Properties of African Mahogany Wood Commercially Available in the United States

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Abstract

The wood of African mahogany (*Khaya* spp.) is known for its high quality and similarity to the more expensive Brazilian mahogany (*Swietenia macrophylla* King). Interest in African mahogany has been increasing because of the reduced availability of native Brazilian mahogany, which has become illegal to harvest. Most African mahogany comes from managed plantations, so the increased consumption of this wood helps to alleviate issues related to illegal harvesting by reducing the trade of Brazilian mahogany. African mahogany has also been gaining popularity in the United States, particularly for use in the wood flooring market. However, there is lack of technical information on the properties of African mahogany material available in the US market, therefore, the objective of this work was to describe anatomical features, evaluate physical–mechanical properties and examine natural resistance of African mahogany wood that is commercially available in the US market. The results of this research provides an increase in knowledge on African mahogany wood properties, natural resistance, and provides technical information that is needed by industry.

Wood is widely used in several applications and the study of specific properties of wood such as anatomy, physical–mechanical properties, and decay resistance are important factors in predicting product quality and best potential end uses for each species (Panshin and DeZeeuw, 1980). African mahogany, which is native to the West Coast of Africa, is a group of high-value hardwoods comprising three main species, *Khaya ivorensis* A. Chev., *Khaya senegalensis* (Desr.) A. Juss. and *Khaya anthotheca* (Welw.) C. DC. (Bartsch 1958; Kukachka 1969). The genuine mahogany (*Swietenia macrophylla* King) naturally occurs in Brazil, and although African mahogany is not as dimensionally stable, the wood is very similar in color and grain to genuine mahogany (*Swietenia macrophylla* King) and, apart from *Swietenia*, *Khaya* is the only genus accepted in the market as genuine mahogany (Koehler 1922).

In 2003, the Convention on International Trade in Endangered Species (CITES Secretariat 2003) added *S. macrophylla* to the list of endangered species, to ensure that natural occurrence of mahogany is maintained (Grogan et al. 2002). Since then, African mahogany has been gaining in popularity; and in the United States, a drastic increase in sales has been noted not only because it is similar in quality to true mahogany, but also owing to a lower price, higher supply, and legal species status in the market.

Unlike African mahogany, plantation-grown *S. macrophylla* is not practical, particularly because this species is extremely susceptible to a lepidopteran shoot borer, *Hypsipyla grandella* Zeller (Castro et al. 2016). This insect causes substantial damage to seedlings and young trees, which results in a low bifurcation and consequently production of wood with little to no commercial value (Bauer and Francis 2000, Grogan et al. 2002). Commercial plantations of *S. macrophylla* are not a viable option because of the damage caused by *H. grandella* and additional cost associated with pest management.

Thus, as a result of the high demand for mahogany wood and a lack of genuine mahogany plantations, a need for a suitable substitute for genuine mahogany has emerged. In order to meet this demand, wood from forest plantations represents the most viable renewable resource. African mahogany is a highly desirable species for plantations because it grows fast and produces high-quality wood and is not susceptible to the borer (Stephen et al. 2016). This has led to increased interest in commercial plantations of African mahogany in Brazil. Previous studies have demonstrated the quality of wood from experimental plantations (França et al. 2015, 2016, 2019), and this wood material is already reaching the US lumber market.

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Table 1.—Anatomical characterization (mean values) of African mahogany specimens.

Samples	1	2	3	4	5	6
Vessel diameter (μm)	83	115	100	79	92	118
Vessel/mm^2	8	6	9	6	8	9
Ray width (no. of cells)	4	3	4	5	6	3
Rays/mm	7	5	6	4	7	7
Fiber lumen/double wall ratio	1.1	2.6	2.2	1.4	1.2	1.9

Therefore, the objective of this study was to evaluate the properties of plantation-grown African mahogany wood currently available in the US market.

Materials and Methods

Sample collection and preparation

African mahogany lumber used in this study was commercially available in the United States, originally sourced from commercial plantations located in the northern part of Brazil. The obtained lumber was rough sawn, and then planed and processed into samples of various sizes for anatomical characterization, physical–mechanical, and degradation tests.

Anatomical characterization

Six samples were selected for examination of their anatomical features. The anatomical features definitions and data collection procedures followed the standard description of wood features as outlined by the International Association of Wood Anatomists – IAWA (Wheeler et al. 1989).

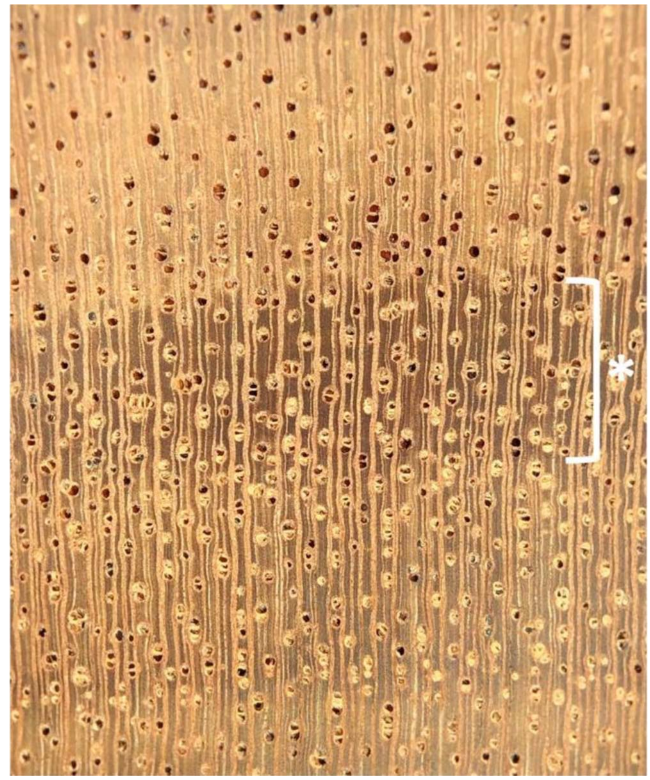

Figure 2.—Macroscopic image of Khaya *sp. Growth rings delineated by a darker zone of fibrous tissue (*). Note the vessel porosity (diffuse-porous), arrangement (radial pattern), and grouping (multiples of two to three). Rays of distinct widths.*

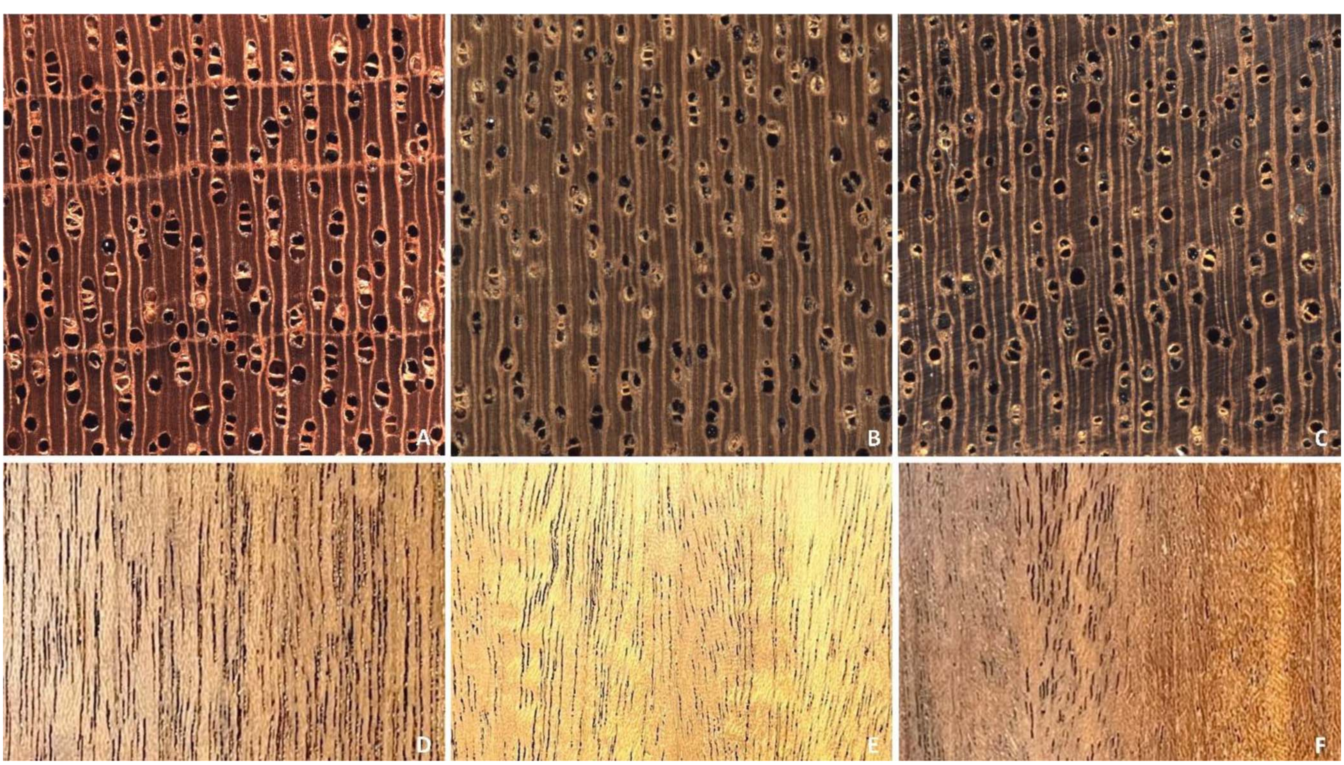

Figure 1.—Comparative images of (a) Swietenia macrophylla; *(b)* Khaya ivorensis; *and (c)* Khaya senegalensis. *(A, B, C) macroscopic image of the transverse plane. (D, E, F) picture of the longitudinal plane, respectively.*

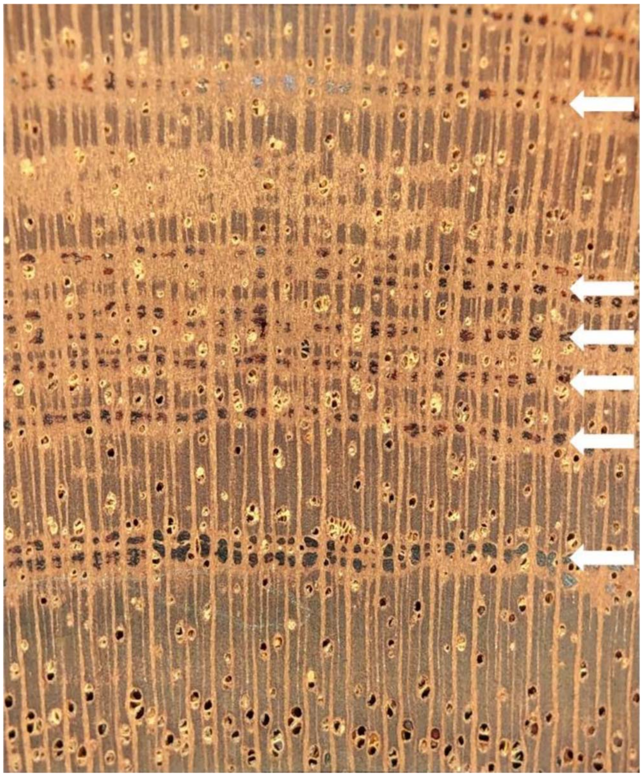

Figure 3.—Macroscopic image of Khaya *sp. Showing intercellular canals of traumatic origin arranged in well-defined concentric lines (arrows).*

The transverse plane of each sample was sanded using 800-grit sandpaper to reveal the anatomical features. Sanded surface samples were only for macroscopic pictures and not for macro for measurements. On a macroscopic level, a 10× hand lens was used to examine the distribution, size, and arrangement of vessels, parenchyma, and rays. Additionally, other features outlined by Wheeler et al. (1989) were observed, such as the presence of deposits in the vessels and the existence of intercellular canals of traumatic origin. Macroscopic images were obtained using a XyloPhone (Wiedenhoeft 2020).

Transverse, radial, and tangential sections (20 μm thick) were prepared using a Spencer 860 sliding microtome. During sectioning, the surface of the sectioning block was wetted with a 50 percent solution of glycerin in an aqueous solution. The sections were stained with 1 percent safranin in aqueous solution and mounted on glass slides in a 50 percent glycerol aqueous solution.

Microscopic images of the observed features were captured at various magnifications using a ProgRes Speed XT core camera mounted on a Nikon eclipse E600 light microscope. Feature measurements were performed using ImageJ software (Rasband 2004). For vessel lumen diameter, 100 vessels were measured from each sample along the radial direction on the transverse section. Vessel frequency was determined by counting vessels per square mm in at least 20 fields. Fiber lumen diameter and wall thickness were measured along the radial direction on the transverse section, with 40 fibers measured for each sample. Ray frequency, defined as rays per mm, was determined on the tangential section, with 20 measurements taken for each sample.

Physical and mechanical properties

After anatomical features were measured, African mahogany samples were cut into physical and mechanical properties specimens according to ASTM D-143 (ASTM 2022). Prior to testing, each sample was weighed and measured, then dried. Physical properties tested included moisture content (MC), density and total shrinkage (radial and tangential). Mechanical properties tested included bending, compression parallel and perpendicular to grain, and Janka hardness parallel and perpendicular. The mechanical tests were performed on an Instron universal testing machine controlled using Bluehill 3 software.

For MC, density and total shrinkage specimens measured 50 by 50 by 150 mm were prepared following the procedures of ASTM D-143 (ASTM 2022). A caliper was used to measure sample dimensions, and ovendried weights (dried at 103°C) were recorded after constant mass was attained.

Samples for static bending measured 50 by 50 by 760 mm following the procedures outlined in the ASTM D-143 (ASTM 2022). A deflectometer (at midspan) synchronized with the

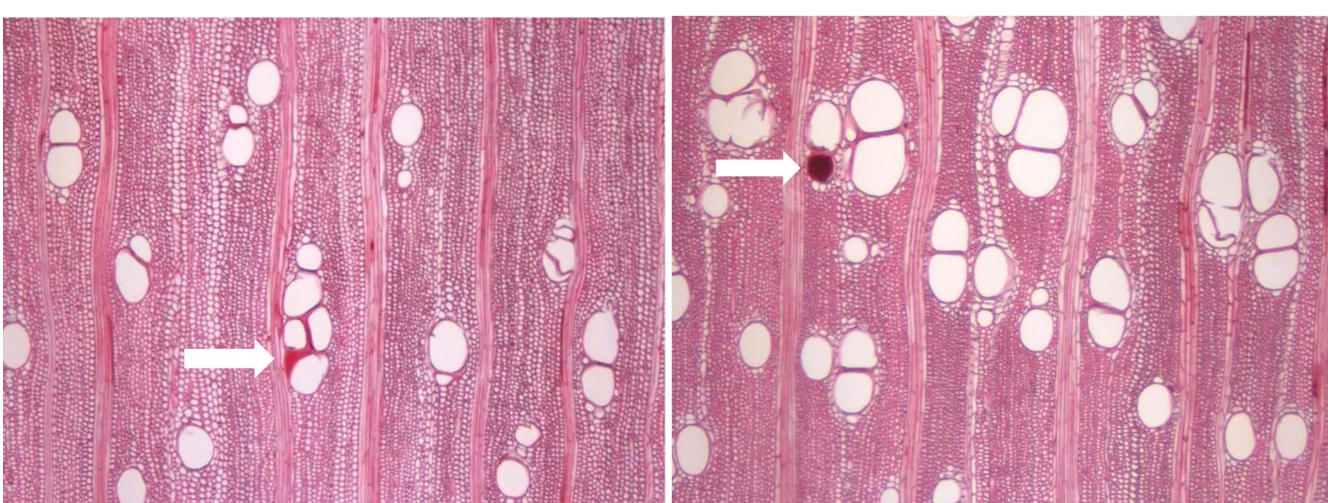

Figure 4.—Transverse section of Khaya *sp. Vessels solitary and in short radial groups of 2 to 4. Dark red content present in some vessels (arrows). Axial parenchyma scanty paratracheal. (Scale bar 100 μm).*

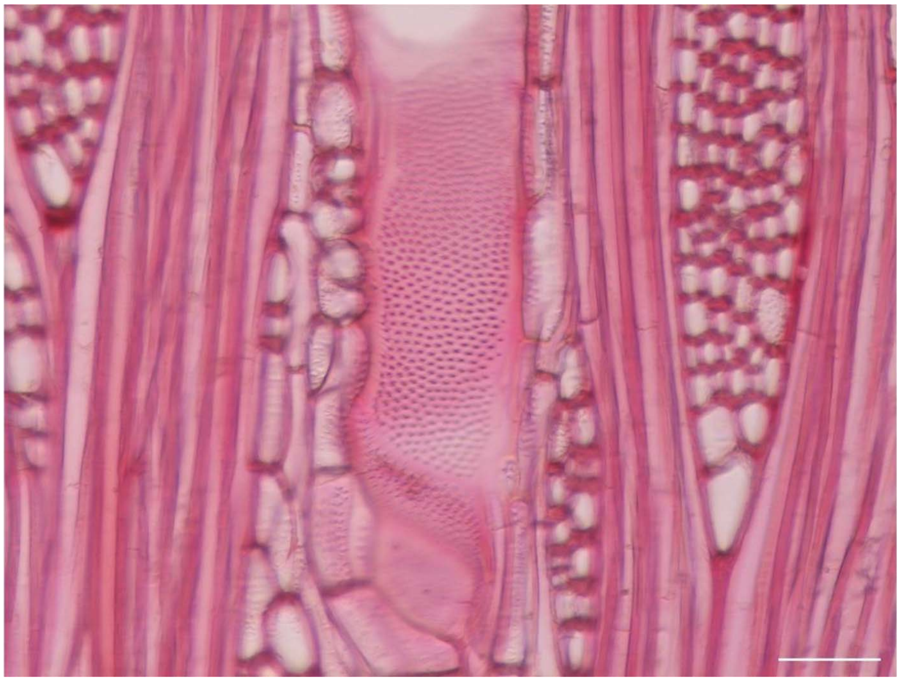

Figure 5.—Tangential section of Khaya *sp. Intervessel pits minute, round, or irregularly polygonal. Fibers thin- to thick-walled, usually septate. (Scale bar 50 μm).*

load in the elastic range to determine modulus of elasticity (MOE) and the maximum load was used to calculate modulus of rupture (MOR). Specimens used for compression parallel, compression perpendicular, and Janka hardness measured 50 by 50 by 200 mm (ASTM D-143; ASTM 2022).

Biodegradation tests

To determine the resistance of African mahogany to fungal decay the AWPA E10 (AWPA 2020) standard test procedure was used. Specimens were exposed to the brown-rot fungus *Gloeophyllum trabeum* MAD-617, or the white-rot fungus, *Trametes versicolor* MAD-697. Control samples consisted of southern pine sapwood (*Pinus* spp.) or sweetgum (*Liquidambar styraciflua* L.) sapwood for brown- and white-rot fungi, respectively. Twenty-five blocks of African mahogany were exposed to each fungus for 12 weeks. At the end of the tests, all samples were removed from the bottles, brushed free of mycelium, and oven-dried. Initial and final weights were recorded when specimens reached a constant mass and used to calculate percent mass loss.

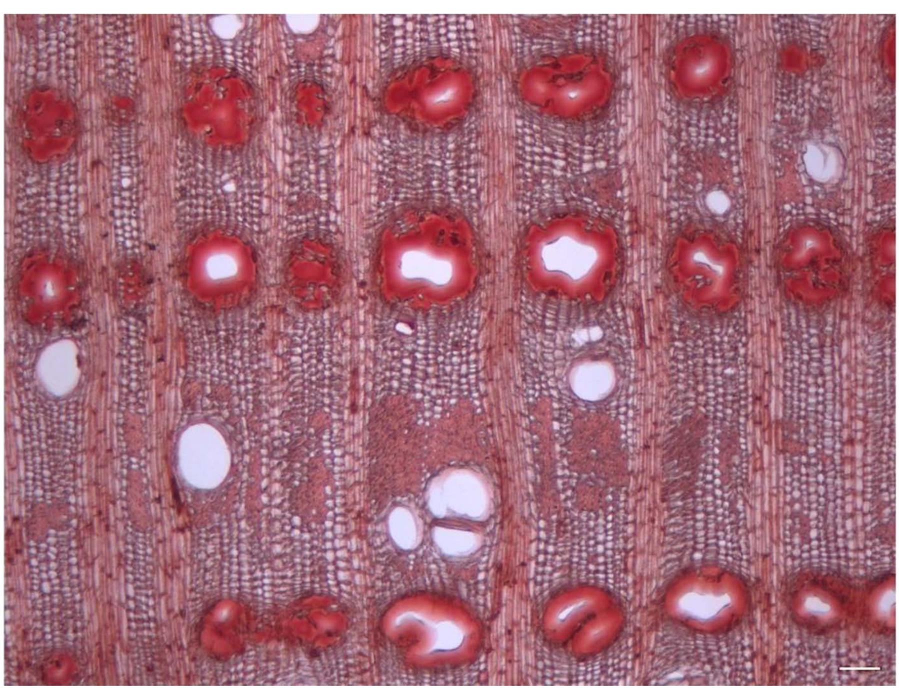

Figure 6.—Transverse section of Khaya *sp. showing traumatic gum canals in tangential rows. (Scale bar 100 μm).*

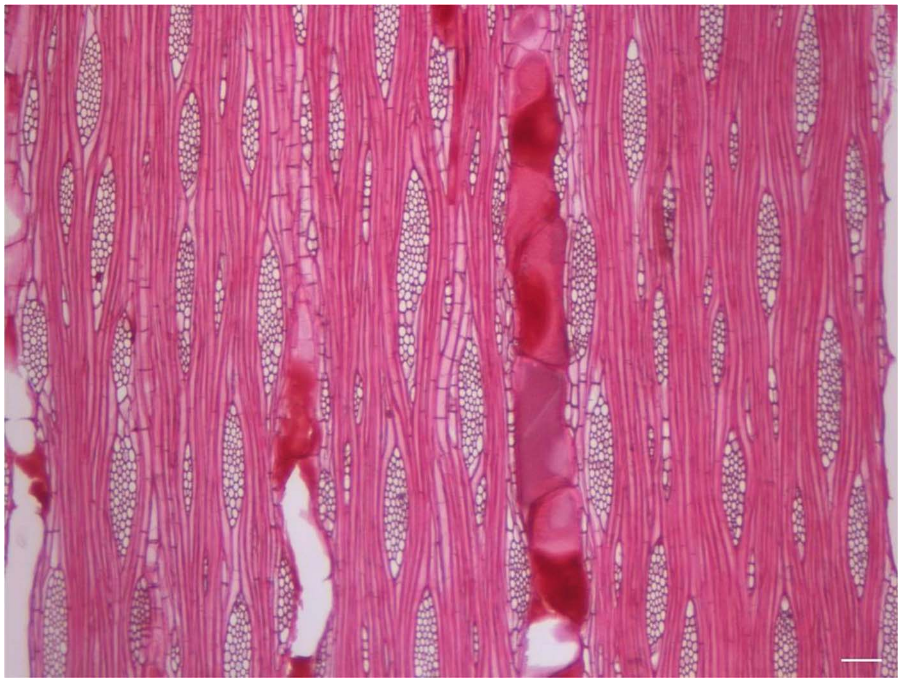

Figure 7.—Tangential section of Khaya *sp. Fibers thin- to thick-walled, usually septate. Dark red content present in some vessels. Note rays of different widths. (Scale bar 100 μm).*

No-choice termite testing was conducted according to AWPA E1 (AWPA 2020). Ten African mahogany specimens were exposed to feeding by subterranean termites, *Reticulitermes* spp. Five specimens of southern yellow pine were used as controls. Samples were exposed for a total of 28 days. Initial and final mass was measured to determine percent mass loss.

Statistical analysis

SAS version 9.4 (SAS 2013) was used to perform the statistical analysis. Descriptive statistics of each test and mass loss for each xylophagous agent were obtained. Mean, median, and coefficients of variation (COV) were calculated for all variables tested.

Results and Discussion

Anatomical characterization

A summary of the anatomical features expressed as means evaluated are shown in Table 1. Figure 1 shows macroscopic comparison of African mahogany and genuine mahogany. Results showed the following characteristics: heartwood light to dark reddish brown, often with a purplish cast; odorless; fine-textured; straight to interlocked grain. Growth rings fairly distinct, occasionally delineated by a darker zone of fibrous tissue (Fig. 2). Wood diffuse-porous with vessels solitary or in short radial groups of two to three surrounded by vasicentric axial parenchyma (Fig. 2). Rays of two sizes, the larger distinctly visible with the naked eye and the smaller barely visible with a 10× hand lens (Fig. 2). Ripple marks absent. Intercellular canals of traumatic origin sometimes present, arranged in well-defined concentric lines in the transverse section (Fig. 3).

Microscopic characteristics of the wood

Vessels solitary and in short radial groups of 2 to 4, occasionally in tangential rows of 2 to 3; vessels round or slightly oval, 2 to 15 (avg. 7.5) per mm^2, diameter ranging from 24 to 198 (avg. 97) μm (Fig. 4); tyloses absent; dark reddish-brown to black contents present in some vessels (Fig. 4). Perforations simple, round, horizontal or nearly so (not shown); intervessel pits very numerous, crowded, minute, round, or irregularly polygonal (Fig. 5). Fibers thin- to thick-walled, lumens 2 to 24 μm in diameter and cell walls 1.3 to 8.5 μm thick, sometimes septate (Fig. 5). Parenchyma paratracheal scanty to vasicentric; in areas with traumatic gum canals (Fig. 6), axial parenchyma

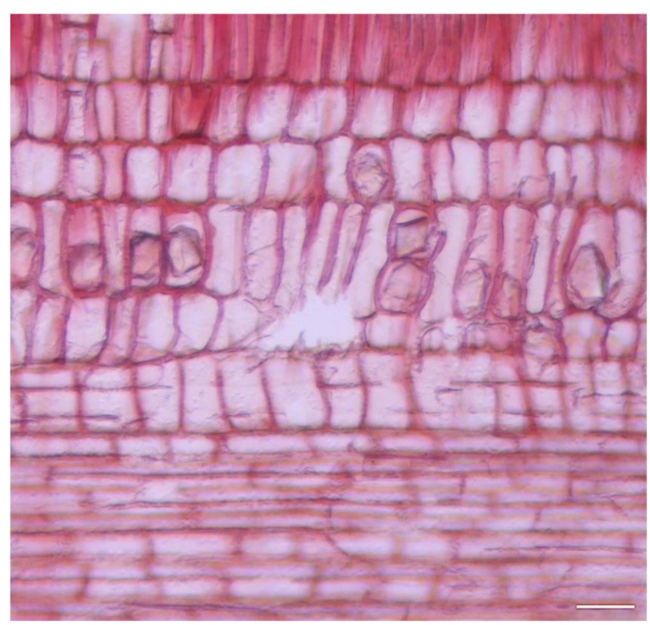

Figure 8.—Radial section of Khaya *sp. showing a heterogeneous ray with five square and upright cells at the margin. Rhomboid crystals present in the square and upright cells. (Scale bar 50 μm).*

Table 2.—Summary of physical properties measured in African mahogany specimens at dry conditions. Max. is maximum, Min. is minimum, and COV (%) is coefficients of variation.

Physical property	*N*	Mean	Min.	Max.	COV (%)
Moisture content (%)	34	6.79	6.38	7.08	2.70
Density (kg·m^{-3})	34	649	521	722	8.44
Total shrinkage (%)					
Radial	34	5.97	2.10	11.69	36.49
Tangential	34	6.76	1.55	10.49	27.07
Tangential/radial	34	1.35	0.13	3.29	53.36

is more abundant. Rays 2 to 10 per mm, nonstoried, of 2 sizes: large rays 6 to 10 (mostly 6) seriate, distinctly heterogeneous, with 1 to5 square or upright cells at each end of the rays forming a long, attenuated tip; small rays 1 to 3 (mostly 1 to 2) seriate (Fig. 7); rhomboid crystals present in the square and upright cells (Fig. 8).

Based on the comprehensive analysis of the anatomical features observed, the lumber obtained for this study appears to be composed of a mixture of *Khaya* species. This adds complexity to the interpretation of the results. The samples exhibited variation in vessel diameter, fiber lumen/double wall ratio, and ray width in number of cells. There are samples with smaller vessel diameters, smaller fiber lumen/double wall ratios, and wider rays; whereas, others have larger vessel diameters, greater fiber lumen/double wall ratios, and narrower rays. Donkor (1997) argues that certain anatomical features are unsuitable for differentiating species because of their lack of statistical significance or significant variation from juvenile to mature wood. However, this author found that the fiber lumen/wall ratio could be used to differentiate four *Khaya* species. It is important to consider the geographical context of the samples. Donkor (1997) focused on trees from Forest Districts in Ghana, whereas the samples in this study originated from plantations in Brazil. Environmental factors such as climate, soil, and topography can influence wood anatomy, so attempting to identify the samples at the species level was not pursued further in this study.

Table 3.—Summary of mechanical properties measured in African mahogany specimens at dry conditions.

Mechanical properties[a]	*N*	Mean	Min.[b]	Max.[c]	COV[d] (%)
Static bending (MPa)					
MOE	31	6.367	4.073	8.001	13.97
MOR	31	55.93	7.89	78.59	28.58
Compression (MPa)					
Parallel	33	54.18	32.24	66.49	15.07
Perpendicular	33	20.99	11.83	34.35	25.01
Janka hardness (kN)					
Radial	37	8.70	5.09	14.10	25.13
Tangential	37	8.95	5.04	18.09	30.14

[a] Modulus of elasticity (MOE) and modulus of rupture (MOR).
[b] Minimum.
[c] Maximum.
[d] Coefficients of variation.

Furthermore, interlocked grain and traumatic gum canals were observed in some samples. Interlocked grain refers to the irregular alignment of wood fibers, occurring when the direction of the fibers deviates from the longitudinal axis, resulting in a twisting or interlocking pattern. Traumatic gum canals are anatomical structures formed in response to mechanical injury or stress, serving as conduits for the transportation of gum or resin and thus providing a defense mechanism against further damage or infection. The association between interlocked grain and traumatic gum canals has been well-documented in previous studies. Dünisch and Baas (2006) reported that these

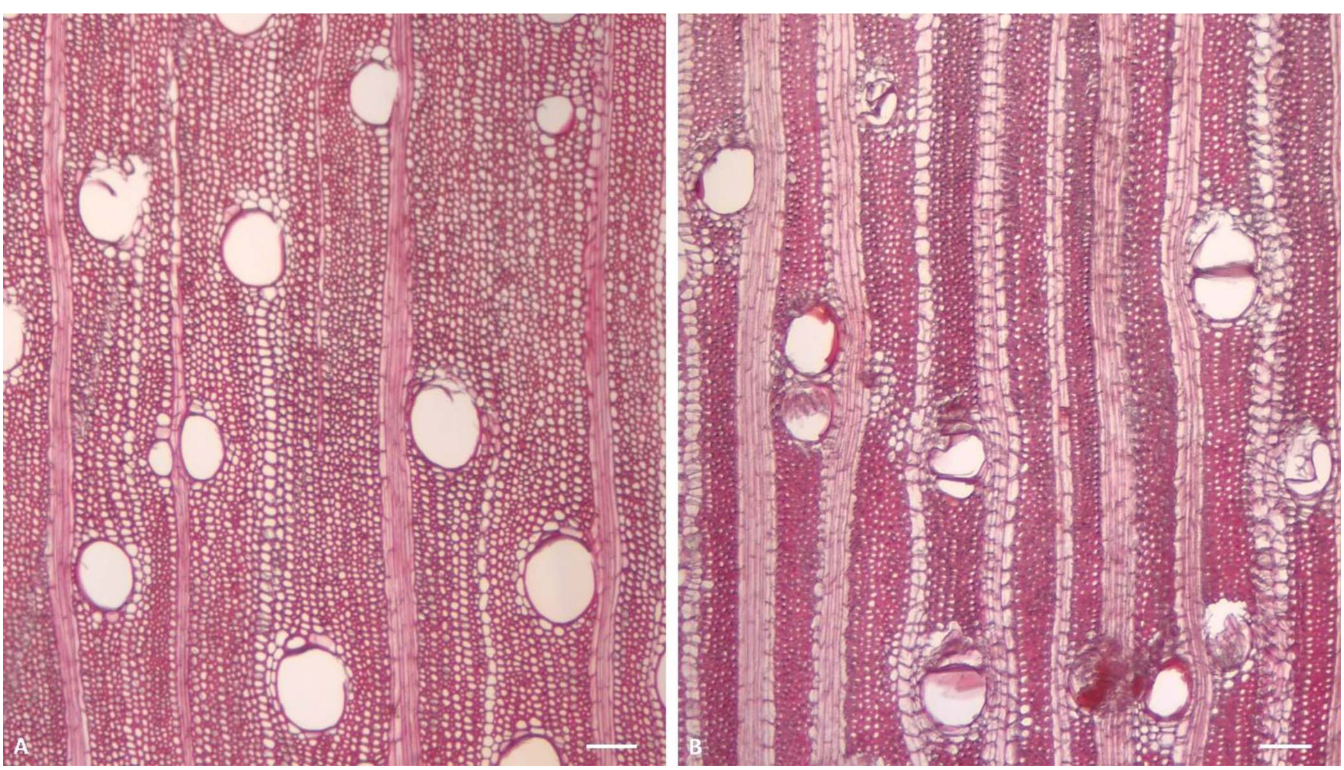

Figure 9.—Comparative images of a less dense African mahogany specimen (a) and a denser specimen (b). Note that in B the fiber cell walls are thicker. (Scale bar 100 μm).

Table 4.—Means, maximum, minimum, and coefficients of variation (COV%) values for African mahogany and control wood species exposed to subterranean termites and decay fungi.

Biological agent	Termite (*Reticulitermes* spp.)		Brown-rot (*Gloeophyllum trabeum*)		White-rot (*Trametes versicolor*)	
Species	African mahogany	Southern yellow pine	African mahogany	Southern yellow pine	African mahogany	Sweetgum
Average mass loss (%)	3.92	85.64	2.88	57.39	1.24	49.62
Maximum (%)	4.79	97.60	4.49	59.92	1.79	61.16
Minimum (%)	3.38	78.54	1.57	54.89	0.87	38.42
COV (%)	0.41	6.62	0.51	1.75	0.26	8.14
Visual grading[a]	9.5	0	HR	NR	HR	NR

[a] Classes of decay resistance based on ASTM D2017 (ASTM 2012) categories. HR: highly resistant; R: resistant; RM: moderately resistant; NR: not resistant. Classes of termite resistance based on AWPA E1–10 categories (AWPA 2020). 10: Sound; 9.5: Trace, surface nibbles permitted; 9: Slight attack, up to 3 percent of cross-sectional area affected; 8: Moderate attack, 3 to 10 percent of cross sectional area affected; 7: Moderate-to-severe attack, penetration, 10 to 30 percent of cross-sectional area affected; 6: Severe attack, 30 to 50 percent of cross-sectional area affected; 4: Very severe attack, 50 to 75 percent of cross-sectional area affected; 0: Failure

features can be related to the presence of high internal growth stresses within tree species in the Meliaceae.

Physical and mechanical properties

The values obtained on the physical properties of African mahogany are presented in Table 2. The primary use of African mahogany wood is for indoor applications such as flooring, decorative furniture, boats and boat components, vehicle bodies, and decorative veneer for plywood (Stephen et al. 2016). To simulate the conditions of use, samples used in this study were equilibrated under 60°C and 35 percent relativity humidity, which corresponds to an equilibrium moisture content of 5.7 percent (Forest Products Laboratory 2021). This MC helped to mimic the final application where African mahogany wood is likely to be used.

Figure 10.—African mahogany (top) and southern yellow pine control samples (bottom) after exposure to subterranean termites.

Figure 11.—African mahogany (top) and southern yellow pine control samples (bottom) after exposure to the brown-rot fungus, Gloeophyllum trabeum.

Wood is an anisotropic material, showing different properties in each direction; therefore, dimensional stability is an important measurement when using wood (Rowell and Banks 1985). African mahogany wood is a strong potential substitute for the genuine mahogany (*S. macrophylla*; Aróstegui 1975, Acevedo and Kikata 1994), so it is important to evaluate shrinkage and swelling properties. The average value for total shrinkage in the radial direction was 5.97 percent, and in the tangential direction, mean value was 6.76 percent. The values reported in the Wood Handbook (Forest Products Laboratory 2021; 2.5% in radial and 4.5% in tangential) were lower than the values found in this study. França et al. (2016) also reported lower total radial shrinkage for *K. ivorensis* and *K. senegalensis* (3.39% and 3.11%, respectively) and tangential for *K. ivorensis* (5.58) and *K. senegalensis* (5.57%).

Another important variable when studying dimensional stability is the tangential to radial shrinkage ratio (T/R), because the closer the T/R value is to 1, the more stable the wood is and the less likely it is to warp (Arévalo and Hernandez 2001). Durlo and Marchiori (1992) grouped wood species according to T/R ratio, where species with T/R from 1.2 to 1.5 are classified as excellent, 1.5 to 2.0 as medium; and >2.0 as not stable. According to these values, genuine mahogany is classified under the excellent category. The T/R value found is this study was 1.35 (Table 2), which also falls under the excellent classification. Arévalo and Hernandez (2001) observed similar T/R value of 1.39 for genuine mahogany (*Swietenia macrophylla*).

The average density for African mahogany was 649 kg·m^{-3}, with values ranging from 521 to 722 kg·m^{-3} (Fig. 9). The African mahogany from this study has medium density (500 to 720 kg·m^{-3}) according to the classification proposed for Amazonia woods by Marques (1997), and moderately heavy (between 500 and 800 kg·m^{-3}) according to the classification proposed by Wong (2002) for evaluating Malaysian timber. The density values found in this study are higher than those found by França et al. (2016) *K. ivorensis* (491 kg·m^{-3}) and *K. senegalensis* (588 kg·m^{-3}) planted in Brazil. Appiah-Kubi et al. (2016) report the densities of African mahogany wood from natural forest (509 kg·m^{-3}) and plantation (539 kg·m^{-3}). The density value of this research was also higher than density values (480 kg·m^{-3}) reported by Lemmens (2008) for *K. ivorensis* planted in Republic of Cameroon. The results of this study were similar to the ones found by Zbonak et al. (2010) and Armstrong et al. (2007) for *K. senegalensis* (670 kg·m^{-3} and 630 kg·m^{-3}, respectively).

Table 3 presents mechanical values obtained for African mahogany. Mean values for MOE and MOR were 6.367 MPa

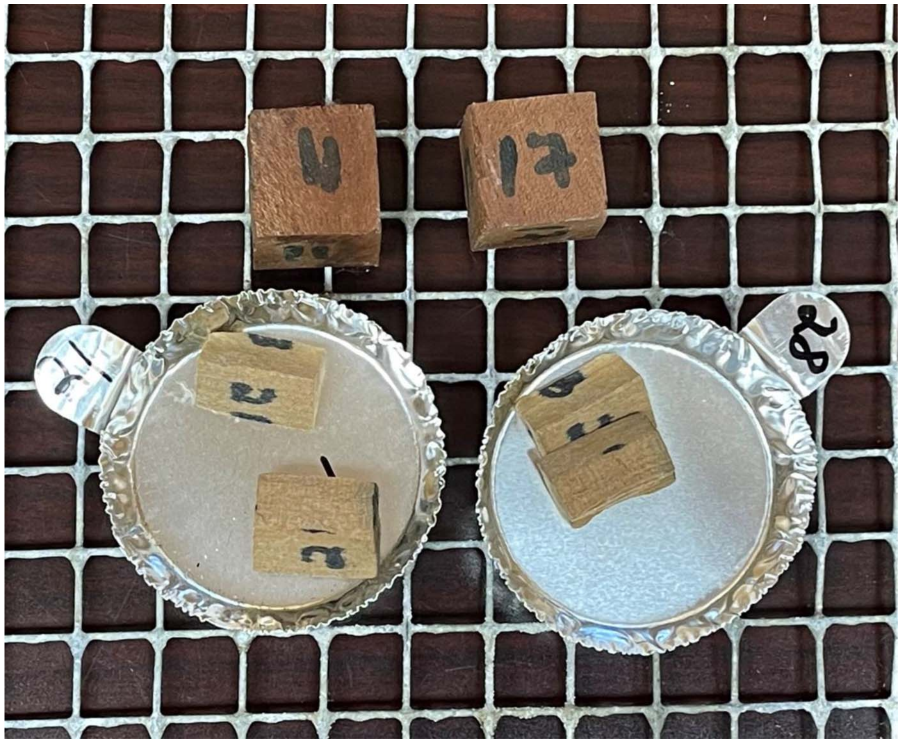

Figure 12.—African mahogany (top) and sweetgum control samples (bottom) after exposure to the white-rot fungus, Trametes versicolor*.*

and 55.93 MPa, respectively. Appiah-Kubi et al. (2016) examined the mechanical properties of planted African mahogany and found higher MOE (7,663.00 MPa) and MOR (65.48 MPa) at 12%MC. The values found by França et al. (2016) for African mahogany planted in Brazil were higher for MOE (9.875 MPa) and MOR (80.80 MPa), as well.

The average value for compression parallel and perpendicular to grain found in the present study was 54.18 MPa and 20.99 MPa, respectively. The compression parallel presented in the Wood Handbook (Forest Products Laboratory 2021) at 12%MC for *Khaya* spp. is lower (46.70 MPa) than the one found in this study.

The Janka hardness for African mahogany in radial was 8.70 kN and in tangential was 8.95 kN, which were higher in both radial (3.49 kN) and tangential (3.65 kN) than the values found for African mahogany traded in Ghana reported by Stephen et al. (2016).

When comparing African mahogany with the genuine mahogany observed by Kukachka (1969), genuine mahogany was higher in MOE (10.61 MPa), MOR (81.36 Mpa), Janka hardness tangential (4.58 kN), and radial (3.55 kN). However, genuine mahogany was lower in compression parallel (46.19 MPa) and perpendicular (8.07 MPa) when compared with the genuine mahogany.

Degradation tests

The natural resistance values for African mahogany specimens exposed to subterranean termites and wood rot fungi are shown in Table 4. African mahogany wood from this study was found to be highly resistant to termite attack. The average mass loss was very low (3.92%), while control SYP wood was much higher with an average mass loss of 85.64 percent. Visual ratings of African mahogany specimens did show some surface nibbles resulting in an average visual rating of 9.5, while control SYP specimens failed, receiving an average visual rating of 0. Examples of African mahogany and control wood samples after exposure to subterranean termites are shown in Figure 10. In another study examining natural resistance to termite feeding of African mahogany from an experimental plantation in Brazil, França et al. (2016) found higher mass loss values for both sapwood (12.9%) and heartwood (4.2%) compared with the values reported in this study. Armstrong et al. (2007) similarly classified African mahogany wood as highly resistant against termite damage.

Fungal decay results on African mahogany and control samples are shown in Figures 11 and 12 for brown- and white-rot fungi, respectively. These results show a similar trend to the termite tests with only slight weight losses observed in African mahogany wood. Average mass loss after exposure to brown- and white-rot was 2.88 percent, and 1.24 percent, respectively. The average mass loss found for control samples was 57.39 percent for SYP (brown-rot fungi) and 49.62 percent for sweetgum (white-rot fungi). Based on the classification provided in ASTM D2017 (ASTM 2012), African mahogany can be classified as a highly resistant wood species against both fungi studied.

The results from the present study are comparable to results from other authors evaluating the decay resistance of *Khaya* spp. For example, Reilly and Robertson (2006) classified African mahogany wood from Australian plantation grown as highly resistant against *Trametes versicolor* (white-rot fungus), with an average mass loss of 3.9 percent. França et al. (2016) also reported similar decay resistance results for *K. senegalensis* heartwood against *G. trabeum* with an average mass loss of 2.6 percent.

Conclusions

This research provides an overall evaluation of certain characteristics of plantation-grown African mahogany wood currently available commercially across US markets. Data showing African mahogany to have similar physical and mechanical properties as Brazilian mahogany help to support the use of plantation-grown African mahogany as a viable substitute wood resource for the overexploited genuine mahogany. Supporting the use of fast-growing, stress-tolerant tree species is valuable for promoting sustainable forest management practices.

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