ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 20 N° 4 2024
pp. 40-48

DETERMINATION OF ANATOMICAL FEATURES, PHYSICAL AND MECHANICAL PROPERTIES OF CASHEW WOOD (*ANACARDIUM OCCIDENTALE* L) FROM SEMI-DECIDUOUS FOREST, GHANA

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Abstract:

This study investigates the anatomical, physical and mechanical properties of cashew wood (Anacardium occidentale) sourced from a semi-deciduous forest in Ghana, addressing its potential as an alternative to threatened tropical hardwoods. Wood remains a crucial material for construction and furniture due to its versatility and sustainability. The research focuses on the anatomical, mechanical, and physical properties of A. occidentale to assess its potential for various applications, in the context of challenges regarding the raw material scarcity and ecosystem degradation. The study is based on a destructive testing method on two mature trees, revealing significant fibre characteristics and mechanical properties variations between trees. Results indicated that, the anatomical, mechanical, and physical properties revealed significant variations between tree 1 and tree 2, underscoring the species' versatility for interior design applications, emphasising the need for sustainable forestry practices.

Key words: *Anacardium occidentale, Semi-deciduous forest, Anatomical, Physical and Mechanical properties.*

INTRODUCTION

Wood continues to be an imperative material in mankind's history because of its exceptional features and broad utilization spectrum. It has remained the most multipurpose construction and furniture material for decades (Chen et al. 2023). Arriaga et al. (2023) emphasized that wood has remained a structural material for ages, ever since its discovery as an accepted renewable resource by mankind. As population rises, there is an increase in the demand for wood in the construction and furniture industry.

According to Aguma and Ogunsanwo (2019) the wood industry has faced the challenge of scarcity of raw materials. This is due to the degradation of the tropical high forest through illegal harvesting and misuse of timber, which has affected the forest ecosystem, causing its depletion (Aguma & Ogunsanwo 2019). Dadzie and Amoah (2015) emphasized that Africa's major commercial tropical hardwood species are threatened with extinction due to over-dependence.

Tippner and Hassan (2017) opined that alternative ways of combating this challenge are through plantation-grown species, lesser-known species (LKS) or lesser-used species (LUS), and Non-Timber Forest Products (NTFPs). Among the lesser-known or lesser-used species is cashew wood (*Anacardium occidentale* L), available in Ghana’s farmlands.

Cashew wood (*Anacardium occidentale* L.) propagates using seeds, and fruits are ripe once they are mature. It is an evergreen tropical species with an average height of 12-14 m where the soil is fertile and the humidity high (Bladzell, 2000). It is well adapted humid and dry tropical climate. Cashew wood is pale yellow or creamy, to some extent gleaming, heavy in weight and soft but firm, not difficult to cut and resistant to deterioration. The grain is straight or uneven and feels moderately rough. It is brittle when green and elastic when well-seasoned. The heartwood is pale yellow and unclearly defined from the sapwood. The wood gradually turns black when well-seasoned. The grain is straight, sometimes spirally, and feels average to

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rough. The cross-section shows a streak or ribbon symbol. The heartwood is unnoticeably resistant to preservatives or additives, but the sapwood is porous (Lovett et al. 2007).

This study seeks to determine the effective utilization of *Anacardium occidentale* wood from a Semi-deciduous forest in Ghana, based on its structural properties. In this context, the main objective was to determine its anatomical, physical and mechanical properties.

MATERIALS AND METHODS

Material acquisition and preparation

Two matured and plantation-grown trees (32-year-old) of *A. occidentale* were extracted from a moist semi-deciduous forest with heartwood and sapwood for the study. The coordinates are 06^0 59’ 36” N, 03^0 19’30” W. The geographical area of the district is primarily of the Lower and Upper Birimian kinds, with the Lower Birimian formation to the east and north-eastern parts of the district. The trees were taken from the Sefwi Wiawso landscape in Ghana and are situated in the Bia-Tano River Basin in the High Forest Zone in the Southwest of Ghana.

A destructive method was adopted to collect the sampled tree for the evaluation of anatomical, mechanical, and physical properties. The trees were labelled tree1 and tree 2 (butt, middle and top) after it has been felled. The logs were later converted into short beams, illustrated in Fig. 1 (A, B), in the moist semi-deciduous forest. They were conveyed to the Furniture and Wood Testing Department of (CSIR-FORIG) for further processing.

The beams with dimensions of 1500mm x 320mm x 110mm are used to prepare the samples for the test, from the outward pith in cross-section (radial) and longitudinal (axial) directions. The radial face of the logs displayed two clear layers: the sapwood, which is the fringe portion just beneath the bark where the active cells of the trees are found. The heartwood is the inactive cells of the tree, where it stores up its food and gives rigidity to the tree in terms of a storm. The two sections (i.e., sapwood and heartwood) were converted into beams with the portable chain saw machine. Further the beams were processing into boards with dimensions of 25mm x 25mm x 1500mm and 1500mm x 55mm x 55mm, denoting the individually experimented trees section (i.e., butt, mid and top end) (Fig. 1 B, C, D).

From the freshly sawn specimens with moisture content above the fibre saturation point, specimens for physical properties were cut into dimensions using the American Standards for Testing Materials (ASTM D 4442) as required. The samples for the physical properties were instantly bagged using black polythene bags to prevent moisture loss and were kept in deep freezers awaiting the test. The samples for mechanical properties were properly stacked with stickers for air-drying under a shed for 2-3 months after drying from the boards were obtained specimens both from sapwood and hardwood, to determine the mechanical properties according to British Standard (BS 373:1957). The well-dried samples were tested with the facilities at the Furniture and Wood Testing Laboratory (CSIR-FORIG).

Fig. 1.
Logging and conversion of sampled trees.

Anatomical Properties

Rajput et al. (2023) stressed that it is important to consider the anatomical characteristics of wood, as these can influence its density, quality of pulp and paper produced, and the nature of fibre-based products. This is especially important for lesser-known (LKS) and lesser-used timber species (LUS). Therefore, according to Chave et al. (2009) the anatomical structure of wood determines the characteristics of a tree's stem, including biomechanical support, water and nutrient transport velocity, and storage capacity for water, nutrients, and chemical compounds like lipids and carbohydrates, which are typically found in the sapwood and heartwood of the tree.

Specimen's Preparation for Maceration and Microtome Slides of *A. occidentale* Wood

A binocular microscope is used in wood analysis to observe the fine details of wood structure by placing prepared wood slices (thin sections) on the microscope stage. The sample is illuminated, and the focus was adjusted using the coarse and fine focus knobs to bring the specimen into clear view. The binocular eyepieces provide a 3D, stereoscopic view, which is essential for distinguishing between various wood components like fibres, tracheids, vessels, and rays. The magnification was adjusted to view both the overall wood anatomy and finer cellular features, allowing for detailed analysis. Proper lighting and contrast adjustments are crucial for revealing the different cell types and structures, making it a vital tool for species identification and studying wood's anatomical properties (IAWA, 1989).

In wood analysis, sample preparation involves these substances to preserve, stain, and enhance the visibility of the wood's cellular structures. The process typically began with Acid-Alcohol to preserve the wood tissue and prevent degradation. After fixation, the sample is dehydrated using ethanol to remove water before embedding it in a medium such as paraffin wax. This embedding helps the wood stay intact during sectioning. Thin sections (10-20 micrometres) are then cut, often with a microtome, and stained with dyes like safranin. Finally, mounting media like Canada Balsam affix the stained sections to glass slides, making them ready for microscopic examination. These substances together facilitate the detailed study of wood's anatomical features under the microscope (IAWA, 1989). We evaluate the macroscopic and microscopic anatomical features such as lumen width, fibre diameter, fibre length, runkel ratio and slenderness ratio.

From *A. occidentale* tree 1 and tree 2, two discs were removed from the top, middle, and butt portions. Twelve samples of 20mm x 20mm were cut from the inner and outer wood to include the heartwood and sapwood, as shown in Fig. 2. In Table 1 are presented the maceration and microtome sections of samples.

Table 1

Maceration and Microtome section dimensions of small clear samples for anatomical experiments

Parameter	Sample measurement (mm)	Standard	Sample size (Number)
Wood section of microtome	20 x 20	IAWA, 1989	12
Wood Maceration	Match stick	IAWA, 1989	12

Fig. 2.
Samples preparation of microtome sectioning and maceration.

Runkel ratio

The runkel ratio measures the shapes of wood fibres, indicating their suitability for pulping and papermaking. It is calculated using the following formula:

$$Runkel\ ratio = \frac{2 \times Wall\ Thickness}{Lumen\ Diameter}$$

Slenderness ratio

The aspect ratio of wood fibres is calculated using the following formula:

$$Aspect\ ratio = \frac{Length\ of\ Fibre}{Diameter\ of\ Fibre}$$

Mechanical Properties

Testing Mechanical Properties of *A. occidentale* Wood

The Inspekt AC 300 Universal Testing Machine (UTM) was used at CSIR-FORIG to evaluate the mechanical properties of clear wood. The tests included compression, static bending, and shear strength. According to Asafu-Adjaye (2012), the tests listed above assess the mechanical performance characteristics of authorized testing small clear specimens.

Static Bending Strength of *A. occidentale* Wood

Specimens 20mm x 20mm x 300mm sawn from *A. occidentale* wood strips denoting individual sections of sapwood and heartwood were used to determine the modulus of elasticity and rupture (Fig. 3 C). An Instron Universal Testing Machine (Model Inspekt 50-1) with a load cell capacity of 50kN was used for the test. The loading rate applied to determine the static bending strength of the specimens was 4mm/min. The test was conducted on 20 specimens. According to BS 373 (1957), the route of loading an individual alignment of a specimen was analogous. Equations 1 and 2 were used to evaluate MOE and MOR.

$$MOE = \frac{PL^3}{4Bh^3}, (\text{N/mm}^2) \tag{1}$$

$$MOR = \frac{P^3Pl}{2bh^2}, (\text{N/mm}^2) \tag{2}$$

where:

ME = modulus of elasticity,
MoR = modulus of rapture,
p = increment of applied load below proportional limit,
l = the sample span, in mm,
b = the sample width, in mm,
h = sample height or depth, in mm,
P = maximum load, in N
∆ = proportional limit deflection in mm.

Compressive Strength Parallel to the Grain of *A. occidentale* Wood

Non-stop weight increase exerted at the axial face of the specimens using a portable device on the equipment which works with a continuous frequency of 0.6mm min^{-1}. The maximum load value at the point of failure was recorded. Fig. 3 shows the setup for this test. They were designed from the section of the tree, which comprised sapwood and heartwood. The dimensions of the specimens were: 20mm x 20mm x 60mm. The compressive strength was calculated based on the formula (3):

$$CS = {}^{P}/_{A} \tag{3}$$

where:

CS = Compressive strength N/mm^2
P = Maximum load (N),
A = the area of cross-section (mm^2)

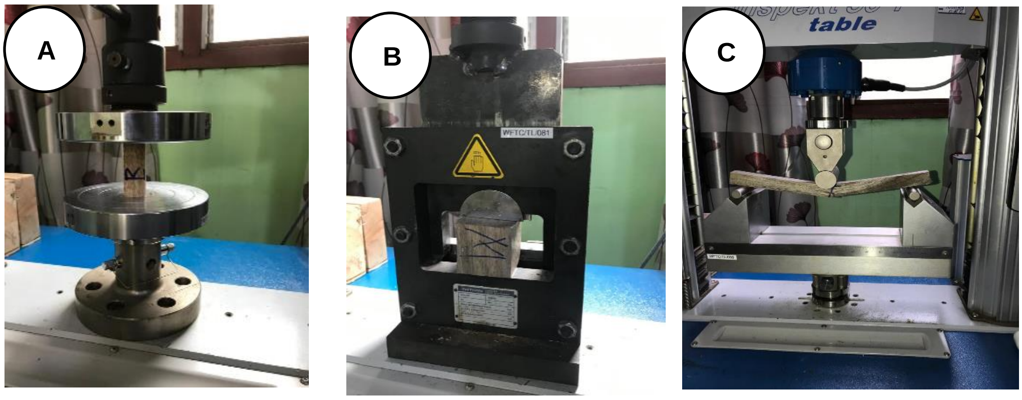


Fig. 3.
Compression, Shear, MOR and MOE tests for A. occidentale wood.

Shear Strength Parallel to the Grain of *A. occidentale* Wood

Twenty specimens were designed which comprised sapwood and heartwood. The test for the shear strength parallel to the grain was executed on square specimens of 50mm using a pivoted arm on the Universal Mechanical Tester operated with a load cell capacity of 50 kN. Shear strength occurred along the grain at a test gear of about 0.11mm/s (Fig. 3).
Equation 5 was used to evaluate the shear strength.

$$SS = \frac{Pmax}{sd} \text{, N/mm}^2 \qquad (5)$$

where:

SS- the shear strength, N/mm^2
$Pmax$ = the maximum load, N
Sd = span and depth of the shear strength surface area.

Physical Properties

Testing Physical Properties of *A. occidentale* Wood

The physical properties tested were moisture content, density, volumetric swelling and shrinkage.

Moisture Content of *A. occidentale* Wood

The original 25mm x 25mm square strips removed from each portion of the trees were planned to the standard thickness of 20mm cubes in each area. Twenty replications with including sapwood and heartwood, were used. The samples were dried at a temperature of 103 ± 2°C and weighed to within a margin of 0.001g. Weighing was done on the specimens every 24 hours. When the difference in weight between two successive samples did not exceed 0.000002kg, the drying process was terminated.

Equation 6 was used to calculate the moisture content.

$$MC = \frac{Iw-Fw}{Fw} \times 100,\% \qquad (6)$$

where:

MC = moisture content, %
Iw = initial weight, g
Fw = final weight, g

Density of *A. occidentale* Wood

Twenty different specimen with dimensions of 20mm x 20mm were used in this test. The specimens were weighed on an electronic scale with an accuracy of 0.001g to estimate the density.

Equation 4 was used to evaluate the density.

$$Density = \frac{W}{V} \qquad (4)$$

where:

W = mass of specimen, kg
V = volume of specimen, m^3

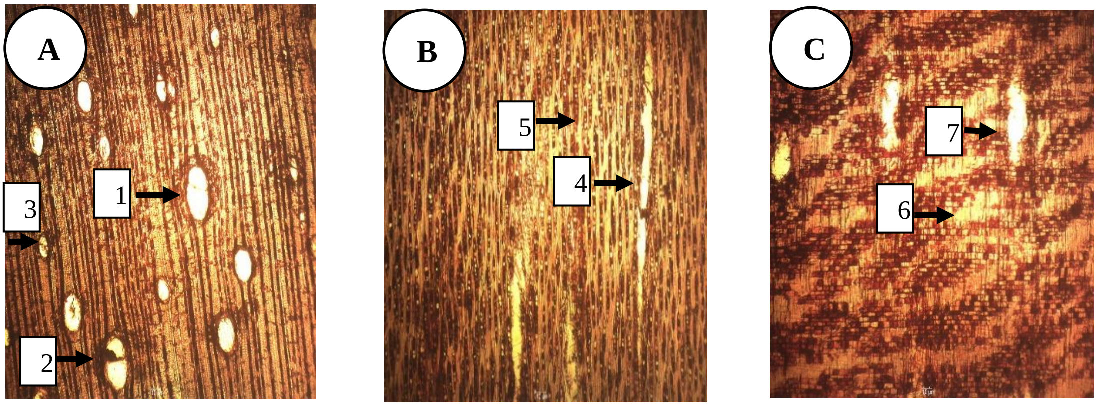
STATISTICAL DATA ANALYSIS

The mechanical data was analysed using descriptive statistics. The means and standard deviation of the data were computed. The anatomical data from the study were analysed using Datasets 2016 Microsoft Excel. Tukey's Multiple Range Test was used to separate means. The average values recorded for variables were compared with (IAWA 1989).

RESULTS AND DISCUSSION

Microscopic Structure of A. occidentale *wood*

The micrographs in Fig. 4 showed the qualitative analyses of the anatomical evaluation of *A. occidentale* wood. In transverse section could be seen vessels (larger diameter hole) and fibres and bundles of ray cells (which are uniseriate). It is a diffuse porous wood. In the tangential section, a lot of parenchyma cells. The radial sections show cells containing broken tissues.



a. Transverse section of *A. occidentale, showing ray vessels of 1-2 (arrowed), axial parenchyma (arrowed A).* 10x magnification

b. Tangential section of *A. occidentale, occidentale showing a lot of parenchyma* 10x magnification

c. Radial section of *A. occidentale,* showing cells containing broken tissues. 10x magnification

Fig. 4.

Micrographs describing microscopic features of A. occidentale wood (A – C), (1) solitary type pores, (2) radial multiple-type pores, (3) tylosis, (4) confluent paratracheal parenchyma, (5) three-series multiseriate rays, (6) radial parenchyma, (7) axial parenchyma.

Fibre Dimensions of *A. occidentale* Wood

The findings, displayed in Table 2, demonstrated a statistically significant variation in the fibre characteristics means, determined from the heartwood and the sapwood along the trunk of the trees. These suggest a variation of fibres in radial and axial directions. This variance greatly influences the wood's physical and mechanical strength qualities for various purposes. According to Monteoliva et al. (2005), the wood density and fibre dimensions are different in both longitudinal and radial directions, as well as within their annual rings. These differences could result from physiologic, genetic, or silvicultural interventions (Ma et al. 2021).

Table 2 revealed a noteworthy variation in the fibre's length, lumen width, double wall thickness of the trees. On the other hand, the aspect ratio, Runkle ratio, and fibre diameter of tree 1 and tree 2 did not differ much. The results show a considerable difference in the aspect ratio, Runkle ratio, fibre diameter, fibre length, and fibre double wall thickness in the trees. The findings showed that the fibre diameter varied significantly.

Vessel Measurement of *A. occidentale* Wood

Most of the water in angiosperms' transpiration stream must travel through vessels in the sapwood to ascend to the canopy (Tyree & Zimmermann, 2002). Therefore, characterizing it will spur the use and value-adding of *A. occidentale* wood. Table 2 show that all of the evaluated parameters of the vessels of tree 1 and tree 2 differed significantly throughout the bole in the heartwood. The findings show that, on average, vessel areas grow as vessel lengths rise. When Jacobsen et al. (2012) calculated a worldwide analysis of xylem vessel length in woody plants, Liu et al. (2018) and Olson et al. obtained similar results (2014).

Table 2

Fibre and vessel measurement of A. occidentale wood

Parameters measured	Tree (t1)	Tree (t2)
Fibre length (µm)	807.33 (54.04)	804.12 (51.02)
Fibre diameter (µm)	17.08 (1.3)	16.64 (1.1)
Lumen width (µm)	9.03 (1.75)	8.12 (1.48)
2x fibre wall thickness (µm)	2x 8.05 (16.1)	2x 7.88 (15.76)
Runkel ratio	0.89	0.97
Slenderness ratio	47.27	48.63
Vessel area [VA] (-µm)	68.9	67.05
Vessel length [VL] (µm)	70.96	69.83
Vessel number [VN]	15	18
Vessel lumen fraction; [VF= VA*VN] ((µm))	1.03	4.68
Size to number ratio [S=VA/VN]	4.59	3.89^{a}

According to Turkey's multiple-range tests, figures with the same alphabet in each row are not significantly different.

Compressive Strength Parallel to the Grain of *A. occidentale* Wood

The results of the compression strength parallel to the grain of *A. occidentale* wood demonstrate a clear difference between the two samples tested, with tree 1 showing a compressive strength of 26.3N/mm² and tree 2 at 21.15N/mm² as indicated in Table 3. The higher strength of tree 1 may indicate superior fibre alignment or lower defects, critical for applications where structural integrity is paramount (Harris et al. 2016). Understanding these differences is essential for optimizing the use of *A. occidentale* wood in construction and furniture manufacturing, as variations can impact performance and durability (Rowell 2012).

Shear Strength Parallel to the Grain of *A. occidentale* Wood

The shear strength parallel to the grain of *A. occidentale* wood showed a close range of values, with tree 1 recorded at 10.6N/mm² and tree 2 at 11.08N/mm² as indicated in Table 3. This relatively small difference suggests that the wood maintains consistent shear properties, which are crucial for applications involving lateral forces, such as furniture construction and interior applications (Kollmann & Côté 1984). The values indicate that *A. occidentale* possesses adequate shear strength for various engineering applications. However, the slight variation may be influenced by factors such as sample preparation, moisture content, or the specific anatomical characteristics of the wood (Panshin & de Zeeuw 1980). Understanding these shear properties is essential for predicting the performance of *A. occidentale* in real-world applications and ensuring its reliability in interior designs (Rowell 2012).

MOR of *A. occidentale* Wood

The comparison of the tensile strengths tree 1 = 42.97(0.81) N/mm^2 and tree 2 = 44.1(0.83) N/mm^2 indicates a slight increase in tensile strength from tree 1 to tree 2, as indicated in Table 3. This change suggests that the material exhibits improved mechanical properties, which could be attributed to variations in composition, processing techniques, or treatment methods (Smith et al. 2020). The standard deviations of 0.81 and 0.83 indicate consistent performance within the datasets, although further statistical analysis would be necessary to establish the significance of this increase. Overall, such enhancements in tensile strength are crucial for applications requiring high durability and performance under stress (Johnson & Lee 2019).

The tensile strengths of Tree 1 (42.97N/mm²) and Tree 2 (44.1N/mm²) are comparable to those of other wood species with similar densities. For instance, White Ash (*Fraxinus americana*), with a density of approximately 600kg/m³ at 12% moisture content, exhibits a flexural strength of 103MPa, which correlates with tensile strength values in the range observed for cashew wood. Similarly, Beech (*Fagus spp*.), known for its density ranging from 700 to 900kg/m³, demonstrates mechanical properties that align with the tensile strengths reported for cashew wood. These comparisons suggest that cashew wood possesses mechanical properties on par with other medium-density hardwoods, indicating its potential suitability for various structural and industrial applications (The Engineering Toolbox 2004).

MOE of *A. occidentale* Wood

The results for the modulus of elasticity (MOE) indicate a notable increase from tree 1 = 5010.16 (311.17) N/mm^2 to tree 2 = 5406 (335.76) N/mm^2 as indicated in Table 3, reflecting an enhancement in the stiffness of the material. This improvement can be attributed to changes in material composition or processing techniques that influence structural integrity (Doe et al. 2021). The relatively low standard deviations of 311.17 and 335.76 suggest that the data points are closely clustered around their means, enhancing the reliability of these measurements. Such advancements in MOE are critical for applications where rigidity and load-bearing capacity are paramount, indicating a positive trend in material performance (Smith & White 2020).

The modulus of elasticity (MOE) values for Tree 1 (5010.16N/mm²) and Tree 2 (5406N/mm²) are comparable to those of other wood species with similar densities. For instance, White Ash (*Fraxinus americana*); With an air-dry density of approximately 600kg/m³, White Ash exhibits a flexural strength of 103MPa. European Oak (*Quercus robur*). This species has an air-dry density around 700kg/m³ and demonstrates mechanical properties that align with the MOE values observed for cashew wood. These comparisons suggest that cashew wood possesses mechanical properties on par with other medium-density hardwoods, indicating its potential suitability for various structural and industrial applications. (Wood Identification 2024).

Table 3

Compressive, Shear, MOR, MOE, Density and Moisture Content values for t1 and t2 of A. occidentale wood

Test ID	**Tree 1 (t1)**	**Tree 2 (t2)**
Compressive	23.6 (0.62)	25.15 (0.53)
Shear	10.6 (0.51)	11.08 (0.7)
Modulus of Rupture	42.97 (0.81)	44.1 (0.83)
Modulus of Elasticity	5010.16 (311.17)	5406 (335.76)
Density	757.56 (40.91)	755.47 (39.96)
Moisture Content	82.16 (1.39)	84.33 (1.56)

Moisture content and Density test of *A. occidentale* wood

Trees' density and moisture content are critical factors influencing their mechanical properties and usability in various applications. In this study, Tree 1 exhibited a density of 757.56kg/m³ (±40.91), while Tree 2 had a slightly lower density of 755.47kg/m³ (±39.96), as indicated in Table 3. Additionally, the moisture content was recorded at 82.16% (±1.39) for Tree 1 and 84.33% (±1.56) for Tree 2.

CONCLUSIONS

In conclusion, this study presented important data concerning the properties of cashew wood (*Anacardium occidentale*) from Ghana's semi-deciduous forests, highlighting its potential as a valuable alternative to traditional timber sources. The determination of the anatomical features, physical, and mechanical properties of cashew wood (*Anacardium occidentale L*.) from Ghana’s semi-deciduous forest is vital for its industrial utilization, as it provides comprehensive data on the wood’s quality, performance, and potential applications. Understanding anatomical characteristics like fibre dimensions and vessel arrangements informs its workability and processing suitability, while physical properties such as density, moisture content, and shrinkage behavior guide its stability and durability under various conditions. Additionally, mechanical properties like strength and elasticity are essential for determining its use in structural applications, furniture, and tool-making. This research enhances the sustainable and economic use of cashew wood, offering an alternative to overexploited species, creating value beyond nut production, and fostering local industries with reliable material data to produce high-quality products.

The anatomical, mechanical, and physical properties revealed significant variations between tree 1 and tree 2, underscoring the species' versatility for interior design applications. Despite challenges in raw material scarcity due to deforestation, findings suggest that *A. occidentale* can be a sustainable option, contributing to forest conservation efforts. Ultimately, the insights gained from this research can guide future utilization strategies, promoting the responsible management of lesser-known wood species while addressing increasing global demands.

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