Evaluation of Density and Anatomical Properties of Stem Wood of Five Commercial Trees in Nigeria using a Non- Destructive Approach

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ABSTRACT

Using a non-destructive approach, this study investigated the density and anatomical features of stem wood from five commercial trees in Nigeria: *Gmelina arborea*, *Nauclea diderrichii*, *Triplochiton scleroxylon*, *Terminalia mantaly*, and *Terminalia catappa.* The increment borer was used to take samples from three trees of each of the five species at breast height (1.37 m). The species' density, fiber length (FL), fiber diameter (FD), lumen width (LW), and cell wall thickness (CWT) were all measured. Result of the mean values of density for the five wood species were 475.05 kg/m^3, 645.18 kg/m^3, 590.05 kg/m^3, 651.73 kg/m^3, and 752.65 kg/m^3 for *G. arborea, T. catappa, T. scleroxylon, N. diderrichii* and*, T. mantaly,* respectively. It was observed that wood samples of *T. mantaly* had the highest (752.65 kg/m^3) density, followed by *N. diderrichii* (651.73 kg/m^3) and *G. arborea* had the lowest (475.05 kg/m^3). Fiber assessment showed that *N. diderrichii* had the longest (1.50 mm) FL while *T. catappa* had the shortest (0.93 mm) FL. However, *N. diderrichii* had the highest mean FD (36.45 μm), and *T. mantaly* had the lowest (15.01 μm). Investigation of the derived values showed that *T. mantaly* had the highest value (70.20) for slenderness ratio, and *G. arborea* had the lowest (36.90). Coefficient of flexibility was observed to be highest in *G. arborea* (56.09%). All the species in this study had Runkel ratio above 1 except *G. arborea* (0.86).

The study showed that influence of species was significant ($P < 0.05$) on the density, anatomical properties and derived values and that utilization potentials varies.

(Keyword: non- destructive, increment borer, density, anatomical properties, derived values, tree species, commercial wood, timber)

INTRODUCTION

Wood has traditionally been the major contributor of basic raw materials for the production of pulp, paper, and various types of fiber-based products, in addition to being a source of energy. It gives about ninety percent of the basis for pulp manufacturing, whilst approximately ten percent originates from non-woody plants [1].

The majority of tree species used in pulp and paper production are threatened by high rates of deforestation, as a result of increasing demand for wood for other commercial purposes. This development has increased the pressure on *Gmelina arborea* plantation, which has been established for use in the paper industry [2]. According to Ogunjobi *et al.* [3], one of the major wood products now recognized in socio-economic development in forest-based industries across the globe is fiber.

Density is a measure of the quantity of cell wall material contained in a specific volume of a piece of wood [4]. Wood density may be considered a measure of internal wood structure, reflecting the combination of features of the various cellular elements that compose wood [5]. Panshin and de Zeeuw [6] reported that density is a general indicator of cell size and is a good predictor of strength, stiffness, ease of drying, machining, hardness and various paper making properties. Brazier and Howell [7] also expressed the opinion that density is one of the most important properties influencing the use of a timber. Therefore, the importance of density to wood utilization cannot be overemphasized.

Anatomical features have great influence on most properties of wood including physical, natural durability and mechanical strength properties [8, 9]. The analysis of fiber characteristics such as fiber length, fiber diameter, lumen width, cell wall thickness and their derived values (Slenderness ratio, flexibility coefficient and Runkel ratio) exhibit an important relationship with the mechanical strength of pulp and paper [2].

According to Horn [10], increase in raw materials fiber length enhances the tearing strength of hardwood pulps. Several investigations found that extensibility of the binding sites is a function of the fiber length [11, 12]. Fiber characteristics vary extensively and to a large extent exhibit influences on bulk density, fiber strength and inter-fiber bonding [13].The fiber length is the number of bonding sites that is available on an individual fiber to form an interwoven network of fibers. It is measured from one end to another end. Long fiber lengths are preferable for manufacture of paper as it gives a more open and less uniform sheet structure. The fiber lumen width is the diameter of the internal cavity. It is the distance between the inside diameter and the outer cavity. It is measured in a transverse direction. The larger the fiber lumen width, the better will be the beating of pulp because of the penetration of liquids into empty spaces of the fibers.

With the increasing demand of materials for paper making, increasing the range of raw materials is a central component of current efforts to increase fiber supply [14]. It is also important to adopt non-destructive strategies in the evaluation of species in order to reduce further destruction of the decreasing forests. This study is therefore aimed at adopting a non-destructive strategy in investigating the properties of the species and situating them with possible utilization potentials.

MATERIALS AND METHODS

Samples from trees of five species (*Gmelina arborea, Terminalia catappa, Terminalia mantaly, Triplochiton scleroxylon and Nauclea diderrichii*) purposively selected for their attributes in commercial utilization were collected with the use of an increment borer from the breast height (4.5 feet or 1.37 m) of each species. An increment borer is a specialized tool used to extract a section of wood tissue from a living tree with relatively minor injury to the plant itself [15]. The use of stem borer is a non-destructive approach of investigating wood properties.

Wood Density

The density was determined in accordance with the procedure described in ISO 3131 [16]. All samples were weighed using an electronic balance with an accuracy of 0.01 g to determine their masses whereas their dimensions for volume determination were measured with an electronic Vernier caliper with an accuracy of 0.1 mm as specified in ISO 3131. The mass, height, length and width of the samples were obtained to compute the density of the wood with the use of standardized formula:

$$Density\left(\frac{kg}{mm3}\right) = \frac{M}{V}$$

Where M = Mass and, V= Volume

Anatomical Properties

Maceration: Investigation of anatomical characteristics was carried out in accordance with ASTM D 1030-95 (2007) and ASTM D 1413-61 (2007). Maceration of the chips was carried out using acetic acid and hydrogen peroxide (1:1). It was placed in an oven for 2 hours at a temperature of 100^{o}C then the solution was vigorously agitated for individual fibers to be separated. Some of the macerated fibers were randomly selected and mounted on slides; examined under a Raichet microscope following the procedure adopted by Dutt *et al*. [18]. The fiber length, fiber diameter, and lumen width were measured using a stage micrometer and eye piece micrometer. Twenty fibers were measured from each representative sample slide in accordance with Jorge *et al*. [19].

Derived Morphological Indices

From the fiber dimensions, three derived values were determined; slenderness ratio as fiber length / fiber diameter, flexibility coefficient as (fiber lumen diameter / fiber diameter) × 100and Runkel ratio as (2 × fiber cell wall thickness)/ lumen diameter [2, 20, 21]. The fiber quality can be determined by Runkel ratio. The Coefficient of flexibility gives the tensile and bursting strength of the fiber, the higher the coefficient, the greater the tensile strength and corresponding bursting strength. Felting rates the ratio of length to its diameter and it gives tearing resistance.

RESULTS AND DISCUSSION

Assessment of Density of the Species

Timber has, over the years, been known by its great potentials in the construction industry. Research has however shown that higher density species tend to have stronger timber than lower density species [22]. It was observed that *T. mantaly* had the highest density mean value of 752.65 kg/m^3 (Table 1) which is higher than 514.71 kg/m^3 at the top core portion to 620.00 kg/m^3 reported by Owoyemi *et al.,* [23] for *Borassus aethiopum*. The second highest (651.73 kg/m^3) which is lower than 750 kg/m^3 reported by Bailey [24] in Coday and Maun [25] was recorded for *Nauclea diderrichii*. *Terminalia catappa* had a mean value of 645.18 kg/m^3, *Triplochiton scleroxylon,* had 590.05 kg/m^3 while *Gmelina arborea* had the lowest value of 475.05 kg/m^3. All the density values recorded in this study are lesser than the density of *C. pachyceras* (867kg/m^3) reported by Kribs [26]. It has been hypothesized that anthropogenic global change may be resulting in a shift towards species like *G. arborea* having lower wood density [27].

According to Polge [28], differences in density may arise simply from differences in the anatomy of the wood modified by the effect of extractives, and, as described by Fries [29] and Mitchell and Denne [30], they may also derive from anatomical differences, such as in cell types and quantitative distribution, thickness of cell walls, and size of cell cavities through the wood. Importantly, the cell wall substance adsorbs and desorbs moisture to and from the environment because wood is a hygroscopic material. One consequence of this is that the cell wall shrinks and swells, and the relative proportions of cell wall substance and pore space thus vary greatly [31]. Species exhibited significant influence ($P<0.05$) on the density of the five different species (Table 2).

Assessment of Anatomical Properties

The study showed that *N. diderrichii* had the longest fiber with a mean value of 1.50 mm followed by *T. scleroxylon with* 1.15 mm while *T. catappa* had the shortest fiber length of 0.93 mm (Table 1). All the values fall within the range of 0.75-1.75 mm for 10 – 12-year-old stands of *Gmelina arborea* reported by Rogue and Fo [32] and 0.99-1.33 mm reported by Ogunkunle [33] for 12 Ficus species. The longest fiber was slightly higher than 1.48 mm reported for *Vitex doniana* [2]. There was no significant difference in the fiber length of both *G. arborea* and *T. catappa* while *N. diderrichii, T. scleroxylon,* and *T. mantaly* were significantly different from one another. However, the species significantly ($P<0.05$) influenced the fiber length. Based on this result and in comparison with other species, the fiber length of all the species in this study is within acceptable range.

The species with the highest fiber diameter was *N. diderrichii* (36.45µm) followed by *G. arborea* (26.19 µm), while *T. mantaly* had the lowest fiber diameter of 15.01 µm (Table 1). All the values fall within the range of 18.5-27.5 µm for *Gmelina arborea* [32] except *T. mantaly* and lower than 36.0-40.0 µm for *Pinus patula* [34]; and 41.5µm for *Ricinodendron heudelotti* [35].

Assessment of lumen width showed that *G. arborea* had the highest mean value (14.65 µm) and the lowest was *T. mantaly* (5.97 µm). The value recorded as the highest in this study is lesser than 30.67 µm for *G. arborea* [36] but higher than 12.7 µm for *Vitex doniana* [3], 12.5 µm for *T. scleroxylon* [37], In addition, all the species in this study had lumen width greater than 8.09 – 9.54 µm for Bamboo [38] except *Terminalia mantaly* and greater than the range (2.47 – 4.94 µm) with a mean of 3.31 µm reported for some indigenous hardwood species in the tropical rainforest ecosystem [39].

It was observed that *N. diderrichii* had the thickest cell wall (12.26 µm) followed by *T. scleroxylon* and *T. catappa* with the same value of 6.17 µm while *T. mantaly* had the lowest value of 4.52 µm. All the values recorded in this study are greater than 3.83 µm for *G. arborea* [33], 3.46- 3.87 µm for *B. vulgaris* [38]. The influence of species was significant ($P<0.05$) on the cell wall thickness.

ASSESSMENT OF THE DERIVED VALUES

The distribution of the derived values for the five wood species is as presented in Table 3. The table presents the mean values for Slenderness ratio, Coefficient of flexibility and Runkel ratio for the different wood species.

Table 1: Showing Mean Values of Density and Anatomical Properties of Different Tree Species.

Species	Density	Fiber length (mm)	Fiber diameter (µm)	Lumen width (µm)	Cell wall thickness (µm)
Gmelina arborea	475.05 ± 46.34^{a}	0.95 ± 0.11^{a}	26.19 ± 0.004^{b}	14.65 ± 0.004^{d}	5.77 ± 0.001^{a}
Terminalia catappa	645.18 ± 75.12^{b}	0.93 ± 0.18^{a}	24.54 ± 0.005^{b}	12.21 ± 0.006^{c}	6.17 ± 0.003^{a}
Triplochiton scleroxylon	590.05 ± 57.84^{c}	1.15 ± 0.15^{c}	22.62 ± 0.003^{b}	10.29 ± 0.003^{b}	6.17 ± 0.001^{a}
Nauclea diderrichii	651.73 ± 19.80^{c}	1.50 ± 0.33^{d}	36.45 ± 0.029^{c}	11.93 ± 0.004^{c}	12.26 ± 0.015^{b}
Terminalia mantaly	752.65 ± 103.15^{d}	1.03 ± 0.16^{b}	15.01 ± 0.003^{a}	5.97 ± 0.002^{a}	4.52 ± 0.001^{a}

Table 2: Analysis of Variance for Significant Difference in Density.

Source of Variation	Df	Density
Species	4	34.761**
Error	70	
Total	75	

Table 3: Showing Mean Values for Derived Values.

Species	Slenderness ratio	Coefficient of Flexibility	Runkel Ratio
Gmelina arborea	36.90 ± 5.97^{a}	56.09 ± 14.29^{c}	0.86 ± 0.39^{a}
Terminalia catappa	39.41 ± 10.99^{a}	48.62 ± 20.96^{b}	1.50 ± 1.13^{ab}
Triplochiton scleroxylon	51.16 ± 7.27^{b}	44.82 ± 9.89^{ab}	1.35 ± 0.57^{ab}
Nauclea diderrichii	54.30 ± 20.88^{b}	44.08 ± 20.06^{ab}	2.71 ± 3.78^{c}
Terminalia mantaly	70.20 ± 14.90^{c}	39.62 ± 6.56^{a}	1.60 ± 0.45^{b}

Table 4: Analysis of Variance for Derived Value.

Source of Variation	Df	Slenderness ratio
Species	4	61.49**
Error	295	
Total	300	

** Significant at $p < 0.05$

The study showed that *T. mantaly* had the highest slenderness ratio (70.20) followed by *N. diderrichii* (54.30) while the least (36.90) was recorded for *G. arborea*. All the values recorded in this study except *G. arborea and T. catappa* fall within the range of 42.38 to 71.99 reported for different Ficus species [33]. Slenderness ratio of fibrous material of more than 33 is considered good for pulp and paper production. The fibers of all the species in this study had slenderness ratio that is higher than 33 and therefore is good for pulp and paper production. Only *T. mantaly* showed significant difference in its slenderness ratio from other species.

Results of coefficient of flexibility showed that *G. arborea* had the highest value (56.09%) followed by *T. catappa* (48.62%). The lowest value (39.62%) was recorded for *T. mantaly.* There are four groups of fibers: High elastic fibers (FC greater than 75); elastic fibers (FC between 50 - 75%); rigid fibers (FC between 30 - 50%) and highly rigid fibers (FC less than 30%) as stated by [40]. This result shows that *G. arborea* falls in the category of elastic fibers, while the remaining species falls in the category of rigid fibers. However, they are within permissible limits.

All the species in this study except *G. arborea* (0.86) had Runkel ratio greater than 1 with *N. diderrichii* having the highest mean value of (2.71). The best value which is recorded for *G. arborea* in this study was greater than 0.79 reported by Ajala [41] for pine species, 0.75 by Awuku [39] for some tropical hardwood species and lower than 0.90-0.97 for *B. vulgaris* [38]. The fibres with a Runkel ratio above one is considered as thick-walled fibers, which are stiffer, less flexible, and form a bulky paper sheet of lower bonded area [18].

CONCLUSION

The study showed that the density of the species varied significantly from one to the other. Both *T. mantaly* and *T. catappa* hitherto considered primarily for the purpose of recreation and shade showed outstanding potential for other purposes based on the density since there exist a relationship between density and strength properties of wood. Both can therefore be considered for industrial purposes. Since both *G. arborea* and *T. catappa* did not show any significant difference in terms of fiber length, fiber diameter and cell wall thickness and *G. arborea* is a prime species for pulping, *T. catappa* beyond being used for fruit, shade and construction can also be used for pulp and paper production. However, the beating of pulp in *G. arborea* will be better because of its outstanding lumen width which will enhance the penetration of liquids into empty spaces of the fibers.

This study further showed that *G. arborea* falls in the category of elastic fibers while the remaining species falls in the category of rigid fibers and will require blending to produce paper of high quality. The high density, cell wall thickness and Runkel ratio of *N. diderrichi i*and *Triplochiton scleroxylon* can be harnessed for the production of mortar, poles, doors, chairs, etc. From this study, therefore, it can be concluded that all the species studied and examined have values which fall in the range of values acceptable hardwoods and can be harnessed for various utilization potentials though there are overlaps. Furtherance to this is the need to discourage destructive approach in the evaluation of species.

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