NUTRITIONAL, THERMAL, PHYSICAL, AND ENGINEERING PROPERTIES OF BAMBARA GROUNDNUTS (Vigna subterranean (L) VERDC.) SEEDS CULTIVATED IN NIGERIA

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ABSTRACT

Bambara groundnut is an underutilized African legume that has the potential to contribute to improved food and nutrition security while providing solutions for environmental sustainability and equity in food availability and affordability. This research aimed to determine the thermal, physical, and engineering resources properties of three varieties of Bambara groundnut seeds grown in Nigeria. The study was a factorial experiment in a completely randomized design. The thermal, physical, and engineering properties of the red, cream, and multi-coloured varieties of Bambara groundnut seeds were determined at moisture contents of 6.00 %, 7.00 %, and 9.94 %. The values for the mean thermal conductivity, specific heat capacity, latent heat, and thermal diffusivity were 0.24 ± 0.02 Wm-1K-1, 1.62 ± 0.11 KJ Kg-1K-1, 20.10 ± 1.20 KJKg-1 and 0.12 ± 0.01×10-7 m2s-1 for the red variety; 0.25 ± 0.01Wm-1K-1, 1.65 ± 0.11 KJ Kg-1K-1, 23.45 ± 0.01 KJKg-1 and 0.11 ± 0.01×10-7 m2s-1for cream variety and 0.24 ± 0.01 Wm-1K-1, 1.62 ± 0.12 KJ Kg-1K-1, 32.96 ± 0.01KJKg-1 and 0.12 ± 0.01 × 10-7 m2s-1. The mean values for bulk density, true density, and porosity were 0.75 ± 0.02 kgm-3, 1.25 ± 0.02 kgm-3 and 40.27 ± 1.29 % for the red variety 0.77 ± 0.01 kgm-3, 1.37 ± 0.01 kgm-3 and 43.91 ± 0.75 % for the cream and 0.70 ± 0.05 kgm-3, 1.23 ± 0.16 kgm-3 and 42.45 ± 11.70 % for the multi-coloured variety. The mean angle of repose and coefficient of static friction over stainless steel, glass, formica, and plywood surfaces were 25.31 ± 1.89o, 0.22 ± 0.02, 0.23 ± 0.35, 0.28 ± 0.05, and 0.28 ± 0.05 for the red, 20.11 ± 1.40o, 0.14 ± 0.02, 0.17 ± 0.03, 0.16 ± 0.01 and 0.18 ± 0.02 for the cream and 22.02 ± 1.36o, 0.21 ± 0.01, 0.18 ± 0.03, 0.20 ± 0.16 and 0.20 ± 0.02 for the multi-coloured variety. This implies that these values are in the normal distribution of properties in heat transfer. These implications are that the transport properties of food during *processing and preservation are based on these parameters. They are, therefore, of utmost importance in predicting heat and mass transfer rates during preservation and optimal design of processing equipment. The physical properties of food and agricultural materials, such as mass, size, shape, surface area, volume, aspect ratio, sphericity, true density, bulk density, porosity, and angle of repose, are the attributes that are relevant to the design and development of harvesting, handling, processing and storage equipment for the specified material. There was no significant (P>0.05) difference between the values of the coefficient of static friction for the red and multi-coloured varieties on stainless steel and glass surfaces. It can be concluded that all varieties of Bambara groundnut grain in Nigeria can withstand processing and preservative stress.*

Keywords: Bambara, Equipment, Engineering Handling Physical

INTRODUCTION

Bambara groundnut is reported to have been widely cultivated in tropical areas of the world since the seventeenth century. Outside sub-Saharan Africa, Bambara groundnut is now enormously distributed and cultivated in Asia, some regions of Northern Australia, and Southern and Central America and Oceania (Baudoin and Mergeai, 2001). It is cultivated throughout Africa (Atiku *et al.*, 2004; Oluwole *et al.*, 2007). It is known to have its origin in the Sahelian area of present West Africa, in the Bambara area, a district occupying the Upper Niger close to Timbuktu, which is now majorly located in Central Mali (Nwanna *et al.*, 2005). Nigeria is considered a major producer of Bambara groundnut in Africa (Ibrahim and Ogunwusi, 2016). Bambara groundnut is an important leguminous crop that has a similar composition to cowpea (Oyeyinka *et al*., 2018). It is an important source of affordable protein in diets, especially in regions where animal protein is comparatively expensive (Mubaiwa *et al*., 2018).

Bambara groundnut is an underutilized African legume that has the potential to contribute to improved food and nutrition security while providing solutions for environmental sustainability and equity in food availability and affordability (Tan *et al*., 2020). Bambara groundnut is a sustainable, low-cost source of complex carbohydrates and plant-based protein. It is low in unsaturated fatty acids and rich in essential minerals. Despite its impressive nutritional and agro-ecological profile, the potential of Bambara groundnut to improve the global food system is undermined by several factors, including resource limitation, knowledge gap, social stigma, and lack of policy incentives (Tan *et al*., 2020). Consumers have always continued to demand food products with high nutritional value and extra health benefits (Mpho, 2020). On average, Bambara seed comprises approximately 19 % protein, 63 % carbohydrate, and 6.5 % fat. The fatty acid composition is mainly linoleic, linolenic, and palmitic (Minka and Bruneteau, 2000; Bamishaiye *et al*., 2011). Bambara groundnut has a higher quantity of lysine than all other legumes, and the seed possesses higher amounts of methionine than all other grain legumes (Addo and Oyeleke, 1986). Bambara groundnuts are a good source of starch that may be potentially used for various industrial applications (Oyeyinka *et al.*, 2019). Bambara starch was modified with lipids for improved functionality (Oyeyinka *et al*., 2016b, c). The use of Bambara starch in complexation with lipids and biofilm application is special in many ways. Bambara starch has an amylose content of 20 % to 35 % (Sirivongpaisal, 2008; Oyeyinka *et al*., 2015), which is higher than that of corn and potato starches (Oyeyinka *et al*., 2016).

According to Burubai and Amber (2014), physical properties of food and agricultural materials such as mass, size, shape, surface area, volume, aspect ratio, sphericity, true density, bulk density, porosity, and angle of repose are the attributes that are relevant to the design and development of harvesting, handling, processing, and storage equipment for the specified material. The mass, size, and shape are essential for sorting, grading, and separation operations (Zare *et al*., 2013; Chandrasekar and Viswanathan, 1999). The static coefficient of friction of seed against the various surfaces is also necessary for designing conveying, transporting, and storing structures (Taser*et al*., 2005). Many researchers have studied agricultural products' thermal, physical, and engineering properties. They have reported thermal, physical, and mechanical properties of roots, seeds, nuts, kernels and fruits such as sweet potato (Obomeghei and Ebabhamiegbebho, 2020), corn seed (Babic *et al*., 2013), flaxseed (Singh *et al*., 2012), arigo seeds (Davies, 2010), lentil seeds (Bagherpour *et al*., 2010), soybeans (Davies and El-Oken, 2009), groundnuts (Davies, 2009), chia seeds (Ixtaina *et al*.,2008), rice (Correa *et al*., 2007), watermelon seeds (Razavi and Milani, 2006), maize (Bart-Plange *et al*., 2005), raw and parboiled paddy (Reddy and Chakraverty, 2004), and hemp seeds (Sacilik *et al*., 2003). Despite these efforts, very little has been done on Bambara groundnut seeds' thermal, physical, and engineering properties. Baryeh (2001) studied the physical properties of Ghanian bambara groundnuts; Mpotokwane *et al*. (2008) studied the physical properties of Bambara groundnuts from Botswana, while Abioye (2016) studied some moisture-dependent physical and thermal properties of Bambara groundnut. According to Mariani *et al*. (2008), interest in the transport properties of foods (thermal conductivity, heat capacity, density, mass and thermal diffusivity, and heat and mass transfer coefficient) appear due to the importance of predicting heat and mass transfer rates during processing, preservation and optimal design of processing equipment. Therefore, the objective of this study was to determine the thermal, physical, and engineering properties of three varieties of Bambara groundnut (red, cream, and multi-coloured) seeds grown in Nigeria.

MATERIALS AND METHODS

Materials

Matured and dried Bambara groundnut seeds were purchased in Uchi Market, Auchi, Nigeria

Experimental Design

The study was carried out as a factorial experiment in a completely randomized design.

Methods

Proximate Composition

The proximate analyses of the dried Bambara groundnut were conducted according to the methods described in AOAC (2010).

Determination of Thermal Properties

Thermal conductivity

The thermal conductivity (K) of food materials is related to the composition of the material and was estimated using the method described by Sweat (1986) as:

$K = 0.25\ mc + 0.155\ mp + 0.16\ mf + 0.135\ ma + 0.58\ mm$.

Where mc = mass of carbohydrate, mp = mass of protein, mf = mass of fat, ma = mass of ash, and mm = mass of moisture in the food material.

Specific heat capacity

The specific heat capacity of the seeds was estimated using the method of Miles *et al*. (1983):

$Cp = mwcw + mscs$ (KJ Kg-1K-1) and

$Cp = 1.424\ mc + 1.549\ mp + 1.675\ mf + 0.837\ ma + 4.187\ mm$ (Singh and Heldman, 1993).

Where Cp = specific heat capacity, mw = mass fraction of water, cw = specific heat capacity of water (4.18 KJ Kg-1k-1), ms = mass fraction of solids, and cs = specific heat capacity of solids (1.46 KJ Kg-1K-1).

Latent heat of fusion

The method of Lamb (1976) was used to estimate the latent heat of fusion as:

$L = 335\ mw$ (KJ Kg-1).

Where mw = mass fraction of water.

Thermal diffusivity

The thermal diffusivity was estimated as described by Lewis (1987) as:

$\alpha = K/\rho Cp$

where α = thermal diffusivity, K = thermal conductivity, ρ = density, Cp = specific heat capacity.

Determination of Physical Properties

Seed Size

Twenty seeds were selected randomly from each batch of the Bambara groundnut varieties. The seed sizes, in terms of the major diameter (L), intermediate diameter (W), and minor diameter (T) of the seed, were measured using a Vernier calliper (Kennedy Tools) reading to 0.01 mm. Determination was replicated twenty times. The average diameter was estimated using the three axial dimensions' arithmetic mean and geometric means. The arithmetic mean diameter, Da, equivalent diameter, Dp, and geometric mean diameter, Dg in mm of seed were estimated using the methods of Galedar *et al*. (2008); Mohsenin (1986) and Bahnasawy (2007), respectively as:

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

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

$$D_p = [L\,\frac{(W+T)2}{4}]^{1/3}$$

Where Da is the arithmetic mean diameter (mm), Dg is the geometric mean diameter (mm), Dp is the equivalent diameter (mm), L is the length (mm), W is the width (mm), and T is the thickness (mm).

Sphericity

The sphericity (Sp), defined as the ratio of the surface area of the sphere having the same volume as that of the seed to the surface area of the seed, was estimated by the method of Mohsenin (1978) as:

$$S_p = \frac{(LWT)1/3}{L}$$

Surface Area

The surface area (S) was estimated using the formula:

$$S = \pi D_g^2$$

Coefficient of Contact Surface

The coefficient of contact surface (C.C.S) was calculated according to the method of Abd Alla *et al*. (1995) as:

C.C.S. = $\frac{Af-At}{Af} \times 100$

Where;

A_f: Flat area surface = $\frac{\pi}{4}$(LW)

A_t: Transverse area surface = $\frac{\pi}{4}$(WT)

Aspect Ratio

The aspect ratio (R_a) was estimated using the method of Omobouwajo *et al*. (2000).

$R_a = [\frac{W}{L}]\ 100$

Where: R_a = aspect ratio, W = width, L = Length

Flakiness ratio (Rf) was determined by the method of Ebrahimzadeh *et al*. (2013) as:

(Rf) = $\frac{T}{W}$

Where: T = Thickness, W = width

1000 Seed Mass

The mass of 1000 seeds was determined by using an electronic balance to an accuracy of 0.001 g. The measurement was replicated five times for 1000 seeds selected at random (Mohsenin, 1978).

Unit Volume

The unit volume of 100 individual seeds was estimated from the values of length (L), width (W), and thickness (T) using the method of Mohsenin (1986):

V = $\frac{\pi}{6}$(LWT)

Gravimetric Properties

True Density

The true density of the seed was determined using the toluene displacement technique. Toluene was used instead of water because it is not easily absorbed by agricultural produce. The volume of toluene displaced was found by immersing a weighed quantity of tiger nuts in toluene (Singh and Goswami, 1996). Determinations were done inside a fume cupboard since toluene is known to be carcinogenic.

$$\rho_t = m/v \quad (4)$$

Where: m is the mass of the seed in kg and v is the volume of the seed in m^3

Bulk Density

The average bulk density of the seeds was determined by packing weighed nuts into a 250 mL measuring cylinder as described by Heidarbeigi *et al*. (2013). The packed seeds were gently tapped to allow them to settle. The volume of the measuring cylinder occupied by the seeds was recorded. The bulk density was calculated in g/mL using the formula:

Bulk density (Pb) = Weight of material packed / bulk volume

Porosity

Porosity (E) was computed as a percentage of the true and bulk densities using the equation below, as described by Varnamkhasti *et al*. (2007):

$$E = 1 - \frac{\rho b}{\rho t} \times 100$$

Where ρb = bulk density, ρt = true density

Engineering Properties

Angle of Repose

The dynamic angle of repose (emptying angle) was determined using the method of Amin *et al*. (2004) and Sessiz *et al*. (2007) as adopted by Idowu and Owolarafe (2015). A regular PVC (Polyvinyl Chloride) cylinder of dimensions 100 mm diameter and 150 mm height was used to determine the angle of repose. The cylinder was placed on the surface filled with the sample and then raised until it formed a cone of seeds. This was replicated ten times. The angle of repose was then calculated using the equation below:

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

Where Θ = Angle of repose, H = Height of the pile, D = Diameter of the pile

Coefficient of Static Friction

The static coefficients of friction (μ) were determined for each structural material, namely formica, plywood, stainless steel, and glass. The static coefficient of friction was determined using an inclined plane (Suthar and Das, 1996). The friction surface, which is part of a special construction, was made to replace it with the required friction surface. The special construction was hinged at one end to lift it gradually at the unhinged end using a pulley device, as described by Bart-Plange and Baryeh (2003). The angle at which the material just began to slide down was recorded as the static angle of friction between the material and the friction surface. Several other investigators who used this method include Baryeh (2001, 2002), Joshi *et al*. (1993), Dutta*et al*. (1988), and Suthar and Das (1996). The coefficient of static friction was calculated as:

$\mu = \tan \beta$

Where μ = coefficient of friction and

β = angle of inclination in degrees

Data Analysis

The data obtained were statistically analysed using Analysis of Variance (ANOVA) using Statistical Package for Social Sciences (SPSS) version 23. The means were compared and separated using Duncan's Multiple Range Test (DMRT) and LSD at $p \leq 0.05$.

RESULTS AND DISCUSSION

Proximate Composition

The results of the proximate analysis of the dried and ground Bambara groundnut seeds are presented in Table 1. The protein, fat, fibre, ash, and carbohydrate reported by Abu El-Gasim and Abdalla (2007) for an unspecified variety of dry raw Bambara groundnut seed were 22.70, 5.00, 3.72, 3.76 and 65.00 %, respectively. These values are similar to those obtained in this study except for crude fibre, which is far lower than the obtained value.

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Table 1. Proximate Composition of Dried Bambara Groundnut Seeds g/ 100g

Parameter	Red	Cream	Multi-coloured
Protein	21.50 ± 0.27[a]	21.30 ± 0.27[ab]	19.71 ± 0.15[b]
Fat	4.17 ± 0.21[b]	5.67 ± 0.42[a]	7.43 ± 0.12[a]
Fiber	11.33 ± 0.58[a]	10.67 ± 0.58[a]	6.54 ± 0.17[b]
Ash	2.00 ± 0.00[b]	1.67 ± 0.58[b]	3.56 ± 0.15[a]
Moisture	6.00 ± 1.00[b]	7.00 ± 1.00[b]	9.84 ± 0.10[a]
Carbohydrate	55.00 ± 1.01[a]	53.69 ± 1.44[b]	52.92 ± 1.10[b]

Values with the same superscript along rows do not differ significantly at P ≥ 0.05 ± SD

Mubaiwa *et al*. (2018) reported lower values of protein (15.6 – 19.6 %), higher values of fat (7.00 – 8.60 %), and similar values of ash (2.5 – 3.2 %) for red and black varieties of Bambara groundnut seeds of different processing methods. The values Adebowale *et al*. (2013) reported for cream-coloured Bambara groundnut were protein, 18.4 %; fat, 7.7 %; fibre, 3.0 %; ash, 2.7 %; moisture, 10.1 %; and carbohydrate, 60.6 %.

Thermal Properties

The results of the thermal properties of Bambara groundnut seeds are presented in Table 2. The three varieties' thermal conductivities, specific heat capacities, and thermal diffusivities were not significantly (P>0.05) different. The latent heat for the red and cream varieties was not significantly different but significantly lower than that obtained for the multi-coloured variety. The thermal conductivities obtained in this experiment are similar to the value 0.26 reported by Abioye *et al*. (2016). The specific heat and thermal diffusivity values were lower than 1.75 KJKg-1K-1 and 0.19×10-7 m2s-1, respectively, as Abioye *et al*. (2016) reported.

Physical Properties

The means of the physical properties of the three varieties of Bambara groundnut studied are shown in Table 3. The mean length, width, thickness, arithmetic mean diameter, geometric mean diameter, equivalent diameter, sphericity, surface area, aspect ratio, and 1000 seed mass for the three varieties studied were not significantly different (P > 0.05). The value for the 1000 seed weight for the cream-coloured variety was found to be significantly higher than the other two varieties. Also, the value for the multi-coloured variety was significantly higher than that of the red variety.

Table 2. Thermal Properties of Dried Bambara Groundnut Seeds

Parameter	Red	Cream	Multi-coloured
Thermal conductivity $Wm^{-1}K^{-1}$	0.24 ± 0.02^a	0.25 ± 0.01^a	0.24 ± 0.01^a
Specific heat capacity $KJ\ Kg^{-1}K^{-1}$	1.62 ± 0.11^a	1.65 ± 0.11^a	1.62 ± 0.12^a
Latent heat of fussion $KJ\ Kg^{-1}$	20.10 ± 1.20^b	23.45 ± 0.01^b	32.96 ± 0.01^a
Thermal diffusivity $\times 10^{-7} m^2 s^{-1}$	0.12 ± 0.01^a	0.11 ± 0.01^a	0.12 ± 0.01^a

Values with the same superscript along rows do not differ significantly at $P \geq 0.05 \pm SD$

Table 3. Physical Properties of Dried Bambara Groundnut Seeds

Parameter	Red	Cream	Multi-coloured
Major diameter (L) mm	12.10 ± 0.21^a	11.12 ± 0.17^a	11.92 ± 0.18^a
Intermediate diameter (W) mm	9.40 ± 0.17^a	9.34 ± 0.17^a	9.93 ± 0.13^a
Minor diameter (T) mm	8.02 ± 0.13^a	8.81 ± 0.16^a	9.10 ± 0.09^a
Arithmetic Mean Diameter (D_a)	9.84 ± 0.14^a	9.76 ± 0.16^a	10.32 ± 0.13^a
Geometric Mean Diameter (D_g)	9.70 ± 0.14^a	9.71 ± 0.16^a	10.25 ± 0.12^a
Equivalent Diameter (D_e)	9.72 ± 0.14^a	9.71 ± 0.16^a	10.26 ± 0.38^a
Sphericity (%)	80.57 ± 10.44^a	87.37 ± 3.80^a	86.00 ± 4.08^a
Surface area mm^2	295.71 ± 5.87^a	296.32 ± 6.39^a	330.20 ± 6.78^a
Coefficient of contact surface	33.72 ± 0.15^a	20.77 ± 0.21^b	24.62 ± 0.17^b
Aspect ratio %	78.32 ± 13.31^a	83.76 ± 5.09^a	83.60 ± 4.62^a
Flakiness ratio	86.16 ± 10.48^b	95.19 ± 2.67^a	91.20 ± 6.56^a
1000 seed mass (g)	7691.48 ± 111.66^c	9470.12 ± 414.42^a	9225.49 ± 999.90^b
Unit volume (mm^3)	477.82 ± 0.23^a	479.29 ± 0.09^a	564.21 ± 0.20^a

Values with the same superscript along rows do not differ significantly at $P \geq 0.05 \pm SD$

Other researchers who reported similar values for length, width, and thickness include Abioye *et al*. (2016) with values of 12.10 mm, 10.71 mm, and 11.36 mm at about 11.23 % moisture content; Mpotokwane *et al*. (2008) with value range of 11.81 – 11.44 mm, 9.41 – 9.77 mm, 8.99 – 9.48 mm at about 8 % moisture and Baryeh (2001) with values of 10.50 mm, 9.0 mm and 8.6 mm at about 7 % moisture contents, respectively.

The values of the physical dimensions are essential considerations in the development of seed sizing, and grading machines are useful in their separation from undesirable materials (Ogunjimi *et al*., 2002) and decorticating equipment (Abioye *et al*., 2016). Geometric properties of seeds are important because they determine interactions between and among particles, as well as with the surrounding air (Abioye *et al*., 2016). According to de Figueiredo *et al*. (2011), the interactions influence almost all the engineering properties of grains that must be considered in designing and evaluating grain storage and handling systems. Mpotokwane *et al*. (2008) reported a value of 9.81 mm for geometric mean diameter, similar to the values obtained in this study.

The sphericity, surface area, and volume obtained in this study are similar to the values 85.8 %, 277 mm2, 462 mm3 and 88 %, 320 mm2, 450mm3 reported by Mpotokwane *et al*. (2008) and Baryeh (2001) respectively. Mpotokwane *et al*. (2008) reported a value of 84.6 % for aspect ratio, which agrees with the values obtained in this work. According to Gharibzahedi *et al*. (2010), sphericity is an expression of a solid shape relative to that of a sphere of the same volume, while the aspect ratio relates the width to the length of the seed, which is indicative of its tendency toward being spherical. The values of sphericity obtained in this experiment show that the seeds are nearly spherical and will roll easily rather than sliding on surfaces, especially in hoppers and dehulling equipment. According to Omobuwajo (1999), the surface area of agricultural produce is generally an index of its pattern of behaviour in a flowing fluid like air, as well as the ease of using pneumatic means to separate extraneous materials from the produce during cleaning. It is also important in heat and mass transfer processes such as drying and other thermal applications (Emurigbo *et al*., 2020).

Gravimetric Properties

The mean densities and porosity of the Bambara groundnut seeds are presented in Table 4. There were no significant differences among the varieties in terms of bulk density, true density, and porosity. The results of this experiment are in agreement with 0.78 and 0.77 reported for bulk density by Abioye *et al*. (2016) and Mpotokwane *et al*. (2008), respectively. The values for true density and porosity obtained in this study are similar to those of 1.28 kgm-3 and 40 % reported by Baryeh (2001). Information on density is useful for the design of hoppers and silos for grain handling and storage (Nalladulai *et al*., 2002) to estimate the weight of agricultural and food products that these containers will handle.

Table 4. The Gravimetric Properties of Bambara Groundnut Seeds

Parameter	Red	Cream	Multi-coloured
True density (kgm^{-3})	1.25 ± 0.02^{a}	1.37 ± 0.01^{a}	1.23 ± 0.16^{a}
Bulk density (kgm^{-3})	0.75 ± 0.02^{a}	0.77 ± 0.01^{a}	0.70 ± 0.05^{a}
Porosity (%)	40.27 ± 1.29^{a}	43.91 ± 0.75^{a}	42.45 ± 11.70^{a}

Values with the same superscript along rows do not differ significantly at $P \geq 0.05 \pm SD$

Engineering Properties

The mean angle of repose (emptying angle) and coefficient of static friction on Formica, glass, stainless steel, and plywood surfaces of the three varieties of Bambara groundnuts are shown in Table 5. The value of the emptying angle for the red variety was significantly ($P \leq 0.05$) higher than the values for the cream and multi-coloured varieties. There was no significant ($P > 0.05$) difference between the cream and multi-coloured varieties values.

Table 5. The Engineering Properties of Bambara Groundnut Seeds

Parameter	**Red**	**Cream**	**Multi-coloured**
Angle of repose	25.31 ± 1.89^{a}	20.11 ± 1.40^{b}	22.02 ± 1.36^{b}
Coefficient of static friction			
Stainless steel	0.22 ± 0.02^{a}	0.14 ± 0.02^{b}	0.21 ± 0.01^{a}
Glass	0.23 ± 0.35^{a}	0.17 ± 0.03^{a}	0.18 ± 0.03^{a}
Formica	0.28 ± 0.05^{a}	0.16 ± 0.01^{b}	0.20 ± 0.16^{b}
Plywood	0.28 ± 0.05^{a}	0.18 ± 0.02^{b}	0.20 ± 0.02^{b}

Values with the same superscript along rows do not differ significantly at $P \geq 0.05 \pm SD$

There were no significant (P>0.05) differences between the values of the coefficient of static friction for the red and multi-coloured varieties on stainless steel and glass surfaces. The value for the cream-coloured variety was significantly lower than those of the other two varieties. The values for the cream and multi-coloured varieties on formica and plywood surfaces are also not significantly different but were significantly lower than those for the red-coloured variety. Baryeh (2001) reported values of 20 and 0.45 for the angle of repose and coefficient of static friction, respectively, on plywood surfaces.

CONCLUSION

All three varieties studied had similar thermal conductivities, specific heat capacities, and thermal diffusivities. The latent heat for the multi-coloured variety was significantly higher than those of other varieties. The mean length, width, thickness, arithmetic mean diameter, geometric mean diameter, equivalent diameter, sphericity, surface area, aspect ratio, and 1000 seed mass for the three varieties studied were not significantly (P > 0.05) different. The values of sphericity obtained in this experiment show that the seeds are nearly spherical and will roll easily rather than slide on surfaces.

All three varieties had similar values of bulk density, true density, and porosity. The angle of repose and coefficient of static friction were low, but stainless steel and glass are recommended for constructing surfaces such as hoppers.

Declaration of Interest

This research has no competing interest

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