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Physical properties of unshelled, shelled and kernel of velvet tamarind (*Dialium guineense)* fruit from Nigeria

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Abstract: Physical properties of agricultural products are the most important parameters to determine the optimum design of grading, conveying, processing, and packaging systems. This study was conducted to investigate some post-harvest physical properties of unshelled (black), shelled (yellow) and kernel of velvet tamarind *(Dialium guineense)* fruit. The physical properties studied include axial dimensions, geometric mean diameter (GMD), arithmetic mean diameter, square mean diameter, equivalent mean diameter, surface area, aspect ratio, specific surface area, sphericity, mass, volume, density, porosity, moisture content, angle of repose and coefficient of static friction on various surfaces. The mean length, width, and thickness of velvet tamarind fruit (unshelled) were found to be 17.4, 16, and 8.1 mm respectively; while for the kernel they were 7.7, 7.2, and 3.6 mm, respectively. The sphericity, porosity, bulk density, and angle of repose of tamarind fruit (unshelled) were 0.75, 12.5%, 843.7 kg/m^3, and 31.5° respectively. The GMD, surface area, and aspect ratio were 13 mm, 46.3 x 10^{-5} m^2, and 0.93 respectively for the unshelled

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PUBLIC INTEREST STATEMENT

Face with present economic recession occasioned by the neglect of the agricultural sector by the previous governments, coupled with the current global fall in the crude oil prices, which is her major sources of foreign income, Nigeria is seriously investing in agricultural mechanization in other to boost its agricultural productivity. Data on the physical properties of velvet tamarind (*Dialium guineense*) fruit, in all its forms, is imperative for determining the design and development of grading, conveying, processing, storage and packaging systems for the post harvest processing of velvet tamarind (*Dialium guineense*) fruit, which is widely consumed and has huge socioeconomic potential to the country.

fruit; but were 9.1 mm, 22.3 × 10^{-5} m^2, and 0.67 respectively for the shelled fruit; and were 5.8 mm, 9.2 × 10^{-5} m^2, and 0.94 respectively for the kernel.

Subjects: Environment & Agriculture; Bioscience; Food Science & Technology; Physical Sciences; Engineering & Technology

Keywords: physical properties; velvet tamarind; *Dialium guineense* fruit; porosity; angle of repose; aspect ratio

1. Introduction

Velvet tamarind (*Dialium guineense*) is a tree of an average height of 30 m. *Dialium guineense* fruit is an important agricultural product in south-eastern Nigeria The fruits are widely sold in local markets in Nigeria and are consumed fresh by people of all ages as a snack. The fruits of the plant are chewed by most women in southeastern Nigeria to improve lactation and check genital infection (Akinpelu, Awotorebo, Agunbiade, Aiyegoro, & Okoh, 2011; Balogun, Oji, Besong, & Umahi, 2013; Nwosu, 2000). The processing method employed is still traditional. There is need, therefore, for a comprehensive study of its physical properties to enable rational development of appropriate technologies for its processing.

Physical properties of agricultural products are the most important parameters to determine the proper standard of design of grading, conveying, processing, and packaging systems (Tabatabaeefar & Rajabipour, 2005). Quality differences in fruits are often detected by difference in density. Mass, volume, and projected area are important in determining sizing systems. When fruits are transported hydraulically, the design fluid velocities are related to both density and shape. Physical characteristics of crops are essential parameters in utilization, development of processing methods, and design of equipment (Bagherpour, Minaei, & Khoshtaghaza, 2010). The shape and size of crops are relevant in the design and selection of appropriate cleaning equipment. Physical attributes of crops such as size, shape, density, are major consideration in designing hopper, drying and aeration systems, as these properties affect the resistance to air flow through the stored materials (Hosseinzadeh, Feyzollahzadeh, & Afkari, 2013).

Several researchers have characterized many world economic seeds and grains, such as pigeon pea (Shepherd & Bhardwaj, 1986), quinoa seeds (Vilche, Gely, & Santalla, 2003), hemp seed (Sacilik, Öztürk, & Keskin, 2003), faba bean (Hacıseferoğulları, Gezer, Bahtiyarca, & Mengeş, 2003), African yam beans (Asoiro & Ani, 2011), rapeseed (Çalışır, Marakoğlu, Öğüt, & Öztürk, 2005), Jatropha (Shkelqim & Joachim, 2010; Sirisomboon, Kitchaiya, Pholpho, & Mahuttanyavanitch, 2007) and blueberry (Hu, Dong, Liu, Opara, & Chen, 2015), but very little information abound on the physical properties of velvet tamarind fruit. The objective of this study was to determine some physical properties of velvet tamarind (*Dialium guineense*), namely: axial dimensions, geometric mean diameter (GMD), arithmetic mean diameter (AMD), square mean diameter (SMD), equivalent mean diameter (EMD), surface area, aspect ratio, specific surface area (SSA), sphericity, mass, volume, density, porosity, moisture content, angle of repose and coefficient of static friction on six different surfaces.

2. Materials and methods

2.1. Sample collection and preparations

Freshly harvested fruits of *Dialium guineense* were sourced from some local farmers at Ogige market, Nsukka local government area of Enugu state, Nigeria. The fruits were cleaned manually by hand to remove all foreign matter such as dust, dirt, pieces of stones, as well as broken and immature fruits. Some of the fruits were manually cracked, grouped and thereafter measured. Determination of the physical properties was carried out in the Food and Bioprocess Laboratory in the University of Nigeria, Nsukka, Nigeria. Figure 1 shows the unshelled, shelled and kernel of *Dialium guineense* fruit.

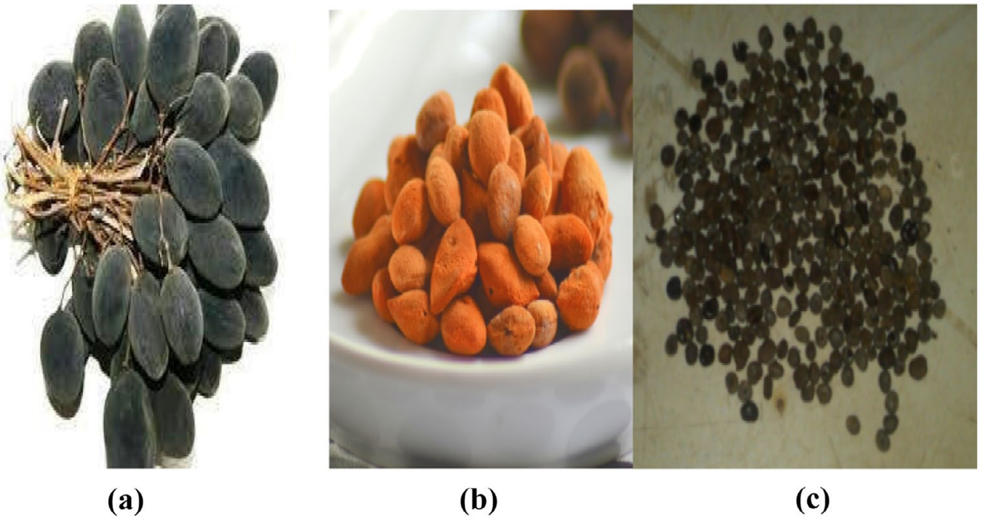

Figure 1. Pictorial view of (a) unshelled, (b) shelled and (c) kernel of *Dialium guineense* fruit.

2.2. Determination of physical properties of unshelled, shelled and kernel of Dialium guineense fruit

2.2.1. Determination of dimensions and shape

A digital vernier calliper (0–150 ± 0.01 mm) was used to measure the dimensions of the unshelled, shelled and kernel of *Dialium guineense* fruits as demonstrated by Mohsenin (1986). The GMD, AMD, EMD and SMD were determined using the expression by Asoegwu, Ohanyere, Kanu, and Iwueke (2006) given in Equations (1) to (4)

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

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

$$D_e = \frac{(D_g + D_a + D_s)}{3} \tag{3}$$

$$D_s = \left[\frac{(LW+WT+TL)}{3}\right]^{\frac{1}{2}} \tag{4}$$

where, D_g is GMD (m), D_a is AMD (m), D_e is EMD (m), D_s is SMD, L is length (m), W is width (m) and T is thickness (m).

The sphericity (S_p) and aspect ratio of the fruit were determined using the expressions by Mohsenin (1986) and Omobuwajo, Akande, and Sanni (1999) given in Equations (5) and (6).

$$S_p = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{5}$$

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

2.2.2. Determination of surface area and specific surface area
The surface area and SSA were estimated by the relationship in Equations (7) and (8) given by Hacıseferoğulları, Gezer, Özcan, and MuratAsma (2007) and Subukola and Onwuka (2011).

$$S = \frac{\pi (WT)^{\frac{1}{2}} L^2}{2L - (WT)^{\frac{1}{2}}} \tag{7}$$

$$S_s = \frac{S \ell_b}{M_s} \tag{8}$$

where, S is surface area (m^2), S_s is SSA ($m^2\ m^{-3}$), l_b is bulk density (kg m^{-3}) and M_s is solid mass (kg) of the fruit.

2.3. Determination of gravimetric properties

2.3.1. Moisture content
The moisture content of the fruit was determined according to ASAE (1983) recommended method for edible beans. This involves the oven drying of fruit samples at 105°C for 24 h. The samples were later weighed and recorded using an electronic digital weight balance (Metler Digital Electric Weighing Balance (Range: 0–30,000 g) ± 0.01 g; Model: ME-702718). The moisture content of the fruit (%) wet basis (wb) and dry basis (db) were calculated using Equations (9) and (10)

$$MC_{wb} = \frac{M_i - M_f}{M_i} \times 100 \tag{9}$$

$$MC_{db} = \frac{M_i - M_f}{M_f} \times 100 \tag{10}$$

where, MC_{wb} is moisture content, wet basis (%); MC_{db} is moisture content, dry basis (%); M_i is initial mass of fruit sample (g) and M_f is final mass of fruit sample (g).

2.3.2. Solid volume and bulk volume
The solid volume (SV) and bulk volume (BV) of the samples were determined by water displacement. In this process, individual and bulk samples were weighed and immersed in a measuring cylinder containing known volume of water thus leading to an increase (rise) in the water volume, the difference between the final level of water in the measuring cylinder and the initial level of water was the solid and BV of the unshelled, shelled and kernel of the fruit samples.

2.3.3. Solid density, bulk density, density ratio and porosity
Solid density (SD) is the ratio of solid mass of the fruit to its SV. Bulk density (BD) is the ratio of the mass of the bulk fruit to its BV. Density ratio is the ratio of SD to BD expressed as a percentage. Porosity is the ratio of free space between fruit to that of the total bulk fruit. It is expressed in percentage. The SD, BD, density ratio and porosity of unshelled, shelled and kernel of *Dialium guineense* fruit were calculated using Equations (11) to (14).

$$\ell_s = \frac{M_s}{V_s} \tag{11}$$

$$\ell_b = \frac{M_b}{V_b} \tag{12}$$

$$\ell_r = \frac{\ell_s}{\ell_b} \times 100 \quad (13)$$

$$\varepsilon = \frac{\ell_s - \ell_b}{\ell_s} \times 100 \quad (14)$$

where, l_s is SD (kg m^{-3}), M_s is solid mass (kg), V_s is SV (m^3), l_b is BD (kg m^{-3}), M_b is bulk mass (kg), V_b is BV (m^3), l_r is density ratio (%) and ε is porosity (%).

2.3.4. Solid mass, bulk mass and 1,000-unit mass

The solid mass, bulk mass and 1,000-unit-mass of the unshelled, shelled and kernel of *Dialium guineense* fruit were determined for randomly selected samples from a mass of 20 kg, weighed and recorded using a digital weight balance (Metler Digital Electric Weighing Balance (Range: 0–30,000 g) ± 0.01 g; Model: ME-702718).

2.4. Determination of functional properties

2.4.1. Coefficient of static friction on various surfaces

The coefficient of static friction of the fruit was determined against six structural material surfaces namely: plywood, corrugated metal sheet, aluminum, asbestos, glass and plastic according to Shepherd and Bhardwaj (1986), Joshi, Das, and Mukherjee (1993) and Pliestic, Dobricevic, Filipovic, and Gospodaric (2006). The coefficient of static friction, μ was calculated from the expression in Equation (15).

$$\mu = \tan\theta \quad (15)$$

2.4.2. Angle of repose

The angle of repose was determined using a hollow cylinder and then trigonometry rules according to Heidarbeigi, Ahmadi, Kheiralipour, and Tabatabaeefar (2008). The angle of repose is the angle with the horizontal at which the material will stand when piled (Paksoy & Aydin, 2004). It was calculated using the expression in Equation (16).

$$\theta = \tan^{-1}\left[\frac{2H}{D}\right] \quad (16)$$

where, θ is angle of repose (°), H is height of the pile (cm) and D is diameter of the pile (cm).

3. Results and discussion

Results of the physical properties of unshelled, shelled and kernel of *Dialium guineense* fruit is shown in Table 1.

3.1. Dimensions and shape

The mean length of the unshelled, shelled and kernel of *Dialium guineense* fruit were 0.0174, 0.0150 and 0.0077 m respectively. The mean widths were 0.0160, 0.0100 and 0.0072 m respectively. The mean thickness of the unshelled, shelled and kernel of the fruit were 0.0081, 0.0052 and 0.0036 m respectively. The GMD, EMD, AMD and SMD for the unshelled, shelled and kernel were 0.0130, 0.0091 and 0.0058 m; 0.0135, 0.0096 and 0.0060 m; 0.0138, 0.0101 and 0.0062 m; and 0.0135, 0.0096 and 0.0060 m respectively. Zare, Salmanizade, and Safiyari (2012) had earlier reported ranges of values of 14.08–26.82, 11.38–18.99 and 11.29–17.59 mm for length, width and thickness of Russian olive fruit respectively. Ranges of values of 15.29–21.69, 13.14–20.45, 13.11–18.76, 14.53–20, 14.5–19.94 and 14.52–19.97 mm had also been reported for length, width, thickness, AMD, GMD and EMD respectively for jujube fruit (Zare, Safiyari, & Salmanizade, 2012). For different varieties of apricot fruit, Hacıseferoğulları et al. (2007) presented values in the ranges of 29.26–46.98 mm, 30.16–40.43, 27.64–36.73 and 28.99–41.15 mm for length, width, thickness and GMD respectively. Geometric mean of the axial dimensions is useful in the estimation of the projected area of a particle moving in the turbulent or near-turbulent region of an air steam. Projected area of particles are generally

Table 1. Physical properties of unshelled, shelled and kernel of *Dialium guineense* fruit

Properties	*N*	Range			Mean			St. dev.		
		Unshelled	Shelled	Kernel	Unshelled	Shelled	Kernel	Unshelled	Shelled	Kernel
Length, *L* (m)	100	0.0138–0.0226	0.0124–0.0187	0.0064–0.0088	0.0174	0.0150	0.0077	0.0021	0.0015	0.0006
Width, *W* (m)	100	0.0121–0.0190	0.0080–0.0139	0.0061–0.0085	0.0160	0.0100	0.0072	0.0171	0.0011	0.0006
Thickness, *T* (m)	100	0.0046–0.0098	0.0032–0.0069	0.0031–0.0042	0.0081	0.0052	0.0036	0.0013	0.0008	0.0002
GMD, D_g (m)	100	0.01–0.0157	0.0080–0.0106	0.0053–0.0064	0.013	0.0091	0.0058	0.0012	0.0004	0.0002
AMD, D_a(m)	100	0.0114–0.0168	0.0089–0.0116	0.0055–0.0069	0.0138	0.0101	0.0062	0.0012	0.0007	0.0003
SMD, D_s (m)	100	0.0108–0.0163	0.0085–0.0110	0.0054–0.0067	0.0135	0.0096	0.0060	0.0012	0.0006	0.0003
E MD, D_e (m)	100	0.0107–0.0163	0.0085–0.0110	0.0054–0.0066	0.0135	0.0096	0.0060	0.0012	0.0006	0.0003
Surface area, *S* (10^{-5}) (m^2)	100	26.6–65.4	16.9–29.7	7.63–10.8	46.3	22.3	9.18	8.46	2.9	0.8
Aspect ratio, R_a	100	0.674–1.148	0.525–1.014	0.768–1.187	0.926	0.674	0.94	0.117	0.108	0.111
SSA, S_s (m^2 m^{-3})	100	126.63–2,482.3	255.01–1,296.08	220.68–965.49	830.14	574.63	521.2	443.78	244.12	175.77
Sphericity, S_p	100	0.6229–0.8426	0.5031–0.7322	0.6767–0.8771	0.7520	0.6132	0.7594	0.0586	0.0545	0.0506
Solid mass, M_s (10^{-5}) (kg)	100	30.3–111.2	17.6–61.1	9.49–19.6	62.4	35.9	15.7	13.4	7.94	2.33
Bulk mass, M_b (kg)	100	0.04–0.0607	0.0235–0.0297	0.0116–0.0176	0.0508	0.0267	0.0142	0.0077	0.0028	0.0021
1,000-unit mass (kg)	100	0.595–0.663	0.328–0.360	0.139–0.152	0.626	0.3476	0.1458	0.0170	0.0083	0.0035
SV, V_s (10^{-7}) (m^3)	50	2–21	2–8	1–4	6.74	4.45	1.95	3.11	1.49	0.66
BV, V_b (10^{-5}) (m^3)	50	4.7–6.9	3.1–3.7	2–2.3	6.02	3.42	2.1	0.90	0.21	0.11
SD, l_s (kg m^{-3})	100	529.62–1,629	431.43–1,844.5	481.75–1,131.82	1,004.59	874.50	849.73	204.70	272.3	145.86
BD, l_b (kg m^{-3})	50	816.27–880	633.79–849.71	577.5–763.48	843.73	780.99	672.60	22.47	80.62	65.55
Density ratio, l_r (%)	100	62.230–185.114	56.6–231.221	66.601–172.483	119.046	112.991	127.404	23.793	35.854	23.99
Porosity, ε (%)	50	−60.694–45.979	−76.882–56.751	−50.147–42.023	12.471	4.049	18.066	19.511	25.926	19.58
Moisture content (%, wb)	100	14.555–18.43	16.914–24.315	5.841–15.169	16.878	19.038	11.829	0.937	1.522	2.15
Moisture content (%, db)	100	17.035–22.594	20.358–32.127	6.204–17.881	20.321	23.558	13.481	1.347	2.359	2.722
Angle of repose (fillingmethod)	100	26.441–34.658	24.692–36.511	24.567–36.422	31.521	30.532	30.591	2.311	2.666	2.526
Coefficient of static friction										
Plywood	100	0.368–0.657	0.519–0.628	0.355–0.462	0.499	0.569	0.408	0.06	0.031	0.024
Corrugated metal	100	0.371–0.644	0.468–0.571	0.384–0.455	0.503	0.513	0.416	0.071	0.027	0.015
Aluminium	100	0.391–0.538	0.439–0.519	0.335–0.422	0.476	0.477	0.408	0.033	0.022	0.024
Asbestos	100	0.376–0.523	0.41–0.549	0.391–0.426	0.461	0.473	0.408	0.039	0.034	0.08
Glass	100	0.348–0.481	0.378–0.468	0.352–0.466	0.419	0.42	0.405	0.039	0.023	0.028
Plastic	100	0.335–0.442	0.466–0.599	0.4–0.506	0.4	0.524	0.449	0.027	0.031	0.023

Notes: *N* is number of replication; St. dev. is standard deviation of the mean; GMD is geometric mean diameter; AMD is arithmetic mean diameter; SMD is square mean diameter; EMD is equivalent mean diameter; SSA is specific surface area; SV is solid volume; BV is bulk volume; SD is solid density and BD is bulk density.

indicative of its pattern of behaviour in a flowing fluid such as air, as well as the ease of separating extraneous materials from the particle during cleaning by pneumatic means. The shape of the unshelled, shelled and kernel of the fruit was close to ellipsoid, with the kernel having a highest sphericity of 0.7594 than the unshelled (0.7520) and shelled (0.6132). Earlier, Çalışır, Özcan, Hacıseferoğulları, and Yıldız (2005) reported sphericity value ranges of 0.897–0.905 between moisture content values of 6.35–15.22% db for Turkey Okra. Jatropha fruit, nut and kernel gave sphericity values of 0.95, 0.64 and 0.68 respectively (Sirisomboon et al., 2007). Based on the result obtained in this study, *Dialium guineense* fruit has the tendency to roll better, when it has a particular orientation. This property is key when designing machine parts such as hoppers and dehulling equipment for seeds.

3.2. Surface area and SSA

The surface area of the unshelled *Dialium guineense* fruit was observed to be higher than that of the shelled fruit and kernel. The surface area of a biomaterial affects the velocity of air stream that can be used in other to separate the product from an unwanted material in pneumatic separator or to convey seed in pneumatic conveying. The SSA for the unshelled, shelled and kernel of the fruit were 830.14, 574.63 and 521.2 $m^2\ m^{-3}$ respectively. As a result of the large SSA of the product, the mass or energy transfer rate through the surfaces of the product will be large. Mass and energy transfer rate through the surfaces of the kernel might be slower than the rate for unshelled and shelled fruit.

3.3. Gravimetric properties

3.3.1. Moisture content

The moisture content (dry basis) values for unshelled, shelled and kernel of *Dailium guineense* fruit was 20.321, 23.558 and 13.481% (db) respectively. Similarly, the moisture content values (wet basis) for the unshelled, shelled and kernel of the fruit were 16.878, 19.038 and 11.829% (wb) respectively. This result shows that the shelled has the highest moisture content, followed by the unshelled and the kernel, as a result of the fact that the shell of the fruit has the capacity to absorb moisture which is stored within. This indicates that bulk drying of the fruit should be carried out after shelling.

3.3.2. SV and BV

SV for the unshelled *Dialium guineense* fruit ranged from 2×10^{-7} to $21 \times 10^{-7}\ m^3$ with a mean value of $6.74 \times 10^{-7}\ m^3$. Shelled fruit had SV which ranged between 2×10^{-7} and $8 \times 10^{-7}\ m^3$ with a mean value of $4.45 \times 10^{-7}\ m^3$, while the kernel has a mean value of $1.95 \times 10^{-7}\ m^3$. The mean BV for the unshelled, shelled and kernel of the fruit were 6.02×10^{-5}, 3.42×10^{-5} and $2.1 \times 10^{-5}\ m^3$ respectively.

3.3.3. BD, SD, density ratio and porosity

The SD, BD and density ratio for the unshelled *Dialium guineense* fruit were 1,004.59, 843.73 $kg\ m^{-3}$ and 119.046% respectively; 874.5, 780.99 $kg\ m^{-3}$ and 112.991% respectively for the shelled; and 849.73, 672.6 $kg\ m^{-3}$ and 127.404% respectively for the fruit kernel. Hacıseferoğulları et al. (2007) investigated and reported similar trend for solid and BD for different species of apricot fruits. The shelled fruit and kernel of *Dialium guineense* fruit were less dense than water (1,000 $kg\ m^{-3}$). From the result of the SD, unshelled fruit is denser than water and had higher values than the shelled and the kernel. Shelled fruit (edible pulp) had relatively same values as the kernel. This makes it possible to separate a mixture of the shelled fruit and kernel from the unshelled *Dialium guineense* fruit and also from other products that are less dense than water. Separation of a mixture of the shelled fruit and kernel could not be done by blowing air or floating in water.

The porosity of the unshelled, shelled and kernel of the fruit were 12.471, 4.049 and 18.066% respectively. The porosity values were generally low, with the kernel having the highest porosity. Similarly, low range of values of porosity had earlier been reported for Azivash seed (Azadbakht & Pourbagher, 2015). During aeration or drying of *Dialium guineense* fruit, high powered fans and motor will be needed to pass cold or heated air through the pore spaces. Natural aeration or drying will be very difficult, slow and an unlikely choice. The result implies that aeration or drying of the bulk kernel and unshelled fruit would be easier than the shelled. Porosity values show how easily a stream of heated air for drying or aeration will pass through a pack of material. This will affect the rate of drying of the material. Porosity values are required in air and heat flow in agricultural materials. Fruit with low porosity value have less pore spaces and hence will dry very slowly.

3.3.4. Solid mass, bulk mass and 1,000-unit mass of seeds

The solid mass and bulk mass for the unshelled, shelled and kernel of fruit were 62.4×10^{-5} and 0.0508 kg; 35.9×10^{-5} and 0.0267 kg; and 15.7×10^{-5} and 0.0142 kg respectively. Values for the 1,000-unit mass were 0.626, 0.3476 and 0.1458 kg for the unshelled, shelled and kernel of fruit respectively. These properties are necessary in the design of transportation, conveying and handling systems for the bulk handling of the fruit in their different forms.

3.4. Frictional properties

3.4.1. Coefficient of static friction on various surfaces

For the unshelled *Dialium guineense* fruit, metal surface had the highest coefficient of static friction (0.503), followed by plywood (0.499), aluminium (0.426), asbestos (0.461), glass (0.419) and plastic (0.4). As for the shelled fruit, Plywood had the highest coefficient of static friction (0.569) followed by plastic (0.524), metal (0.513), aluminium (0.476), asbestos (0.473) and glass (0.42). Plastic had the highest mean coefficient of static friction (0.449) for the kernel, followed by metal (0.416), plywood and asbestos (0.408), glass (0.405) and aluminium (0.388). Surface roughness, as shown from the results, affected the coefficient of static friction, particularly for the unshelled and shelled fruit. The more the roughness of these material surfaces the higher the coefficient of static friction. Slippery surfaces, sphericity (shape) and hardness of the kernel enabled them to move easily on the surfaces tested. Hence, the relatively lower values of coefficient of static friction observed. Coefficient of static friction values determine how a pack of seeds or grain will flow in systems (surfaces). This is a design parameter needed in the design of agricultural machine hoppers and other conveying equipment.

3.4.2. Angle of repose

Using the filling method, the value for the angle of repose of unshelled, shelled and kernel of *Dialium guineense* fruit were 31.521°, 30.532° and 30.591° respectively. This property helps to determine the minimum slope of flow in self emptying bin and minimum slope of flow in a hopper. The unshelled fruit has the lowest flow ability compared to the shelled fruit and the kernel.

4. Conclusion

Several post harvest physical properties of the unshelled, shelled and kernel of the *Dialium guinense* fruit were investigated and reported. The mean length, width and thickness of unshelled, shelled and kernel of the fruit were 0.0174, 0.016 and 0.0081 m; 0.015, 0.01 and 0.0052 m; and 0.0077, 0.0072 and 0.0036 m respectively. The fruit kernel had the highest sphericity and aspect ratio values of 0.7594 and 0.94 respectively, when compared with the unshelled which had values of 0.7520 and 0.926 respectively; and the shelled which had values of 0.6132 and 0.674 respectively. The porosity of the unshelled (12.471%), shelled (4.049%) and kernel (18.066%) were observed to be generally low. Natural convection is not advisable during aeration or drying, based on this observation. Forced convection induced by with high-powered fan is required to achieve better drying for these purposes. Individual unshelled fruits are denser than water, consequently would easily sink in water. This makes separation of the unshelled fruit from the shelled, kernel and other contaminants less dense than water possible, during separation. The coefficient of static friction for the unshelled fruit was highest on metal (0.503) and lowest on plastic (0.4); highest on plywood (0.569) and lowest on glass (0.42); and highest on plastic (0.449) and lowest on glass (0.388) for the unshelled, shelled and kernel of the fruit respectively. Unshelled fruit had the highest angle of repose (31.521°), compared to the shelled fruit (30.532°) and kernel (30.591°).

The mean surface and SSA of unshelled *Dialium guineense* fruit is about two times higher than that of the shelled fruit and five folds higher the kernel. The mass and energy transfer rate across the surface of unshelled *Dialium guineense* fruit during drying would be faster than for shelled *Dialium guineense* fruit and kernel. The SSA of unshelled *Dialium guineense* fruit is 1.3 times higher than that of shelled *Dialium guineense* fruit and kernel. Unshelled *Dialium guineense* fruit would therefore require higher air flow rate to be pneumatically cleaned or conveyed.

The unshelled *Dialium guineense* fruit has the highest mean value of specific volume, followed by the shelled fruit, and then the kernel. The mean solid, bulk mass, and 1,000-unit mass of unshelled *Dialium guineense* fruit are higher than that of the shelled fruit and kernel. The difference between the masses shows that the unshelled fruit is composed of about 42.4% shell, 32.4% edible portion, and 25.2% kernel. Both the mean solid, and BV of unshelled *Dialium guineense* fruit are higher than that of shelled fruit and kernel. The mean moisture content of the edible pulp of *Dialium guineense* fruit is higher than that of the kernel.

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References

Akinpelu, A. D., Awotorebo, T. O., Agunbiade, O. M., Aiyegoro, A. O., & Okoh, I. A. (2011). Anti-*Vibrio* and preliminary phytochemical characteristics of crude methanolic extracts of the leaves of *Dialium guineense* (Wild). *Journal of Medicinal Plants Research, 5*, 2398–2404.

ASAE. (1983). *Standard S 358.2, Moisture measurement of grain and seeds* (37th ed.). St. Joseph. MI: Author.

Asoegwu, S. N., Ohanyere, S. O., Kanu, O. P., & Iwueke, C. N. (2006). Physical properties of African oil bean seed (Pentaclethramacrophylla). *Agricultural Engineering International: the CIGR Ejournal, vii*, 1–15.

Asoiro, F. U., & Ani, A. O. (2011). Determination of some physical properties of African yam beans. *Pacific Journal of Science and Technology, 12*, 374–380.

Azadbakht, M., & Pourbagher, R. (2015). Determining some physical properties of Azivash (*Corchorus Olitorious* L.) seed. *Agricultural Engineering International: CIGR Journal*, 17, 3. Retrieved from http://www.cigrjournal.org

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

Balogun, M. E., Oji, J. O., Besong, E. E., & Umahi, G. O. (2013). Evaluation of the anti-ulcer properties of aqueous leaf extract of *Dialium guineense* (Velvet Tamarind) on experimentally induced ulcer models in rats. *International Journal of Development Research, 3*, 106–110.

Çalışır, S., Marakoğlu, T., Öğüt, H., & Öztürk, Ö. (2005). Physical properties of rapeseed (*Brassica napus oleifera* L.). *Journal of Food Engineering, 69*, 61–66. http://dx.doi.org/10.1016/j.jfoodeng.2004.07.010

Çalışır, S., Özcan, M., Hacıseferoğulları, H., & Yıldız, M. U. (2005). A study on some physico- chemical properties of Turkey okra (Hibiscus esculenta L.) seeds. *Journal of Food Engineering, 68*, 73–78. http://dx.doi.org/10.1016/j.jfoodeng.2004.05.023

Hacıseferoğulları, H., Gezer, İ., Bahtiyarca, Y. C., & Mengeş, H. O. (2003). Determination of some chemical and physical properties of Sakız faba bean (*Vicia faba* L. Var. major). *Journal of Food Engineering, 60*, 475–479. http://dx.doi.org/10.1016/S0260-8774(03)00075-X

Hacıseferoğulları, H., Gezer, İ., Özcan, M. M., & MuratAsma, B. (2007). Post harvest chemical and physical–mechanical properties of some apricot varieties cultivated in Turkey. *Journal of Food Engineering, 79*, 364–373. http://dx.doi.org/10.1016/j.jfoodeng.2006.02.003

Heidarbeigi, K., Ahmadi, H., Kheiralipour, K., & Tabatabaeefar, A. (2008). Some physical and mechanical properties of Iranian wild *Pistachio* (*Pistachio mutica* L.). *American-Eurasian Journal of Agricultural & Environmental, 3*, 521–525.

Hosseinzadeh, J., Feyzollahzadeh, M., & Afkari, A. H. (2013). The physical and chemical properties of kiwifruit harvested at four stages. *Bulgarian Journal of Agricultural Science, 19*, 174–180.

Hu, M., Dong, Q., Liu, B., Opara, U. L., & Chen, L. (2015). Estimating blueberry mechanical properties based on random frog selected hyperspectral data. *Postharvest Biology and Technology, 106*, 1–10. http://dx.doi.org/10.1016/j.postharvbio.2015.03.014

Joshi, D. C., Das, S. K., & Mukherjee, R. K. (1993). Physical properties of pumpkin seeds. *Journal of Agricultural Engineering Research, 54*, 219–229. http://dx.doi.org/10.1006/jaer.1993.1016

Mohsenin, N. N. (1986). *Physical properties of plant and animal materials* (pp. 51–87, 734). New York, NY: Gordon and Breach Science Publishers.

Nwosu, M. O. (2000). Plant resources used by traditional women as herbal medicine and cosmetics in Southwest Nigeria. *Arzte fur Natur Fahr, 41*, 760–767.

Omobuwajo, T. O., Akande, E. A., & Sanni, L. A. (1999). Selected physical, mechanical and aerodynamic properties of African breadfruit (*Treculia Africana*) seeds. *Journal of*

Food Engineering, 40, 241–244. http://dx.doi.org/10.1016/S0260-8774(99)00060-6

Paksoy, M., & Aydin, C. (2004). Some physical properties of edible squash (*Cucurbita pepo* L.) seeds. *Journal of Food Engineering, 65*, 225–231. http://dx.doi.org/10.1016/j.jfoodeng.2004.01.019

Pliestic, S., Dobricevic, N., Filipovic, D., & Gospodaric, Z. (2006). Physical properties of filbert nut and kernel. *Biosystems Engineering, 93*, 173–178. http://dx.doi.org/10.1016/j.biosystemseng.2005.11.008

Sacilik, K., Öztürk, R., & Keskin, R. (2003). Some physical properties of hemp seed. *Biosystems Engineering, 86*, 191–198. http://dx.doi.org/10.1016/S1537-5110(03)00130-2

Shepherd, H., & Bhardwaj, R. K. (1986). Moisture-dependent physical properties of pigeon pea. *Journal of Agricultural Engineering Research, 35*, 227–234. http://dx.doi.org/10.1016/S0021-8634(86)80060-9

Shkelqim, K., & Joachim, M. (2010). Determination of physical, mechanical and chemical properties of seeds and kernels of *Jatropha curcas* L. *Industrial Crops and Products, 32*, 129–138.

Sirisomboon, P., Kitchaiya, P., Pholpho, T., & Mahuttanyavanitch, W. (2007). Physical and mechanical properties of Jatropha curcas L. fruits, nuts and kernels. *Biosystems Engineering, 97*, 201–207. http://dx.doi.org/10.1016/j.biosystemseng.2007.02.011

Subukola, O. P., & Onwuka, V. I. (2011). Effects of moisture content on some physical properties of locust bean seed (Parkiafillicoidea). *Journal of Food Process Engineering, 34*, 1947–1961.

Tabatabaeefar, A., & Rajabipour, A. (2005). Modeling the mass of apples by geometrical attributes. *Scientia Horticulturae, 105*, 373–382. http://dx.doi.org/10.1016/j.scienta.2005.01.030

Vilche, C., Gely, M., & Santalla, E. (2003). Physical properties of quinoa seeds. *Biosystems Engineering, 86*, 59–65. http://dx.doi.org/10.1016/S1537-5110(03)00114-4

Zare, D., Safiyari, H., & Salmanizade, F. (2012). Some physical and mechanical properties of jujube fruit. *World Academy of Science, Engineering and Technology, International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering, 6*, 672–675.

Zare, D., Salmanizade, F., & Safiyari, H. (2012). Some physical and mechanical properties of Russian olive fruit. *World Academy of Science, Engineering and Technology, International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering, 6*, 668–671.