Physical, Mechanical and Frictional Properties of Two Fruit Morphotypes of Canarium Schweinfurthii Linn (African Elemi)

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Abstract
Canarium schweinfurthii Linn (locally called atili or African elemi) is an underutilised indigenous oil-bearing fruit widely distributed across tropical Africa, whose postharvest handling and processing remain largely manual in Nigeria for lack of documented engineering design data. This study determined and compared the physical, frictional and mechanical properties of two fruit morphotypes of C. schweinfurthii Linn (oblong and round) at moisture contents of 11.43% and 11.19% (wet basis), respectively. Fifty fruits per morphotype were used to determine axial dimensions, derived size/shape parameters, gravimetric properties and frictional behaviour on glass, mild steel and plywood surfaces, while ninety-eight fruits were subjected to uniaxial compression on a universal testing machine at longitudinal and axial orientations for hard (unsoftened) and soft (softened) textures. Data were analysed by ANOVA ($P \leq 0.05$) with Duncan's multiple range test using SPSS version 20. Mean length, width and geometric mean diameter were 37.11 mm, 17.45 mm and 22.43 mm for oblong fruits and 21.05 mm, 18.62 mm and 19.27 mm for round fruits. Round fruits were markedly more spherical (91.9%) than oblong fruits (59.9%), while oblong fruits recorded higher bulk density, true density, volume, surface area and 1000-fruit mass. Angle of repose, coefficient of friction and coefficient of internal friction were consistently highest on plywood and lowest on glass, and were significantly higher for oblong than round fruits on all three surfaces ($P < 0.05$). Compressive force, deflection, strain and energy at peak, yield and break were consistently greater in the longitudinal than the axial orientation and in hard than in soft fruits, with the oblong morphotype generally requiring greater force and energy to fail. These findings provide baseline engineering data required for the design of cleaning, grading, conveying, storage and size-reduction equipment for C. schweinfurthii Linn fruit processing.

Keywords: *Canarium schweinfurthii Linn; atili fruit; physical properties; frictional properties; mechanical properties; postharvest engineering*

1. Introduction

Canarium schweinfurthii Linn, known locally as atili and commercially as African elemi or black olive, is a tree of the family Burseraceae that grows wild in the equatorial forest belt of East, Central and West Africa and is found in commercial abundance around the Plateau, Nasarawa, Kaduna and Bauchi highlands of Nigeria (Ehiem et al., 2022). The fruit resembles the olive (Olea europaea) in shape and colour, although the two are botanically unrelated (Omeje et al., 2022). The fruit pulp (mesocarp) contains between 30 and 50% oil, which has been reported to possess analgesic properties and is used domestically for cooking as well as industrially in the manufacture of soap, shampoo, biodiesel and biolubricants (Omeje et al., 2022). Extracts of the bark, leaves and resin are used in traditional medicine to treat fever, diarrhoea, wounds and microbial infections (Omeje et al., 2022).

Despite its wide distribution and industrial potential, harvesting, sorting and oil extraction from C. schweinfurthii Linn fruit in Nigeria remain almost entirely manual, largely because engineering data needed to design appropriate handling, cleaning, grading and processing equipment are scarce. Reliable knowledge of the physical (size, shape, density, porosity), frictional (angle of repose, coefficient of friction) and mechanical (force–deformation) properties of an agricultural material is a prerequisite for the rational design of hoppers, conveyors, separators, storage structures and size-reduction machinery (Omale et al., 2023; Panda et al., 2020; Ikegwu & Onuedo, 2023). While such properties have been extensively documented for many oilseeds and fruits, only limited and fragmented data exist for C. schweinfurthii, and comparative data for its two commonly recognised fruit morphotypes — oblong and round — has not previously been reported.

The objective of this study was therefore to determine and statistically compare the physical, frictional and mechanical properties of oblong and round C. schweinfurthii Linn fruits, so as to generate baseline design data for the mechanisation of its postharvest handling and processing.

2. Materials and Methods

2.1 Sample collection and preparation

Ripe oblong and round C. schweinfurthii Linn fruits (20 kg of each type) were hand-harvested from Vom village, Plateau State, Nigeria, in the cool morning hours from trees with a history of high oil content, and transported in clean polythene bags to the Agricultural and Environmental Engineering Laboratory, Federal University of Agriculture, Makurdi, for analysis. For each morphotype, 5 kg of raw (unsoftened) fruit was used to determine physical and frictional properties, while both raw (hard-textured) and softened (soft-textured) fruits — obtained by steeping in warm water (18–20 °C) for 15 minutes — were used for the mechanical property tests.

2.2 Determination of physical properties

Moisture content was determined in triplicate by the hot-oil distillation method: fruit samples were immersed in a vegetable-oil bath maintained at 134 °C for 15–20 minutes, and the moisture driven off was calculated on a wet-weight basis (Ikegwu & Onuedo, 2023).

Length (L) and width (W) of fifty randomly selected fruits per morphotype were measured with a digital vernier caliper (accuracy 0.01 mm) following Ikegwu et al. (2016). These dimensions were used to compute the arithmetic mean diameter (AMD), geometric mean diameter (GMD), square mean diameter (SMD), sphericity, sphericity index, aspect ratio and surface area using standard relations (Panda et al., 2020):

$AMD = (L + 2W) / 3$

$GMD = (LW^2)1/3$

$SMD = [(LW + W^2 + WL)/3]1/2$

$Sphericity\ (\%) = (GMD/L) \times 100$; $Sphericity\ index = GMD/L$; $Aspect\ ratio = W/L$; $Surface\ area = \pi(GMD)^2$

Fruit volume was estimated from $V = (\pi/6)LW^2$. Bulk density was determined by filling a graduated 1000 cm^3 cylinder with fruit from a fixed drop height, tapping to consolidate, and dividing the fruit mass by the occupied volume (five replications). True density was determined by the water-displacement method on a known fruit mass, and porosity was calculated from bulk and true density using the relation of Mohsenin (1986): Porosity (%) = $[(\delta t - \rho b)/\delta t] \times 100$. One-thousand-fruit mass was obtained by weighing 100 randomly selected fruits (precision balance, 0.01 g accuracy) and scaling to 1000, replicated five times. Specific gravity was determined by the water-displacement method on 50 fruits per morphotype.

2.3 Determination of frictional properties

Angle of repose, coefficient of friction and coefficient/angle of internal friction were determined against three structural surfaces — glass, mild steel and plywood — using an adjustable tilting-plate apparatus. For angle of repose and coefficient of friction, a topless, bottomless wooden box (25 × 15 cm) filled with fruit was placed on the test surface and the surface inclination increased gradually by a screw-jack mechanism until the fruit began to slide; the tilt angle (θ) was read from a graduated scale, and both properties were computed as $\tan\theta = x/y$, where x and y are the height and base radius of the fruit heap, respectively (Panda et al., 2020; Zhang et al., 2022). Coefficient and angle of internal friction were determined similarly using a filled box (25 × 15 × 8 cm) resting directly on each surface. Each measurement was replicated five times per surface.

2.4 Determination of mechanical properties

Compression tests were carried out on both morphotypes (hard and soft texture) at longitudinal and axial orientations using a Monsanto Universal Testing Machine (Instron Model 3369, 50 kN) at the National Centre for Agricultural Mechanisation (NCAM), Ilorin, Nigeria, at a constant deformation rate of 10 mm/min. A total of 98 fruits were tested. Force, deflection, strain and absorbed energy were recorded at the peak, yield and break points for each fruit.

2.5 Statistical analysis

Physical properties followed a 2 × 50 completely randomised design (CRD; 100 observations); frictional properties a 2 × 3 × 5 CRD (30 observations: two fruit types, three surfaces, five replicates); and mechanical properties a 2 × 2 × 2 × 5 CRD (40 observations: two fruit types, two textures, two orientations, five replicates). Data were analysed by one-way and factorial analysis of variance (ANOVA) in SPSS version 20, with mean separation by Duncan's Multiple Range Test at $P \leq 0.05$ and a 95% confidence level.

3. Results and Discussion

3.1 Physical properties

Table 1 summarises the physical properties of oblong and round C. schweinfurthii Linn fruits at 11.43% and 11.19% moisture content (w.b.), respectively.

Property	Oblong Mean ± SD	Round Mean ± SD	Sig.
Moisture content (% w.b.)	11.43	11.19	-
Length (mm)	37.11 ± 1.08	21.05 ± 1.20	S
Width (mm)	17.45 ± 0.83	18.62 ± 0.94	S
Arithmetic mean diameter, AMD (mm)	22.33 ± 0.89	19.43 ± 0.75	S
Geometric mean diameter, GMD (mm)	22.43 ± 0.89	19.27 ± 0.74	S
Square mean diameter, SMD (mm)	22.78 ± 0.12	19.13 ± 0.11	NS
Sphericity (%)	59.92 ± 1.17	91.92 ± 4.37	S
Sphericity index	0.59 ± 1.17	0.92 ± 4.37	S
Aspect ratio	0.47 ± 1.98	0.89 ± 6.04	S
Volume (cm^3)	5.92 ± 0.68	3.84 ± 0.47	S
Surface area (cm^2)	156.35 ± 12.69	116.40 ± 9.49	S

Property	Oblong Mean ± SD	Round Mean ± SD	Sig.
1000-fruit mass (g)	956.8 ± 12.2	582.6 ± 69.7	S
True density (g/cm³)	1.070 ± 0.142	0.995 ± 0.054	NS
Bulk density (g/cm³)	0.655 ± 0.007	0.624 ± 0.005	S
Porosity (%)	37.89 ± 7.37	37.17 ± 3.19	NS
Specific gravity	1.014 ± 0.411	1.039 ± 0.031	S

S = significant difference between morphotypes at P < 0.05; NS = not significant.

Mean length and width were 37.11 mm and 17.45 mm for oblong fruits and 21.05 mm and 18.62 mm for round fruits, giving GMD values of 22.43 mm and 19.27 mm, respectively — dimensions broadly comparable with the large and long fruit classes of the related species Canarium schweinfurthii Engl. reported by Ehiem et al. (2016) at a similar moisture content. These axial dimensions are important for selecting sieve aperture sizes in cleaning and grading machinery (Panda et al., 2020).

Round fruits recorded a substantially higher sphericity (91.9%) and aspect ratio (0.89) than oblong fruits (59.9% and 0.47), indicating that round fruits roll more readily on inclined and vibrating surfaces — a property of direct relevance to the design of pneumatic and gravity separators and rolling-type grading equipment (Panda et al., 2020). Conversely, oblong fruits had significantly higher volume, surface area, 1000-fruit mass, true density and bulk density, attributable to their more elongated geometry.

Both morphotypes exhibited relatively low porosity (37.9% for oblong, 37.2% for round), a property relevant to airflow and heat-transfer calculations during bulk storage and drying (Panda et al., 2020), while bulk fruit mass and volume inform the sizing of hoppers, storage bins and packaging equipment (Panda et al., 2020). ANOVA confirmed significant differences (P < 0.05) between morphotypes for all measured physical properties except square mean diameter, true density and porosity.

3.2 Frictional properties

Table 2 presents the frictional properties of oblong and round fruits on glass, mild steel and plywood surfaces.

Property	Surface	Oblong Mean ± SD	Round Mean ± SD	Sig.
Angle of repose (°)	Glass	18.25 ± 0.50	12.47 ± 0.45	S
	Steel	21.35 ± 0.21	16.47 ± 0.73	S
	Plywood	24.21 ± 0.57	18.60 ± 0.47	S
Coefficient of friction	Glass	0.329 ± 0.009	0.222 ± 0.60	S
	Steel	0.352 ± 0.014	0.296 ± 0.531	S
	Plywood	0.449 ± 0.015	0.357 ± 0.581	S
Coefficient of internal friction	Glass	0.424 ± 0.005	0.282 ± 0.009	S
	Steel	0.475 ± 0.002	0.348 ± 0.005	S
	Plywood	0.511 ± 0.10	0.426 ± 0.20	S
Angle of internal friction (°)	Glass	22.99 ± 0.25	15.84 ± 0.47	S
	Steel	25.45 ± 0.34	19.02 ± 0.51	S
	Plywood	27.16 ± 0.43	22.96 ± 0.95	S

All values significant at P < 0.05 between morphotypes and between surfaces (ANOVA).

For all three frictional properties, plywood consistently produced the highest values and glass the lowest, reflecting the relative roughness of the surfaces; this pattern was consistent for both morphotypes. Oblong fruits recorded significantly higher angle of repose, coefficient of friction and coefficient/angle of internal friction than round fruits on every surface tested ($P < 0.05$), a behaviour attributable to their lower sphericity, which restricts free rolling and increases resistance to sliding relative to the more spherical round fruits. These trends are consistent with reports for other agricultural materials in which more spherical particles exhibit lower frictional resistance (Zhang et al., 2022). Angle of repose data are directly applicable to the design of hopper wall angles and conveyor inclinations, while coefficient of internal friction informs the design of storage-bin walls for reliable gravity flow (Ehiem et al., 2022).

3.3 Mechanical properties

Table 3 presents the force, deflection, strain and energy of oblong and round fruits at peak, yield and break for hard and soft textures at longitudinal and axial orientations.

Parameter	Variety	Longitudinal Hard	Longitudinal Soft	Axial Hard	Axial Soft
Force at peak (N)	Oblong	1640.65 ± 422.35	747.66 ± 124.85	27.42 ± 8.43	6.85 ± 1.55
	Round	1564.46 ± 537.82	404.76 ± 57.39	11.90 ± 3.97	6.94 ± 1.55
Deflection at peak (mm)	Oblong	5.22 ± 0.57	4.88 ± 0.41	3.23 ± 0.38	1.41 ± 0.21
	Round	4.01 ± 0.73	2.46 ± 0.60	2.59 ± 0.52	1.23 ± 0.15
Strain at peak (%)	Oblong	15.55 ± 1.23	6.72 ± 1.19	16.15 ± 1.89	6.85 ± 1.29
	Round	16.04 ± 2.93	10.65 ± 1.96	13.99 ± 2.29	6.84 ± 1.29
Energy at peak (Nm)	Oblong	3.74 ± 1.49	0.81 ± 0.61	0.04 ± 0.01	0.01 ± 0.01
	Round	1.93 ± 0.66	0.42 ± 0.32	0.02 ± 0.06	0.004 ± 0.001
Force at yield (N)	Oblong	1640.64 ± 4.12	634.46 ± 88.99	29.37 ± 8.55	6.68 ± 1.58
	Round	1496.88 ± 8.89	318.50 ± 81.19	10.20 ± 5.47	6.68 ± 1.58
Deflection at yield (mm)	Oblong	5.22 ± 0.77	3.51 ± 0.54	2.98 ± 0.50	1.32 ± 0.28
	Round	4.01 ± 0.54	2.66 ± 0.48	2.25 ± 1.02	1.32 ± 0.32
Strain at yield (%)	Oblong	15.55 ± 1.23	6.59 ± 1.08	15.84 ± 2.02	6.62 ± 1.43
	Round	16.11 ± 3.06	6.62 ± 1.40	11.22 ± 3.05	6.62 ± 1.43
Energy at yield (Nm)	Oblong	3.05 ± 0.95	1.12 ± 0.47	0.04 ± 0.01	0.003 ± 0.003
	Round	2.01 ± 0.68	0.31 ± 0.12	0.33 ± 0.11	0.004 ± 0.002
Force at break (N)	Oblong	1261.40 ± 400.06	612.18 ± 41.52	28.84 ± 8.92	6.47 ± 1.61
	Round	1384.44 ± 715.90	351.51 ± 68.33	10.63 ± 4.11	6.47 ± 1.61

Parameter	Variety	Longitudinal Hard	Longitudinal Soft	Axial Hard	Axial Soft
Deflection at break (mm)	Oblong	5.65 ± 0.36	4.47 ± 0.36	3.29 ± 0.36	1.44 ± 0.25
	Round	4.23 ± 0.84	3.38 ± 0.41	3.00 ± 0.32	1.44 ± 0.25
Strain at break (%)	Oblong	17.22 ± 1.20	9.80 ± 3.26	16.43 ± 1.81	7.22 ± 1.25
	Round	16.86 ± 3.26	10.24 ± 2.07	15.01 ± 1.58	7.22 ± 1.25
Energy at break (Nm)	Oblong	2.76 ± 0.99	0.89 ± 0.35	0.04 ± 0.01	0.004 ± 0.001
	Round	1.93 ± 0.66	0.88 ± 0.32	0.017 ± 0.006	0.004 ± 0.002

Values are mean ± SD (n = 5).

Across all texture and orientation combinations, hard (unsoftened) fruits consistently required greater compressive force and absorbed more energy before failure than soft (softened) fruits, reflecting the loss of structural rigidity that accompanies water-softening. Likewise, force, deflection and energy were consistently higher in the longitudinal than the axial orientation for both morphotypes, which is attributable to the greater proportion of fibrous pulp material along the axial axis, offering less resistance to compression. Oblong fruits generally recorded the highest force values (peak force of 1640.6 N in the hard-longitudinal orientation, versus 1564.5 N for round fruits), consistent with their greater bulk density and lower porosity.

Table 4 summarises the effects of fruit type, orientation and texture on the mechanical properties, based on the full factorial ANOVA.

Property	Fruit type (oblong vs round)	Orientation (long. vs axial)	Texture (hard vs soft)
Force (peak/yield/break)	NS	S (p<0.001)	S (p<0.001)
Deflection (peak/yield/break)	S (p<0.001–0.001)	S (p<0.001)	S (p<0.001)
Strain (peak/yield/break)	NS (mostly)	S (p<0.05)	S (p<0.001)
Energy (peak/yield/break)	S (peak, p=0.001)	S (p<0.001)	S (p<0.001)

S = significant at P < 0.05; NS = not significant.

Orientation and texture had a statistically significant effect ($P < 0.05$) on virtually all mechanical parameters, whereas fruit type (oblong vs round) significantly affected only deflection and energy, but not force or strain, at most failure points — suggesting that while overall fruit strength is broadly comparable between morphotypes, their deformation behaviour under load differs measurably. These results are directly applicable to sizing the impact and shear capacity of size-reduction and dehulling machinery, and to specifying safe loading limits for bulk storage structures (Zhang et al., 2022; Santos et al., 2024).

4. Conclusion

The physical, frictional and mechanical properties of oblong and round C. schweinfurthii Linn fruits were significantly different for the majority of parameters investigated. Round fruits were more spherical and easier to roll, while oblong fruits were denser, heavier and generally required greater force and energy to deform. Plywood produced the highest, and glass the lowest, frictional values for both morphotypes on all frictional parameters measured. Hard-textured fruit in the longitudinal orientation offered the greatest resistance to compressive failure for both morphotypes. These data provide a quantitative basis for the design of cleaning, grading, conveying, storage and size-reduction equipment for C. schweinfurthii Linn, an underutilized but industrially promising oil-bearing fruit.

References

Aina, A. M., Harith, H. H., Hashim, N., & Shukery, M. F. M. (2024). The influence of papaya shape on its mass model and mechanical properties. Journal of Food Process Engineering, 47(5), e14627. https://doi.org/10.1111/jfpe.14627

Ban, Z., Chen, H., Fang, C., Jin, L., Kitazawa, H., Chen, C., Liu, L., & Lu, J. (2024). Investigating the damage characteristics of kiwifruits through the integration of compressive load and finite element method. Journal of Food Engineering, 383, 112247. https://doi.org/10.1016/j.jfoodeng.2024.112247

Ehiem, J. C., Ndirika, V. I. O., Onwuka, U. N., Yvan, G., & Raghavan, G. S. V. (2022). Determination of some physical properties of Canarium schweinfurthii Engl nuts from Nigeria. Journal of Agricultural Engineering and Technology, 27(1).

Ndukwu, M. C., Ehiem, J. C., Mbanasor, J., & Obasi, N. E. (2022). Thermal softening kinetics of African black olive fruit: Influence of temperature and water absorption on the thermal maceration dynamics and thermophysical properties. Journal of Food Processing and Preservation, 46, e17021. https://doi.org/10.1111/jfpp.17021

Omale, P. A., Aremu, A. K., and Omobowale, M. O. (2023) Modeling of Physical and Compressive Test Properties of Tiger nut Using Response Surface Approach. Journal of Engineering Research and Reports, Volume 24, Issue 2, Page 1-14, 2023; DOI: 10.9734/JERR/2023/v24i2798

Omeje, K. O., Ezema, B. O., Ozioko, J. N., Omeje, H. C., Ossai, E. C., Eze, S. O. O., Okpala, C. O. R., & Korzeniowska, M. (2022). Biochemical characterization of Soxhlet extracted pulp oil of Canarium schweinfurthii Engl. fruit in Nigeria. Scientific Reports, 12, 10291. https://doi.org/10.1038/s41598-022-14381-w

Panda, G., Vivek, K., & Mishra, S. (2020). Physical characterization and mass modeling of Kendu (Diospyros melanoxylon Roxb.) fruit. International Journal of Fruit Science, 20(S3), S2005–S2017. https://doi.org/10.1080/15538362.2020.1851339

Pu, Y., Li, A., Wang, S., Chun, C., Chen, Z., Yang, M., & Yang, L. (2024). Mechanical characteristics test of navel orange extrusion damage and its parameter identification ethod. Transactions of the Chinese Society of Agricultural Engineering, 40(22), 273–282. https://doi.org/10.11975/j.issn.1002-6819.202406156

Santos, F. L., Pereira, R. V., Scinocca, F., Grupioni, C. M. F., & Castro, R. P. (2024). Macauba palm endocarps under compression forces considering the different treatments: A study about physical and mechanical properties for seed extraction. Industrial Crops and Products, 220, 119121. https://doi.org/10.1016/j.indcrop.2024.119121

Zhang, S., Fu, J., Zhang, R., Zhang, Y., & Yuan, H. (2022). Experimental study on the mechanical properties of friction, collision and compression of tiger nut tubers. Agriculture, 12(1), 65. https://doi.org/10.3390/agriculture12010065

Zhu, Y., Zhu, L., Guo, W., Han, Z., Wang, R., Zhang, W., Yuan, Y., Gao, J., & Liu, S. (2024). Multiscale static compressive damage characteristics of kiwifruit based on the finite element method. Foods, 13(5), 785. https://doi.org/10.3390/foods13050785