

An Examination of Selected Wood Properties of Some Economic Tropical Timber Species.

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Abstract
Characterizing wood is necessary in order to make information available to interested users of a particular timber species. In this study we characterized *Aningeria robusta (A.Chev.) Aubrev.& Pelleger*,(Asanfena), *Terminalia ivorensis A.Chev.*, (Emeri), *Terminalia superba Engl. & Diel., (*Ofram), *Khaya ivorensis A.Chev.*, (Mahogany) and *Entandrophragma cylindricum Sprague.*, (Sapele) according to their anatomical and physical properties. This work discussed the macroscopic physical properties in terms of densities (air/oven dry), colour and surface roughness of the five wood species. Cell properties studied included vessel, fibre and parenchyma cell dimensions as well as their pore arrangements. It was clear that, the proportion of fibres per mm^2 of the species, as well as their corresponding cell wall thicknesses values seems to bear some relationship with their densities
Keywords: maceration; optical microscopy; roughness; wood anatomy; wood density

1. Introduction and background

Ghana has a land area of about 230,020km^2. The savannah occupies 65.5%, of the land area to the north (covering approximately 15.6 million ha) and moist forest takes up the remaining 34.5% (8.2 million ha). Hawthorne and Abu-Jaum (1993), described four broad ecological zones : the wet evergreen type, the moist evergreen type, the moist semi-deciduous type, and the dry semi-deciduous type. The moist forest is the most important zone in Ghana economically and environmentally, as timber logging and harvesting is mainly concentrated to this ecological region. Reservation of forest areas began shortly after World War I and currently forest reserves consist of about 1.37M ha of production forest and 0.43M ha of protected forest. Timber trade therefore started as a result of abundant forest resources and a high demand in tropical wood from the west in building and construction.

Since the beginning of the 20th century, timber exports are a major contributor to Ghana's GDP. The first quarter wood products exports in 2011 were valued at (41.35M US$) resulting from a volume of 89,680 m^3 of timber. The major export markets in Europe including Germany, Italy, Spain, England and North America contributed 14.55M US$ or 35.19% of total exports. Secondary exports, such as veneer and plywood generated a total of 88.65% (36.65M US$), while tertiary product exports, such as furniture components and flooring totaled 8.31% (3.44M US$). Ghana's exports to African countries, particularly those within ECOWAS region (mainly Senegal, Nigeria, Niger, Gambia, Mali, Benin, Burkina Faso and Togo) were in the region of 15.37M US$ which was 86.16% of the total exports (17.84M US$) to Africa. This total wood volume to Africa was 37,803 cubic meters or 42.15% of total exports. The emerging markets in Asia and the Middle East contributed 21.44% (8.86M US$) to the total wood export (Anonymous 2011).

This study makes use of timber species from the moist forest based on the, forest availability, forest rotation, use (or potential) in plantation development and their prominence in the timber trade. We therefore selected *Entandrophragma cylindricum Sprague* (Sapele), *Khaya ivorensis (A.Chev).*, (Mahogany), *Terminalia ivorensis A.Chev.*, (Emeri), *Terminalia superba Engl. & Diel., (*Ofram) and *Aningeria robusta (A.Chev.) Aubrev.& Pelleger.*, (Asanfena). For the timber to be readily accepted both locally and internationally, information regarding the wood anatomy and its physical properties must be known.

1.1 Wood anatomy

The anatomy of wood shows a large variability among species. In tropical hardwoods, three wood elements are typically distinguishable: vessels, parenchyma cells and fibres. Vessel elements are relatively large in diameter but thin walled and may vary in size from 20µm to 500µm in diameter (Jane 1970). They may occur in singles (solitary) or groups (multiples) and also vary in size among and within species.(Hoadley 2000). Hardwoods with pores distributed fairly evenly between two successive growth rings are called diffuse porous woods (Panshin and De Zeeuw 1964). The average vessel proportion in temperate hardwoods is approximately 30% (Panshin and de Zeeuw, 1980). Wood fibres vary in length from 2mm to about 5mm. The proportion of fibres and the average cell wall thickness determine the wood density (Butterfield and Meyland 1980). Typically the proportion of fibers accounts for 20-70% of the wood volume, depending on the species. Parenchyma cells are brick-shaped, short cells with thin walls. Phillips (1948) calls parenchyma cells abundant when five or more cells are present per square millimeter of transverse section. Parenchyma cells can be aligned axial or radial. Axial parenchyma makes up 1-18% of the volume of temperate woods, but this may reach 50% in tropical hardwoods. Ray parenchyma cells may comprise 5-30% of the wood volume (Siau, 1995). Hardwood rays vary in size and appearance with the smallest rays being only a cell wide (uniseriate). However, on the extreme some rays may be up to 40 cells wide (multiseriate) and conspicuous to the naked eye (Hoadley 2000). The density within a growth ring is directly related to the diameter of the cell and its wall thickness (Panshin and de Zeeuw, 1980).

1.2 Description of four selected Ghanaian hardwood species

Entandrophragma cylindricum Sprague., (Sapele) is one of the few tropical hardwood species that can be grown to useful timber in a relatively short rotation of about 35- 40 years (Hall et al. 2003). It is widely distributed in the semi-deciduous forest. Sapele is described by Pernia and Miller (1991) as a diffuse porous wood in the IAWA hardwood codes. The mean diameter of the vessel lumina is between 100-200µm with 5–20 vessels per mm^2. Gum and other deposits can be found in the heartwood vessels. The heartwood is pinkish brown when freshly cut, darkening upon exposure to reddish brown or purplish brown, which is different from the creamy white to purplish grey sapwood. Axial parenchyma cells are present. The wood is medium-weight, with an average density of $0.65 g/cm^3$. A wood anatomical description of Sapele is also given in the Prota data base (2009). According to Anonymous (1994), the wood can be used for various applications, such as quality furniture and joinery, doors, frames, boat construction, veneer, plywood, turnery and carvings

Khaya ivorensis A.Chev., (Mahogany) is a timber species that is most abundant in evergreen forest, but can also be found in moist semi-deciduous forest. When grown in plantations, it is considered one of the most important timber species combining fast growth (rotation 35 years) and good timber quality (Opuni-Frimpong 2006). It is described by Pernia and Miller (1991) in the IAWA hardwood codes as diffuse porous with vessel lumina ranging from 100–200 µm in diameter. It has at least 5 vessels per mm^2 with gums and other deposits in the heartwood vessels. Axial parenchyma cells are present. Mahogany has an average density of $0.55 g/cm^3$ at 12% moisture content. Anonymous (1994) reports Mahogany as a suitable species for joinery, doors and window frames, boat constructions, as well as veneer and plywood production.

Terminalia ivorensis A.Chev., (Emeri) is grown in tropical West Africa from Guinea to Cameroon and is abundant in the primary and secondary forests as well as transition zones. It is also a successful plantation species. It is a fast grown timber species with a forestry rotation of about 25-30 years (Boateng 1992) . The heartwood is yellowish to pink - brown and the sapwood is somewhat paler. The texture is coarse and the basic density as $0.55 g/cm^3$ (Anonymous 1994). It is a good general purpose timber for furniture components, such as joinery, decorative paneling, veneers, flooring and light constructions.

*Terminalia superba Engl. & Diel., (*Ofram) occurs in rain and savanna forests and is a favored plantation species in West Africa. It is most common in moist semi-deciduous forest, but can also be found in evergreen forest. Anonymous (1994), classified Ofram (250-1000m^3/km^2) as plentiful in the forest. Unlike Emeri, it has a shorter forestry rotation and may reach useful timber in about 20 years ((Opuni-Frimpong 2006). The heartwood is yellowish brown, sometimes with nearly black markings producing an attractive figure and the sapwood is not distinct from heartwood. The texture is coarse. The basic density is $0.45 g/cm^3$ (Anonymous 1994). Ofram is commonly used for plywood, furniture, interior joinery as well as decorative veneers.

Aningeria robusta (A.Chev.) Aubrev.& Pelleger., (Asanfena) is one of the few hardwood species which occurs in the driest types of semi-deciduous forest and is described by Anonymous (1994) as a plentiful species that occurs in different ecological areas in the forest zone. The heartwood is reddish brown to pink and the sapwood is not distinguishable from the heartwood. It has silky and straight grain. The density is $0.55 g/cm^3$ at 12% moisture content. Asanfena dries easily but is prone to staining when freshly cut. It is mostly used for veneer production, for interior joinery and, paneling.

Anonymous (1994), classified Ofram and Asanfena as plentiful while Mahogany, Emeri and Sapele were found in average quantities in the forests, with an occurrence of at least 250 m^3/ km^2. Primarily used species, such as Odum, which are durable and used for a wide variety of applications are getting depleted since they are difficult to grow in plantations. In contrast, Asanfena, Emeri, Mahogany, Ofram and Sapele have been grown successfully in plantations and are currently used as substitutes for these primary species in the domestic market, as well as for export. Although all of the above species have been physically characterized according to their properties, information about these species cannot be found at a glance. This work is an attempt to fill this gap. Researchers interested in wood science from diverse background will find this work useful (including wood treatment/permeability, pulp and paper and surface science).

In this study Asanfena, Emeri, Mahogany, Ofram and Sapele are characterized with regards to their physical and wood anatomical properties.

2. Materials and Methods

2.1 Sample preparation

2.1.1 Sectioning

Tangential, defect free boards of Asanfena, Emeri, Mahogany, Ofram and Sapele were cut into 15mm thick boards with multiple rip saws and subsequently planed. All boards were prepared with the same equipment. 30 samples of each species were prepared with the dimensions of 300mm x 100mm x 15mm and conditioned for two weeks at 20°C and 65% relative humidity.

Small blocks measuring 14mm x 9mm x 6mm were cut from three arbitrary samples for each of the five species, and softened at 85^{o}C in distilled water for 8 hours.

Fifteen sections with a thickness 80µm were cut from each block with a microtome at an angle of 14º. The five topmost sections were discarded and the remaining 10 were kept for microscopic analysis.

2.1.2 Fibre maceration

Fibres were separated by maceration of match stick sized wood pieces originating from 5 arbitrary chosen samples per species in Jeffrey's solution at 40ºC for 4h. The resulting cell suspension was washed thoroughly with distilled water. Fibres were spread from this suspension onto a glass slide and left to dry for 12h.

2.2 Optical Microscopy

2.2.1. Vessel diameter and ratio, Fibre length and Parenchyma cells

A Leica EZ 4D microscope was used to determine the diameter and ratio of vessels, as well as the fibre length and amount of parenchyma cells. Ten images were acquired per section for cell analysis. To determine the number of vessels per mm^2 and the vessel diameter, images were acquired with a magnification of 20x and all visible vessels counted and their diameter recorded. Five images of the cell suspension were acquired for each species at a magnification of 35x, and the length of fibres, and parenchyma cells, as well as their amount per mm^2 were determined.

2.2.2 .*Fibre diameter and cell wall thickness*

A Nikon Eclipse E-800 Light microscope was used to determine the fibre diameter and cell wall thickness. The fiber diameter and cell wall thickness were determined from five images acquired with a magnification of 400x. Fiber diameter and cell wall thickness were measured on all visible cells in the image.

2.3 Surface Colour

A portable spectrophotometer, MICROMATCH PLUS with a spectral reflectance within the visible spectrum of wavelengths between 400 and 700nm was used for all colour measurements. The CIELAB system measuring L*, a*, b* and ∆E parameters were measured on each sample, totaling ninety. In the CIELAB system, the L* axis represents the lightness (L* varies from 100(for white) to zero (for black), and a* and b* are the chromaticity coordinates. (+a* is for red, -a* for green, +b* for yellow, -b* for blue). L*, a* and b* values were used to calculate the overall colour changes ∆E using the equation:

$\Delta E= [(\Delta L^*)^2+ (\Delta a^*)^2+(\Delta b^*)^2]^{½}$

where ∆L*, ∆a* and ∆b* are the difference of initial and final values before and after UV irradiation) of L*, a* and b* respectively. For this work we considered only changes in Lightness (∆L*) and Yellowness (∆b*).

2.4 Surface Roughness

Roughness measurement was carried out by MarSurf PS1 compact roughness measuring instrument. The maximum measuring range was 350µm (0.35mm) (-200 µm to + 150 µm) (-0.2mm to + 0.15mm). The maximum traversing length was 17.5mm and complies with ISO 3274. The Ra roughness parameter was measured to evaluate surface roughness of wood surfaces. Ra represents the arithmetic mean of the 10-point height of irregularities. Before the surface roughness measurements, all wood samples were conditioned to equilibrium moisture content so that the moisture content could not alter the results of measurements. Ninety wood samples with dimensions 300x100x15mm and measurements taken at three different positions were used to evaluate the surface roughness.

2.4 Oven dry density

Thirty samples were dried for 24 h at 105 C before being tested for density according to (ASTM D 792 2004) . The sample size was approximately 20 x 20 x 10mm.

Air dry density

Thirty defect-free flat sawn boards of each wood species were carefully selected and stored in a conditioning room at 20ºC and 65% RH. Specimen dimensions were 300mm x 100mm x15mm

3. Results and Discussion

Table 1 shows macroscopic physical properties of the five wood species. Air-dry and oven-dry density was the highest in Emeri, followed by Sapele, Asanfena, Mahogany and Ofram. Emeri also had the roughest surface followed by Ofram, Asanfena and Mahogany with Sapele being the smoothest. From the darkest wood is Mahogany and the lightest wood is Asanfena, with Emeri having the largest yellowness factor. Colour and density measurements are consistent with the findings of Prota (2009).

Table 1: Mean values of density, colour and surface roughness of five wood species.

Species	Oven-dry density [g/cm^3]	Air-dry density [g/cm^3]	Lightness [ΔL*]	Yellowness [Δb*]	Roughness [µm]
Asanfena	0.535 (0.05)	0.558 (0.06)	-30.84(3.89	23.68 (1.58)	8.75 (2.28)
Emeri	0.600 (0.08)	0.668 (0.09)	-33.81 (2.15)	27.56 (1.83)	10.61 (3.37)
Mahogany	0.533 (0.11)	0.536 (0.08)	-37.0 (4.86)	21.47 (2.4)	7.95 (2.23)
Ofram	0.447 (0.03)	0.509 (0.05)	-32.27(5.31)	24.71 (3.62)	9.63 (2.72)
Sapele	0.580.(0.07)	0.597 (0.04)	-36.56(2.75)	22.34 (2.94)	6.87 (1.79)

Table 2a: Vessel and Fibre mean values.

Species	Vessel diameter [µm]	No. of vessels [no/mm^2]	Fibre diameter [µm]	Fibre length [mm]	Fibre cell wall thickness [µm]
Asanfena	127 (13.73)	7.11 (3.83)	37.91 (9.18)	1.48 (0.36)	13.51 (2.79)
Emeri	103 (43.85)	3.27 (2.02)	38.73 (8.96)	1.26 (0.26)	15.15 (2.89)
Mahogany	172 (61.49)	1.18 (0.94)	50.25 (16.53)	1.37 (0.35)	15.03 (3.70)
Ofram	171 (39.98)	1.75 (1.53)	40.88 (11.72)	1.48 (0.29)	16.31 (4.67)
Sapele	150 (25.32)	2.97 (1.96)	37.43 (11.24)	1.75 (0.51)	18.50 (4.15)

Table 2b: Fibre and parenchyma cell values

Species	No. of fibres [no/mm^2]	Parenchyma cell length [µm]	No. of parenchyma cells [no/mm^2]
Asanfena	20.00 (7.16)	110.8 (3.8)	17.33 (7.81)
Emeri	40.20(14.65)	141.8 (11.6)	21.25 (4.0)
Mahogany	31.33 (21.48)	109.8 (12.6)	45.44 (27.96)
Ofram	17.12 (8.13)	117.0 (3.0)	48.50 (16.33)
Sapele	48.18 (22.72)	164.4 (53.2)	26.36 (15.95)

Asanfena had about 7 vessels per mm^2, making it the largest amount of vessels followed by Emeri and Sapele, which had both around 3 vessels per mm^2 and Ofram and Mahogany, which had on average 1.8 and 1.2 vessels per mm^2. The values determined for Mahogany and Sapele are lower than the values cited in literature, where both species were found to have 5 or more vessels per mm^2. It was possible that these species reported in the literature may have been extracted under a geographical location other than Ghana. The ecological conditions (soil, moisture, organic matter, temperature etc.) may be different and probably accounted for the variations in vessel diameters and amounts determined.

The largest vessel diameter was found in the species with the least amount of vessels in Ofram and Mahogany, followed by Sapele, Asanfena and Emeri. Vessel diameter and vessel amount seem to be negatively correlated.

Sapele hah by far the highest values for fibre length and cell wall thickness, but the lowest for fibre diameter. In contrast, Mahogany had the least values for almost the fibre length and cell wall thickness, but the largest cell wall diameter. Interestingly, fibre diameter and cell wall thickness seem to be negatively correlated. However some positive correlation could be seen between fibre length and cell wall thickness.

The proportion of fibres per mm^2 was greatest in Sapele followed by Emeri and Mahogany, decreasing sharply to Ofram. The proportion of fibres per mm^2 of the species, as well as their corresponding cell wall thicknesses values seems to bear some relationship with the densities (Butterfield and Meylan 1980). Parenchyma cell length was longest in Sapele which incidentally had the thickest cell wall through to Mahogany with the largest fibre diameter.

4. Conclusion

Conclusions drawn from the attempted characterization of these five Ghanaian hardwood species commonly used for the export market, i.e. Asanfena, Emeri, Mahogany, Ofram and Sapele according to their physical and anatomical properties are that:

a. all the species were found to be diffuse porous wood with their rays ranging from uniseriate to multiseriate.

b. Asanfena recorded the highest number of vessels per mm^2 and also the least cell wall thickness.

c. the highest number of fibres per mm^2 were seen in Sapele which incidentally also had the greatest cell wall thickness and the longest fibre length.

d. the largest vessel diameter was found in the species with the least amount of vessels in Ofram and Mahogany

e. it was clear that, the proportion of fibres per mm^2 of the species, as well as their corresponding cell wall thicknesses values seems to bear some relationship with the densities.

f. that vessel diameter and amount seemed to be negatively correlated.

g. fibre diameter and cell wall thickness also seemed to be negatively correlated.

h. although both Emeri and Ofram belong to the same family, Ofram had the lowest amount of fibres per mm^2, but recorded the highest amount of parenchyma cells which also reflected in its low density.
i. Sapele was the darkest with the lowest roughness.
j. Asanfena was the lightest with Emere having the highest roughest surface.

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