngoziechukwu Anyanwu: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Nneoma Nkem Anekwe: Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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