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Research Article

Investigation of Some Technological Properties of Three African Tropical Woods: Ayous, Iroko, Sapelli

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Abstract

Aim of study: This study aim to investigate the anatomical features, density values, surface roughness, hardness and color parameters of three African tropical hardwood species: Ayous (*Triplochiton scleroxylon* K.Schum.), Iroko (*Milicia excelsa* (Welw.) C.C.Berg) and Sapelli (*Entandrophragma cylindricum* (Sprague) Sprague & Hoyle).

Material and method: Anatomical properties of tropical wood samples were determined by sectioning and preparation, and fiber characteristics were determined using the Schultze maceration method. Two density values were calculated for wood samples at 0% and 12% moisture content, namely oven dry and air dry, respectively. Surface roughness, hardness, and color were measured on radial and tangential surfaces.

Main results: All three tropical woods have diffuse-porous. Sapelli was found to have the greatest density values, while Ayous had the smallest. It was determined that both radial and tangential surfaces of Sapelli were harder compared to other species; and according to the average roughness value, the roughness values of both radial and tangential surfaces of Iroko were smaller than the roughness values of other species. The lightness value (L*), one of the color parameters, was found to be greatest for Ayous and smallest for Sapelli.

Research highlights: This study filled the gap in these research areas by determining especially the quantitative anatomical features in wood anatomy and surface features of Ayous, Iroko and Sapelli.

Keywords: African Tropical Woods, Anatomical Properties, Surface Properties, Wood Density

Üç Tropikal Afrika Odununun Teknolojik Özelliklerinin Araştırılması: Ayous, Iroko, Sapelli

Öz

Çalışmanın amacı: Bu çalışmanın amacı, Afrika'da yetişen üç tropikal sert ağaç türü olan Ayous (*Triplochiton scleroxylon*), Iroko (*Milicia excelsa*) ve Sapelli'nin (*Entandrophragma cylindricum*) anatomik özelliklerini, yoğunluk değerlerini, yüzey pürüzlülüğünü, sertliğini ve renk parametrelerini araştırmaktır.

Materyal ve yöntem: Kesit alma ve preparasyon işlemleri yapılarak tropikal odun örneklerinin anatomik özellikleri ve Schultze maserasyon metodu kullanarak lif karakteristikleri belirlenmiştir. Odun örneklerinin %0 ve %12 rutubet değerlerinde sırasıyla tam kuru ve hava kurusu olmak üzere iki yoğunluk değeri hesaplanmıştır. Radyal ve teğet yüzeylerde yüzey pürüzlülüğü, yüzey sertliği ve renk ölçümleri gerçekleştirilmiştir.

Temel sonuçlar: Her üç tropikal odun dağınık trahelidir. Sapelli'nin yoğunluk değerlerinin en büyük Ayous'un yoğunluk değerlerinin en küçük olduğu bulunmuştur. Sapelli'nin hem radyal hem de teğet yüzeylerinin diğer türlere kıyasla daha sert olduğu; ortalama pürüzlülük değerine göre Iroko'nun hem radyal hem de teğet yüzeylerinin pürüzlülük değerlerinin diğer türlerin pürüzlülük değerlerinden daha küçük olduğu belirlenmiştir. Renk parametrelerinden biri olan ışıklılık değeri (L^*) Ayous için en büyük, Sapelli için en küçük bulunmuştur.

Araştırma vurguları: Bu çalışma, Ayous, Iroko ve Sapelli'nin özellikle odun anatomisi alanındaki sayısal anatomik özelliklerini ve yüzey özelliklerini belirleyerek bu araştırma alanlarındaki boşluğu doldurmuştur.

Anahtar Kelimeler: Afrika Tropikal Odunları, Anatomik Özellikler, Yüzey Özellikleri, Odun Yoğunluğu

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Introduction

The moist forests found in tropical climates are the source of tropical hardwood. The three regions where these forests are densely located are West and Central Africa, Southeast Asia and tropical Oceania, and Tropical Latin America and the Caribbean (Tropical Hardwood Handbook, 1984). The total area of forests worldwide is 4.06 billion hectares (ha). This is 31% of the total land area. Forty-five percent of the world's forests are found in the tropical domain. According to 2020 data, 21.3% of Africa's land comprises forest areas (Food and Agriculture Organization, 2020). From the Sahara Desert to tropical rainforests and the fynbos vegetation of Southern Africa, Africa has diverse ecosystems (Linder & Verboom, 2015; Droissart et al., 2018). Africa's forest resources support various forest functions such as market services and non-market services. The market for African hardwood and goods has grown over time, contributing to the economic performance of certain nations. It has also been stated that approximately 30% of tropical timber produced in Africa is exported as unprocessed logs (Tieguhong et al., 2019; Lin & Ge, 2020; Molua, 2023). Fayolle et al. (2014) focused on tropical forests in Africa and used correspondence analysis and tree inventories from 455 locations with 1175 different types of trees to identify six floristic groups (Droissart et al., 2018).

Iroko, Sapelli and Ayous are among the round woods imported to Türkiye. Iroko and Sapelli stand out as the most significant tropical round trees. These trees are used to make flooring, veneer, and furniture (Akkaya et al., 2020). Ayous (*Triplochiton scleroxylon* K. Schum.), whose common commercial name is Obeche, belongs to the Malvaceae family (Gérard et al., 2017). Obeche is distributed in Ghana, Nigeria, Cameroon, and the Ivory Coast (Kukachka, 1970), and this species is widely dispersed over Guinea and Cameroon in tropical West Africa. White to pale straw-colored wood without differentiation heartwood or sapwood (Chudnoff, 1980). Its main uses are millwork, furniture components, interior joinery, matches, boxes, crates, coffins, pencils, blockboard, plywood, fiberboard, sliced veneer, artificial limbs, paneling, and sculpture. In addition, Ayous is substitute for Poplar for various end purposes, such as light furniture and paneling. (Chudnoff, 1980, Jackson & Day, 1991, Gérard et al., 2017). Iroko (*Milicia excelsa* (Welw.) C.C. Berg), which is native to tropical Africa, in the Moraceae family (Titmuss, 1971; Chudnoff, 1980; Gérard et al., 2017). The species is synonymous with *Chlorophora excelsa* (Welw.) Benth and Hook. (Berg, 1982; POWO, 2024). It ranges from the coast of the Ivory Coast east across the continent into East Africa, and southward to Angola (Kukachka, 1970). The color of the heartwood ranges from light yellow-brown to dark chocolate-brown and the sapwood is yellowish-white (Chudnoff, 1980). Its common uses are joinery, shipbuilding, furniture, paneling, glued laminated, flooring, railroad crossties, decking, veneer, cabinetwork, cooperage, shop fittings. It is also recommended as an alternative to teak (Chudnoff, 1980; Gérard et al., 2017). Sapelli (*Entandrophragma cylindricum* (Sprague) Sprague), whose common commercial name is Sapele, belongs to the Meliaceae family (Chudnoff, 1980; Gérard et al., 2017). Sapelli stretches eastward through Zaire and Uganda, from the Ivory Coast to the Cameroons. This species occurs in forest forms that are transitional, deciduous, and evergreen. Heartwood is a purplish-brown or medium to dark reddish-brown color, and sapwood is distinct, white or pale yellow (Chudnoff, 1980). It is a hardwood with moderately fine and uniform texture (Titmuss, 1971). Its main uses are furniture and cabinetwork, built-in furniture or mobile item, ship building (planking and deck), decorative veneers, plywood, joinery, flooring, paneling, framing, stairs (inside), coffins (Chudnoff, 1980; Gérard et al., 2017).

The technological characteristics and uses of important African tropical trees have been published in the main books in the literature (Kukachka, 1970; Titmuss, 1971; Chudnoff, 1980, Gérard et al., 2017), and at the same time these references are important databases. However, there are insufficient references to anatomical features, especially quantitative anatomical characteristics and surface characteristics for necessary African timbers. Microscopic identification of tropical wood species, exported to Türkiye and having many uses in the forest products industry, is important to ensure that they are the correct timber. In addition, the surface characteristics of solid wood, such as surface hardness and surface roughness, are necessary for using wood and other production processes, such as finishing and adhesion resistance. In this context, a systematic study of the technological properties of three different African tropical wood species is critical to determine the potential areas of use of these species. This study aims to investigate some technological properties, including their anatomical, physical, and mechanical properties, of African tropical woods, which are widely used in the international market, and to provide more information to the literature about these species. It is also aimed to fill existing gaps in the technological properties of tropical wood species and to create a valuable database for industrial applications and research. Further research on local tropical wood species could help to provide helpful information for the database of these species which are used commercially in Türkiye.

Material and Methods

Preparation of Test Samples

Three African tropical woods, named Ayous (*Triplochiton scleroxylon*), Iroko (*Milicia excelsa*), and Sapelli (*Entandrophragma cylindricum*) were used for this study. These woods were obtained from a sawmill located in Trabzon, Türkiye. Wood samples were prepared from the samples shown in Figure 1. Small wood specimens of 1 cm (tangential) × 1 cm (radial) × 1 cm (longitudinal) to determine anatomical features and 2 cm (tangential) × 2 cm (radial) × 3 cm (longitudinal) for density and moisture experiments were cut from these samples. Before the test, the wood specimens were air dried in a climate chamber until the humidity reaching 12% moisture content.

Figure 1. Samples of tropical wood studied

Measurement Anatomical Features

To examine the anatomical structure of tropical wood specimens, cubic samples measuring 1 × 1 × 1 cm were prepared. Sectioning of the samples was conducted using standard microtomy protocols as outlined by Ives (2001). Thin slices in transverse, tangential, and radial orientations were obtained with a Richter sliding microtome, with section thickness ranging between 15 and 20 μm.

For certain preparations, the sections were immersed in sodium hypochlorite solution for approximately 10-15 minutes until decolorized, followed by rinsing in distilled water. Residual chemicals were neutralized with 1-2 drops of acetic acid for 2-3 minutes, and the sections were subsequently washed again with distilled water. The stained sections were treated with 1% safranin solution for 3-5 minutes, washed, and then dehydrated through a graded ethanol series of 50%, 75%, and 95%.

Additionally, fiber elements were isolated by maceration using the Schultze method described by Normand (1972). Permanent slides were mounted in a basic fuchsine-colored glycerin-gelatin medium. Digital micrographs were captured using an Olympus BX50 photomicroscope.

Quantitative anatomical analyses were carried out using the Bs200ProP image analysis software developed by BAB Imaging Systems Ltd. (Ankara, Türkiye). Quantitative anatomical features measured included vessel frequency (per mm²), vessel tangential and radial diameters, vessel length, ray height and width, ray density (per mm), as well as fiber length, width, wall thickness, and lumen diameter. All anatomical descriptions and terminology were based on the standard criteria provided by the International Association of Wood Anatomists (Wheeler et al., 1989).

Moisture Content and Wood Density Values

The moisture content (MC) was determined according to the oven drying method (Kolman & Côté Jr., 1968). The wet weight of wood specimens with moisture was measured. Specimens were then dried at 103 ± 2 °C to obtain the oven dry weight. Moisture content was calculated mathematically, as reported by Denig et al. (2000).

Wood density values were measured according to TS ISO 13061-2 (2021) standard using small wood specimens with dimensions of 2 cm (tangential) × 2 cm (radial) × 3 cm (longitudinal). Two density values were calculated based on the weight and volume at the same moisture content as the oven-dry density (q_0, g cm^{-3}) at 0% MC and air-dry density (q_{12}, g cm^{-3}) at 12% MC. Thirty wood specimens were used for each moisture content and density measurements.

Surface Hardness and Surface Roughness

Insize ISH-SDM Shore D hardness tester with a measuring range of 0 to 100 was used to measure of surface hardness of wood samples. Fifteen measurements were performed on each of the radial and tangential sections of the samples shown in Figure 1.

Surface roughness parameters were determined on the radial and tangential sections of the unsanded samples with Mitutoyo Surftest SJ-210 device according to ISO 21920-2 (2021) standard. Fifteen measurements were made on each section. Roughness parameters, namely R_a (average surface roughness), R_q (root mean square roughness) and R_z (ten-point mean roughness) were recorded and these values were used for the surface quality of the samples.

Color Measurements

Color measurements were performed on radial and tangential sections of clear samples with a portable spectrophotometer Konica Minolta CM-2600d. Ten measurements were recorded on each section of samples. The CIELAB color space (L*, a*, and b*) were used. In this space, L* indicates lightness. The a^* axis represents the contrasting colors green and red; negative values move toward green, positive values toward red. The b* axis represents the contrasting colors blue and yellow; negative values move toward blue, positive values toward yellow.

Data Analysis

Descriptive statistics of anatomical features, moisture content, density values, surface hardness, surface roughness and color parameters of tropical wood specimens were tested using the SPSS 23.0 program.

Results and Discussion

Wood Anatomical Features

The three tropical tree species selected for this study are diffuse-porous woods. According to Wheeler et al. (1989), wood diffuse-porous is defined as the vessel having approximately the same diameter throughout the growth ring. Descriptive statistics for measured wood anatomical features were summarized in Table 1. As shown in Table 1 and Figures 2-4, Ayous wood had the largest vessel diameter, and the most vessel number per mm^2 belonged to Sapelli wood. The largest vessel diameters were generally measured in Ayous wood, and the narrowest diameters were measured in Sapelli wood. The mean tangential diameter of *Triplochiton scleroxylon* was reported by Adeniyi et al. (2013) as 234.47 µ. Generally, wood species with wide pores such as *Triplochiton scleroxylon* have a coarse texture, and these features explain the reason why these species are used in the production of matches, boxes, cabinets and light furniture (Adeniyi et al., 2013).

Table 1. Descriptive statistics for measured wood anatomical features

Anatomical features	Wood species		
	Ayous	Iroko	Sapelli
Vessel tangential diameter (µm)	217.71 (26.55)*	212.81 (39.28)	207.11 (23.45)
Vessel radial diameter (µm)	223.11 (35.32)	208.57 (53.38)	203.71 (33.63)
Vessel element length (µm)	274.82 (48.95)	98.61 (27.21)	417.12 (90.49)
Vessel number per mm^2	2 (1.23)	3 (0.90)	8 (0.99)
Ray height (µm)	367.54 (125.40)	378.97 (86.31)	327.49 (47.01)
Ray width (µm)	45.36 (13.71)	37.99 (5.72)	41.05 (8.00)
Ray number per mm	6 (0.65)	5 (0.71)	5 (0.79)

*Standard deviation is indicated in parentheses

Compared to other species, the longest vessel element belonged to Sapelli wood. The vessel per mm^2 in Sapelli wood is greater than of Ayous and Iroko. Iroko had the greatest ray height, while Sapelli had the smallest. The ray number per mm of Ayous, Iroko and Sapelli was 6, 5, and 5, respectively. Manga Bengono et al. (2023) reported the vessel diameter, vessel number per mm^2, ray height, and ray width of Sapelli (*Entandrophragma cylindricum*), which is located in the rainforests of Cameron, to be 111.82 µm, 13, 323.44 µm and 36.35 µm, respectively.

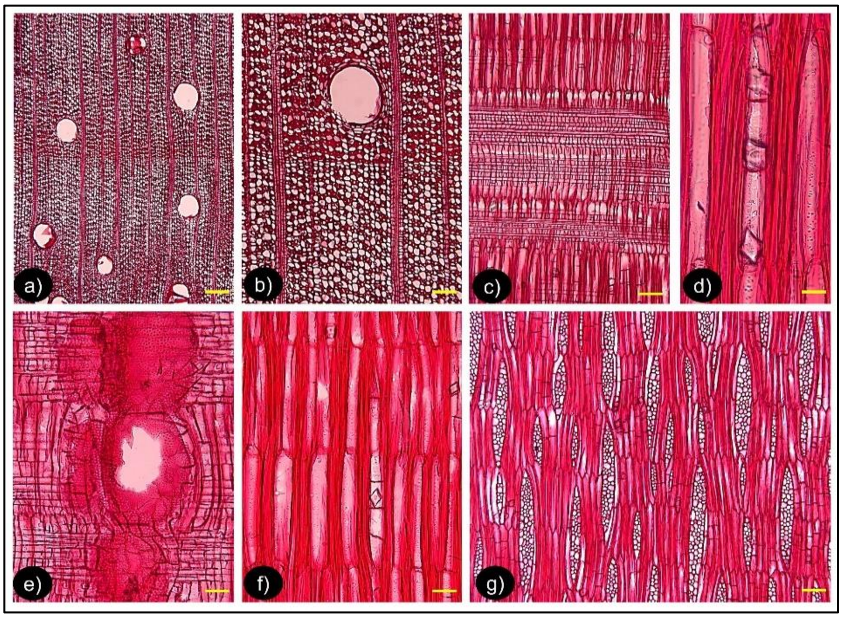

Figure 2. Anatomical features of Ayous (*Triplochiton scleroxylon*) wood. A, B- wood diffuse-porous, growth ring boundaries distinct, tyloses present, diffuse axial parenchyma in aggregates is predominant; C, E- heterocellular rays with procumbent, square and upright cells mixed throughout the ray, prismatic crystals in upright and / or square ray cells, simple perforation plates, intervessel pits alternate, shape of alternate pits polygonal; D, F- prismatic crystals in chambered axial parenchyma cells, prismatic crystals in non-chambered axial parenchyma cells, fibres storied; G- multiseriate rays, low rays storied, high rays non-storied. (A-B: transverse section, C-D-E-F: radial section, G: tangential section. Scale bar for A = 250 µm, for B-C-G = 100 µm, for F = 50 µm, for D-E = 25 µm)

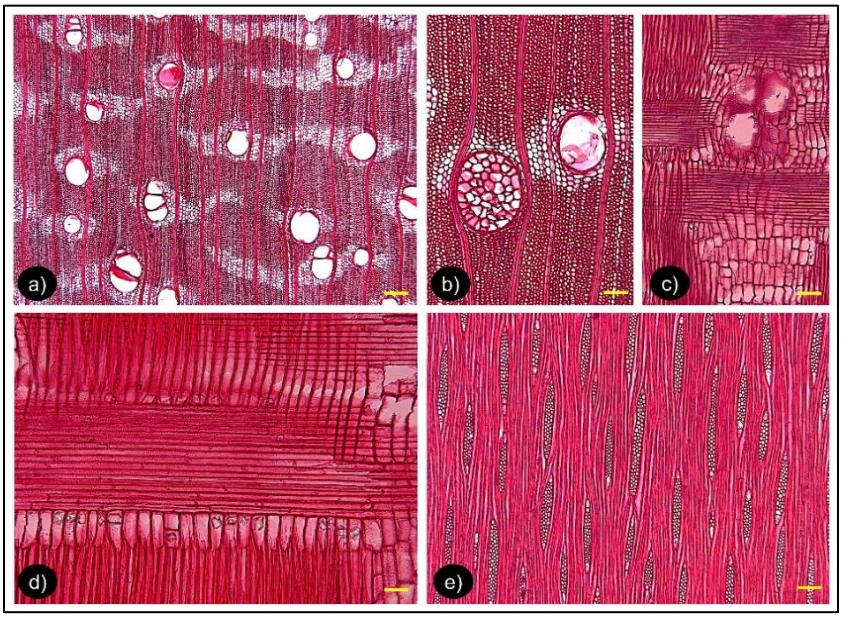

Figure 3. Anatomical features of Iroko (*Milicia excelsa*) wood. A, B- wood diffuse-porous, growth ring boundaries indistinct or absent, tyloses present, confluent aliform axial parenchyma is predominant; C, D- heterocellular rays, body ray cells procumbent with one row of upright and / or square marginal cells, prismatic crystals in upright and / or square ray cells, simple perforation plates, intervessel pits alternate, shape of alternate pits polygonal; E- multiseriate rays 3–4 cells wide (A-B: transverse section, C-D: radial section, E: tangential section. Scale bar for A = 250 µm, for B-C-E = 100 µm, for F = 50 µm)

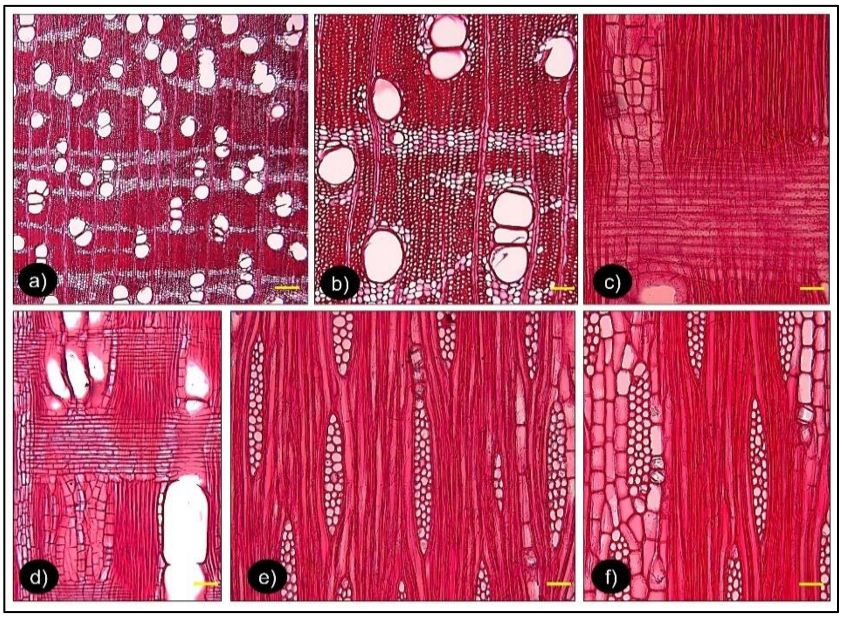

Figure 4. Anatomical features of Sapelli (*Entandrophragma cylindricum*) wood. A, B- wood diffuse-porous, growth ring boundaries distinct, sometimes indistinct or absent, banded apotracheal axial parenchyma is predominant; C, D- all ray cells procumbent, body ray cells procumbent with one row of upright and / or square marginal cells, prismatic crystals in upright and / or square ray cells, simple perforation plates; E, F- multiseriate rays 1–3 cells wide, prismatic crystals in chambered axial parenchyma cells, all rays storied. (A-B: transverse section, C-D: radial section, E-F: tangential section. Scale bar for A = 250 µm, for B-D = 100 µm, for C-E-F = 50 µm)

Fiber Dimensions

The quantitative anatomical features of the tropical wood species are summarized in Table 2. The fiber length of tropical wood specimens occurred in the following order: Sapelli > Ayous > Iroko. According to this result, Sapelli wood had the longest fibers. Jayeola et al. (2009) determined the fiber length of Iroko (*Milicia excelsa*), one of the popular wood species in Nigeria, ranged between 600-1700 μm. The fiber length of Sapelli (*Entandrophragma cylindricum*) taken from the natural forest reserves of Ghana was reported as 1478.90 μm (Dadzie et al., 2018). Hidayat et al. (2017) reported that fiber length is an important wood characteristic for producing stronger papers in the paper industry.

Table 2. Fiber dimensions of tropical woods

Wood species	Fiber dimensions			
	Fiber length (μm)	Fiber width (μm)	Fiber lumen diameter (μm)	Fiber cell thickness (μm)
Ayous	1560.53 (220.71) *	20.86 (2.69)	13.87 (2.69)	3.50 (0.84)
Iroko	1475.08 (186.05)	21.98 (3.94)	13.98 (3.45)	4.00 (0.92)
Sapelli	1651.00 (238.68)	21.46 (3.40)	11.54 (3.04)	4.96 (0.99)

*Standard deviation is indicated in parentheses

The fiber width of Ayous wood was smaller and its fiber wall was thinner-walled compared to Sapelli and Iroko. The fiber diameter, cell wall and lumen width of *Triplochiton scleroxylon* were reported by Adeniyi et al. (2013) as 18 μ, 4 μ and 10 μ, respectively. Antwi-Boasiako & Ayimasu (2012) determined that the fiber length, fiber diameter, fiber lumen width and fiber wall thickness of *Triplochiton scleroxylon* to be 1.43 mm, 24.97 μm, 18.46 μm and 3.26 μm, respectively. In addition, the fiber lumen diameter of Sapelli wood was narrower and its fiber wall was thicker-walled compared to other species (Table 2). As a result, Sapelli wood with higher density had thicker fiber wall, higher quantity of vessel number, and narrower vessel diameter than the other species.

Moisture Content (MC) and Wood Density

Water in wood has a considerable influence on the properties of wood, and wood-water connections significantly impact the industrial usage of wood (Wiedenhoeft, 2010). MC was found to be 10.55%, 10.20%, and 10.51% for Ayous, Iroko, and Sapelli, respectively. According to these results, it is possible to say that three tropical wood species are within safe limits for industrial use. Because their moisture values are below 20%. In preventing the spread of wood-damaging fungi, 20% wood moisture content is generally regarded as a "not to exceed" limit for confidence (Carll and Wiedenhoeft, 2009).

The results for wood density values of *Triplochiton scleroxylon, Milicia excelsa*, and *Entandrophragma cylindricum* are shown in Figure 5. Wood density is a characteristic critical to many wood finish applications (Ruffinatto et al., 2023). As shown in Figure 5, oven-dry density was 0.35 g cm^{-3}, 0.51 g cm^{-3} and 0.58 g cm^{-3} for Ayous, Iroko and Sapelli, respectively. Air-dry density was 0.39 g cm^{-3}, 0.55 g $cm^{-3}$and 0.61 g cm^{-3} for Ayous, Iroko and Sapelli, respectively. Density values of three tropical woods occurred in the following order: Ayous < Iroko < Sapelli.

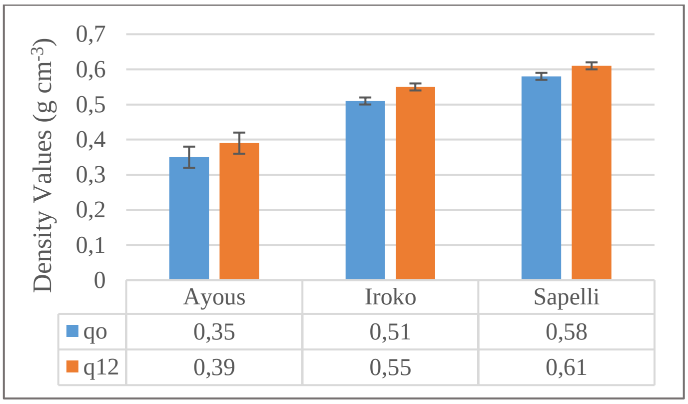

Figure 5. Wood density values of tropical woods

It can be said that the study results are close those of previous studies. Reyes et al. (1992) relate that the wood density values of *Triplochiton scleroxylon, Milicia excelsa*, and *Entandrophragma cylindricum* trees were reported as 0.32 g cm^{-3}, 0.55 g cm^{-3}, and 0.55 g cm^{-3}, respectively. The oven-dry density values of Ayous (*Triplochiton scleroxylon*) and Iroko (*Milicia excelsa*), which are indigenous Nigerian wood species, were determined by Falemara et al. (2012) as 0.41 g cm^{-3} and 0.65 g cm^{-3}, respectively. In a study prepared by Jamala et al. (2013) the oven-dried density of Iroko (*Melicea excelsa*) and Ayous (*Triplochiton scleroxylon*) in the Tropical Rainforest Ecosystem in Nigeria was reported as 0.65 g cm^{-3} and 0.37 g cm^{-3}, respectively. The density value at 10±4% MC of Sapelli (*Entandrophragma cylindricum*) growing in natural forest stands in Ghana was reported as 0.66 g cm^{-3} (Dadzie et al., 2016). Density values at 12% moisture content of Ayous (*Triplochiton scleroxylon*), Iroko (*Milicia excelsa)*, Sapelli (*Entandrophragma cylindricum*) grown in the African continent were reported to be 0.38 g cm^{-3}, 0.64 g cm^{-3} and 0.69 g cm^{-3}, respectively (Gérard et al., 2017). Ayata (2020) reported the air-dry density of Ayous (*Triplochiton scleroxylon*) to be 0.38 g cm^{-3}. Manga Bengono et al. (2023) also determined the density of Sapelli (*Entandrophragma cylindricum*) found in the rainforest of Cameroon to be 0.68 g cm^{-3}. As is known, the site conditions can affect the wood properties. Muller-Landau (2004) concluded in a study on tropical trees that wood specific gravity varied significantly among sites and that density varied among tree species within sites. Da Silva et al. (2014) also reported wood density depends chiefly on cell wall thickness. The fiber wall thickness findings of this study are consistent with the wood density findings. Our results showed that Sapelli had the thickest fiber wall thickness, had the greatest density. Additionally, our study determined that among the three tropical species, the wood species with the widest vessel diameter had the smallest wood density and the wood species with the narrowest vessel diameter had the greatest density. However, it was reported by Fichtler & Worbes (2012) that wood density was negatively related to vessel diameter.

Surface Hardness

The hardness of wood is significant as one of the primary indicators of wood quality and there is a good relationship between hardness and various mechanical properties of wood (Hirata et al., 2001). As seen in Figure 6, the hardness value of the radial section is greater than that of the tangential section for all three tree species. For most wood species, the radial surface has a harder surface than the tangential one, and the supporting effect of latewood in the radial section causes the hardness to be greater in radial section (Hirata et al., 2001; Heräjärvi, 2004; Peng et al., 2016). In this study, it was determined that Ayous wood had a softer wood than Iroko and Sapelli. Ayata (2020) reported the shore-d hardness of Ayous (*Triplochiton scleroxylon*) to be 37.65. In another study, Esteves et al. (2021) reported the shore-d hardness value of Sapelli (*Entandrophragma cylindricum*) as 61.80, and this result was consistent with the value shown in Figure 6.

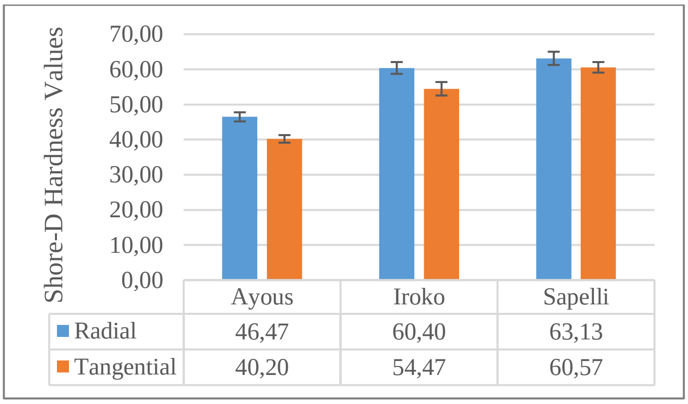

Figure 6. Surface hardness values of tropical woods

Factors such as the anatomical structure of the wood, the arrangement of the wood cells, and, the density of earlywood and latewood can affect the hardness of the wood. Several studies report a positive linear relationship between wood density and hardness (Hirata et al., 2001; Heräjärvi, 2004). Da Silva et al. (2014) concluded that as wood density increases, hardness increases. The surface hardness of tropical woods occurred in the following order: Ayous < Iroko < Sapelli and this trend was consistent with the density values shown in Figure 5.

Surface Roughness

Surface roughness parameters of tropical woods are shown in Figure 7a for radial section and Figure 7b for tangential section. For three wood species, surface roughness values on the radial surface were greater than those on the tangential surface. According to the average surface roughness value (R_a) obtained, the smallest R_a value in both radial and tangential sections belonged to Iroko. That is, the radial and tangential surfaces of Iroko were less rough than those of Ayous and Sapelli. The radial section generally showed greater roughness than the tangential section as Jankowska (2020) reported, explaining the presence of fibers cut in different directions on the radial section of the wood. Additionally, in their study on the surface roughness of Amazonian tropical hardwoods, Amorim et al. (2013) observed that the arrangement of anatomical elements on the radial section confirmed the highest roughness value. In our study, as seen in Figures 2-4, the difference in the arrangement and size of the vessel in the vertical direction and the ray cells in the horizontal direction may explain the different roughness of the wood sections.

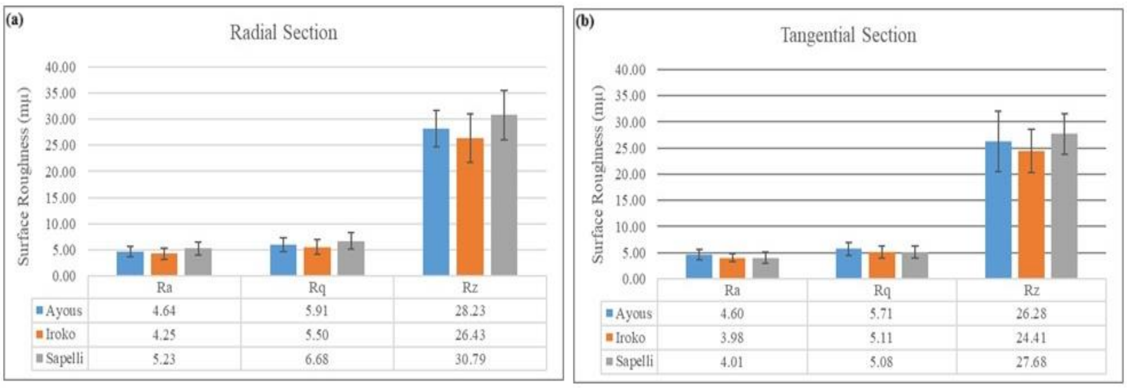

Figure 7. Surface roughness parameters of tropical woods

Kollmann & Côté Jr., (1968) reported that the surface quality of wood also depends on the wood species. The tropical wood species investigated in this study have diffuse-porous woods. Wood texture and the texture uniformity can affect the roughness of the wood surface. Normally diffuse-porous woods tend to be the most uniformly textured than very large-pore woods such as oak (Thoma et al., 2015). Qing et al. (2018) emphasized that the effect of wood structure on roughness is obvious and requires consideration of wood structure and different sections when evaluating surface roughness.

Color Parameters

Colorimetric parameters for tropical wood samples are given in Table 3. As seen in Table 3, L^* values are listed from greatest to smallest: Ayous>Iroko>Sapelli. This result confirms that among the three tropical woods, Sapelli wood is the darkest and Ayous wood is the lightest compared to the others, as seen in Figure 1. The greatest a^* value belonged to Sapelli wood and the smallest a^* value belonged to Ayous wood. That is, Sapelli wood is redder than others. However, the greatest b^* value belonged to Iroko wood and the smallest b^* value belonged to Sapelli wood. According to this result, Iroko wood is more yellow than others. It was also determined that the L^*, a^* and b^* values recorded on the radial and tangential sections were very close. The macroscopically observed color is cream white, light brown, and dark brown for Ayous, Iroko and Sapelli, respectively (Figure 1). Similar to our results, in a study conducted by Falemara et al. (2012), it was observed that Ayous (*Triplochiton scleroxylon*) was cream white and Iroko (*Milicia excelsa*) was greyish and brown.

Table 3. Average values of color coordinates for tropical woods

Wood species	Section	Color coordinates		
		L^* (lightness)	a^* (redness)	b^* (yellowness)
Ayous	Radial	75.37 (1.06)**	6.45 (0.18)	26.08 (0.51)
	Tangential	76.54 (0.88)	5.60 (0.33)	24.79 (0.56)
Iroko	Radial	68.24 (0.95)	7.93 (0.32)	28.68 (0.27)
	Tangential	66.15 (0.68)	8.30 (0.28)	28.54 (0.57)
Sapelli	Radial	51.12 (2.15)	13.52 (0.36)	19.94 (0.69)
	Tangential	53.27 (2.00)	13.16 (0.36)	20.18 (0.69)

** Standard deviation is indicated in parentheses

Aesthetic qualities of wood, like color and gloss, are especially unequaled in producing of high-quality furniture (Tolvaj, 2023). There are significant differences in wood color within a tree, across trees of the same species, and between species (Nishino et al., 1998; Liu et al., 2005; Moya & Calvo-Alvarado, 2012). Wood color may differ considerably within a species because of different environmental factors and practices used in silviculture (Derkyi et al., 2010). Compared to the lighter colored woods, the darker colored tropical woods displayed higher fiber wall proportion, higher vessel frequency, narrower vessels, and higher wood density (Bessa et al., 2023). Therefore, in this study, growing conditions, environmental factors, wood density and anatomical features of all three tropical trees may explain the color differences of the woods.

Conclusions

This study explored wood density and surface properties, and some wood anatomical features of Ayous (*Triplochiton scleroxylon*), Iroko (*Milicia excelsa*) and Sapelli (*Entandrophragma cylindricum*), which are the most preferred wood species in the international market. Accordingly, the results are drawn as follows:

1. The greatest values for certain anatomical features, such as vessel diameter and ray width, were observed in Ayous, which also exhibited the smallest density value and the thinnest fiber wall.
2. The fiber length of Sapelli was longer than the others. Sapelli, which had the thickest fiber wall thickness, had the greatest wood density.
3. The radial sections of tropical species were rougher and harder than the tangential sections. Ayous had softer wood than Iroko and Sapelli. Ayous

had a lighter colored wood than Iroko and Sapelli.

4. By examining the technological properties of three different African tropical woods, this study has provided an important database for the more efficient and sustainable use of these wood species in industrial applications.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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