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Moisture Dependent Physico-Mechanical Properties of the TVSu-1874 Variety of Bambara Nut

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A B S T R A C T

Moisture dependence of some physical and mechanical properties of the TVSu-1874 variety of Bambara nut (Vigna subterranea (L.) Verdc.) was determined, at 8%, 14% and 20% dry basis moisture levels. Size, shape, gravimetric, bulk flow and friction properties were determined. Results showed that as moisture content increased, seed dimensions and densities also increased. Major diameter ranged between 8.28 - 15.06 mm, while intermediated and minor diameters ranged between 6.40 -13.18 mm and 4.68 - 11.46 mm, at 8% moisture content. However, as moisture content increased to 20%, marked gains of 10.44%, 12.29%, and 10.65%, respectively, were recorded in these dimensions. Similar trends were observed for other size and shape properties. Bulk and true densities increased from 0.74 g/cm3 to 0.85 g/cm3 and 1.22 g/cm3 to 1.32 g/cm3 while tapped density (at 1250 tap frequency) decreased from 0.92 g/cm3 to 0.84 g/cm3 as seed moisture changed from 8% to 20%; within the same moisture range, angle of repose rose from 19.27° to 25.69° while coefficient of static friction rose from 0.41 to 0.53. There were strong indications of changes in the flow behavior of seeds as levels of moisture in the produce changed. These physical and mechanical properties are of direct relevance to postharvest handling and processing of the crop.

Keywords: Bambara, size, shape, density, friction, flow, moisture

1. Introduction

Bambara nut (*Vigna subterranea* (L.) Verdc.), a resilient legume native to Africa's semi-arid regions (Majola *et al.*, 2021), is variedly commonly known as Bambara beans, earth pea, congo goober and hog peanut (Adaora, Nkeoma, & Chinelo, 2023; Kumar, Mehra, Kumar, & Kumar, 2022) and has been a dietary staple for centuries. It is a significant crop in many parts of Africa, praised for its nutritional profile; dried Bambara seeds are 64.4% carbohydrates, 23.6% protein, 6.5% fat and 5.5% fiber. The seeds are also rich in micronutrients being 11.44–19.35 mg potassium, 4.9–48 mg iron, 2.9–12.0 mg sodium and 95.8–99 mg calcium, per 100g of seed (Khan *et al.*, 2021; Tan *et al.*, 2020; Paliwal *et al.*, 2021). Bambara nut is taunted to be a nutritionally complete or balanced staple (Khan *et al.*, 2021) and holds significant potential for food security and income generation in different parts of Africa. Commercial production of the crop is impeded by factors which border on its classification as a food of the poor, barely subsistent level cultivation by mainly smallholder farmers, low mechanization of production activities and the cumbersome nature of the predominantly manual means of hulling employed when processing the crop.

Bambara seed is produced enclosed in a hard pod and has to be separated from the pod through a process called hulling for it to be utilized. Hulling involves removing the hard pericarp of Bambara nut to access the seed or kernel within (Kareem *et al.*, 2014). This process is traditionally performed manually in most Bambara nut growing areas (Kabir & Fadele, 2018). Some of the methods reported include breaking the pods on hard surfaces with stones, pounding them in wooden mortars with pestles, and cracking them manually between fingers (Kabir & Fadele, 2018). More arduous techniques like trampling under foot or beating the pods with sticks are also employed (Patricia, 2014). These methods are not only time-consuming and labor-intensive but also result in high rates of seed or kernel breakage, significant contamination, reduction of product quality and lowering of market value (Msuya, 2019). In addition, manual hulling is mostly left to womenfolk and children, is physically exerting, leaves workers prone to injuries and health hazards and limits overall productivity (Aviara *et al.*, 2013; Mbosso *et al.*, 2020). The seasonal nature of Bambara nut production worsens labor shortage situations as demand for labor coincides with other agricultural activities. Mechanized production, postharvest handling and processing are the main plausible routes for unlocking the full potentials of Bambara nut. Mechanical shelling involves the use of machines for hull removal, offers potential for increased production efficiency, reductions in labor cost and better final product quality through minimization of kernel breakage and contamination.

The pod of Bambara nut is hard; variable pericarp structure and thickness obtains across lines and varieties with significant influences on hullability (Oluwole *et al.*, 2007). The presence of fibrous material within the pod further complicates hulling as this leads to clogging of hulling equipment. Variability in pod size and shape in single harvests are reported which necessitate adaptable hulling mechanisms (Alonge *et al.*, 2016). The delicate nature of seeds or kernels suggests precise control of hulling forces is required to prevent seed damage just as insufficient application of force leads to inadequate hull removal. The abrasive nature of pod material can cause rapid wear of machine components.

Nigeria is a major producer of Bambara nut and produces 100, 000 metric tons of the crop annually, followed by Burkina Faso and Mali who produce 44,712 metric tons and 25,165 metric tons, respectively (Tan *et al.*, 2020). The most common varieties produced in Northern Nigeria are the TVSu-1874, TVSu-2042 and TVSu-1733 varieties. Among these, the TVSu-1874, reported to be of medium seed size with smooth seed coat, sandy-brown color and white helium is the most produced, for reasons of high yield, disease resistance, draught tolerance and good market value (Tan *et al.*, 2020). An understanding of the physical and mechanical properties of the crop is essential to efficient postharvest handling and processing, including drying, cleaning, sorting, handling and storage.

2. Materials and Methods

2.1 Samples

Bulk quantities of freshly harvested TVSu-1874 variety of Bambara nut (*Vigna subterranea (L.) Verdc*.) purchased from farm gates in Alkaleri, Nigeria were used for the study. The produce was manually hulled, cleaned and sorted to remove impurities and immature and broken fractions.

2.2 Tests, Equipment and Analytical Procedures

2.3 Determination of moisture content

Moisture contents of samples were determined in accordance with ISO 712 by oven drying at 130±2°C for 2 hours in a GenLab N53C model hot air oven (GenLab Ltd, Cheshire, UK). Sample moisture contents, in dry basis, were determined using equation 1 (Akangbe *et al.*, 2015):

$$MC_{db} = 100 \times \left[\frac{W_a - W_b}{W_b}\right] \quad (1)$$

Where:

MC_{db} is moisture content in dry basis, %

W_a is mass of sample before drying, g

W_b is mass of sample after drying, g

Three naturally attained produce moisture levels of 20%, 14% and 8%, in dry basis, were employed for this study. The procedure employed involved bringing hulled Bambara nut samples from the initial harvest moisture content of 36.30%, in dry basis, to the required test moisture level through open sun drying at an average ambient condition of 39.27˚C and 51.29% relative humidity over a 10 hour daily duration for 3 – 6 days. The corresponding sample weight at the desired moisture level was determined using equation 2:

$$W_f = W_i - \left[\frac{100(M_i - M_f)W_i}{100 - M_f}\right] \quad (2)$$

Where:

W_i is the initial mass of seeds before drying, g

W_f is the final mass of seeds after drying, g

M_i is the initial moisture content before drying, %

M_f is the final moisture content after drying, %

2.4 Size properties

Major, minor, and intermediate diameters of 50 randomly selected seeds along three mutually perpendicular axes were determined using the method of the photographic enlarger, as recommended by Mohsenin (1986), at the three moisture levels. A schematic representation of these dimensions is shown in Figure 1.

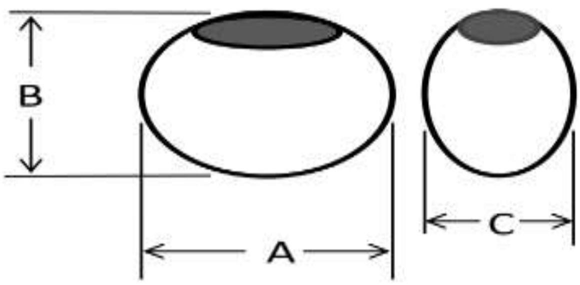

Fig. 1: Acquisition of axial dimensions

The geometric mean diameter (GMD) of the seeds was subsequently determined using equation 3, as reported by (Gharib-Zahedi *et al.*, 2010):

$$GMD = (A \times B \times C)^{\frac{1}{3}} \tag{3}$$

Where:

A is major diameter, mm

B is minor diameter, mm

C is intermediate diameter, mm

2.5 Shape

The sphericity of each seed was determined by inscribing and circumscribing its projected profile in natural rest (indicating the major and minor diameters) with circles for graphical acquisition of the diameters of these circles. Subsequently, sphericity (ϕ) was computed using equation 4, as described by Mohsenin, (1986):

$$\phi = \frac{d_i}{d_c} \tag{4}$$

Where:

d_i is the diameter of largest inscribed circle, mm

d_c is the diameter of smallest circumscribed circle, mm

2.6 Seed volume and surface area

The volume (V) and surface area (S) of a single seed of Bambara nut was determined using equations 5 – 7 from methods advanced by (Baryeh, 2001, 2002; Jain & Bal, 1997; McCabe *et al.*, 1993).

$$V = \frac{\pi Q^2 A^2}{6(2A - Q)} \tag{5}$$

and

$$S = \frac{\pi Q A^2}{2A - Q} \tag{6}$$

Where:

$$Q = \sqrt{BC} \tag{7}$$

All other terms are as already defined.

2.7 One thousand seed mass

In order to establish representative mass for single seeds of the TVSu-1874 variety of Bambara nut, masses of replicate samples of one thousand randomly selected seeds were acquired at the three moisture levels in line with established procedures (Babic *et al.*, 2013; Jafari *et al.*, 2011) using a Adam Equipment® PGL 2002 top loading type electronic balance (Adam Equipment S.A. (Pty) Ltd, Johannesburg, South Africa) with 0.01 g accuracy.

2.8 Bulk density

Bulk densities (ρ_b) of seeds at the various moisture contents were determined as described by (Garnayak *et al.*, 2008) by filling a 150 ml metallic cylinder, freely, under gravity and taking care to level-off the fill with a knife edge, without compacting the seeds. Bulk density was calculated to be the ratio of the mass of seeds filling the container to its known volume, as indicated in equation 8:

$$\rho_b = \frac{M_1 - M_2}{V} \qquad (8)$$

Where:

M_1 is mass of filled cylinder, g

M_2 is mass of empty cylinder, g

V is volume of the cylinder, g

2.9 Solid density

The solid density (ρ_s) of seeds at the various moisture contents was determined through liquid displacement, using toluene; the appropriate computational relation (equation 9) is (Mohsenin, 1986; Pradhan *et al.*, 2013):

$$\gamma_S = \left(\gamma_T \times \frac{m_S}{m_{TD}}\right) \qquad (9)$$

γ_S is specific gravity of seed, dimensionless

γ_T is specific gravity of toluene, dimensionless

m_S is mass of sample, g

m_{TD} is mass of toluene displace, g

2.10Tapped density

Tapped densities of seeds of Bambara nut at various moisture levels were determined using methods reported in literature; the setup was subjected to 50, 100, and 1250 cumulative taps in accordance with recommended standards and the resulting densities were computed using equation 10 (Hetclova *et al.*, 2020; Pekel *et al.*, 2022; Yao *et al.*, 2022):

$$\rho_T = \frac{m_s}{V_{tap}} \qquad (10)$$

Where:

ρ_T is tapped density, kg/m^3

m_s is mass of the sample, g

V_{tap} is consolidate volume after tapping, m^3

2.11 Porosity

Porosity (ε) is the proportional fraction of void spaces in the bulk volume of the seeds to the total volume. This was determined using equation 10 (Mohsenin, 1986).

$$\varepsilon = 100 \times \left[1 - \frac{\rho_b}{\rho_U}\right] \qquad (11)$$

Where:

ρ_b is bulk density of seeds, g/cm^3

ρ_U is solid density of seeds, g/cm^3

2.12 Angle of repose

A glass funnel of known wide end diameter, positioned on a beaker with the wide end up and in the horizontal plane at some known height (h_1) above a datum, was filled with Bambara seeds to some height such that it formed a conical pile, on the funnel, whose height above the datum, at its apex, is h_2 (Mohsenin, 1986). The angle of repose was then calculated using equation 11:

$$\theta = tan^{-1}\left(\frac{h_2 - h_1}{r}\right) \qquad (12)$$

Where:

θ is the angle of repose, °

h_2 is the height of the apex of the conical seed pile above the datum, mm

h_1 is the height of the base of the conical seed pile above the datum, mm

r is the radius of the base of the conical seed pile, mm

2.13 Coefficient of static friction

The coefficient of static friction for seeds was determined against a non-corroded mild steel surface using the inclined plane method. This involved filling a 150mm hollow cubical box made of lightweight plastic material with kernels and placing the open side on an adjustable tilting surface made of mild steel, ensuring that the kernels were in direct contact with the sheet surface. The inclination of the plate was gradually increased until the seeds began to slide down. At that point, the angle of tilt, α was recorded on a graduated scale (protractor). Subsequently, the angle of inclination with respect to the horizontal was transposed using equation 12 to obtain the coeffient of static friction, on mild steel (Gharib-Zahedi *et al.*, 2010):

$$\mu = tan \propto \qquad (13)$$

Where:

μ is static coefficient of friction, –

$\propto$ is angle of tilt, °

2.14 Data Analysis

Test data were subjected to the analysis of variance using the generalised linear model in GenStat. Treatment effects were evaluated using Duncan's multiple range test. Numerical computations and data transforms were carried out using Microsoft Excel.

3. Results and Discussion

The results obtained for the physico-mechanical properties of the Bambara nut (TVSu-1874) variety at moisture contents of 8%, 14%, and 20% (dry basis) are presented in Tables 1 – 4. From Table 1, it was observed that axial dimensions increased as moisture content increased. Minimum values of major, intermediate and minor diameters of the seeds ranged between 8.28 - 9.80 mm, 6.40 - 7.69 mm and 4.68 - 6.20 mm, while maximum values were between 15.06 - 16.28 mm, 13.18 - 14.4 mm and 11.46 - 12.68 mm, respectively, within the 8 – 20% moisture bracket. The major, intermediate, and minor diameters of the seeds increased by 10.44%, 12.29% and 10.65%, respectively, as seed moisture content increased from 8% to 20%. Similar trends were reported for ellipsoidal seeds (cowpea and soybean) by other authors Moses & Zibokere (2011) and Kibar & Öztürk (2008).

Table 1: Seed axial dimensions

MC (%)	Major Diameter (mm)			Intermediate Diameter (mm)			Minor Diameter (mm)		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean

8	8.28	15.06	11.88^{b} (1.81)†	6.40	13.18	10.01^{b} (1.81)	4.68	11.46	8.30^{b} (1.84)
14	8.70	15.64	12.28^{b} (1.80)	7.57	13.60	10.52^{b} (1.69)	5.85	11.88	8.91^{ab} (1.71)
20	9.80	16.28	13.12^{a} (1.78)	7.69	14.40	11.24^{a} (1.80)	6.20	12.68	9.53^{a} (1.81)

†Standard deviation (in brackets). MC, Min. and Max refer to moisture content, minimum value and maximum value, respectively. Mean comparison is column-wise. Similar alphabets indicate homogeneous subsets. Significant effects are valid at the 5% level of significance.

Whereas moisture effects were statistically at par for values within the 8 – 14% moisture bracket, effects were significantly high as moisture content of 20% was attained, within all size categories (Table 1). Geometric mean diameter (GMD), sphericity, volume, surface area and 1000 seed mass all increased as moisture content increased from 8 to 20% (Table 2). Moisture increase resulted in 12.53%, 1.24% and 41.51% gain in geometric mean diameter, sphericity and seed volume, respectively; similar trends were observed with surface area and seed mass which increased by 26.60% and 7.91%, respectively, as moisture rose from 8% to 20%. Findings by Tavakoli *et al.*, (2009) and Karaj & Müller (2010), for soybeans and jatropha seeds are in agreement with these. Baryeh (2001), however, evaluated two techniques for the determination of shape and found results from the two methods to differ significantly over a wide margin.

Table 2: Geometric mean diameter, sphericity, volume, surface area and kernel mass

Moisture Content (%)	GMD (mm)	Sphericity (%)	Volume (mm^3)	Surface Area (mm^2)	1000 Kernel Mass (g)
8	9.95^{b} (1.84)†	86.18^{c} (22.29)	466.36^{b} (254.11)	286.16^{b} (106.09)	894.25^{c} (8.94)
14	10.47^{b} (1.73)	87.56^{a} (21.16)	541.24^{b} (267.05)	317.31^{b} (105.71)	924.78^{b} (5.97)
20	11.19^{a} (1.81)	87.25^{b} (19.94)	659.95^{a} (321.23)	362.22^{a} (119.10)	964.96^{a} (6.58)

†Standard deviation (in brackets). Mean values are compared column-wise. Similar alphabets indicate homogeneous subsets. Significant effects are valid at the 5% level of significance.

Both bulk density and true density increased as the seeds gained moisture. As moisture increased from 8% to 20%, gains in both densities were 14.86% and 13.93%, respectively. Within this range, moisture gain did significantly influence increase in material density (Table 3). Although significant differences in porosities of bulk seeds at the various moisture contents are indicated (Table 3), these gains were marginal. Positive correlations between porosity and moisture gain are reported for.

Table 3: Bulk density, true density, porosity and tapped density

Moisture Content (%)	Bulk Density (g/cm^3)	True Density (g/cm^3)	Porosity (%)	Tapped Density (g/cm^3)		
				50taps	100taps	1250taps
8	0.74^{c}	1.22^{c}	39.34^{b}	0.85^{cd}	0.89^{b}	0.92^{a}
	(0.01)†	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
14	0.80^{b}	1.32^{b}	39.39^{a}	0.81^{e}	0.88^{bc}	0.90^{ab}
	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
20	0.85^{a}	1.39^{a}	38.85^{c}	0.76^{f}	0.83^{de}	0.84^{de}
	(0.01)	(0.01)	(0.00)	(0.04)	(0.01)	(0.01)

†Standard deviation (in brackets). Except for tapped density, mean comparison is column-wise; tapped density values are compared section-wide. Effects are significant at the 5% level for homogeneous subsets with same letters.

spherical and ellipsoidal seeds (Altuntas & Demirtola, 2007; Altuntaş & Yıldız, 2007; Darvishi, 2012).

Tapped densities are indicators of bulk flow characteristics of the seeds and are presented in Table 3. At all moisture levels, significant consolidation of the bulk material and gains in density of bulk seeds occurred as the frequency of disturbance of the material increased (Table 3). Further still, as moisture content increased, the tapped density became lower for every frequency of disturbance of the bulk material. This suggests less room for packing at the higher moisture levels. However, very wide margins as to the degree of pack resulted at all moisture levels; very low compressibility are indicative of poor handling or flow property and influence deterioration of produce in storage (Pekel *et al.*, 2022).

Angles of repose and coefficients of static friction were higher at the higher levels of moisture; gain in each of these indices with every rise in moisture level was significant. Similar trends were reported for angles of repose and coefficients of static friction of millet and Bambara nut within a moisture range of 5% to 20% on mild steel and galvanized steel (Baryeh, 2001, 2002). Gupta & Das (1997) reported similar trends for angles of repose and coefficients of friction of coffee beans and sunflower seeds, respectively.

Table 4: Angle of repose, coefficient of friction and compressive strength

Moisture content (%)	Angle of repose (°)	Coefficient of friction (–)
8	19.27[c]	0.41[c]
	(0.75)[†]	(0.005)
14	21.59[b]	0.48[b]
	(0.61)	(0.010)
20	25.69[a]	0.53[a]
	(1.14)	(0.015)

[†]Standard deviation (in brackets). Mean values are compared column-wise. Similar alphabets indicate homogeneous subsets. Significant effects are valid at the 5% level of significance.

CONCLUSION

In this study, the influence of three naturally attained levels of moisture (8%, 14% and 20%, in dry basis) in seeds of the TVSu-1874 variety of Bambara nut on some physical and mechanical properties of the crop was determined. Properties of the seeds were significantly influenced by moisture presence. As moisture content increased from 8% to 20%, major, intermediate, and minor diameters of Bambara nut increased by 10.44%, 12.29%, and 10.65%, respectively. Quantified gains in geometric mean diameter, seed volume, surface area, bulk density and true density were: 12.53%, 41.51%, 26.60%, 14.86% and 13.93%, respectively. As moisture content increased from 8% to 20%, angle of repose increased by 33.55% and coefficient of friction rose by 29.27%. These findings are of critical importance in the handling, processing, and storage of Bambara nut.

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