SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.24-22

Characterization of Wood Cellular Structure of Plantation Grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* in the Savannah Ecological Zone, Ghana

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Citation: Tampori GE, Bih KF, Appiah-Kubi E, Chakural I, Awotwe-Mensah M, Donkoh BM, 2024. Characterization of Wood Cellular Structure of Plantation Grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* in the S avannah Ecological Zone, Ghana. *South-east Eur for* 15(2): 201-210. https://doi.org/10.15177/seefor.24-22.

Received: 02 Oct 2024; **Revised:** 07 Dec 2024; **Accepted:** 09 Dec 2024; **Published online:** 28 Dec 2024

ABSTRACT

The decreasing availability of economic hardwood timber species throughout tropical countries has necessitated the need to adopt plantation grown exotic timber species into the mainstream of raw materials in the furniture and wood manufacturing industries. However, published research on the material properties of most of these exotic timber species grown in the Savannah Ecological Zone of Ghana is limited. The wood properties of these species when known could result in their optimal utilization and broad acceptance in the wood industries as an alternative for the extinct tropical timber species. This study determines the anatomical properties of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* trees grown in the Savannah Ecological Zone of Ghana. Wood discs were obtained from three stem heights (butt, mid and top) from which cubes measuring 40 mm x 20 mm x 20 mm were produced for the microtome sections and macerated tissues, viewed under a microscope with Motic Image Plus software. Descriptions of wood anatomy followed IAWA's microscopic characteristics. It was observed that in the sapwood, there were more vessels than in heartwood, though the vessels were smaller in diameters, suggesting resistance to sap conduction which gives wood high aesthetic value and dimensional stability during drying. The species vessel diameter fell within the medium category and large vessels, demonstrating that wood will possess a greater mechanical strength since it will be denser, consequently possessing significant mechanical strength that can be compared favorably to other commercial timber species. This might be a major breakthrough in the production of quality and durable furniture as well as other wood products by using the exotic plantation grown timber species.

Keywords: vessel diameter; fiber morphology; plantation grown timber; wood anatomy

INTRODUCTION

Timber resources exhibiting favorable fiber properties usually designated as commercially viable wood species have been overexploited in the forests of Ghana. As a result, the sustainable supply of tropical hardwood species from natural forest kept on diminishing on daily basis, which is a worrying environmental threat. Forest depletion is reported to be at a high rate of over 5% per year, with major stakeholders being individuals, and groups within communities situated near forest reserves (Kwawuvi et al. 2021, Appiah-Badu et al. 2022). According to Kyere-Boateng and Marek (2021) some government agencies also constitute pivotal stakeholders, as their role in the enforcement and policy execution significantly impacts the frequency of these illicit activities. This brings about low wood material supply in the country leading to low production, and job losses due to the collapse of some wood processing and manufacturing industries (Sarfo-Adu 2021). These events constitute a serious concern for the nation's economic growth and the future supply of timber. To prevent this trend, there is the need to find a sustainable alternative supply of timber species that could be substituted for the commercially diminishing timber species in the Ghanaian forest for furniture production.

Plantation forestry is gaining prominence in Ghana's Savannah Ecological Zone as a sustainable means of addressing deforestation and meeting the increasing demand for timber. Plantation grown exotic timber species accounts for about 25-32% of the total wood volume in the tropical zones (Opuni-Frimpong et al. 2021). Utilization of these plantation-cultivated timber species is identified as a major breakthrough for increasing Ghana's timber resource base in order to meet the demand for timber (Tampori et al. 2024, Appiah-Kubi et al. 2019). Among the cultivated species, *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* are the two abundant plantation grown timber species. These species are generally long-lived and evergreen and belong to the Fabaceae and Myrtaceae families, respectively. *Anogeissus leiocarpa* is locally known as kane and *Eucalyptus camaldulensis* is known as white oak. They are exotic timber species, native to tropical regions of Asia and are widely used as medicinal plants (Stackpole et al. 2011, Salih et al. 2020). Currently, the wood of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* is structurally used only for fencing and thatch roofing. But they are locally exploited for a wide range of non-timber products such as fodder, medicine, fire wood, charcoal, farm input handles and are planted as ornamental plants on the streets, as well as around government departments in the Savannah zones. According to Lata et al. (2023) and Maqsood et al. (2023)' *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* fit into patterns of rapid growth, and most importantly are considered promising for reforestation, reaching 30-60 and 40-70 meters in height, respectively.

Undoubtedly, diversifying their use will in no small way improve wood supply for the timber sector in Ghana as they would ignite a huge prospect for local production and global trade. Despite their prevalence, there is a notable lack of scientific data regarding their wood properties, including the anatomical properties under specific ecological conditions of the Savannah zone. This absence of data presents a critical challenge for the effective utilization of these species in the construction, furniture, and other wood-based industries. Furthermore, the limited understanding of the performance of plantation-grown timber in Ghana’s unique Savannah environment has hindered informed decision-making by policymakers, plantation managers, and industrial stakeholders. Addressing these knowledge gaps is crucial to unlocking the economic and ecological potential of plantation forestry in the Savannah zone. This brings to the fore the necessity to provide comprehensive data on the material properties of the plantation grown timber species. However, vital wood cellular structural components such as fiber length, fiber diameter, lumen width, cell wall thickness and the ratio of earlywood to latewood significantly affect the mechanical strength, durability, and workability of wood species (Palermo et al. 2015, Kessels et al. 2017). The primary role of the vascular structures of wood is to facilitate the transportation of sap, whereas the fibrous components provide structural strength and rigidity. Mechanically, wood is regarded as a composite of tubular components formed from vessels and fibers that are tightly integrated by lignin (Hounlonon et al. 2022).

Apparently, Riki et al. (2019) reported that increased vessel diameters enhance water conductivity, but potentially reduce wood mechanical strength and durability. In contrast, woods that exhibits greater density, characterized by smaller vessels and thicker cell walls, is typically stronger and exhibits enhanced resistance to decay, thus rendering it particularly suitable for construction and furniture production. The uniformity and consistency of wood grain contributes significantly to its aesthetic appeal and the ease of machining, whereas the presence of knots and irregular growth rings reduces wood durability as well as its market value. Most of the wood elements are elongated vertically and show radial symmetry (Uetimane Jr and Ali 2017). These properties influence the multipurpose application of wood as a biological material, thus rendering it essential that an exhaustive understanding of the microstructural attributes of wood should precede its endorsement. It is obvious that the anatomical properties of wood can have influence on wood density and quality in terms of furniture production (Hamdan et al. 2020, Siam et al. 2022). Thus, the variations in wood anatomic structure could affect its quality for construction and furniture production. Yahya et al. (2017) emphasized that the efficient use of wood timber species for designing and constructing artefacts is greatly influenced by the anatomical properties. Appiah-Kubi et al. (2019) conclude that the choice of timber as material for furniture production depends on its durability and industrial characteristics. Therefore, appropriate information on their material properties would enhance better prediction and substantiation of their strength properties (Tete et al. 2014, Tampori et al. 2024). The aim of the current study was to characterize the wood cellular structure of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* in Ghana's Savannah Ecological Zone.

MATERIALS AND METHODS

Characteristics of the Study Site

Study samples were obtained and harvested from an on-reserve forest at the Tamale plantation reserve in Ghana, between latitudes 9º16' and 9º34' North and longitudes 0º36' and 0º57' West. It is located in the Savannah Ecological Zone, associated with monomodal rainfall pattern with an annual rainfall range of 900-1000 mm which often takes place in July - early November. During the rainy and dry seasons, the average daily temperature is 22°C and 34°C, respectively. Maximum relative humidity recorded in the plantation site is about 80% during the rainy season and drops to 35% during the dry season. With a hardpan beneath the top soil layer, the loamy sand soil is brownish in color, free of concretion, and quite shallow (SARI 2007).

Sample Collection and Preparation

Five (5) mature trees of each plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* were sampled for the study. Purposeful sampling technique was adopted based on the diameter at breast height (dbh) exceeding 50 cm, the overall linearity of the trunk, as well as the absence of defects to minimize tree-to-tree variance. The chronological age of the studied species was approximately 53 years. Trees with similar diameters ranging from 61-65 cm at breast height (1.3 m) were felled with the aid of a chain saw. The commercially viable length of the straight trunk of each tree was measured and cut into three equal divisions, labelled as butt, mid and top (Figure 1). A stem sectional disc with approximate thickness of 7.5 cm was cut at each extreme end of the sections for the anatomical investigations. To accommodate for axial position variation, clear samples from stem sectional discs were extracted from the middle portion of each section of the three axial locations (butt, mid, and top) and radial locations (heartwood and sapwood) of each tree. The samples were air dried before maceration of fiber. The IAWA Committee's catalog of microscopic characteristics for hardwood identification was followed in the descriptions of the anatomical features (IAWA 1989). The preparation of the wood test specimens was carried out at the Tamale Technical University Wood Technology workshop, while the experimental study was conducted at the Anatomy Laboratory of the Council for Scientific and Industrial Research (CSIR) of the Forestry Research Institute of Ghana (FORIG), Fumesua - Kumasi, Ghana.

Determination of Fiber Dimensions

Franklin (1937) wood maceration procedures were used to separate the wood elements based on fiber diameters. Two specimens of a matchstick were removed from each of the discs obtained at each axial height, and placed in a separate labelled vial tube with equal proportion of hydrogen peroxide and acetic acid (1:1). Having cocked each vial tube with cotton wool, the samples were kept in an oven set to 60?, while others were boiled on an electronic burner till complete macerations was attained. Following that, the macerates were transferred into a clean vial tube and rinsed thoroughly with distilled water to flash out chemical traces. To preserve the macerate, distilled water and alcohol was added, while a piece of the macerate from each section was scooped into a petri dish, and drops of glycerol were then added and meticulously teased out the macerate for microscopic studies of fiber characteristics.

Having successfully teased the macerated wood fragments, drops were transported to the glass slide with a dissecting needle and then mounted on a Zeiss light microscope (standard 25). The photomicrographs were then obtained from the macerates using a digital microscope equipped with Motic Image Plus software (2.0 ml) at X40 magnifications. On macerates, the length of the fibers, the diameter of the lumen, and the thickness of both walls were measured using one-hundred and eighty (180) complete and straight fibers per each timber species, i.e. {(30 samples x 3 stem sections (butt, mid and top) x 2 wood portions (heartwood and sapwood)) x 2 species = 360 fibers}.

Fiber characteristics were determined as follows:

$$\text{Cell wall thickness} = \frac{\text{Fibre thickness-Lumen width}}{2} \quad (1)$$

$$\text{Slenderness ratio} = \frac{\text{Length of fibre}}{\text{Diameter of fibre}} \quad (2)$$

Sectioning of Wood Test Samples

For the preparation of thin sections using microtome, 40 mm x 20 mm x 20 mm samples were made from the sectional disc obtained from the heartwood and sapwood of the butt, mid and the uppermost part of the tree of each species. The specimens were put in distilled water for 21 days for softening, and then soaked in a blend of 100 ml ethanol and 100 ml glycerol between 14 and 30 additional days for further softening in accordance with the species and position from where the specimen were

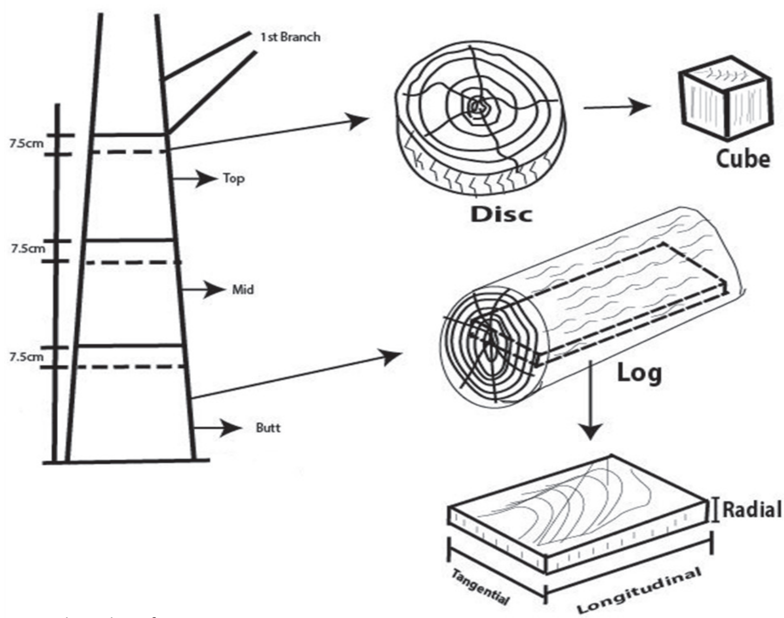

Figure 1. Schematic sampling plan of trees.

taken. *Anogeissus leiocarpa* took more time, between 14 and 21 days for the softening process, while *Eucalyptus camaldulensis* took between 7 and 18 days to get softer. The softened woods were then sectioned with a Reichert-Jung (Hn 40, Microm, Walldorf, Germany) sledge microtome. Thin sections measuring approximately 15 µm in thickness were sliced from the transverse, tangential, and radial surfaces of each cube obtained. The sections were taken and placed into a petri dish containing distilled water in order to remove ethanol and glycerol.

In order to facilitate the differentiation of the cell contents from the cell walls, the best selected sections were stained in a 1% safranin in a 50% alcohol solution for at least 10 minutes. Subsequently, the sections were dehydrated in the increasing concentration of ethanol for about 15 minutes starting from 30%, 50%, 70%, 95% and 100%. The purpose was to gradually remove moisture from the sections and to prevent them from disintegrating. Sections of the dehydrated microtome were subsequently each immersed in five milliliters of xylene and clove oil for another 15 minutes to get rid of tiny water traces. Single sections for the three-dimensional face were mounted in Canadian balsam on glass slides and allowed to dry at 60°C for 48 hours to make the slide permanent. The slides were then stored for vessel lumen diameter measurements and photomicrographs, using the same digital microscope as in the case of the fiber measurements. However, with the sections, the photomicrographs were taken at X4 magnifications, wood tissue dimensions, and the cross-section photomicrographs were angled at 45° in the Motic Image Plus software with relation to the direction of the radial parenchyma. The anatomical measurements for the study were all done using the Motic Image Plus software.

Data and Anatomical Analysis

The variance in the fiber morphology along trees' stem height was determined and descriptive statistics comprising means with standard deviations were presented for each timber species used in the study. First assessments were undertaken to verify that there were no infringements on the principles of normality, linearity, and variance homogeneity. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) software (version 23). The significance levels of mean values were set at p<0.001 confidence level. All pairwise multiple comparison procedure (Tukey HSD method) was employed as a follow-up study in cases where notable variations were found among means of the trees, whereas a light microscope equipped with Mitic Image plus 2.0 ML software was employed for photo acquisition, and the analyses of the photomicrographs. Each tree fiber characteristic was measured from the butt, mid and top.

RESULTS

Fiber Morphology of Plantation Grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*

The fiber parameters of plantation grown exotic timber species (*Anogeissus leiocarpa* and *Eucalyptus camaldulensis*) are presented in Table 1 and 2. The results show that the fiber length in both species reduces from the butt to the top segment, with an average fiber length of 1156.82 µm and 1078.27 µm recorded for *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*, respectively. In terms of fiber diameter, an average of 16.28 µm and 15.45 µm was recorded for *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*, respectively. An average of 7.41 µm was recorded for both *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*. The sapwood portions in both species had higher values with a decreasing trend from the butt to the top portions. An average of 8.87 µm and 8.04 µm was recorded as double cell wall thickness for *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*, respectively. For slenderness ratio, an average of 72.34 and 70.39 was recorded for *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*, respectively. The studied fiber morphological parameters of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood varied axially in relation to stem height (butt to top) part of the trees. All the parameters except slenderness ratio seem to reduce from the butt to the uppermost section of each species. The double cell wall thickness of *Eucalyptus camaldulensis* demonstrated an increase from the butt to the top part of the trees. Radially, all the parameters recorded higher values in the heartwood portion than the sapwood. However, all parameters of *Anogeissus leiocarpa* values except lumen width were higher (Table 2) as compared to that of *Eucalyptus camaldulensis.*

Tissue Proportions of Plantation Grown Anogeissus leiocarpa and Eucalyptus camaldulensis

Table 3 reports the vessel diameter of the plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* timber. *Anogeissus leiocarpa* recorded an average of 56.08 µm, 60.62 µm and 66.56 µm for the butt, mid and top respectively. *Eucalyptus camaldulensis* recorded an average of 142.46 µm, 164.68 µm and 180.22 µm for the butt, mid and top respectively. The results illustrate that, both radial and axial positions significantly impact vessel diameter, with radial position contributing 80% and axial position contributing 81.9% to the variability (P<0.001). The observed pattern of vessel diameter increasing from the butt to the top and from sapwood to heartwood, implying that wood structure varies systematically within the tree, likely affecting water transport efficiency and mechanical properties (Table 4).

Anatomical Features of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*

Figure 2 presents the micrographs describing the anatomical features of plantation grown *Anogeissus leiocarpa* (a, b, c) and *Eucalyptus camaldulensis* (d, e, f) at 10x magnification. The transverse section (a) of *Anogeissus leiocarpa* shows solitary and radial multiples of 2-3(4) small to medium diameter vessels, diffuse-porous and axial parenchyma which are extremely rare. Tangential section (b) indicates narrow width and numerous homocellular rays, whereas the radial section (c) exhibits non-septate fibers with few streaks of prismatic crystals.

Eucalyptus camaldulensis transverse section (d) is diffuse-porous, exclusively solitary with only few radial multiples of 2-3 medium to large diameter vessels, and typically in an echelon arrangement. The tangential section (e) shows narrow width and numerous rays, and the radial section (f) shows streaks of ray cells.

DISCUSSION

Table 1. Selected anatomical properties of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis.*

Tree	Tree portion	Fiber length (µm)		Fiber diameter (µm)		Lumen width (µm)		Double cell wall thickness (µm)		Slenderness ratio	
		h	s	h	s	h	s	H	s	h	s
Anogeissus leiocarpa	Top	1179.83 (±42.41)	1102.70 (±48.85)	16.94 (±0.91)	13.44 (±0.52)	6.03 (±0.63)	7.45 (±0.34)	10.90 (±1.12)	5.99 (±0.58)	69.90 (±5.24)	82.16 (±5.17)
	Mid	1192.13 (±54.47)	1118.83 (±46.82)	17.96 (±0.97)	13.84 (±0.74)	6.71 (±0.56)	7.56 (±0.49)	11.25 (±1.01)	6.26 (±0.90)	66.53 (±4.20)	81.15 (±5.27)
	Butt	1205.13 (±69.66)	1142.23 (±40.13)	20.03 (±0.76)	15.48 (±0.75)	7.53 (±0.54)	9.16 (±0.64)	12.50 (±0.71)	6.32 (±0.14)	60.24 (±3.85)	74.02 (±5.20)
Eucalyptus camaldulensis	Top	1062.00 (±47.77)	1047.37 (±35.45)	15.75 (±0.52)	13.44 (±0.43)	5.80 (±0.47)	7.51 (±0.26)	9.93 (±0.76)	5.93 (±0.47)	67.59 (±4.01)	78.01 (±3.62)
	Mid	1099.30 (±48.59)	1059.30 (±47.25)	16.90 (±0.64)	13.99 (±0.72)	7.15 (±0.53)	8.06 (±0.59)	9.75 (±0.84)	5.93 (±0.87)	65.16 (±4.00)	75.89 (±4.96)
	Butt	1126.53 (±43.27)	1075.10 (±49.89)	17.14 (±0.85)	15.46 (±0.68)	7.41 (±0.50)	8.51 (±0.31)	9.73 (±0.97)	6.95 (±0.73)	65.91 (±4.52)	69.70 (±4.75)

Note: Average value and standard deviation in parentheses; h = heartwood; s = sapwood

Table 2. Fiber dimensions of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*.

	Anogeissus leiocarpa	*Eucalyptus camaldulensis*
Fiber length (µm)	1156.82	1078.27
Fiber diameter (µm)	16.28	15.45
Lumen width (µm)	7.41	7.41
Double cell wall thickness (µm)	8.87	8.04
Slenderness ratio	72.34	70.38

Table 3. Vessel diameter (µm) of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis.*

Species	Tree portion	Butt	Mid	Top	Total
Anogeissus leiocarpa	h	51.32 (±3.49)	55.21 (±3.77)	62.10 (±3.27)	56.21 (±3.51)
	s	60.84 (±2.87)	66.02 (±1.88)	71.02 (±3.41)	65.96 (±2.72)
Eucalyptus camaldulensis	h	126.64 (±8.00)	157.23 (±6.86)	162.53 (±3.74)	148.80 (±6.20)
	s	158.28 (±3.70)	172.13 (±5.12)	197.91 (±6.43)	176.11 (±5.08)

Note: Average value and standard deviation in parentheses; h = heartwood; s = sapwood

Table 4. One-way ANOVA of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* vessel diameter.

Source	df	Mean Square	F	Sig.	η^2
Species	1	924975.913	41649.324	.000	.992
Radial	1	30868.580	1389.934	.000	.800
Axial	2	17503.480	788.137	.000	.819
Species * Radial	1	6955.615	313.194	.000	.474
Species * Axial	2	5756.546	259.203	.000	.598
Radial * Axial	2	739.831	33.313	.000	.161
Species * Radial * Axial	2	1058.454	47.659	.000	.215
Error	348	22.209			
Total	360				
Corrected Total	359				

Note: Statistically significant at 0.05 level of significance; η^2 = partial eta squared; R^2 = .882

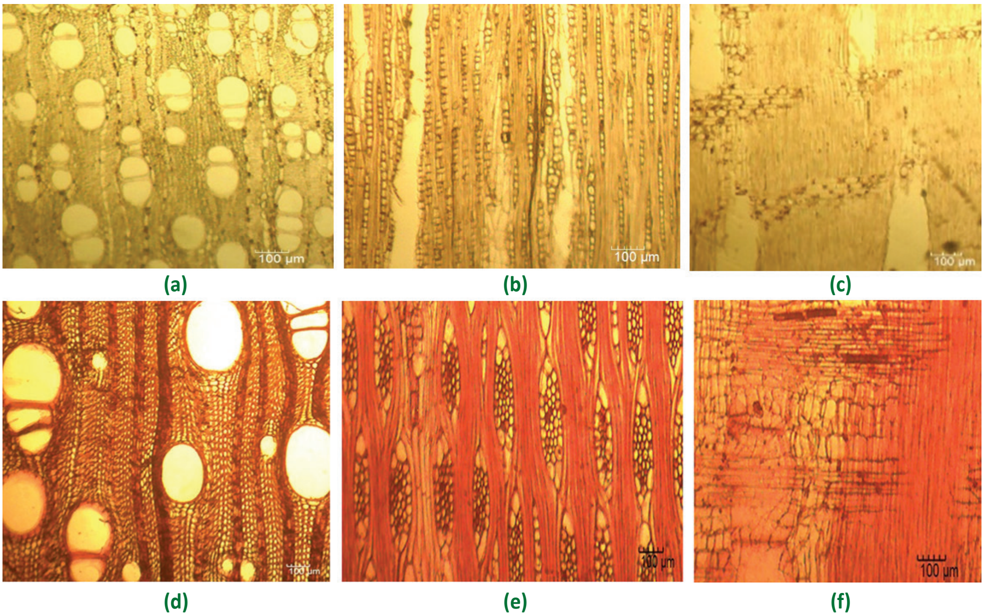

Figure 2. Transverse **(a, d)**, tangential **(b, e)** and radial **(c, f)** sections for plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*, respectively.

Fiber Morphology of Plantation Grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*

The observations made on the fiber properties of two (2) plantation grown timber species in the Savannah Ecological Zone, Ghana, appeared to compare favorably with most tropical timber species in literature. The mean fiber length recorded for the plantation grown *Anogeissus leiocarpa* (1156.82 µm) and *Eucalyptus camaldulensis* (1078.27 µm) determined was within an acceptable range of fiber length (1160 – 1240 µm) reported for *Tectona grandis* (Thulasidas and Bhat 2012, Amoah and Inyong 2019). It is worthy to note that *Tectona grandis* is also an exotic timber species, but presently one of the most accepted wood used for furniture production in Ghana. The fact is that furniture and other wood products requiring strength might benefit more from fibrous materials with thick cell walls (Dadzie and Amoah 2015, Ofosu et al. 2020). Generally, it appeared that the studied timber species demonstrated comparatively recommended fiber length values. Ramírez et al. (2009) classified fibers above 1000 µm in length as long. Going by this classification, the wood of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* has long fibers given that all of their mean fiber lengths are more than 1000 µm as presented in Table 1. This finding validates previous studies and observations that reported the average fiber length was about 1000 µm and 3000 µm in hardwoods and coniferous woods, respectively (Uetimane Jr. and Ali 2017).

Similarly, Dadzie et al. (2018) reported that fiber lengths of less than 1600 µm were recorded in certain Ghanaian hardwood species that are mostly used in the construction and furniture industries. In this study, the fact that the plantation grown timber species exhibited long mean fiber length might explain why these timber species are more likely to possess higher hardness values that can be compared to some of the tropical hardwoods that are mostly used for furniture production. The fiber length of the heartwood compared to the sapwood portions of both species exhibit statistically significant differences at ($p<0.05$). Among the studied species, the fiber length reduces from the butt to the top. *Anogeissus leiocarpa* heartwood had significant longer fibers than its sapwood portions, while *Eucalyptus camaldulensis* heartwood had the shortest fiber length than its sapwood portions. This is an illustration showing that, generally, the fiber length of the species reduces with increasing tree heights. The variations between the heartwood and sapwood within trees is a pattern that the plantation genus has identified as the primary cause of variation inside a tree (Jorge et al. 2011). Based on the analysis of variance, there were statistically significant variations in the length of the fiber of the timber species studied.

Wood fiber diameter is a major factor that varies among trees and the portions from which the samples were taken. The findings showed that the studied species recorded high value for fiber diameter in the heartwood portion at the butt with a decreasing trend to the top portions. The variation pattern of the wood fiber diameter is consistent with the models of axial variation within plantation grown timber species, increasing from butt to top (Dadzie and Amoah 2015) and from pith to bark (Quilho et al. 2006). According to Yahya et al. (2017), the increase in fiber diameter correlates with the molecular and physiological transformations that take place in the vascular cambium alongside the augmentation of wood cell walls during the process of tree growth. It is important to note that the mean fiber diameters recorded in this study for both species were comparable to 12.77 -16.74 µm for *Eucalyptus globulus* as indicated by Aguayo et al. (2010), surpassing the measurement of 22.85 µm reported by Dadzie et al. (2022) for *Cedrela odorata*. This result suggests that *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood is suitable for furniture construction.

Moreover, the average lumen width found in this study recorded higher values in the sapwood than the heartwood portions (P≤0.05), with a decrease from the butt to the top in both species. The reduction of lumen width from the heartwood to the sapwood sections, and from the base to the apex in the axial orientation was also reported by H'ng et al. (2009) and Dadzie et al. (2018). According to Dorwu et al. (2024), the differences in lumen width in trees are influenced by escalating cell dimensions and physiological maturation of the wood as the girth of the tree increases due to age advancement. This phenomenon according to Siam et al. (2022) is due to fiber length increase as influenced by increasing cambium layer due to growth. The average lumen width values recorded in the plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood was smaller (7.41 µm) than the value of 19.35 µm reported by Thulasidas and Bhat (2012) for plantation grown *Tectona grandis*, but comparable to the value reported by Gasson et al. (2011) for hardwoods. The mean fiber lumen width of the sapwood of the plantation grown timber species were significantly wider ($p<0.05$) than that of their heartwood, and reduced from the butt to the top portions (Table 1). This variation pattern matches the radial variation models within the tree that are frequently described for plantation genera, increasing from pith to bark (Miranda and Pereira 2007). Smaller fiber lumen of the studied species is an indication that there will be a strong interaction between the anatomical features and strength properties.

Moreover, double cell-wall thickness varied from the heartwood to the sapwood portions. Fibers from the heartwood sampled from the butt portions recorded higher values than the top. The same pattern of radial variation was reported for *Anogeissus latifolia* (Singh et al. 2022), *Eucalyptus urophylla hybrids* (Quilhó et al. 2006), *Eucalyptus globulus* and for *Eucalyptus grandis* clones (Ramírez et al. 2009). The anatomical feature trends and proportions seem to support previous research findings, such as those by Adeniyi et al. (2022) and Siam et al. (2022). According to Yahya et al. (2017), thicker fiber cell walls with narrow vessel diameter produce wood that has relatively higher density. According Sharma et al. (2011), compressive strength and mechanical properties of wood are largely influenced by thickness of the two walls of fibers. The studied species recorded thicker cell walls (8.87 µm) than *Tectona grandis* (8.50 µm), *Mansonia altissima* (6.24 µm) and *Gmelina arborea* (5.10 µm) as reported by Adeniyi et al. (2022). *Eucalyptus camaldulensis* wood cell-wall thickness was comparable to *Terminalia superba* wood. This is an indication that the studied species are more likely to be well-suited for furniture production. Fibers with thick cell-walled elements produce good quality wood for furniture production (Erdene-Ochir et al. 2020). Abdelatif et al. (2023) reported that wood materials with thicker cell wall would be more suitable for construction purposes as they would be robust, heavier and stiffer than wood with thin-walled elements.

The average slenderness ratio of the studied species are quite higher than 51.24 reported for *Eucalyptus grandis* (Palermo et al. 2015). In both species, the slenderness values increased axially from the butt to the uppermost parts. This suggests that the wood obtained from the stem of the butt would be more structurally stable and less susceptible to buckling than the top-most portions. This consistency suggests a more uniform fiber structure throughout the tree, which may be advantageous for applications requiring uniform mechanical properties. The narrower variation in slenderness ratio along the axial portions of the studied species could contribute to the consistency in wood quality as required for furniture production (Zobel 1961, Andre Luis et al. 2013). Based on Gasson et al. (2011) classifications, the studied plantation grown exotic timber species might have potential for furniture production. Therefore, slenderness ratio of wood fibers refers to their length and width ratio, which is an important parameter in determining their strength, flexibility and usability in the furniture industry (Sadiku and Abdukareem 2019). According to Wheeler and Baas (1998), fiber slenderness ratio significantly influences the breaking length, tearing and also allows for good bonding between fibers, which is important for producing strong wood products with quality surface appearance. In all, the findings revealed a statistically significant variation in the means of all the fiber parameters evaluated from the heartwood and sapwood along the vertical axis of the tree, therefore suggesting a disparity in the fiber characteristics of the investigated species in both axial and radial orientations. Although descriptions of the fiber morphology of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* from the Savannah Ecological Zone appear unavailable and not sighted, by inferring from findings from different areas, it could be said that the descriptions obtained in this study represent the true features of tropical hardwoods anatomy. Based on these parameters, the wood is more likely to be suitable for various structural applications, including furniture making.

Tissue Proportions of Plantation Grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*

Wood formation constitutes a multifaceted developmental process that encompasses the differentiation of vascular cambial initials into diverse xylem tissues, cellular elongation, and the synthesis of secondary walls (Zhang et al. 2021). Damayanti and Rulliaty (2010) reported that secondary wall constitutes the fibers as the vessels undergo substantial thickening, thereby significantly affecting wood quality. The vessel diameter of the studied species varied significantly between the heartwood and sapwood (Table 3). It was significantly higher (162.46 µm) in *Eucalyptus camaldulensis* as compared to *Anogeissus leiocarpa* wood (60.09 µm). In the axial direction, the wood vessel diameter increased from the butt to the top part of the trees, whilst the heartwood decreased to the sapwood portions in the radial direction. The analysis of variance showed the significant differences between and within the trees, which was also reported by Riki et al. (2019) and Liu et al. (2020). Apparently, the vessel diameter of *Anogeissus leiocarpa* seems to be narrower as compared to the *Eucalyptus camaldulensis.* As such, *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood can be categorized as small to medium-sized and medium to large-sized vessels, respectively (IAWA 1989). This finding apparently suggests that there could be density variances, such as variances in permeability and treatability among the studied species. However, these trends and dimensions appear to be in agreement with earlier research findings including those by Dadzie and Amoah (2015), Dadzie et al. (2018) and Hamdan et al. (2020). It will be prudent to recommend the plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood for use in the furniture manufacturing industries due to their tissue potential.

Anatomical Features of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*

The anatomical features of timber species aid to describe wood identification, an indication of wood potential suitability for use in the furniture construction industry. Observations made on the micrographs of the plantation grown timber species indicates that vessels of *Anogeissus leiocarpa* predominantly manifest as solitary structures and in radial aggregates of 2-4, exhibiting simple perforation patterns. There are rarely deposits since the axial parenchyma is characterized as vasicentric and diffuse, but becomes discernible as white dots in cross-sectional views when observed under hand lens. The rays are predominantly uniseriate, although they may occasionally present as biseriates, comprising procumbent cells. The fibers are non-septate with crystalline formations existing within the chambered axial parenchyma, devoid of silica grains. The wood vessels of *Eucalyptus camaldulensis* are similarly structured as solitary entities and in radial aggregates of 2-3, characterized by simple perforations. Deposits including tyloses are absent, and the paratracheal axial parenchyma is minimal, vasicentric, and organized into narrow bands. The rays multiseriate in nature, with no-septate fibers and absent silica grain. The studied exotic timber plantation species possessed greater percentage of cell wall with high ray volume, indicating higher specific gravity and greater strength. Apparently, the percentage of gelatinous fibers was rarely present in both timber species. This probably may be due to the silvicultural management practice, including regular thinning and equal planting spacing implemented by the forest authorities.

The structural composition of wood fibers has been documented as pivotal in affording structural integrity in hardwood species. As such, Siam et al. (2022) reported that the more numerous are the fibers, the higher is the load carrying capacity of fiber in the wood. It is one of the characteristics of wood that affects the mechanical characteristics of the material. However, it is worthy to note that the studied species exhibiting smaller mean vessel diameters is an indication that the wood would likely record high mechanical properties. Also, the rays provide certain advantages in the context of furniture and other wood products, but may require finishes to improve surface beauty. The presence of ray and scattered deposits in the plantation grown timber species is more likely to contribute enormously in improving the wood surface beauty that will result in producing beautiful appearance upon application of finishes to the wood products. This will be a major contributing factor that will make the exotic timber species become preferable for furniture production in Ghana. The extremely rare presence of parenchyma cells in the studied species is an indication that they would be less susceptible to biodegradation. The fact is that parenchyma cells serve as reservoirs for carbohydrates within wood, thus rendering them the initial point of attack by biological agents that destroy wood. Artefacts that would be made from the plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood will be durable and could withstand weather conditions.

CONCLUSIONS

In the light of the findings derived from the study, it can be concluded that the wood cellular structure of the plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* was found to have anatomical characteristics similar to other Ghanaian tropical hardwoods. With the fiber morphology results obtained, the studied species show that the fibers were relatively long with narrow lumens which are associated with thicker cell walls. This shows that the plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* timber species would produce denser and stronger wood materials. This potentially makes the plantation grown timber species more suitable for load-bearing structural applications in the construction and furniture production firms. It was also observed that the vessels range from medium to large, an indication that the wood would be resistant to indentation owing to the fact that there is always a strong correlation between wood fiber size and strength. The micrographs also revealed that the wood fibers were more compacted with extracts that would produce artefacts with high durability, aesthetic appeal and finishing quality. This confirmed the suitability of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood for furniture construction and other structural applications. Apparently, these exotic timber species can be a good substitute for the diminishing tropical hardwoods that are mostly used in the furniture industry. However, it is necessary to sensitize woodworkers and all stakeholders in the furniture industry about the potential benefits for using the fast-growing plantation grown timber species which are in abundance within the Savannah Ecological Zone in Ghana.

Author Contributions

TGE, BKF, AE conceived and designed the research, TGE, CI collect the data, AM, TGE processed the data and performed statistical analysis, BKF, AE supervised the research, proofread and validated the writeup, TGE, CI, drafted the manuscript, DBM, BKF improved the manuscript draft. All authors read, discussed the results and contributed to the final version of the manuscript.

Funding

This research received no external funding; it was self-sponsored by the corresponding author.

Acknowledgments

The authors are grateful to the management and staff, especially Dr. Emmanuel Ebayele of the Forestry Research Institute of Ghana – Fumesua, Kumasi for making their xylem laboratory available for the study, as well as Tamale Technical University, Department of Wood Technology for making the workshop available for processing the timber for the study.

Conflicts of Interest

The authors declare no conflict of interest. Supporting entities had no role in the study's design; in the collection, analysis, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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