

Morphological structures of *A. heterophyllus*, *A. altilis* and *A. camansi*

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Abstract

The tropical tree species *Artocarpus heterophyllus* (jackfruit), *Artocarpus altilis* (breadfruit), and *Artocarpus camansi* (breadnut) are highly valuable for global food security, yet their close genetic relationships often lead to taxonomic ambiguities and misidentification. This study evaluated the comparative macromorphological and micromorphological configurations of these three species to establish clear diagnostic boundaries. Plant materials were collected from Aguluezechukwu, Anambra State, Nigeria, and formally authenticated at the Nnamdi Azikiwe University herbarium. Qualitative and quantitative leaf architecture was evaluated using standard botanical frameworks across twenty leaves per species. Qualitative macromorphological assessments revealed that *A. heterophyllus* possesses simple, elliptical leaves with entire margins and cauliflorous fruiting, whereas *A. altilis* and *A. camansi* exhibit terminal fruiting and deeply pinnately lobed laminas. Quantitative morphometric analysis confirmed that *A. camansi* yields the highest leaf blade length (70.42 $\pm$ 1.48 cm), width (41.50 $\pm$ 0.55 cm), and petiole length (5.68 $\pm$ 0.49 cm), while *A. altilis* exhibits the highest lateral vein density (27.60 $\pm$ 0.14). Anatomically, *A. altilis* produces seedless syncarps, contrasting with the many-seeded fruits of *A. camansi* and *A. heterophyllus*. In conclusion, explicit vegetative and reproductive structural variations provide definitive taxonomic markers for these taxa. These findings provide essential baseline data for accurate germplasm authentication, biodiversity conservation, and agricultural selection programs

Submitted:- ; Reviewed:- ; Accepted:-

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DOI. 10.22373/natura

Keyword

Artocarpus, *Macromorphology*, *Leaf Architecture*, *Syncarp*, *Taxonomy*

1. Introduction

The genus *Artocarpus*, a vital component of the Moraceae family, comprises prominent tropical tree species celebrated for their dietary significance, ecological resilience, and economic versatility (Akhil et al., 2014; Basnett et al., 2023). Among these, *Artocarpus heterophyllus* (jackfruit), *Artocarpus altilis* (breadfruit), and *Artocarpus camansi* (breadnut) exhibit distinctive macromorphological configurations in their leaves, stems, and reproductive organs. These differences facilitate environmental adaptation and chemotaxonomic classification (Clement & Weiblen, 2009; Gardner & Zerega, 2021). Deeper exploration of their unique architectural differences highlights why these species serve as invaluable nutritional and agricultural assets (Abdul & Martin, 2015; Jones et al., 2011). Foliar structural variations represent the most reliable vegetative diagnostic markers among the three species. Leaves of *Artocarpus heterophyllus* are typically smaller, elliptic or obovate, and predominantly possess entire margins, though young seedlings occasionally display transiently lobed variations (Elevitch & Manner, 2006; Obijekwu et al., 2022). Thick coriaceous textures and glossy, deep green adaxial surfaces characterize the mature foliage of *A. heterophyllus* (Periyanayagam & Karthikeyan, 2013). In contrast, *Artocarpus altilis* and *Artocarpus camansi* feature massive, deeply pinnatifid leaves with highly pronounced lobing patterns. This architectural design maximizes solar radiation interception in competitive rainforest canopies (Heuzé et al., 2017; National Tropical Botanical Garden, 2017). The leaves of *A. altilis* possess a thick, coriaceous laminate structure with moderately deep incisions creating five to eleven distinct lobes (Akinloye et al., 2015).

Foliar margins of *Artocarpus camansi* exhibit the most dramatic architectural complexity. Its blade structures are more deeply incised, containing highly extended, acuminate lobes that are covered with stiff, microscopic trichomes along the primary veins (Godofredo & Stuart Jr, 2023). These structural discrepancies in leaf incision depth, trichome distribution, and surface texture provide

excellent anatomical landmarks for differentiating these close relatives (Akinloye *et al.*, 2015; Fatoki *et al.*, 2024).

The macro-structural attributes of the stems and trunks within this trio illustrate their diverse timber qualities and structural functions. All three species develop robust, erect trunks that exude a thick, white, protective milky latex upon mechanical injury or vascular rupture (Jagtap & Bapat, 2010; Pereira & Kaplan, 2013). *Artocarpus heterophyllus* often develops a highly branched canopy with dark, grey-brown bark surfaces that turn rough and flaked as the tree ages (Orwa *et al.*, 2009). Its wood features strong mechanical properties, supported by specialized axial parenchyma arrangements and dense wood fibers (Obijekwu *et al.*, 2022). Trees of *Artocarpus altilis* generally display a taller, smoother, grayish trunk architecture reinforced by strong buttress roots. These roots anchor the massive, top-heavy canopy in soft, tropical soils (Heuzé *et al.*, 2017). The bark structure of *A. altilis* remains relatively smooth, marked by thin lenticels that facilitate gas exchange through the outer protective periderm layer (Amponsah *et al.*, 2014).

Trunk configurations of *Artocarpus camansi* reveal a highly dynamic branching mechanism with a light-colored, soft-textured wood composition. This wood possesses low specific gravity and high hydraulic flexibility, which helps the tree survive moisture fluctuations (Ante *et al.*, 2016). These structural modifications in cauline thickness and protective bark traits directly influence the commercial value of their wood for pulp, paper, and structural carpentry (Ogunleye *et al.*, 2017). The reproductive structures and composite fruits (syncarps) showcase the most recognizable morphological boundaries among these taxa. *Artocarpus heterophyllus* is unique for its cauliflorous flowering pattern, producing immense syncarps directly from the main trunk and old primary branches (Dhakar *et al.*, 2020). These oblong, massive structures are the largest tree-borne fruits globally. Their thick yellow rinds are covered in thousands of short, hard, pyramidal spines (Karunakaran *et al.*, 2025). Within the fibrous syncarp core of *A. heterophyllus*, hundreds of oval, smooth seeds are embedded in fleshy, sweet, yellow perianth structures (Ajayi, 2008).

Artocarpus altilis and *Artocarpus camansi* produce syncarps on the terminal ends of their young, leafy branches (Heuzé *et al.*, 2017). The syncarp of *A. altilis* is round or slightly oval, featuring a smooth, green surface patterned with faint hexagonal structures (Jones *et al.*, 2011). Because commercial *A. altilis* varieties are highly domesticated, they are typically seedless or contain only a few aborted, non-viable ovules within their dense, starchy white pulp (Heuzé *et al.*, 2017). *Artocarpus camansi* serves as the wild, ancestral progenitor to the cultivated breadfruit. It features a round syncarp covered in flexible, elongated green spines that give it a distinctive bristly appearance (Mohammed & Wickham, 2011). The inner structure of *A. camansi* contains a thin, minimal pulp layer that encloses numerous large, round, light brown seeds (Adeleke & Abiodun, 2010). These seeds are highly prized for their unique protein profiles and exceptional nutritional content (Adeleke & Abiodun, 2010; Amadi *et al.*, 2019). These structural variations in reproductive anatomy reflect distinct paths of artificial selection and evolutionary adaptation across the genus.

The primary importance of studying the morphological structures of *Artocarpus heterophyllus*, *Artocarpus altilis*, and *Artocarpus camansi* lies in resolving taxonomic ambiguities and maximizing their underutilized agricultural and industrial potential. Although these species are critical for food security and economic sustainability (Abdul & Martin, 2015; Jones *et al.*, 2011), significant gaps remain in their systematic documentation. Historically, relying on overlapping vegetative characters has caused misidentification, particularly between the closely related *A. altilis* and *A. camansi* (Akinloye *et al.*, 2015; Gardner & Zerega, 2021).

Furthermore, while current literature heavily favors broad nutritional and phytochemical profiling (Adeleke & Abiodun, 2010; Fatoki *et al.*, 2024), it leaves a distinct gap in linking macromorphological traits with internal anatomical functionality. Comprehensive comparative structural data spanning foliar architecture, cauline properties, and reproductive syncarp variations which remains insufficient (Clement & Weiblen, 2009; Obijekwu *et al.*, 2022). Establishing these explicit structural baselines is essential. It provides the diagnostic keys needed for precise germplasm conservation, aids breeders in identifying superior climate-resilient genotypes (Dhakar *et al.*, 2020), and evaluates fiber suitability indices for industrial pulp and paper manufacturing (Ogunleye *et al.*, 2017).

2. Methodology

2.1 Source of Materials.

The test samples, (the leaves and stem of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi*) were obtained from Aguluezechukwu, in Aguata Local Government Area of Anambra State, Nigeria. The town is known for agriculture and a strong community-driven development approach. It was founded by an individual from Uga who hunted an elephant in the forest ("Agu"). The town, led by traditional ruler Igwe F.E. Ebelendu, faces erosion issues but is actively growing, developing infrastructure like roads, schools, and the Nkwo market. Chemicals and facilities used in the practical were obtained from the laboratory of Food and Nutrition Department and Plant Science and Biotechnology Laboratory, University of Nigeria Nsukka, Nigeria.

2.2 Identification of Materials

All plant materials for this study were identified by Prof. C. A. Ezeabara, a Plant Taxonomist in Botany Department, Nnamdi Azikiwe University, Awka and given herbarium numbers as NAUH - 264^A for *Artocarpus heterophyllus*, NAUH - 077^B for *Artocarpus altilis* and NAUH - 265^A for *Artocarpus camansi*,

2.3 Macromorphological Study

The qualitative parameters of the vegetative parts such as the leaf architecture (leaf apex, leaf shape, arrangements, margin, attachment, base and tip, and venation patterns) were assessed following the method described by Ash *et al.* (1999). Quantitative parameters such as leaf size, petiole length and number of lateral veins were determined using thread and meter rule in accordance with Oduoye *et al.* (2013).

2.4 Qualitative Macromorphological Evaluation

The qualitative macromorphological evaluation of the leaf architectural parameters was conducted using standard botanical terminology and taxonomic keys. Leaf layouts were reviewed based on standard plant anatomy frameworks by sampling five fully expanded leaves from the outer third of healthy canopy branches on each tree. Investigators recorded the spatial arrangement of leaves along the stem, their structural texturing, and their general geometry. Leaf margins were carefully evaluated for diagnostic cuts to separate the entire margins of *A. heterophyllus* from the deeply lobed, pinnate segments of *A. altilis* and *A. camansi*, while lobe counts, vein coloration, and surface hairs were confirmed using a hand lens.

2.5 Quantitative Morphometric Analysis

Quantitative morphometric analysis was gathered from a randomized pool of twenty clean leaves per species to evaluate physical variations. For lamina tracing, leaf blade length was measured along the central midrib from the apex tip to the petiole insertion point using a flexible meter rule, and leaf blade width was measured across the widest horizontal section of the lamina. For the deeply lobed leaves of *A. altilis* and *A. camansi*, a non-elastic thread was guided along the leaf surface to account for structural curves before transferring the measurement to a rigid rule. Petiole lengths were recorded from the base of the lamina to the stem attachment using a digital vernier caliper, and the total number of lateral veins was determined by counting the absolute number of secondary veins emerging directly from the primary midrib on both sides of the blade.

2.6 Biostatistical Data Processing

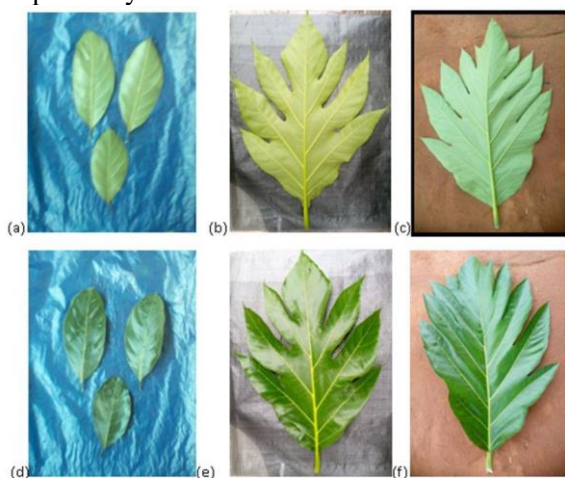
Finally, biostatistical data processing was managed by organizing the gathered quantitative measurements into structured datasets to run comparative statistical analyses. The mean values and standard errors were calculated for each physical dimension, and the structural variance across the three independent plant groups was tested using a One-Way Analysis of Variance, where a probability threshold of $P \leq 0.05$ defined statistically significant differences. When the global F-test indicated a significant result where $P < 0.01$, Duncan's Multiple Range Test was applied as a post-hoc analysis for precise pair-wise comparisons and to assign statistical significance letters to the different species.

3. Results

3.1 Leaves and Growth Habits of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi*.

Clear observation of the leaf structure showed that *Artocarpus heterophyllus* has simple leaf that is oval in shape with entire leaf margin. *Artocarpus camansi* and *Artocarpus altilis* have simple leaves that are lobed but *A. altilis* has reddish or pale veins while *A. camansi* has green veins (Plate 1).

For *A. heterophyllus*, the tree displays straight short trunk with dense, rounded crown and greyish brown bark. For *A. altilis*, the tree has light colour, while *A. camansi* showed stretched stem that gains height before branching and the bark is rough and scaly (Plate 2). The abaxial and adaxial leaf pictures were shown in Plates 1a-f while the tree pictures of the three plant species were shown in Plate 2a-c respectively.



Plates 1: a. abaxial leaf sample of *A. heterophyllus*, b. abaxial leaf sample of *A. altilis*, c. abaxial leaf sample of *A. camansi*, d. adaxial leaf sample of *A. heterophyllus*, e. adaxial leaf sample of *A. altilis*, f. adaxial leaf sample of *A. camansi*.



Plate 2: a. Habit of *A. heterophyllus*, b. Habit of *A. altilis*, c. Habit of *A. camansi*

3.2 Morphological Studies of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi*

3.2.1 Qualitative Morphological Studies of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi*

Morphological studies of the features of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi* showed a close resemblance in their leaves and overall tree structure. The detailed qualitative morphological expressions are stated in Table 1.

Table 1: Comparative Qualitative Morphological Studies of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi*.

Features	<i>Artocarpus heterophyllus</i>	<i>Artocarpus altilis</i>	<i>Artocarpus camansi</i>
Habit	Perennial evergreen tree.	Perennial evergreen tree.	Perennial evergreen tree.

Leaf morph-ology	Simple, alternately arranged along the stem, glossy with a leathery texture, typically elliptical to oval in shape, dark green leaves of up to 16 cm long. Leaf margin is entire.	Simple, alternately arranged along the stem, large ranging from 20-80cm long and 15-50 cm wide, pinnately lobe (deeply cut into segments like a feather), leathery and varies in colour from dark green on the upper surface to a lighter green with reddish or pale hairs on the veins, spirally arranged and ranges from ovate to oblong. Leaf margin is serrated.	Simple, alternately arranged along the stem, large and leathery, ranging from ovate to oblong-ovate, deep lobed with a distinctive (hand-like) appearance. Leaf ranges from 40-60cm long and 25-45 cm wide, with 4-6 lobes. The blade is dull green, hairy and the veins are green. Leaf margin is serrated.
Fruit	Oval in shape, big, greenish yellow in colour, hard and spined.	A large round to oblong fruit, ranging in size from 10 to 30 centimeters in diameter. Fruit skin is spiny and its colour changes from light green to yellow or golden as it ripens.	Dull green to green-yellow when ripe with pointed, flexible tips. Scanty, yellow-whiteish pulp and sweet aroma, taste and numerous large seeds. Relatively small, oval to rounded, ranging from 7 to 12 cm in diameter and contains between 12-150 seeds per fruit.
Seed	Bean-shaped coated with a firm yellowish arid (seed coat).	Seedless	Oval to oblong with thin, light brown outer coat
Stem (bark)	A straight, relatively short trunk, often with a dense, rounded crown. Greyish-brown, rough, scaly bark. When injured releases a milky juice. Lateral branching pattern.	Smooth, light-coloured bark, with a sturdy trunk of 0.6- 1.8 meters in diameter. Gold in colour when freshly cut but darkens upon exposure to air. Milky latex present in all the stem.	Single stemmed, trunk 1m in diameter or larger, often growing to a height of 5m before branching. Trunk can exhibit buttresses at the base. Rough, scaly bark with a greyish-brown colour and exudes white milky latex when cut. Forms a 30 degree angle with the trunk.
Root	Tap root system	Tap root system	Tap root system

3.2.2 Quantitative Morphological Studies of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi*

The result of the morphological investigation of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi* is shown in Table 2. The Table 2 showed that *Artocarpus camansi* gave a higher centimeter of leaf blade length (70.42 ± 1.48), leaf blade width (41.50 ± 0.55), and petiole length (5.68 ± 0.49) while *A. altilis* gave higher centimeter of number of lateral vein (27.60 ± 0.14).

Table 2: Quantitative Morphological Studies of *Artocarpus heterophyllus*, *Artocarpus altilis* and *Artocarpus camansi*

Parameter	<i>A. heterophyllus</i>	<i>A. altilis</i>	<i>A. camansi</i>	P-value
Leaf Blade Length (cm)	12.43 ± 0.56^{ab}	48.40 ± 0.45^b	70.42 ± 1.48^c	0.00
Leaf Blade Width (cm)	7.66 ± 0.41^a	32.78 ± 1.55^b	41.50 ± 0.55^c	0.00
Petiole Length (cm)	1.41 ± 0.12^a	4.20 ± 0.27^b	5.68 ± 0.49^c	0.00
No. of Lateral vein	16.60 ± 1.0^a	27.60 ± 0.14^b	26.80 ± 1.92^b	0.00

Discussion

The morphological evaluations revealed key architectural divergences among the studied taxa. Morphological investigations of *Artocarpus heterophyllus* showed a simple, oval leaf with an entire margin, which exhibits a thick, leathery texture. This finding agreed with Obijekwu *et al.* (2022), who reported highly glossy, coriaceous foliage as a distinct vegetative marker for mature jackfruit. In contrast, *Artocarpus altilis* and *Artocarpus camansi* developed deeply lobed foliage. While *A. altilis*

features reddish or pale hairs on its veins, *A. camansi* displays green veins traversing its dulled green, hairy blades. This structural divergence aligns with observations by Akinloye *et al.* (2015), where foliar trichome distribution and coloration were established as valid diagnostics to separate these closely related species. Quantitative metrics verified these variations; *A. camansi* yielded the highest leaf length (70.42 $\pm$ 1.48 cm), leaf width (41.50 $\pm$ 0.55 cm), and petiole length (5.68 $\pm$ 0.49 cm). In a related study, Fatoki *et al.* (2024) confirmed that breadnut systematically develops larger, more dramatically incised laminas than breadfruit to maximize light capture in closed forest canopies. Conversely, *A. altilis* exhibited the highest lateral vein count (27.60 $\pm$ 0.14), showing its specialized dense vascularization pattern.

Stem and habit traits also differentiated the species. *Artocarpus heterophyllus* presented a straight, short trunk with a rounded crown and greyish-brown bark. This characterization is consistent with growth habits outlined by Orwa *et al.* (2009). In contrast, *A. camansi* exhibited a stretched stem that gains significant height before generating branches at restrictive 30-degree angles. This finding agreed with description traits documented by Godofredo and Stuart Jr (2023). Regarding reproductive structures, *A. heterophyllus* produced massive, spiny, greenish-yellow syncarps containing bean-shaped seeds coated in firm yellow arils. This specific composition matches the specialized cauliflorous configurations observed by Karunakaran *et al.* (2025). In contrast, *A. altilis* produced large, oblong fruits that are entirely seedless. This finding agreed with Heuzé *et al.* (2017), who verified that commercial breadfruit varieties are highly domesticated clones containing only vestigial ovules. Conversely, *A. camansi* developed smaller, dull-green syncarps packed with up to 150 large, oval seeds. In a related study, Adeleke and Abiodun (2010) emphasized that the abundance of true seeds in *A. camansi* serves as the primary morphological and evolutionary boundary separating it from its seedless derivative, *A. altilis*.

The qualitative and quantitative morphological variations among *Artocarpus heterophyllus*, *Artocarpus altilis*, and *Artocarpus camansi* underscore their distinct taxonomic classifications despite shared familial traits like taproots and milky latex. Statistically significant variations in leaf blade length, width, and petiole length with *A. camansi* demonstrating the highest dimensions highlight clear evolutionary divergence pathways useful for botanical identification. Understanding these distinct physical disparities provides rich data that can be integrated into secondary school biology through computer animations to stimulate student interest (Nnalue *et al.*, 2023). Transitioning such complex botanical data into virtual classrooms (Christian-Ike *et al.*, 2025) can foster critical self-regulatory learning skills (Rita & Henrieta, 2025). Furthermore, applying real-world morphological datasets helps evaluate how school locations influence student science process skills (Obikezie *et al.*, 2025) and acts as a predictor of academic achievement in higher education science courses (Chukwunazo *et al.*, 2025). To optimize these learning outcomes, adaptive AI-driven educational leadership frameworks (Ofozoba *et al.*, 2024) can personalize botanical teaching modules. Ultimately, utilizing tangible taxonomic results within innovative AI-driven service-learning models can vastly improve sustainability education regarding green natural materials (Anakpua *et al.*, 2025; Ofozoba *et al.*, 2025).

Conclusion

This comparative study establishes that while *Artocarpus heterophyllus*, *Artocarpus altilis*, and *Artocarpus camansi* share a close evolutionary affinity within the Moraceae family, they possess distinct macromorphological and quantitative structural boundaries. Foliar architectural evaluations confirm that *A. heterophyllus* is readily distinguished by its smaller, simple, elliptical leaves with entire margins. This finding stands in sharp contrast to the massive, deeply pinnately lobed laminas characterizing both *A. altilis* and *A. camansi*. On a quantitative scale, *A. camansi* systematically exhibits the highest leaf blade length, leaf blade width, and petiole length, whereas *A. altilis* is distinguished by its significantly higher density of lateral veins. Furthermore, cauline habits and reproductive syncarp variations provide definitive taxonomic markers for species discrimination. *Artocarpus heterophyllus* exhibits a unique cauliflorous fruiting pattern, producing massive spiny fruits directly from a short trunk with rough, scaly bark. Conversely, *A. altilis* and *A. camansi* employ terminal branching fruiting habits. The highly domesticated *A. altilis* produces large, seedless syncarps with a smooth rind, whereas *A. camansi* retains its ancestral wild characteristics, producing smaller fruits covered in flexible, pointed tips that enclose numerous large, starchy seeds. Ultimately, the explicit morphological baselines established in this study

provide essential diagnostic keys for accurate germplasm identification, biodiversity conservation, and the selection of superior agronomic genotypes for industrial and nutritional applications.

References

- Abdul, M., & Martin, K. A. (2015). Poor Man's Fruits: Now a Miracle Food. *Food Chemist*, 5(4), 123-134.
- Adeleke, R. O., & Abiodun, O. A. (2010). Nutritional composition of breadnut seeds (*Artocarpus camansi*). *African Journal of Agricultural Research*, 5(11), 1273–1276.
- Ajayi, I. A. (2008). Comparative Study of the Chemical Composition and Mineral Element Content of *Artocarpus heterophyllus* and *Treculia africana* Seeds and Seed Oils. *Bioresource Technology*, 99(11), 5125-5129.
- Akhil, H., Revikumar, K. G., & Divya, D. (2014). *Artocarpus*: A Review of Its Phytochemistry and Pharmacology. *Journal of Pharma Search*, 9(1), 7.
- Akinloye, A. J., Borokini, T. I., & Adeniji, K. A. (2015). Comparative anatomical studies of *Artocarpus altilis* (Parkinson) Fosberg and *Artocarpus communis* (J. R. & G. Forster) in Nigeria. *Sciences in Cold and Arid Regions*, 7(6), 0709–0721.
- Amadi, J. A. C., David-Chuku, N. P., & Asinobi, C. O. (2019). Effect of boiling and fermentation on nutrient profile of breadnut (*Artocarpus camansi*) seed flours. *Nigerian Journal of Nutritional Sciences*, 40(1), 49-54.
- Amponsah, I. K., Annan, K., Koffuor, G. A., Sarkodie, J. A., Umerie, I. J., & Oseiwuse, S. (2014). Anti-inflammatory and antioxidant properties of the ethanolic stem bark extract of *Artocarpus altilis* (Parkinson) Fosberg (Moraceae). *Der Pharmacia Lettre*, 6(3), 211-217.
- Anakpua, B. C., Onyemauche C. Inweregbuh, C. O. Odimkpa, Chinwe J. Enemuo, C. A. Ofozoba, P. A. Isidi, Uchenna F. Muogbo, Obioma H. Nnalue, Regina E. Obiadazie, and O. C. Okudo. (2025). "Enhancing STEM Education Through AI-Driven Service-Learning: Fostering Student Understanding of Nanotechnology-Based Green Materials For Sustainability." *International Journal of Environmental Sciences*, 11(20s),
- Ante, I., Aboaba, S., Siddiqui, H., & Choudhary, M. I. (2016). Essential oils of the leaf, stem-bark, and nut of *Artocarpus camansi*: Gas Chromatography-Mass Spectrometry analysis and activities against multidrug-resistant bacteria. *Journal of Herbs, Spices & Medicinal Plants*, 22(3), 203-210. <https://doi.org/10.1080/10496475.2016.1159638>
- Ash, A., Ellis, B., Johnson, K. and Wilf, P. (1999), Manual of Leaf Architecture - morphological description and categorization of dicotyledonous and net-veined monocotyledonous angiosperms by Leaf Architecture Working Group. 65p.
- Basnett, B., Banerjee, M., & Chowdhury, S. K. (2023). A review on medicinal values and pharmacological importance of Moraceae. *Plant Science Today*, Early Access. <https://doi.org/10.14719/pst.2385>
- Christian-Ike, N. O., Nnalue, O. H., & Obili, M. O. (2025). Perception and attitudes of basic science teachers towards the use of virtual classroom in Awka education zone. *Journal of science education and research*, 3(1), 45-60.
- Chukwunazo, O. M., Ebele, A. E., Obioma, N. H., Amobi, U. V., & Uche, E. D. (2025). Undergraduate students' science process skills as predictor of academic achievement in science education courses. *Journal Plus Education*, 38(Special Issue), 371-384.
- Clement, W. L., & Weiblen, G. D. (2009). Morphological Evolution in the Mulberry Family (Moraceae). *Systematic Botany*, 34, 530–552.
- Dhakar, M. K., Bikash, D., Sarkar, P. K., Nath, V., Singh, A. K., & Bhatt, B. P. (2020). Diversity in jackfruit (*Artocarpus heterophyllus* Lam.): Insights into fruit characterization for the identification of superior genotypes. *Plant Genetic Resources: Characterization and Utilization*, 1-9.
- Elevitch, C. R., & Manner, H. I. (2006). *Artocarpus heterophyllus* (Jackfruit), Species profiles for pacific island agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawaii.
- Fatoki, H. O., Ojebiyi, O. O., Fasina, F. B., Adegbenro, E. O., Olawale, S. O., & Tewogbade, A. B. (2024). Proximate and phytochemical analysis of breadnut (*Artocarpus camansi*) and breadfruit (*Artocarpus altilis*) leaves. *Nigerian Journal of Animal Production*, 1573–1576.

- Gardner, E. M., & Zerega, N. J. C. (2021). Taxonomic updates to *Artocarpus* subgenus *Artocarpus* (Moraceae) and allied taxa with a particular focus on the species native to Singapore. *Gardens' Bulletin Singapore*, 332. doi:10.26492/gbs73(2).2021-08
- Godofredo, U., & Stuart Jr, M. D. (2023). *Kamansi/ Artocarpus camansi Blanco/ Breadnut*. StuartXchange. <https://www.stuartxchange.org/Kamansi.html>
- Heuzé, V., Tran, G., Hassoun, P., Bastianelli, D., & Lebas, F. (2017). *Breadfruit (Artocarpus altilis)*. Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. <https://www.feedipedia.org/node/523>
- Jagtap, B. U., & Bapat, V. A. (2010). *Artocarpus*: A review of its traditional uses, phytochemistry and pharmacology. *Journal of Ethnopharmacology*, 129(2), 142-166.
- Jones, A. M. P., Ragone, D., Tavana, N. G., Bernotas, D. W., & Murch, S. J. (2011). Beyond the bounty: Breadfruit (*Artocarpus altilis*) for food security and novel foods in the 21st Century. *Ethnobotany Journal*, 9, 131-132.
- Karunakaran, G., Dinesh, M. R., Ravishankar, K. V., Prakash, K., Kanupriya, C., Singh, P., Arivalagan, M., & Ruchitha, T. (2025). Characterization of jackfruit *Artocarpus heterophyllus* Lam. for economic traits in dry zones of Karnataka, India. *Scientific Reports*, 15, 6830. <https://doi.org/10.1038/s41598-025-91810-6>
- Mohammed, M., & Wickham, L. D. (2011). Breadnut (*Artocarpus camansi* Blanco). In *Postharvest biology and technology of tropical and subtropical fruits*, Chapter 13(2), 272-289. Woodhead Publications Ltd, USA. <https://doi.org/10.1533/9780857092762.272>
- National Tropical Botanical Garden. (2017). *Breadfruit Species*. ntbg.org.
- Nnalue, O. H., Christian-Ike, N. O., & Orafu, G. T. C. (2023). Effect of computer animation on secondary school students' interest in biology in Anambra State. *African Journal of Educational Management, Teaching and Entrepreneurship Studies*, 10(1), 127-137.
- Obijekwu, E. J., Izundu, A. I., & Ugwoke, C. E. (2022). The morphological structures and anatomical composition of jackfruit (*Artocarpus heterophyllus* Lam) and African breadfruit (*Treculia africana* Decne). *International Academic Association Journal of Applied Science*, 8(1), 53-68.
- Obikezie, M. C., Onyebuch, E. D., Akachukwu, E. E., & Nnalue, H. O. (2025). School locations and gender variables on students' science process skills as a predictor of academic achievement in senior secondary school. *Eureka: Journal of Educational Research*, 4(1), 1-7.
- Oduoye, O. T., Ogundipe, O. T. and Olowokudejo, J. D. (2013), Morphological study of Ioganiaceae diversity in West Africa. *Journal of Biology, Agriculture and Healthcare*, 3(10):1-10.
- Ofozoba, C. A., Henry, E. U. M., Henrietta, N. O., Oguechuo, G. A., & Ofozoba, O. P. (2024). Education Leadership and Artificial Intelligence: Implications for Adaptive Learning Outcomes. *AJSTME*, Volume. 10, Issue 6. 1086-1094,
- Ofozoba, C.A., Okafor, P.C., Ikegbusi, N.G., Manafa, F.U., Egwu, J.U., Nwobu, C.M., Okafor, S.O., Onafowope, M.A., Olofinkua, V.K., Adeagbo, J.O. and Gbaeprekumo, O.V., (2025). AI-driven service-learning to enhance students' understanding of green nanomaterials in sustainability education. *Multidisciplinary Reviews*, 8(12), p.2025429.
- Ogunleye, B. M., Fuwape, J. A., Oluyeye, A. O., Ajayi, B., & Fabiyi, J. S. (2017). Evaluation of fiber characteristics of *Ricinodendron heudelotii* (Baill, Pierre Ex Pax) for pulp and paper making. *International Journal of Science and Technology*, 6(1).
- Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Anthony, S. (2009). *Agroforestry Database: a Tree Reference and Selection Guide Version 4.0*. World Agroforestry Centre.
- Pereira, V. J., & Kaplan, M. (2013). *Artocarpus*: um gênero exótico de grande bioatividade. *Floresta e Ambiente*, 20, 1-15.
- Periyanayagam, K., & Karthikeyan, V. (2013). Pharmacognostical, SEM and XRF profile of the leaves of *Artocarpus heterophyllus* Lam. (Moraceae) – a contribution to combat the NTD. *Innovare Journal of Life Sciences*, 1, 23-28.
- Rita, N. N., & Henrieta, N. O. (2025). Student's self-regulatory skills as correlate of their academic achievement in biology in public secondary schools in Anambra state. *UNIZIK Journal of STM Education*, 8(2), 180-191.