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Anatomical and Physico-Mechanical Properties of *Ficus exasperata* Vahl Wood

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ABSTRACT

Most of the commercial timber in Ghana are getting extinct thereby posing a big challenge to the timber industry. There is therefore the need to determine the properties of some of the lesser-used and lesser-known timber species available in the Ghanaian forest for utilization. This study was carried out at Council for Scientific and Industrial Research-Forestry Research Institute of Ghana campus to evaluate the suitability of some anatomical, physical, and mechanical properties of timber obtained from *Ficus exasperata* trees and its utilization potential in the timber industry. Two trees were extracted and the logs from them were processed into beams. Boards were prepared from these beams and test specimens were

prepared for the determination of physical (density), anatomical (fibre measurement, number of vessels, vessel width, vessel diameter) and mechanical (bending, compression, shear, hardness) properties based on internationally acceptable standards. At an average moisture content of 12.16%, the result obtained indicate that the mean values for the properties tested increased from the butt to the top sections of the two trees. However, there was no significant variation in the mean values obtained for the static bending, compression parallel to the grain and shear properties of the middle and top sections of both trees, whereas these properties varied significantly at the butt section of both trees. Generally, the properties tested increased with age from the top to the butt. Thirty-one-year-old *F. exasperata* recorded an average density of 414.34 kg/m^3 whereas the twenty-seven-year-old recorded 385.35 kg/m^3. Among the age gradations, the thirty-one-year-old *F. exasperata* registered maximum values for the evaluated parameters, namely; anatomical, density, modulus of elasticity, modulus of rupture, compression parallel to the grain, shear and hardness. The results of the study suggest that *F. exasperata* timber is a low-density wood and hence, can be used as substitute of *Alstonia boonei and Hannoa klaineana* which are also classified in the D30 strength class. Thus, suitable for the production of particleboards, mouldings, core veneer for plywood, boxes, crates, packing cases, pencil, food containers, light furniture industry and other fitments. Hence, it should be promoted in the timber industry.

Keywords: anatomy, compressive strength, density Ficus exasperata, hardness, shear strength, static bending.

INTRODUCTION

Heavy exploitation of few commercially valuable timber species such as *Pericopsis elata* (Afromosia), *Cynometra ananta* (Ananta), *Turreanthus africanus* (Avodire), (*Guibourtia ehie*) Hyedua*, Milicia excelsa* (Odum), due in major part to the insatiable demand from consumer markets, has meant that many species are now threatened with extinction. This has led to many of the tropical forests being plundered for these highly prized timber species. Even in the forests where there are good levels of forest management, there is a risk of a shift in species composition in natural forest stands. This over-exploitation can also dissuade many forest managers from obtaining Forest Stewardship Council Certification (FSCC) for their concessions, as many of these high value timber species are rarely available in sufficient quantity to cover all of the associated cost of certification.

Currently, Ghana has a little over 90 species of timber that are regularly exploited and traded (Hansen *et al.,* (2012). In order to make responsible forest management sustainable over the long term, markets must be developed for lesser-known timber species (LKS) and lesser-used timber species (LUS). Many forest concessions in the tropics can contain over 100 different tree species, yet only a handful are heavily harvested commercially, due to their known current market demand. Many of these species' characteristics are simply not even known, and could have similar and even better performance for some specific end-uses just as well as many of the traditionally harvested species. They can also have a more distinctive and unique appearance compared to more popular ones. The utilization of wider portfolio of species including LKS and LUS would help relieve pressure on the traditionally harvested and heavily exploited species.

Moreover, the utilization of these species in combination with FSCC, and access to high value export markets, could help make sustainable forest management a more viable alternative in many of world wildlife fund (WWF) priority places.

Ficus exasperata (known in Ghana as Nyankyereni) species is a member of Moraceae family and well known all over the world as "fig plants" (OladosuI 2009). Joseph and Raj (2010) emphasized that *Ficus exasperata* plants have vast traditional role in indigenous system of medicine like *Ayurveda*, *Siddha*, *Unani* and *Homoeopathy*. The bark, leaves, fruits and latex are considered to be very effective in diabetes, skin diseases, ulcers, dysentery, diarrhea, stomachache, hemorrhoids and as carminative, astringent, anti-inflammatory, anti-oxidant and anti-cancer agents. Bafor and Igbinuwen (2009) confirmed that *Ficus exasperata* Vahl. (Moraceae), popularly referred to as "Sandpaper leaf tree" owing to the rough surface of the leaves, is increasingly being used for a number of ailments and hence, studies validating the traditional claims are on the increase. Available reports indicate that leaves of *F. exasperata* exhibit antiulcer, hypotensive, hypoglycemic, hypolipidemic, anti inflammatory, anxiolytic, oxytocin inhibiting, anticonvulsant, antinociceptive, antipyretic, anti microbial, anti candidal, insecticidal and pesticidal activities, Adewole *et al.,* (2011); Akah *et al.,* (1998); Bafor *et al.,* (2011); Woode *et al.,* (2009).

Ficus exasperata is cited by Baillie *et al.,* (2004) as a lower risk least concern species with no endemism. Hence, adding industrial utilization value to *F. exasperata* wood (a lesser-known timber species LKS) and winning its adoption by wood users will be guaranteed if the wood is well characterized. Recommended uses of *F. exasperata* wood will be based on comprehensive knowledge of anatomical, physical and mechanical properties. However, information on these technological properties is not available. To enhance the visibility of the species to the limelight of the timber utilization industry, appreciation of the anatomical, physical and mechanical properties of the timber species is of paramount importance. Usually, the anatomical characteristics of a wood species relate to its physical properties, mechanical strength and durability properties (Bakar *et al*., 2013). Thus, the urgent need to investigate into this 'unattentioned' timber species. The utilization and promotion of LKS and LUS can often act as a substitute for more traditionally used species in terms of performance and aesthetic in most applications. They are also generally more cost effective because they are often abundant in the forest. Also, some of the LKS and LUS available have rich, truly beautiful colours and textures, which can provide new design opportunities for many industry sectors. Moreover, the use of LKS and LUS can alleviate pressure on the over-exploited timber species, and increase the economic viability of responsible forest management.

MATERIALS AND METHODS

Wood Materials

Two *Ficus exasperata* stem specimens; Trees 1 (GP: 6°42.7400'N; 1°31.5400'W) and 2 (GP: 6°42.7400'N; 1°31.5400'W) of ages 31 and 27 years respectively, were obtained from Council for Scientific and Industrial Research-Forestry Research Institute of Ghana campus at Fumesua near Ejisu in the Ashanti Region, a Moist Semi-deciduous Forest area for the study. The harvested trees were divided into three non-equal parts: butt, middle and top with a average diameter at breast height (DBH) of 25.59 cm. Three discs of 20 mm thick from the three

sections/billets of each stem making 9, hence 18 for the 2 stems, were prepared for the anatomical studies.

Evaluation of Anatomical Properties

Preparation of Microtome Slides:

Eighteen (18) discs 20 mm thick were labelled and transported to the laboratory. Samples of 30 mm cube were prepared from the inner and outer wood to represent heartwood and sapwood respectively. In labelled vials, the samples were saturated with water for 21 days. Later, the water was replaced with an equal part (1:1) mixture of ethanol and glycerol for another 25 days. Thin sections, 28 µm thick were produced on a Leica sliding microtome. Best sections were washed in distilled water and stained with 1 % safranin solution for about 10-20 minutes. After staining they were washed in distilled water and dehydrated in increasing concentration of ethanol: 30, 50, 70, 85, 90 and 100. After dehydration, they were permanently mounted in Canada balsam.

Wood Maceration:

Ten match-stick-sizes of *F. exasperata* specimens were put into 6 test-tubes containing equal volumes of glacial acetic acid and hydrogen peroxide, heated in a water-bath at a temperature of 60 ^{0}C for 48 hours. The resultant macerated specimens were then washed under distilled water, tested and mounted on glass specimen slide. The slides were observed under microscope for fibre measurement, in accordance with Mensah *et al.,* (2021).

Microscopic Examinations and Measurements

Preparation of Permanent Slides For Wood Description:

All the anatomical examinations and measurements were done under light microscope platform (National DC5-163 digital microscope equipped with Motic Image plus 2.0 ML software for live image captioning using a computer). The analyses of all photomicrographs were done with ImageJ software installed on *DELL* CORE i5 laptop-Latitude 5420. The nature and arrangement of various tissues were described based upon IAWA hardwood identification checklist (IAWA, 1989). Anatomical measurements were done using the eyepiece magnification of 10x against 4x objective lenses of magnification ranging from 4x to 40x. The number of vessels per square millimeter was determined by counting the number of vessels within a scale grid eyepiece with the field area of 1.4963 mm^{2}. Counts were replicated 5 times for each sample. Vessels and fibres proportions were determined on the slides for each sample using 4x objective lens and 4x eyepiece with a dot grid scale of 20 points. The dot scale was placed five times at different areas on the slide and at each placement; the number of points covering any tissue was counted and expressed as a percentage of the total number of points. The transverse or cross-sectional diameter of vessels in the base, middle and top diameters of the tangential rays were determined by measuring the diameter of 48 vessels and 54 rays for each species.

Fibre Measurement:

Fibre length, lumen width and the double wall thickness were measured for 316 complete and straight fibres per a tree from the base, the middle and the top. Images of fibres were captured and saved with sample names. Images were loaded in ImageJ software for measurements. Fibre

characteristics were measured on 110 selected fibres from the butt, 106 for the middle 100 for the top of *F. exasperata* stem.

Number of Vessels:

Frequency of vessels was determined as was done by Nazri *et al.,* (2012). Number of vessels per square millimeters was evaluated by counting all vessels individually (30 count per each specimen). Table 1a shows the classification for the number of vessels (IAWA, 1989).

Vessel Width:

Vessel was randomly selected and their width measurements were taken in the transverse section of the specimens using the widest part of the vessel opening. Figures obtained from the cross-section diameter of the vessel would be useful for describing the vessel width. Table 1a shows 4 classifications of vessels width (IAWA, 1989). Average vessel width was obtained from 60 measurements.

Table 1: Classification of anatomical properties (IAWA, 1989)

a: number of vessels

Category	**Vessel number per mm²**
Very few	Less than 5
Few	Between 5 and 20
Moderately few	Between 20 and 40
Numerous	Between 40 and 100
Very numerous	More than 100

b: vessels diameter/width

Category	**Vessel width (µm)**
Small	Less than 50
Moderately small	Between 50 and 100
Medium	Between 100 and 200
Large	More than 200

Evaluation of Density

Ficus exasperata specimens of sizes 20 x 20 x 20 mm were prepared from the two trees and soaked in clear water for 24 hours as reported by Shukla *et al.,* (2007) and Ofori *et al.,* (2009). The density on swollen volume and the oven-dry mass basis was determined by the immersion method. The weight of the beaker and the water it contained was determined by a digital balance of 0.01 g precision and then re-zeroed. The specimen was then submerged in the water, and the mass of the container plus water plus specimen was determined. The increase in the mass of water displaced by the specimen in grams is numerically equal to the volume of water displaced in cm^3 since water has a density of 1. 120 wood samples were oven-dried at 103-105 °C to constant mass and the oven-dry mass was determined and density recorded in kg/m^3 according to Equation 1. Method as used by Ohemeng *et al.,* (2023) and Shukla *et al.,* (2007).

Equation 1: Determination of Density of *F. exasperata*

$$Density = \frac{Oven\ mass}{Green\ volume\ of\ wood} \quad (1)$$

Evaluation of Moduli of Elasticity and Rupture

Moduli of Elasticity (MoE) and Rupture (MoR) of *F. exasperata* were determined in accordance with standard; ISO 13061-4:2014. 120 Specimens of size 20 x 20 x 300 was prepared from the two trees of *F. exasperata*. An Instron Universal Testing Machine (UMT) (Model inspekt 50-1) operating with a load cell capacity of 50 kN was used for the test. The loading rate applied to determine the MoE and MoR was 4 mm/min.

Strength Properties

This refers to the qualities of wood that indicate its ability to resist applied external forces. They are important criteria in determining the relative suitability of the different wood species for various uses. These species are classified into five (5) strength groups or classes in accordance with BS 2568-2 as shown in Table 2.

Table 2: Hardwood strength classes based on BS 2568-2

	D30	D40	D50	D60	D70
Mean	9500	10800	15000	18500	21000
Minimum	6000	7500	12600	15600	18000

Evaluation of Compression Strength Parallel to the Grain

BS 373:1957 was employed in conducting the test using Instron Universal Testing Machine (UTM) (Model 4482) operating with a load cell capacity of 100 kN at the rate of 0.635 mm per min to determine the behavior 120 strips of 20 mm x 20 mm x 60 mm *F. exasperata* specimens under applied crushing load. The results of the compression strength at maximum load in N/mm^2 were generated electronically with a computer controlled UTM.

Evaluation of Shear Strength Parallel to the Grain

Shear strength parallel to the grain of *F. exasperata* was determined in accordance with BS 373 (1957) standard, using 120 pieces of the specimens (from the two trees) dimensioned 50 mm x 50 mm x 50 mm. Instron Universal Testing Machine (UMT) (Model inspekt 50-1) operating with a load cell capacity of 50 kN at rate of 0.635 mm per min was used for the test. The direction of the shearing was parallel to the longitudinal direction of the grain.

Evaluation of Hardness

Janka ball test was used for determining the hardness of 120 specimens prepared from *F. exasperata* wood using Instron UTM (Model 4482) operating with a load cell capacity of 100 kN at the rate of penetration of 6.35 mm per min. The test was conducted radially and tangentially to determine the load required to force a steel ball of 11.278 ± 0.0508 mm in diameter into the wood specimen to a depth of 0.222 inches.

Data Analysis

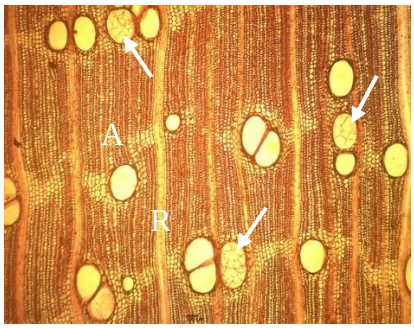
The data obtained were analysed using descriptive and inferential statistics. Statistical software used for the analyses was version 20 of Statistical Package for Social Scientists (SPSS). The mean

and standard deviation of all the properties considered in this study were computed, and Tukey's multiple comparison of means was used to establish significant difference between means at 5% level of significance. The average values recorded for the anatomical variables were compared with IAWA standards.

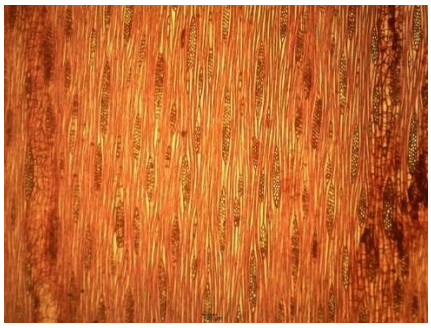
RESULTS AND DISCUSSION

Anatomical Features

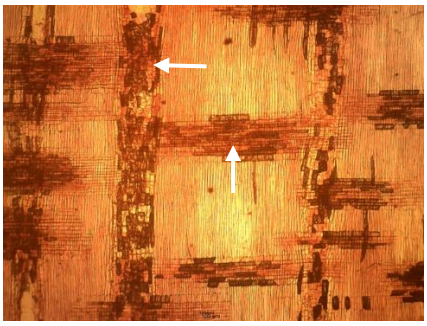
Figures 1 and 2 show the micrographic qualitative analyses of the anatomical evaluation of *F. exasperata* wood. The transverse sections of tree 1 (31-year-old) illustrates solitary vessel in radial multiples of 1-2 vessels (Figure 1a). Whereas that of tree 2 (27-year-old) shows solitary radial multiples of vessels with some occluded with tyloses (Figures 2a). In the tangential sections, the rays were multiseriate homocellular in the two trees (Figure 1b and 2b). The radial sections show rays with some visible crystals in t1 (Figure 1c), as there are few of the same in t2 (Figure 2c).



a. Transverse section of *F. exasperata* showing solitary and radial multiples of 1-2 vessels, diffuse to diffuse-in-aggregates axial parenchyma (A), with tyloses inclusions (arrowed).10x magnification.

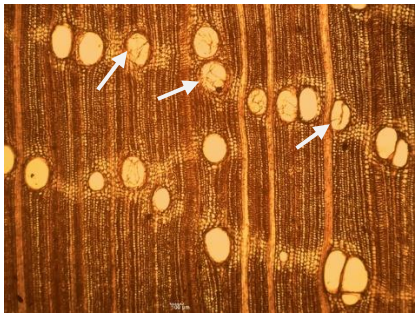


b. Tangential section of *F. exasperata* showing multiseriate homocellular rays. 10x magnification.



c. Radial section of *F. exasperata* showing ray cells containing some perismatic crystals (arrowed). 10x magnification

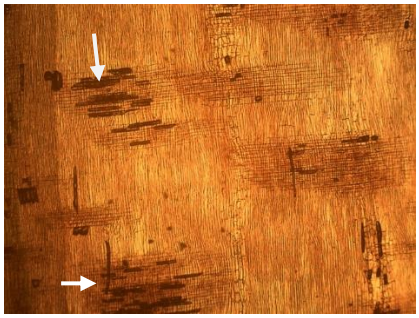
Figure 1: Micrographs of the heart wood of the butt section of tree 1 (31-year-old) of *Ficus exasperata*.



a. Transverse section of *F. exasperata* showing solitary and radial multiples of vessels with tyloses inclusions [arrowed],



b. Tangential section of *F. exasperata* showing multiseriate homocellular rays. 10x magnification.



c. Radial section of *F. exasperata* showing ray cells containing few streaks of perismatic

diffuse to diffuse-in-aggregates axial parenchyma (A). 10x magnification.

crystals (arrowed). 10x magnification.

Figure 2: Micrographs of the heart wood of the butt section of tree 2 (27-year-old) of *Ficus exasperata*.

Vessel Measurement:

Table 3 shows the vessel morphology of the timber from the two trees of *Ficus exasperata*. All the evaluated characteristics of the vessels in both trees varied considerably along the bole (Tables 3). The results indicate that generally, the vessel areas increase with increasing vessel lengths. Similar results were obtained by Jacobsen *et al.,* (2012); Liu *et al.,* (2018); Olson *et al.,* (2014). Tyree & Zimmermann, (2002) have indicated that vessels are the conduits through which most water in the transpiration stream of hardwoods pass during its ascent to the canopy. Again, Ogasa *et al*. (2010) stated that vessel area and distribution have significant effect on water conduction efficiency. Thus, with the mean vessel distribution of 56 vessels/mm^2, and a maximum vessel area of 411 µm^2, it is expected that *F. exasperata* will have high water uptake. Formation of tyloses in the vessels could enhance the resistance of the timber to pathogenic activities (Dickson, 2000). It was also observed that there were more vessels at the top section of the timber than at the middle and the butt. According to IAWA (1989) *F. exasperata* is described as medium and numerous vessel timber (Table 1a & b).

Table 3: Vessel morphology of timber obtained from two *Ficus exasperata* trees

	Sample section	Vessel area (µm^2)	Vessel length (µm)	Vessel number
Tree 1	Butt	344.02 (56.76)	166.66 (27.76)	65.60 (7.15)
	Middle	354.74 (49.86)	171.28 (28.35)	62.03 (7.47)
	Top	368.52 (53.70)	189.79 (49.18)	57.37 (7.50)
Tree 2	Butt	457.73 (52.01)	173.49 (30.50)	56.57 (6.69)
	Middle	470.18 (52.41)	174.01 (28.59)	52.50 (6.54)
	Top	477. 48 (53.38)	179.58 (28.44)	44.07 (6.42)

Standard error of the mean (SEM) in parenthesis.

Fibre Morphology:

Fibre character evaluation was done as illustrate in Figure 3, using complete and clear 316 fibres obtained from the two *F. exasperata* trees. The suitability of a tree as raw material for timber, fibre-based products, and pulp and paper production could be evaluated by its anatomical properties (Boadu *et al.,* 2022). The results indicate a variation in the fibre properties of *F. exasperata,* which could be an impetus to the physical and mechanical strength properties of the wood for different uses. Monteoliva *et al.,* (2005) emphasised that variations in wood density and fibre dimensions are present in timber in the radial and longitudinal direction and within the annual rings, and Zheng and Martínez-Cabrera, (2013) and Moraes *et al.,* (2023) indicated that these variations may be due to genetic, physiological or silvicultural treatments.

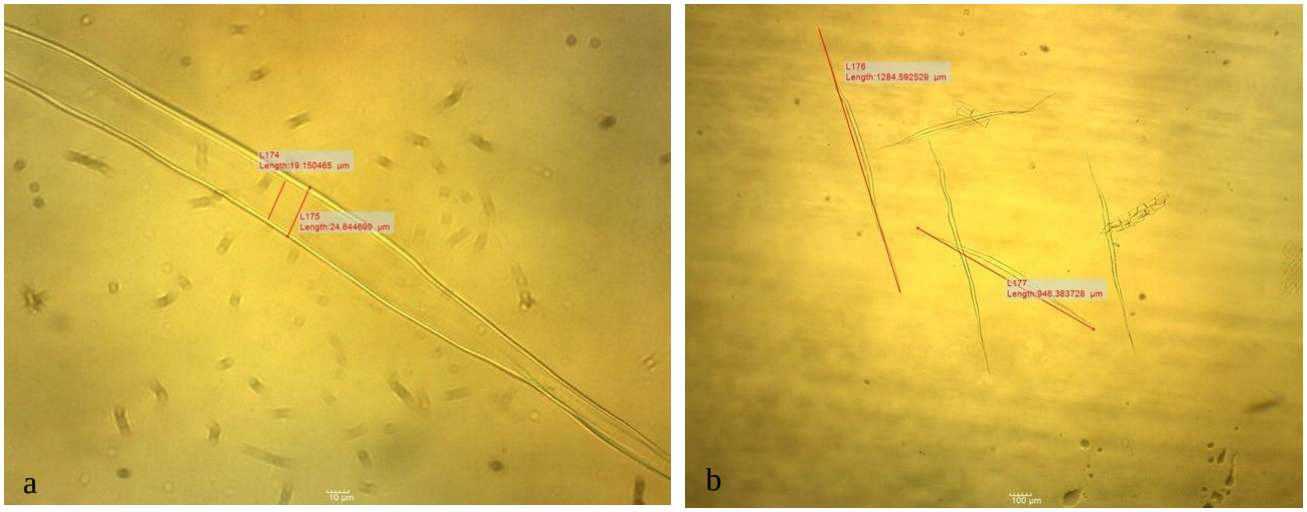


Figure 3: Measuring the fibre diameter (a) and fibre length (b)

Table 4: Fibre morphology of timber obtained from two *Ficus exasperata* trees

	Sample section	Fibre length (µm)	Fibre width (µm)	Lumen diameter (µm)	Double wall thickness (µm)	Runkle ratio	Aspect ratio	Coefficient of flexibility	Coefficient of rigidity
Tree 1	Representation of the main trunk	1035.63 (180.19)	21.36 (5.09)	16.97 (4.72)	4.39 (1.26)	0.57 (0.25)	51.84 (19.41)	0.79 (0.07)	0.43 (0.14)
Tree 2	Representation of the main trunk	898.57 (129.05)	18.11 (4.13)	13.34 (4.36)	4.77 (1.66)	0.83 (0.47)	53.01 (18.01)	0.72 (0.11)	0.55 (0.22)

Standard error of the mean (SEM) in parenthesis

Fibre Length:

Wood fibres are usually cellulosic elements that are extracted from tress and used for the manufacture of pulp and paper or fibreboards. The fibre morphological characteristics (Figure 3) are essential since they determine the suitability of the lignocellulosic materials before proceeding to production (San *et al.,* 2016). Average values of fibre morphology of *F. exasperata* are presented in Table 4. Fibre length increases with increase in the age of the tree. Peszlen (1994) emphasized that age had a significant effect on anatomical characteristics of timber. Similar results were obtained by Bhat *et al.,* (2001); Mäkinen *et al.,* (2002); Zhu *et al.,* (2008).

The results indicate that the studied timber has characteristics similar to that of *Sorbus torminalis* (Bahmani *et al.,* 2020); *Strombosia glaucescens* (Awaku, 1994); *Hevea brasiliensis*, (Amorim *et al.,* 2021), which are already in utilisation in the timber industry. Thus, according to IAWA (1989), *F. exasperata* is classified as medium length fibre wood. Migneault *et al*., (2008), emphasised that fibre length has a significant influence on the strength properties of fibre-based products such as fibreboard. These authors again affirmed that fibre length determine whether the quality of a raw material is suitable for a specific use in the paper industry or not because of its impacts on paper characteristics, such as strength, optical properties and surface quality. Species with high fibre lengths are preferred in fibreboard, pulp

and paper production for a better mechanical interconnectivity among them to enhance high resistance and better static bending properties. Hence, Monteoliva *et al*., (2002) confirmed that fibres longer than 1000 µm (as recorded by *F. exasperata* in this study) are preferred for pulp and paper manufacturing. Mitchual *et al.,* (2020) emphasized that fibres with high aspect ratio are suitable in the particleboard industry, as they enhance the static bending and internal bond strength properties of the manufacture panel.

Density of *Ficus exasperate:*

At 12.16% moisture content, the average density of *F. exasperata* tree 1 was 482.63 (43.92) kg/m^3, whereas that of tree 2 was 427.73 (42.57) kg/m^3 (Table 5). It is worthy to note that the samples extracted from the butt sections of the trees have higher densities as compared to the top parts of the trees. Similar observation was made in a study by Nenning *et al.,* (2024). Tomczak *et al.,* (2015) emphasized that generally wood density is usually higher at the butt, due to the higher compaction of the stump tissues exerted by overlapping cells along the bole and tree crown. The density of *F. exasperata* is within that of commercially available timber in the market and hence, classified as low-density timber based on BS EN 338:2016.

Table 5: Sectional density of two *F. exasperata* trees

Trees	Density (Kg/m^3)		
	Butt	Middle	Top
Tree 1	482.63^a (43.92)	424.40^c (12.69)	376.38^e (18.44)
Tree 2	427.73^b (42.57)	401.29^d (21.30)	336.03^f (10.33)

Figures in columns with the same letters are not significantly different according to Tukey's multiple tests. Standard deviation in parenthesis.

Mechanical Properties

Moduli of Elasticity and Rupture:

The average Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) recorded by the *F. exasperata* timber is seen in Figures 4 and 5 respectively. Results obtained from a three-point static bending indicated that the mean value of MoE for *F. exasperata* tree 1 was 5410.29 (566.84) MPa and that of tree 2 was 5155.75 (312.16) MPa. Whereas MoR for tree 1 was 38.19 (8.29) MPa and tree 2 was 31.87 MPa (4.61). The results also indicate that the strength of the timber obtained from *F. exasperata* reduces from the butt towards the top of the trees. Zobel and Jett, (2012) hinted that this is as a result of the age of the cambium, the tree morphology and by internal changes through genetic differences or controls. Other studies that obtained similar results included but not limited to Gallego *et al.,* (2021). It is therefore essential to recognize that from Figure 4 and 5 the strength properties of *F. exasperata* increases with increase in age, confirming the studies done by Gil-Moreno *et al.,* (2024); Kauniste *et al.,* (2024).

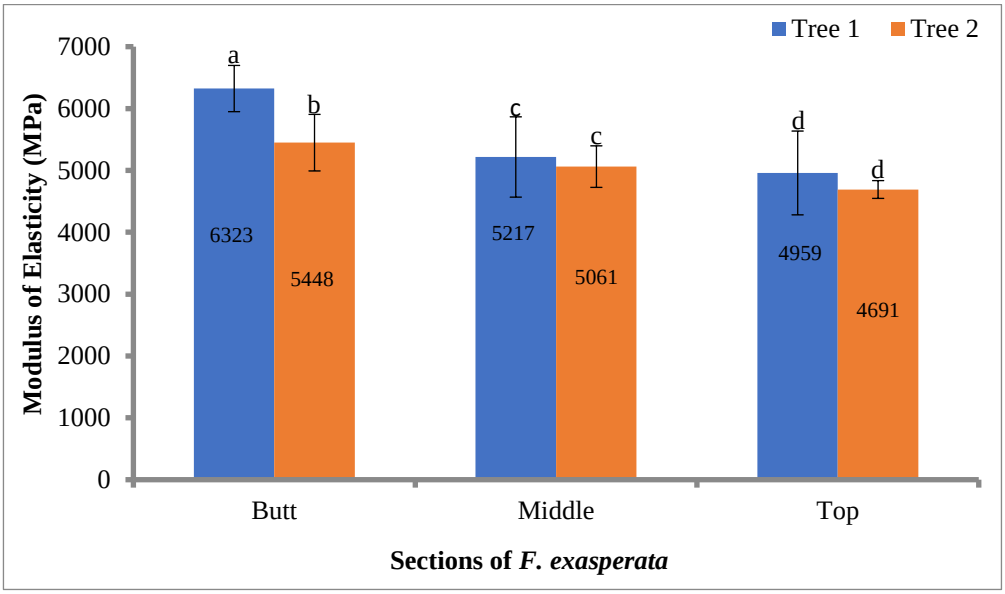


Figure 4: Modulus of Elasticity of wood from two *F. exasperata* trees.
NB: Bars with the same letter are not significantly different according to Turkey's multiple range tests.

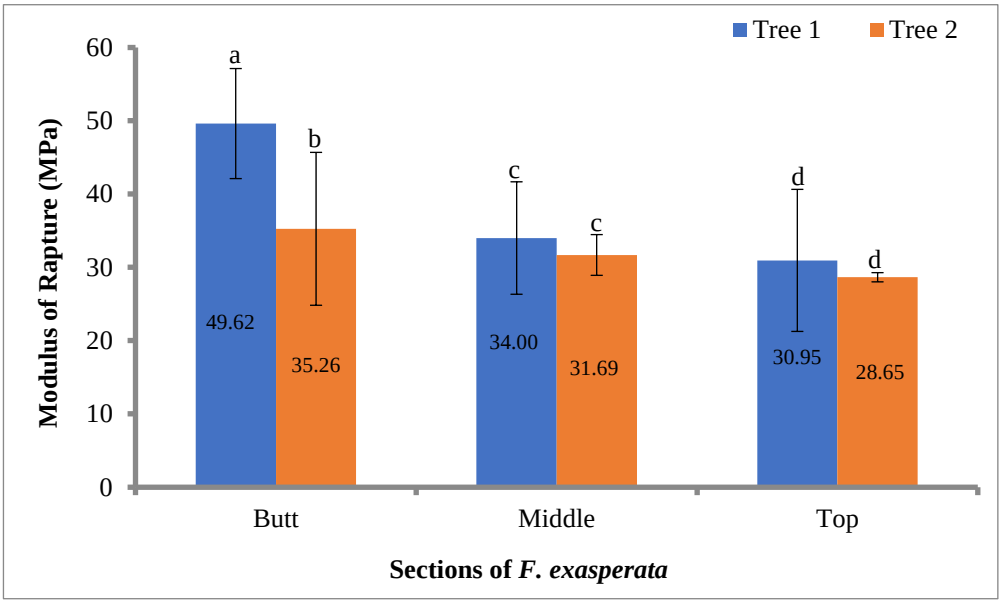


Figure 5: Modulus of Rupture of wood from two *F. exasperata* trees.
NB: Bars with the same letter are not significantly different according to Turkey's multiple range tests.

The average strength to weight ratio exhibited by *F. exasperata* timber obtained from tree 1 were 12.86 for MoE and 0.09 for MoR. Whereas that of tree 2 were 13.05 for MoE and 0.08 for MoR, which are considered to be high according to Sesan *et al.,* (2016). Hence, the strength properties of *F. exasperata* is significantly influenced by its density.

Compression Strength Parallel to Grain:

Ficus exasperata trees 1 and 2 recorded an average of 28.01 (3.81) N/mm^2 and 24.60 (2.20) N/mm^2 for compression strength parallel to grain test (Figure 6).

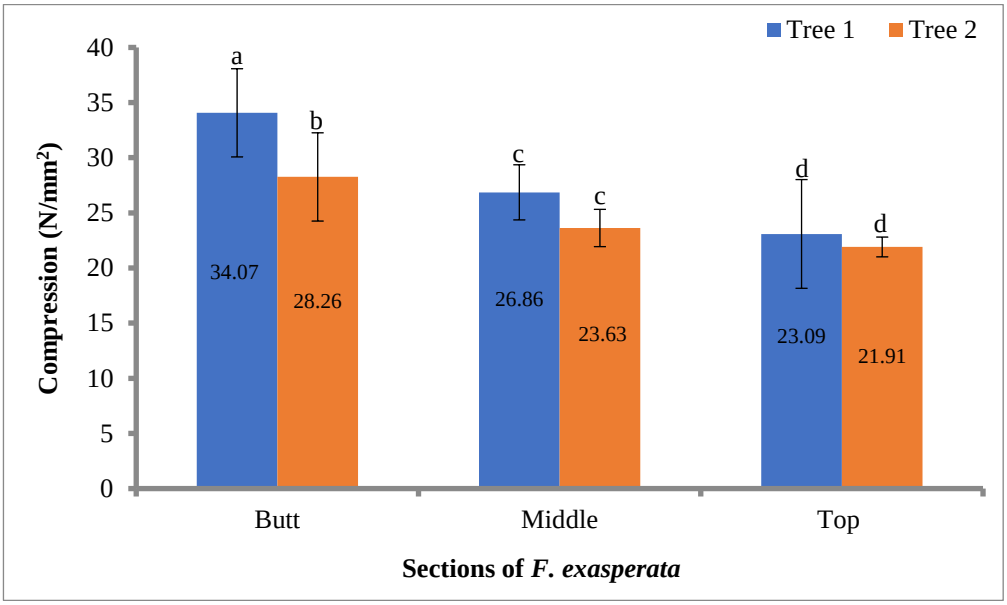


Figure 6: Compression strength parallel to grain of two *F. exasperata* trees.
NB: Bars with the same letter are not significantly different according to Turkey's multiple range tests

The current study showed that compression strength parallel to grain increases with age which was in accordance with the findings of Horáček *et al.,* (2018) in *Picea abies*/L./Karst; Yang *et al.,* (2022) in aged timber members. The increase in compression strength parallel to grain according to age may be as a result of variation in some morphological factor such as fibre length, wall thickness and diameter (Chowdhury *et al.,* 2012; Kiaei, 2013; Saravanan *et al.,* 2014).

Shear Strength Properties of *Ficus exasperata*

Blackham *et al.,* (2020) provided shear strength rating as exhibited in Table 6 for use in the classification of LKS/LUS in Ghana.

Table 6: Shear strength rating

Shear strength classification	N/mm²
Weak	4 – 9
Medium	10 – 15
Strong	16 – 19
Very strong	> 20

Source: BVRio 2020

The results obtained in Figure 7 indicate that *F. exasperata* is a weak wood recording a mean shear strength of 9.35 N/mm². Hence this specie has weak resistance to the internal slippage of one part on another along the grain. Similar species that are in utilization in the timber and pulp and paper industry include but not limited to spruce (6.2 N/mm²), balsam fir (4.6 N/mm²), and black walnut (8.4 N/mm²) as recorded by Kretschmann, (2010). The shear strength properties of timber can vary significantly depending on factors such as the species, growth conditions, age of the tree, wood density, and the specific characteristics of the wood fibres and structure Rocha *et al.,* (2019) and Zink-Sharp (2003).

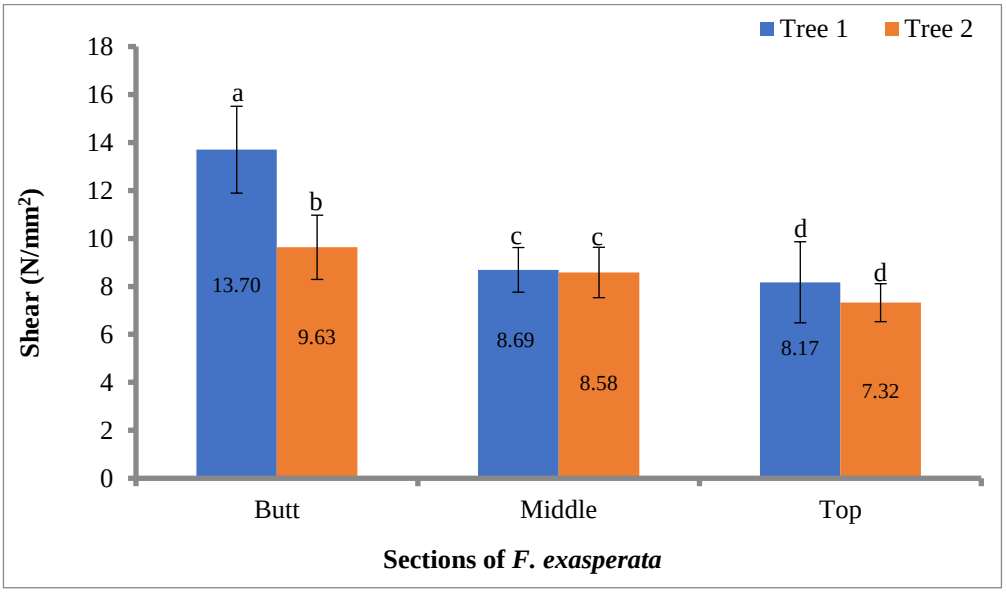


Figure 7: Shear strength of wood from two *F. exasperata* trees.

NB: Bars with the same letter are not significantly different according to Turkey's multiple range tests.

Derikvand *et al.,* (2019); Ofori *et al,* (2009); Saravanan *et al.,* (2014) have emphasised that shear strength parallel to the grain is an important property that comes into play in the structural use of timber in jointing and furniture production. The mean value of shear strength parallel to the grain on 120 samples of *F. exasperata* trees 1 and 2 were 10.19 N/mm^2 (1.48) and 8.51 N/mm^2 (1.06) respectively.

Hardness Properties of *Ficus exasperata*

This is generally defined as resistance to indentation using a modified Janka hardness test. Results presented Figure 8 are the average of radial and tangential penetrations.

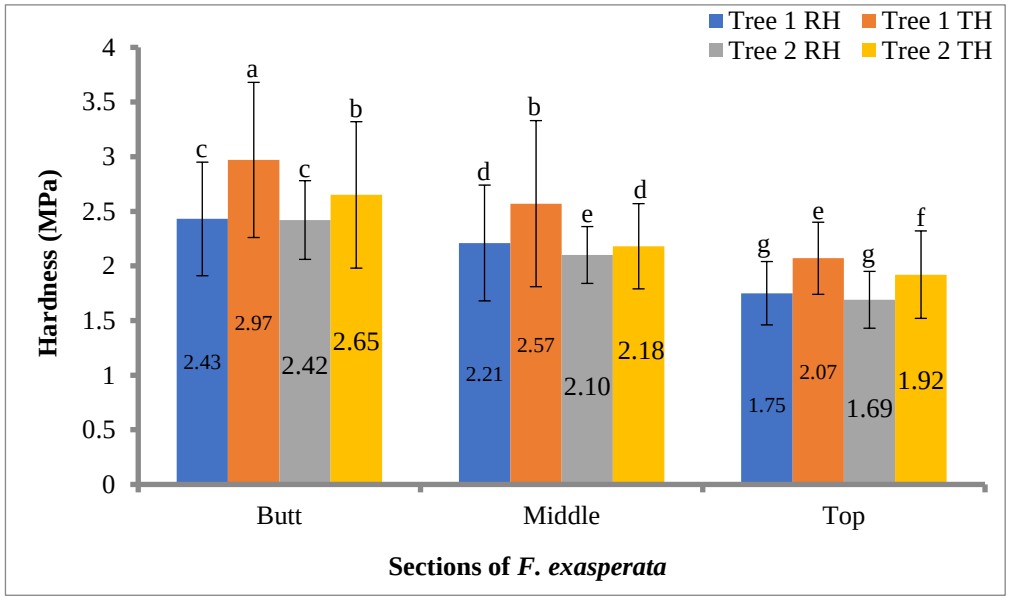


Figure 8: Radial (RH) and Tangential Hardness (TH) of two *F. exasperata* trees.

NB: Bars with the same letter are not significantly different according to Turkey's multiple range tests

Ficus exasperata tree 1 recorded 2.13 MPa (0.45) mean radial hardness and 2.54 MPa (0.60) mean tangential hardness, whereas tree 2 obtained 2.07 MPa (0.29) and 2.25 MPa (0.48) radial and tangential hardness respectively.

Different levels of hardness make certain types of timber more suitable for specific applications. For example, harder woods may be preferred for flooring or furniture where durability is a priority, while softer woods may be chosen for applications where flexibility or ease of carving is important.

Similarity of *Ficus exasperata* with other species

Comparatively, *F. exasperata* could be used in the areas of light construction, light carpentry, open boats, moulding, interior joinery, frames, boxes, crates, match sticks, pencils, sculptures, veneer and plywood, and particleboard, as it shares some common technological properties with *Alstonia boonei, Cola gigantea, Hannoa klaineana, Lannea welwitschii, Parkia bicolor* among other, which are already in use for those purposes (Table 6).

Table 6: Some industrial technological properties of *F. exasperata* with other timber species.

Species	Density (Kg/m^3)	MoE (N/mm^2)	MoR (N/mm^2)	Compression (N/mm^2)	Shear (N/mm^2)	Side hardness (N)	Classification (Density & Strength)
Ficus exasperata	336-482	4691-6323	28-50	21-34	7-14	1916-2965	Low & D30
Alstonia boonei	360-420	5790-10500	48-73	27-37	6-7	1820	Low & D30
Hannoa klaineana	350	3800-8200	44-53	15	--	1080	Low & D30
Lannea welwitschii	321-701	8356-12540	46-91	11-30	6-10	2450-3370	Low & D40
Parkia bicolor	460-630	9500-11600	35-126	34-44	6-7	2470	Low & D40

Sources: Owusu *et al.,* (2020)

Correlation Analysis of The Effect of Properties of *F. exasperata*

The correlation analysis was used to evaluate the association between the variables considered in this study. The relationship between these variables deserves expedient attention, as they contribute to the general technological properties that the timber industry depends on for the utilisation of timber species. Table 7 exhibit the Pearson product correlation results, which indicate that the relationship between density and modulus of elasticity (MoE), modulus of rupture (MoR), Compressive strength (Comp), Shear strength, radial hardness (RH) and tangential hardness (TH) was found to be moderately positive and statistically significant (r = 0.425 – 0.663; $p < 0.01$). This shows that an increase in density will lead to higher mechanical properties of *F. exasperata*. Chowdhury *et al.,* (2012) emphasized that density is the most important determinant of compressive strength and bending strength in timber. Whereas the

tree ages and sections (butt, middle and top) although were statistically significant ($p < 0.01$), but correlate weakly with density (r = -0.370 and -0.759). However, correlation was not significant in the relationship with density and the anatomical properties considered in this study, but there were positive correlations between fibre length (FL), fibre width (FW), lumen diameter (LD), vessel area (VA), vessel length (VL), vessel number (VN) and basic density. Cell wall thickness and cell dimensions were major factors in the variation of wood density (Chowdhury *et al.,* 2012). Double wall thickness (DWT) was negative but not significantly correlated with density. Similar results were obtained by Chowdhury *et al.* (2012), from the variation in anatomical properties and correlations with wood density and compressive strength in *Casuarina equisetifolia* growing in Bangladesh.

Table 7: Correlation coefficient array of the association between the properties of *F. exasperata* considered in this study.

	Tree_Portion	Tree_Age	MoE	MoR	Comp	Shear	RH	TH	Density	FL	FW	LD	DWT	VA	VL	VN
Tree_Sections	1															
Tree_Ages	0	1														
MoE	-.448**	-.224*	1													
MoR	-.520**	-.318**	.560**	1												
Com	-.677**	-.326**	.411**	.500**	1											
Shear	-.657**	-.345**	.474**	.555**	.658**	1										
RH	-.594**	-0.06	.260**	.274**	.346**	.320**	1									
TH	-.532**	-0.141	.419**	.399**	.454**	.525**	.288**	1								
Density	-.759**	-.370**	.425**	.537**	.545**	.663**	.484**	.512**	1							
FL	-0.252	.c	0.068	-0.032	0.139	0.114	0.074	0.104	0.199	1						
FW	0.015	.c	-0.14	-0.023	0.049	0.013	0.105	0.036	0.164	0.077	1					
LD	-0.05	.c	-0.117	0.043	0.046	0.062	0.121	0.035	0.271	0.034	.970**	1				
DWT	0.247	.c	-0.125	-0.251	0.025	-0.18	-0.031	0.017	-0.353	0.182	.402*	0.165	1			
VA	0.343	.c	-0.177	-0.163	-.374*	-.382*	0.239	-0.135	0.019	0.028	0.253	0.266	0.027	1		
VL	0.345	.c	-0.18	-0.166	-.376*	-.383*	0.237	-0.139	0.013	0.027	0.254	0.266	0.028	1.000**	1	
VN	0.211	.c	-0.199	-0.176	-0.335	-0.227	0.219	-0.246	0.094	0.112	0.201	0.22	-0.01	.754**	.754**	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed). c. Cannot be computed because at least one of the variables is constant. Legend: MoE = Modulus of Elasticity; MoR = Modulus of Rupture; Comp = Compressive strength; RH = Radial hardness; TH = Tangential hardness; FL = Fibre length; FW = Fibre width; LD = Lumen diameter; DWT = Double wall thickness; VA = Vessel area; VL = Vessel length; VN = Vessel number.

CONCLUSION

The study investigated the some anatomical, physical and mechanical properties of *Ficus exasperata.* The anatomical properties exhibited by the species show that they are similar to the other regularly used timber species in the market. It should be appreciated that the fibres and the vessels of *Ficus exasperata* trees exhibited properties suitable for utilisation in fibre, pulp and paper industry. The densities increase with an increase in age. All the mechanical

properties tested increase with increase in age. The results obtained for the physical and mechanical properties of *Ficus exasperata* indicate that the species could be used for industrial purposes as does the commercial timber in the market today. Thus, contributing to the sustainable utilization of the available forest resources. The evaluation of decay resistance properties of *F. exasperata* timber therefore becomes very essential, in order to enhance its utilization.

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Author's Contribution

Prosper Mensah wrote the Introduction, Materials and Methods, Results and Discussion. He also performed the statistical part of the paper, including all analyses of data. Francis Wilson Owusu designed the whole study. Joshua Kwasi Adzigodie did all the anatomical measurements. Felix Boakye did all the practical work related to the mechanical property determination. Emmanuel Minkah did the data organization and proof reading of the manuscript.

Conflict of Interest Disclosure

The authors certify that there is no conflict of interest whatsoever with any organization regarding the materials discussed in this manuscript.

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