RESEARCH ARTICLE

European Journal of Agriculture and Food Sciences
www.ejfood.org

Evaluation of Selected Physical Properties of *Blighia sapida* K. Koenig Wood

Clement M. Olayanu, Ayodeji O. Omole, Segun M. Adeyemo, Adelodun R. Majekobaje, and Olusola S. Areo

ABSTRACT

***Blighia sapida*, a Lesser-Used Species is being processed into sawn timber to meet the demand for wood. The knowledge of its wood quality would enhance its effective utilization. However, there is little information known on the physical properties of this species that could enhance its acceptability and optimum utilization. This, therefore, necessitate the need to investigate the physical properties of this wood species.**

Three standing trees of *B. sapida* were purposively felled for this study. Billets of 500 mm were obtained from the wood disc at the base, middle, and top of the tree. Each wood disc was partitioned into three; innerwood, middlewood, and outerwood following specified international standards for the physical properties test (wood colour, proportion of sapwood and heartwood, bark thickness, density, moisture content, and volumetric shrinkage).

***B. sapida* wood density with a mean value of 709.78±8.88 kg/m^3, ranged from (571.59±13.45 to 854.81±7.08 kg/m^3. Moisture content percentage of average value 70.62±1.23%, ranged from 53.84±1.40 to 89.00±2.75%. Volumetric shrinkage of average value 15.24±0.25%, range from 13.38±0.66 to 16.89±0.83%. The range of *B. sapida* wood density value of the study falls within the range that could be categorized as medium density wood of medium construction strength properties. The 1:1.5% tangential–radial shrinkage observed in this study was low, an indicator of a low risk of deformation while seasoning the wood, as the ratios of tangential-radial shrinkage that is high are those over 2.2%.**

Keywords: Lesser-Used Species, Physical properties, Tropical trees, Volumetric Shrinkage.

Submitted : March 06, 2022
Published : March 31, 2022
ISSN: 2684-1827
DOI: 10.24018/ejfood.2022.4.2.477

C. M. Olayanu
Department of Forest Production and Products, University of Ibadan, Ibadan, Oyo, Nigeria.
(e-mail: olayanuclement@gmail.com)
A. O. Omole
Department of Forest Production and Products, University of Ibadan, Ibadan, Oyo, Nigeria.
(e-mail: ao.omole@mail.ui.edu.ng)
S. M. Adeyemo*
Forestry Department, Mississippi State University, Starkville, Mississippi, USA.
(e-mail: sma451@msstate.edu)
A. R. Majekobaje
School of Renewable Natural Resources, Louisiana State University, Baton Rouge, LA, USA.
(e-mail: amajek1@lsu.edu)
O. S. Areo
Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, Ibadan, Oyo, Nigeria.
(e-mail: areosola73@gmail.com)

Corresponding Author

I. Introduction

Technically, wood is the xylem and the rigid portion between the pith and the bark that has chemical constituents of cellulose, hemicellulose, lignin, and extractives with various inherent properties that make it suitable for diverse end uses. Due to the high demand for timber for wood-based products and structural applications which resulted in the scarcity of very strong and durable economic timber species, attention is now drawn to lesser-used species such as wood from *Artocarpus altilis* (Bread fruit), *Irvingia spp* (African mango), *Mangifera indica* (Mango), *Cola acuminate* (Kola nut), *Anacardium occidentale* (Cashew), *Borassus aethiopum* (Borassus) and so on as a result of their availability to be used as a substitute for the economic timber species which are no longer readily available and their high cost of procurement when made available in the forest or timber market. In the same vein, the rate at which the forest is being depleted due to population growth, indiscriminate logging, and removal for construction purposes and farming are very alarming [1]. The indiscriminate felling of trees resulting from urbanization, farmland cultivation, and charcoal production has made it difficult for the saplings of economic timber species, to develop to mature timber, to meet up with the demand of the wood end users. This has paved the way for the lesser-used timber species, which could be considered substitutes.

Blighia sapida tree species, a tropical hardwood species with its cultivation mainly known for fruit production, could also serve as good timber species which could be processed into sawn timber to meet the increasing demand for wood. It belongs to the family Sapindaceae, with the common name as ackee apple, and in Nigeria called "Isin" by the Yoruba people. The fruit serves as a source of income in the rural areas for farmers who plant the tree species in large numbers because the fruit is used for cooking, which serves as a substitute for meat in soups. The fruits, seeds, and capsules of the fruits serve as raw materials for some industries for manufacturing certain products such as margarine and soap. *B. sapida* is a very nice ornamental tree, which is brightly decorated with red colour fruits. The soil under the tree is rich in soil organic matter as a result of mineralization of its leaf droppings, which made it considered useful for planting to improve soil fertility and to reduce erosion through its large rooting system [2]. *B. sapida* may be as high as 13-15m, cylindrical with a large crown. *B. sapida* wood due to the high cultivation of the tree species in Imeko- Afon Local Government Area of Ogun State, has been found useful in the area and the other Southwestern States of Nigeria for general utility purposes; especially medium-strength constructions and structural works, utility furniture such as benches, stools, boxes, a trading cabinet for petty traders and so on.

The physical properties of wood are a great phenomenon that should be clearly understood before the wood is put into any utilization class to ensure effective fitness for a particular use of the wood. One of the major physical properties of wood, which is the density should be clearly defined to better understand other properties of the wood. Kayumba [3] stated that the basic density of any wood provides an index of wood quality to which all end uses can relate. Physical properties are the quantitative characteristics of wood and its behavior to external influences other than applied forces. The familiarity with the physical properties of timber species is very essential as they can significantly influence the strength as well as the performance of wood used in structural applications [4] and it could also be used to categorize wood into various classes of wood utilization.

B. sapida is categorized as a lesser-used species but may also serve as good timber species. Koenig [2] reported that the wood of *B. sapida* is currently not commercially important, but it is a multipurpose tree as a result of being a source of edible fruits (arils) and traditional medicine as well as being popularly planted as ornamental shade. Therefore, the lack of detailed information on the physical properties of *B. sapida* wood species has limited the preference of the wood being employed for certain construction and structural purposes. Hence, for the wood to be effectively utilized, the selected physical properties of the wood were evaluated to provide information on the inherent physical properties of the wood that can serve as the best fit for diverse utilization purposes of wood and to ensure the acceptability of the wood as best alternative for scarce economic wood species in the timber market.

II. Materials and Methods

A. Study Area

The wood samples of the research were collected from the University of Ibadan campus located between latitude 7.4433° N and longitude 3.9003° E. The property tests were carried out at the Forestry Research Institute of Nigeria, Ibadan. The soil is well-drained clayey loam soil. The colour of the soil is greyish brown, fertile, and supports growth and development. The vegetation is a mixture of savannah belts and sparse forests. The University of Ibadan has a tropical wet and dry climate, with a lengthy wet season and relatively constant temperatures throughout the year. The mean daily temperature is 26.46 °C or 79.63 °F, the mean minimum 21.42 °C or 70.56 °F, and the relative humidity is 74.55%.

B. Sampling Technique

Three matured trees of *B. sapida* were felled, delimbed, and crosscut at the merchantable height. Bolts of 500 mm long were collected at the base (10%), middle (50%), and the top (90%) of the merchantable length of each tree [5]. From each bolt, a centre plank of 500 mm long was removed, and the radial length was partitioned into innerwood, middlewood, and outerwood i.e., from the pith to the bark for all the properties tested. Following the sample dimension used by Ogunsanwo and Akinlade [6].

C. Preparation of Wood Samples

Test samples of 500 mm long centre planks were cut from all sample demarcations i.e., the base, middle, and top from bolts extracted from the sampled trees, and then reconverted to various dimensions needed for the property tests.

The wood samples were processed using a circular machine and plane machine to a dimension of 20 mm × 20 mm × 60 mm for wood density, moisture content determination, and wood shrinkage in accordance with [7]. Physical properties: 45 test samples were obtained from each tree which will make a total of 135 each for Density, Moisture content, and Wood shrinkage, making a total of 405 samples altogether.

The selected wood indices and their corresponding number of test samples are listed below.

D. Physical Properties Determination

1) Wood Colour Determination

The colour determination was carried out by visual observation of the wood samples and compared with colours obtained from colour chart according to Falemara *et al.* [8].

2) Heartwood Proportion

Heartwood proportion was evaluated by visual estimation of the difference in the colour of the wood zones. The brownish zone was taken as the heartwood proportion and the lighter colour zone as the sapwood proportion. The diameter of the sapwood was measured with a calibrated ruler, which was then subtracted from the diameter of the wood to get the heartwood diameter [9].

$$\text{HWD} = \frac{WD - SWD}{2} \quad (1)$$

where HWD is the heartwood diameter, WD is the wood diameter, SWD is the sapwood diameter.

3) Sapwood Proportion

Sapwood wood proportion was evaluated by visual estimation of the difference in the colour of the wood zones. The brownish zone was taken as the heartwood proportion and the lighter colour zone as the sapwood proportion. The diameter of the heartwood was measured with a calibrated ruler, which was then subtracted from the diameter of the wood to get the sapwood diameter [2].

$$\text{SWD} = \frac{WD - HWD}{2} \quad (2)$$

where SWD is the sapwood diameter, WD is the wood diameter, HWD is the heartwood diameter.

4) Bark Proportion

The diameter of trees from the base, middle and top was measured with the aid of a calibrated ruler, placed on the transverse surface of each disc. The diameter was first determined over bark to obtain the tree diameter, followed by measurement of diameter under (inside) bark to obtain the actual wood diameter. The bark thickness was determined by subtracting the diameter under bark from diameter over bark [10].

$$Bark\ thickness = \frac{Diameter\ over\ bark - Diameter\ under\ bark}{2} \quad (3)$$

5) Determination of Wood Density

The 20 mm × 20 mm × 60 mm wood samples were collected from the bolts at the base, middle, and top of the wood merchantable length, then partitioned into innerwood, middlewood and outerwood in accordance with ASTM [7]. The volume of samples at green weight was measured, recorded, and oven-dried to a constant weight at 103±2 °C for 18 hours which was afterward recorded. The formula below was used for the calculation of wood density as adopted by Olaoye *et al.* [11].

$$D = \frac{m}{v}\ (kg/m^3) \quad (4)$$

where D is the density, *m* is the oven-dried mass, *v* is the green volume of the test samples.

6) Determination of Moisture Content

Wood samples of (20 mm x 20 mm x 60 mm) dimension were collected in accordance with ASTM [7]. The samples were weighed when wet (wet weight), and then dried to a constant weight at 103±2 °C in an oven for 18 hours, after which samples were re-weighed (oven-dry weight). The loss of weight of the wood samples on drying to a constant weight was taken note. Moisture content was then calculated as a percentage of the oven-dry weight of the wood samples using the formula below as adopted by Olaoye *et al.* [11].

$$MC = \frac{ww - ow}{ow} \times 100 \quad (5)$$

where MC is the moisture content, *ww* is the wet weight, and *ow* is the oven-dry weight.

7) Determination of Wood Shrinkage

Test specimens of 20 mm × 20 mm × 60 mm in accordance with ASTM [7] were used while the tangential, radial, and longitudinal planes were labelled and numbered appropriately. The test specimen was soaked in distilled water for 72 hours to condition them to wetness exceeding the moisture equilibrium point. Test specimens were then taken in sequence and left to drain out surplus water; subsequently, with the aid of sensitive veneer calipers, their dimensions were read to the nearby millimeter in wet conditions. Following the oven drying of the samples at 103±2^{0}C, the percentage of shrinkage was determined in the tangential and radial planes as the shrinkage of longitudinal is less important. This is in accordance with the method used by Areo *et al.* [12].

$$S = \frac{Ds - Do}{Ds} \times 100 \quad (6)$$

where S is the shrinkage, *Ds* is the saturated condition size. *Do* is the oven-dry condition size.

$$VS = S_R + S_T \quad (7)$$

where VS is the volumetric shrinkage, S_R is the radial shrinkage, and S_T is the tangential shrinkage.

E. Experimental Design

The experimental design adopted was a two-factor split-plot in a Randomized Complete Block Design (RCBD), with the three trees felled standing as replicate. The following are the variables representing the functions:

i. Sampling Height- Base, Middle, and Top
ii. Radial Position – Innerwood, Middlewood, and Outer wood.

In the split-plot design, the longitudinal section represented the main factor (Base, Middle, and Top) while the radial regions represented the sub-factor (Innerwood, Middlewood, and Outerwood).

III. Results and Discussion

A. Visual Observation of B. sapida wood colour

The *B. sapida* wood showed golden colour when it was felled, with no distinction in the colour of sapwood and heartwood portion of the wood as shown in Fig. 1. *B. sapida* wood golden colour shown was like that of *Nauclea diderichii* as found in Falemara *et al.* [8] colour chart. However, few days after conversion, the sapwood portion changed to cream colour like that of *Triplochiton scleroxylon* and the heartwood changed to light brown colour like that of *Milicia excelsa* but not like the dark brown of *Mansonia altissima* as found in Falemara *et al.* [8] colour chart and as shown in Fig. 2. The colour change may have been as a result of loss of moisture content of the wood with some volatile extraneous materials when it was exposed to air as drying of wood tends to be from the surface of the wood before the inner portion, which is a process that is very essential before wood could be put to use. As reported by Sundqvist [13] the colour change could also be a result of complex changes and degradation of hemicelluloses, lignin, and certain extractive compounds. The colour can help to distinguish it from other hardwood species and enable a wood user to select the best portion of the wood to be used as there is a clear distinction between the sapwood and heartwood. As reported by Falemara *et al.* [8] and as documented by Regis [14] that general wood identification can often be made quickly based on readily visible characteristics such as color, odor, density, or grain pattern.

Fig. 1. *B. sapida* wood showing golden colour immediately after felling.
Source: Field survey (2021).

Fig. 2. *B. sapida* wood showing cream and light brown colours days after conversion. Source: Field survey (2021).

B. Proportions of Sapwood, Heartwood, and Bark in B. sapida wood

The mean value recorded for heartwood proportion for *B. sapida* wood was 80.30±1.74%. The proportion of heartwood decreased from the base to the top of the tree, with the base having 85.78±1.23%, the middle 80.51±1.24%, and the top 74.62±1.59% as presented in Table I. The analysis of variance in Table II showed that there were significant differences among the heartwood proportions along the sampling heights of the trees with the p-value (0.0035). The heartwood is the inner portion of the wood that is composed of dead cells. The presence of extractives in it helps it develop natural durability than sapwood. According to Taylor and Cooper [15], it is the inner portion of the wood where food begins to break down into a compound referred to as the extractive or a portion of the wood with coloured extractives. *B. sapida* heartwood decreased from the base to the top. This heartwood pattern of variation conforms to the pattern observed by Sotannde *et al.* [16] on a 9-year-old plantation of *Khaya senegalensis* wood species and Riki *et al.* [9] on *Ziziphus mauritiana* wood species. The decrease observed in the heartwood proportion towards the top may have been a result of the extent of parenchyma cell death. As opined by Taylor *et al.* [17] complete parenchyma cell death marks the transformation of sapwood into the heartwood. Taylor *et al.* [17] stated that most evidence suggests that parenchyma activity gradually declines with increasing distance from the cambium. With increasing wood tapers, there is a reduction in wood girth, and wood formed at the upper region of wood tends to be closer to the cambium than at the base of wood with large girth. Therefore, the proportion of heartwood increases along the bole length of wood with the tree age. The heartwood adds little or no contribution to the strength and physical properties of the wood [16] [18]. But because of the extractives around the heartwood, it develops natural durability against agents of biodegradation.

The mean value for *B. sapida* sapwood proportion was 16.15±1.89 %. The sapwood increased from the base to the top, with the base having 10.37±1.48%, the middle 15.91±1.44%, and the top 22.17±1.95% as presented in Table I. The analysis of variance (Table II) shows that there was a significant difference among the sapwood proportions along the sampling heights of the tree with the p-value (0.0067). The sapwood of *B. sapida* wood increased from the base to the top. This pattern of sapwood variation along the tree height agreed with the report of Sotannde *et al.* [16] on 9-year-old plantation-grown *Khaya senegalensis*, Sotannde and Riki [19], and Riki *et al.* [9] on *Ziziphus mauritiana* wood species. The sapwood portion of the wood is the area with living cells that aid the translocation of biochemical substances and their storage. The sapwood is distinguished from the heartwood due to its light colour, most especially in wood that has distinct sapwood and heartwood. The increase in sapwood at the top may have been a result of more cell differentiation at the upper portion of the wood in response to the need for the continuous growth of the tree. The heartwood volumes are cumulative in the tree whereas sapwood volumes are the sum of the new sapwood from the new annual increments [17]. However, sapwood as a result of its low extractive content brings about a reduction in the chemical consumption during the pulping and bleaching process in paper production.

The average value of the *B. sapida* wood bark proportion was 3.51±0.17%. The bark proportion slightly decreased from the base to the top, with the base having 3.78±0.26%, the middle 3.57±0.19%, and the top 3.19±0.39%. The analysis of variance in Table II shows that there were no significant differences among the bark proportions along with the sampling height of the tree with the p-value (>0.05). The bark is the outermost portion of the wood which is produced as a result of the activities of cambium in the production of wood. The xylem is produced inwardly which results in wood and the phloem is produced outwardly which results in bark. The bark protects the wood from the harsh environmental condition and against mechanical injury of the inner tissues of the tree. According to Sotannde *et al.* [16] it is rich in chemical substances such as tannin and dyes derived from plant metabolism. Bark thickness slightly decreased from the base to the top. This pattern of variation agreed with the report of Sotannde and Riki [19] on some wood species and Riki *et al.* [9] on *Ziziphus mauritiana*. The decrease from the base to the top may have been as a result of the fast production of xylem at the upper part of wood than the phloem to increase in girth. It may also have been as a result of the taper of the tree at the upper portion of the tree.

TABLE I: *B. SAPIDA* HEARTWOOD, SAPWOOD, AND BARK PROPORTION VARIATION

Sampling Height	Heartwood (%)	Sapwood (%)	Bark (%)
Base	85.78±1.23^{a}	10.37±1.48^{b}	3.78±0.26^{a}
Middle	80.51±1.24^{b}	15.91±1.44^{b}	3.57±0.19^{a}
Top	74.62±1.59^{c}	22.17±1.95^{a}	3.19±0.39^{a}
Pooled Mean	80.30±1.74	16.15±1.89	3.51±0.17

Values with the same superscript are not significantly different at 95 % confidence level.

TABLE II: MEAN DIFFERENCES AMONG THE PROPORTION OF HEARTWOOD, SAPWOOD, AND BARK IN *B. SAPIDA*

Source	Df	Sapwood	Heartwood	Bark
Axial	2	0.0067*	0.0035*	0.4223^{ns}
Error	6			
Total	8			

"ns" represents not significant (p-values > 0.05), while "*" represents significant (p-values < 0.05).

C. Wood Density

Wood density serves as a great index in any timber species utilization classification as it is a good predictor of the strength properties of wood and is highly correlated with other properties. The mean density of *B. sapida* was 709.78±8.88 kg/m^3. Density decreased from the base to the top of the sampled trees, with the base having the mean density of 806.55±9.98 kg/m^3, and the middle having the mean density of 685.70±12.44 kg/m^3, and the top having the mean density of 637.08±10.97 kg/m^3 as shown in Table III. The mean density of *B. sapida* wood was within the category of medium construction timber utilization class. As documented by Kityo and Plumptre [20] and as reported by Areo *et al.* [12], timber species are classified into four main classes, heavy construction (>720 kgm^3), medium construction (480-720 kgm^3), light construction (400-480 kgm^3) and the very light construction (< 400 kgm^3) timber species. However, according to Appiah-Kubi *et al.* [21] who reported the density of *B. sapida* to be 899 kg/m^3 in Ghana and corroborated by Quartey [22] who worked on anatomical properties of three lesser utilised Ghanaian hardwood species taking *B. sapida* as one of the species reported 892 kg/m^3 as density. The mean density obtained in this study is almost the same as those of Ghana though slightly minimal, this could be as a result of factors such as site, climatic conditions, age of the trees studied, and the portion along the bole from which samples were collected [12].

Radially, density increased from inner wood to the outerwood, with the innerwood having the mean density of 640.54±14.58 kg/m^3, followed by middlewood with a mean density of 718.56±12.96 kg/m^3 and the outerwood having the mean density of 770.24±12.10 kg/m^3. The analysis of variance presented in Table IV shows that there was a significant difference at a 0.05 probability level between the trees, along the sampling heights and radial directions, while their interaction was not significant at (P = 0.0815). The follow-up test in Table III further showed significant differences. The reduction of density from the base to the top conforms to the findings reported by Akachuku [23] for the wood density of Nigerian Grown *Gmelinea arborea*. Fuwape and Fabiyi [24] also reported similar observations for plantation-grown *Nauclea diderichii* wood density. Izekor *et al*. [25], Sotannde *et al.* [26], Riki *et al.* [27], and Riki *et al.* [9] also reported a similar trend for *Tectona grandis*, *Azadirachta indica*, *Pinus caribaea*, and *Ziziphus mauritiana* wood species. The wood density decreased from the base to the top of the tree species. This is in conformity with the auxin gradient theory by Larson [28] who stated that, the endogenous auxin that is produced at the apical region of growing shoots enhance the cambial division as well as xylem differentiation. As a result, there is high production of juvenile wood close to the crown that greatly contributes to the low density at the top of the tree.

According to Zobel and Buijtenen [29] wood density is normally high at the base due to the higher proportion of heartwood formation at the stump and higher proportion of juvenile wood near the top. The values obtained for wood density in the study validated the fact that timber species have a wide range of densities with varied differences between earlywood and latewood, between the pith and outer rings, and even between the trees growing on the same site [30].

TABLE III: The mean values of Density, Moisture Content, Tangential Shrinkage, Radial Shrinkage, and Volumetric Shrinkage of *B. sapida* wood

Sampling Height	Radial Direction	Density (kg/m^3)	Moisture (%)	Tangential shrinkage (%)	Radial shrinkage (%)	Volumetric shrinkage (%)
Base	Innerwood	752.73±18.17^{c}	67.92±2.77^{a}	10.23±0.56^{a}	6.38±0.30^{b}	16.61±0.61^{a}
	Middlewood	812.12±13.57^{b}	59.18±1.38^{b}	9.40±0.32^{a}	7.48±0.33^{a}	16.89±0.83^{a}
	Outerwood	854.81±7.08^{a}	53.84±1.40^{b}	10.11±0.58^{a}	6.32±0.42^{b}	16.43±0.83^{a}
Pooled Mean		**806.55±9.98**	**60.31±1.41**	**9.91±0.29**	**6.73±0.21**	**16.64±0.38**
Middle	Innerwood	597.29±11.02^{c}	85.87±2.78^{a}	7.76±.43^{b}	5.62±0.32^{a}	13.38±.66^{b}
	Middlewood	693.04±14.60^{b}	74.58±2.17^{b}	9.82±0.60^{a}	6.12±0.32^{a}	15.94±.63^{a}
	Outerwood	766.78±9.69^{a}	63.14±2.17^{c}	9.51±0.57^{a}	6.65±0.45^{a}	16.16±0.93^{a}
Pooled Mean		**685.70±12.44**	**74.53±1.94**	**9.03±0.33**	**6.13±0.22**	**15.16±0.46**
Top	Innerwood	571.59±13.45^{b}	89.00±2.75^{a}	8.45±0.40^{a}	5.10±0.30^{a}	13.56±0.55^{a}
	Middlewood	650.51±13.63^{a}	74.65±2.69^{b}	7.78±0.47^{a}	6.00±0.43^{a}	13.79±0.75^{a}
	Outerwood	689.14±15.97^{a}	67.38±3.13^{b}	8.53±.51^{a}	5.83±0.28^{a}	14.37±0.61^{a}
Pooled Mean		**637.08±10.97**	**77.01±2.11**	**8.26±0.26**	**5.65±0.20**	**13.91±0.36**
Total Mean		**709.78±8.88**	**70.62±1.23**	**9.07±0.18**	**6.17±0.12**	**15.24±0.25**

Means ± Standard mean error of 5 replicate samples. Values with the same superscript are not significantly different at 95 % confidence level.

TABLE IV: Analysis of variance of means of density, moisture content, tangential shrinkage, radial shrinkage, and volumetric shrinkage of *B. sapida* (ackee apple) wood.

Sources of variation	df	Density	Moisture content	Tangential shrinkage	Radial shrinkage	Volumetric shrinkage
Tree	2	0.0091*	0.21^{ns}	0.00*	0.0007*	0.00*
Axial (Sampling Height) SH	2	0.00*	0.00*	0.00*	0.0008*	0.00*
Main plot error	4					
Radial Direction (RD)	2	0.00*	0.00*	0.26^{ns}	0.0110*	0.029*
SH x RD	4	0.082^{ns}	0.31^{ns}	0.0076*	0.1748^{ns}	0.070^{ns}
Subplot error	120					
Total	134					

"ns" represents not significant (p-values > 0.05), while "*" represents significant (p-values < 0.05).

The analysis of variance at a 95% confidence level revealed that there is a significant difference among the sampled trees, the axial direction as well as the radial positions in wood. The increase in density from the innerwood to the outerwood may have been a result of an increase in the age of the cambium (tree age) [12] [25] [31]. By implication, the density variation (axial and radial) would suggest a careful selection of the portion to be used depending on the intended purpose. The wood density value for *B. sapida* as revealed by the study falls within the range that compared well with some commercial tropical African timbers such as *Mansonia altissima* which is (590–

720 kg/m^3), *Tectona grandis* which is (480–850 kg/m^3), *Khaya grandifoliola* which is (640–730 kg/m^3), *Tieghemella africana* which is (600–800 kg/m^3), *Pterocarpus soyauxi* (675–815 kg/m^3), *Pericopsis elata* (620–700 kg/m^3), *Milicia excelsa* (550–750 kg/m^3) [26] and 629.99 kg/m^3 to 702.41 kg.m/^{3} was reported on neem wood harvested from free areas in the Sahel savanna zone of Nigeria [32]. From background information obtained, *Blighia sapida* wood showcases a fine lustre when used for furniture works such as stools, traders' cabinets, benches, and tables for indoor applications; these can be attributed to its density value. Riki *et al*. [9] in their study observed that the wood density values obtained in this study fall within the range of species suitable for furniture, sheeting, and lining, paquet, veneer wood production. However, Jacobsen *et al*. [33] and Hugo *et al*. [34] stated that variation in wood density is mainly driven by variation in fibre lumen diameter which is directly related to cell size and to the cell wall thickness. The density was higher at the base than at the top as a result of higher cell wall thickness and lower fibre lumen diameter than the top, while the top is of lower cell wall thickness and higher fibre lumen diameter.

D. Wood Moisture Content

The mean moisture content (in %) of *B. sapida* wood was 70.62±1.23%. Along the sampling height, moisture content percentage increased from the base to the top with the base having 60.31±1.41%, the middle having 74.53±1.94%, and the top having 77.01±2.11% as shown in Table III.

Radially, moisture content decreased from innerwood to outerwood with the innerwood having an average of 80.93±2.09%, the middlewood having 69.47±1.63%, and the outerwood having 61.45±1.57%. The mean moisture content of *B. sapida* wood as revealed through the study was relatively high and according to Riki *et al.* [9] who reported an average moisture content of 66.40% for *Ziziphus mauritiana* wood proved that the moisture content observed isn't an unexpected outcome. The high moisture content of *B. sapida* could be a result of wood anatomy, tree age, and species which could necessitate the need to dry the wood before use as it could impact strength, efficient handling during processing for structures, transportation, and preservation of the wood for storage.

The analysis of variance in Table IV showed no significant differences in the moisture content of the *B. sapida* trees and the interaction between the sampling height and radial direction but along the sampling heights as well as radially, there were significant differences at a 5% probability level. In Table III, the follow-up result at a probability level of 0.05 further shows the level of significant differences. Moisture is greatly needed by trees used for timber and it is very essential in carrying out physiological processes effectively. It is very essential for the translocation of materials in a living tree. The amount of moisture in wood may be due to the available sorption sites in the wood Olaoye *et al*. [11]. Moisture content is the ratio of the oven-dried weight of a given volume of wood to the weight of an equal volume of water [35].

The moisture content increased from the base to the top of the sampled trees, and this is in accordance with the result reported by Olaoye *et al*. [11] for *Aningeria robusta* wood. It was further submitted that the top wood with the highest mean moisture content of the three sampling height positions may have been from either larger or more sorption sites at the top portion of the wood: or as a result of larger lumen width in the top region of the wood. This is also supported by the findings of Okon [36] and Noah *et al.* [37], who observed the moisture content inconsistency in *Gmelina arborea* wood. However, a wood having a high percentage of moisture content and more sorption sites will tend to lower the density and influence other strength properties of the wood. Ogunbajo *et al.* [38] observed that samples of timber from *Uacapa guineensis* show average moisture content with the least value of 20% and its effect could be seen in the higher values of the mechanical strength properties such as modulus of rupture, modulus of elasticity, and maximum compressive strength.

There was no significant difference among the sampled trees but at the sampling height and radial direction of the tree species studied, the means at the corresponding positions were significantly different from one another. This is an indication that *B. sapida* tree species have the same average moisture content but at different proportions across the tree. However, for the wood species to be effectively utilized, there is a need to carry out a proper seasoning of the wood as a result of its high moisture content to impact strength, bring about a reduction in weight, dimensional stability, and high penetration and permeability when treated with preservatives.

E. Wood Shrinkage

1) Tangential Shrinkage

The mean tangential shrinkage of *B. sapida* wood was 9.07±0.18%. Axially, tangential shrinkage decreased from the base to the top, with the base having an average of 9.91±0.29%, the middle having 9.03±0.33%, and the top having 8.26±0.26% as presented in Table III. The mean tangential shrinkage of *B. sapid*a (at oven-dry weight) was slightly higher than some other wood species; *Khaya grandifoliola* (8.64%) and *Azadirachta indica* (7.93%) as reported in the studies of Aguma and Ogunsanwo [39] and Sotannde *et al.* [26].

Radially, it increased from innerwood to outerwood, with the innerwood having an average of 8.81±0.30%, the middlewood having 9.00±0.30%, and outerwood having 9.38±0.33%. The analysis of variance showed significant differences among the tangential shrinkage of the trees and sampling height, but not significantly different along the radial direction. The interaction was also significant between the sampling height and radial direction in Table IV. The follow-up test shows the level of significant differences (P = 0.05) as presented in Table III. Tangential shrinkage decreased from the base to the top, a phenomenon in line with the report of Aguma and Ogunsanwo [39]. In the studies of Okon [36] on 25-year-old *Gmelina arborea*, Areo *et al.* [12] on *Artocarpus altilis,* and Sotannde *et al*. [26] on *Azadirachta indica*, tangential shrinkage was reported to increase from base to the top. On the other hand, studies on *Ziziphus mauritiana* [9] a shrub, also revealed a different trend as it was reported that tangential shrinkage increased to the middle and then decreased to the top. The inconsistent variation in the tangential shrinkage of both tree species and shrubs could be opined to the variations in the anatomical structure of wood species. An inconsistent variation in the tangential shrinkage was also reported for *Terminalia catappa* wood in the study of Emerhi and David-Sarogoro [40] where tangential shrinkage decreased from base to middle and then increased to the top. The decrease from the base to the top for tangential shrinkage may have been a result of changes caused by the cell size variation as well as earlywood volume caused by the increasing age of the cambium. Also, the variation may have been a result of the fact that natural variation exists in wood and the variability in the wood properties most especially the anatomical features.

It was observed from the average value that tangential shrinkage slightly increased from the innerwood to the outerwood in the radial direction though not significantly different from one another. This is supported and in conformity with the result of Okon [36] for 25-year-old *Gmelina arborea* wood, Kumar [41] for *Grevillea robusta*, and Aguma and Ogunsanwo [39] for *Khaya grandifoliola.*

The ratio of *B. sapida* wood tangential shrinkage was 1.5% greater than radial shrinkage, which is close to 1.7% observed by Sotannde *et al*. [26] for *Azadirachta indica* wood. The value also falls within the range of 1.5% to 3.0% shrinkage factor according to Bodig and Jayne [42]. The study of Schniewind [43] submitted that the variation between shrinkage of different surfaces was a result of the cellular structure and cellulose chain molecules' physical organization within the cell walls. The 1:1.5% tangential–radial shrinkage observed in this study was low, an indicator of a low risk of deformation in wood during drying. According to Rijsdijk [44], the ratios of tangential-radial shrinkage that are considered to be high are those of over 2.2%.

2) Radial Shrinkage

Radial shrinkage of *B. sapida* has an average value of 6.17±0.12%. Axially, radial shrinkage decreased from the base to the top with the base having an average value of 6.73±0.21%, the middle 6.13±0.22%, and the top having 5.65±0.20% as shown in Table III.

Radially, shrinkage increased from innerwood to the middlewood and then decreased towards the outerwood with innerwood having an average value of 5.70±0.19%, middlewood 6.54±0.23%, and outerwood having 6.27±0.22%. There were significant differences within and between the trees of *Blighia sapida* wood radial shrinkage (< 0.05) as presented in the analysis of variance in Table IV but the interaction between sampling heights and radial direction was not significant. At a 95% confidence level, the follow-up test further showed the level of significant differences as presented in Table III. The radial shrinkage of *B. sapida* wood reported at oven-dry weight was higher than 1.42% in *Artocarpus altilis* observed by Areo *et al.* [12]. It was also slightly higher than 4.53% observed by Aguma and Ogunsanwo [39] for *Khaya grandifoliola* wood and 4.64% observed by Sotannde *et al.* [26] for *Azadirachta indica* wood. This may have been a result of more sorption sites and high moisture content in *B. sapida* wood.

Axially, radial shrinkage as observed in *B. sapida* wood decreased from the base to the top portion of the wood. This is in line with the report on *Ziziphus mauritiana* wood according to Riki *et al.* [9]. The result is also in accordance with the report of Sotannde and Riki [19] on some wood species; *Azadirachta indica*, E*ucalyptus camaldulensis*, and *Khaya grandifoliola* wood.

This is not supported by the report of Areo *et al.* [12], Okon [36], Aguma and Ogunsanwo [39], and Emerhi and David-Sarogoro [40] who reported an increase in radial shrinkage from the base to the top. It was also not in line at the base but conforms with the result at the top of radial shrinkage in *Khaya grandifoliola* wood as reported by Aguma and Ogunsanwo Okon [39], who reported that it increased to the middle and then decreased to the top. It is also similar to the report of Sotannde and Riki [19], for wood species studied as it decreased from the base to the middle but later increased to the top.

Radially, shrinkage increased from innerwood to the middlewood and then slightly decreased towards the outerwood, which is an inconsistency that was observed by Okon [36] and Aguma and Ogunsanwo [39] for *Gmelina arborea* and *Khaya grandifoliola*. This may have been as a result of changes caused by the cell size variation as well as earlywood volume caused by the increasing age of the cambium. However, radial shrinkage is twice the tangential shrinkage as reported by various studies and as it was observed in this study which is in a ratio of 1:1.5% radial to tangential. According to the study by Panshin and de Zeeuw [45] who opined that tangential shrinkage is generally about the double radial shrinkage, and the radial shrinkage of this study revealed the same. The differences could be a result of the restricting effect of the rays on the radial plane as well as the degree of lignification between the radial and tangential walls, the microfibrillar angle between the two walls, and the increased thickness of the lamella in the tangential direction as reported in the studies of Okon [36]. In the same vein, Kollman and Cote [46] documented that shrinkage differs in tangential and radial directions as a result of the restraining effect of the rays and fibril angle effects in the cell wall.

3) Volumetric Shrinkage

Wood shrinkage occurs as the wood changes moisture content in response to daily as well as seasonal changes in accordance with the relative humidity of the atmosphere, i.e., when the air is dry, wood losses moisture and shrinks, and when the air is humid wood absorbs moisture [41]. The mean volumetric shrinkage of *B. sapida* was 15.24±0.25%. Axially, volumetric shrinkage decreased from the base to the top with the base having an average value of 16.64±0.38%, the middle having 15.16±0.46%, and the top having 13.91±0.36%. Radially, volumetric shrinkage increased from innerwood to the outerwood, with innerwood having an average value of 14.52±0.41%, the middlewood having 15.54±0.41%, and the outerwood having 15.66±0.47% as presented in Table III.
The analysis of variance in Table IV showed that there were significant differences among the volumetric shrinkage of the trees, along the sampling heights and the radial direction. While the interaction between the sampling height and radial direction showed no significant differences (>0.05). The follow-up test at a probability level of 0.05, showed further the level of significant differences.

The analysis of variance showed that volumetric shrinkage of the sampled trees, along the sampling heights and radial direction were significantly different from one another. The average volumetric shrinkage of *B. sapida* wood was 15.24% similar to the 13.3% that was recorded for *Khaya* *grandifoliola* wood. The result was higher than the 10.11% observed by Riki *et al.* [9]. The result was also slightly higher than the 11.32% observed by Okon [36] for 25-year-old *Gmelina arborea* wood. The result was also a bit close to 12.78% observed for *Azadirachta indica* by Sotannde *et al.* [26]. The high value recorded in this study for volumetric shrinkage, which was a bit higher than the values for some other lesser-used tropical hardwood species may have been a result of a bit high density recorded and the high moisture content of the wood. According to Harte [47], woods with high-density value tends to shrink and swell more with changes in moisture content than wood of low density.

Volumetric shrinkage also followed the same pattern with the tangential and the radial shrinkage as both give the volumetric shrinkage. However, longitudinal shrinkage was not recorded for this study as a result of its minute negligible value. The difference between the longitudinal, radial, and tangential shrinkage is a result of the alignment of wood cells [48]. As free water is removed from the cell lumen till the point it reaches the bound water in the cell wall, which is the fibre saturation point and beyond, the cells tend to move closer and become compacted. The movement in the tangential and radial directions is several times greater than in the longitudinal direction [31] and that tends to make shrinkage more prominent than in the longitudinal direction.

The volumetric shrinkage decreased from the base to the top, a variation trend that conformed to the report by Emerhi and David-Sarogoro [40] on *Terminalia catappa* as it was reported that it decreased from the base to the top. It was not in conformity with the result of Okon [36] as the mode of variation along the vertical axis indicated that volumetric shrinkage increased from the base to the top. While it conformed to the trend observed from the radial direction where shrinkage decreased from outerwood to innerwood. This may have been a result of more dead cells in the inner portion of the wood as the inner portion is full of heartwood which is composed of dead parenchyma cells while the outerwood which is majorly composed of sapwood is expected to have more living cells for conductivity and as drying takes place it becomes compacted and shrink. Also, according to Harte [47] wood of high density tends to shrink more than wood of low density. Therefore, the wood with a high proportion of heartwood will tend to be more stable in service than the sapwood.

IV. Conclusions

B. sapida wood showed golden colour like that of *Nauclea diderichii* immediately after felling. However, a few days after conversion, the sapwood portion changed to a cream colour like that of *Triplochiton scleroxylon* and the heartwood changed to light brown colour like that of *Milicia excelsa*. This observed colour distinction in the wood species can help to distinguish it from other hardwood species as a clear distinction was shown between the heartwood and sapwood of the tree along the axial direction.

The range of *B, sapida* wood density value of the study falls within the range that could be categorized as medium density wood of medium construction strength properties. The moisture content was high and varied significantly both radially and axially. This is an indication that the wood species must be seasoned very well to impact strength. The 1:1.5% tangential–radial shrinkage observed in this study was low, an indicator of a low risk of deformation in wood during drying as the ratios of tangential-radial shrinkage that is considered to be high are those over 2.2%. The wood species compared favourably with other economic tree species such as *Tectona grandis, Khaya senegalensis, Milicia excelsa*, and *Mansonia altissima*, it could therefore be recommended that the timber species would be suitable for carpentry, furniture, sheeting and lining, cabinet works, veneer wood production and so on. It could also be recommended that end users' sensitization is done to acquaint them of the inherent properties of the timber species for better acceptability and optimum utilization.

Conflict of Interest

Authors declare that they do not have any conflict of interest.

References

[1] Adekunle VA, Akande SO, Fuwape JA. Impacts of over exploitation on biodiversity yield and sustainable use of tropical rainforest ecosystem: A case study of Omo Forest Reserve, South West Nigeria. *Proceedings of the 28th Annual Conf: Forestry Association of Nigeria*, pp. 252-263, Nigeria, 2002.

[2] Koenig KD. *Blighia sapida*. In: Prota 7th ed. Vol. 2, Lemmens RHMJ, Louppe D, Oteng-Amoako AA, Ed. Netherlands: Wageningen, 2010, pp. 17-24.

[3] Kayumba I. Selected wood properties of two lesser known and lesser utilized indigenous agroforestry species from Kilosa District, Tanzania. M.S. Thesis, Sokoine University of Agriculture, Tanzania, 2015.

[4] Winandy JE. Wood properties. *USDA-Forest Service, Forest Products Laboratory*, Wisconsin Arntzen, Charles J., ed. Encyclopedia of Agricultural Science. Orlando, FL: Academic Press: 554. Vol. 4. October 1994.

[5] Oyelere AT, Riki JTB, Adeyemo SM, Majekobaje AR, Oluwadare AO. Radial and axial variation in ring width of Caribbean pine (*Pinus caribaea* Morelet) in Afaka plantation, Kaduna state, Nigeria. *Journal of Research in forestry, wildlife & environment.* 2019; 11(3): 81-89.

[6] Ogunsanwo OY, Akinlade AS. Effects of Age and Sampling Position on Wood Property Variations in Nigerian Grown *Gmelina arborea*. *Journal of Agriculture and Social Research* (JASR) Vol. 11, No. 2, 2011. Pp 103-112.

[7] *Annual Book of Standards,* Vol. D09, American Society for Testing and Materials Wood, Philadelphia, PA, 1991, pp. 12-13.

[8] Falemara BC, Owoyemi JM, Olufemi B. Physical Properties of Ten Selected Indigenous Wood Species in Akure, Ondo State, Nigeria. *Journal of Sustainable Environmental Management.* 2012; 4: 16-23.

[9] Riki JT, Sotannde OA, Oluwadare AO. Selected Physical Properties and Microscopic Description of *Ziziphus mauritiana* Lam. Wood in Sudano-Sahelian Region of Nigeria. *Asian Journal of Applied Sciences.* 2019; 7(6): 758.

[10] Bieker D, Rust S. Non-destructive estimation of sapwood and heartwood width in Scots pine (*Pinus sylvestris* L.). *Silva Fennica*. 2010; 44(2): 267–273.

[11] Olaoye KO, Ariwoola OS, Ibiyeye DE. Selected Physico-Mechanical Properties of *Aningeria robusta* (A.Chev) Wood for the Manufacture of Talking Drum. *Journal of Agriculture and Veterinary Science (IOSR-JAVS)*. 2016; 9(2): 58.

[12] Areo OS, Omole OA, Adejoba AL. (2020). Evaluation of Selected Physical Properties of Breadfruit Wood (*Artocarpus altilis*, Parkinson ex. F.A. Zorn) Fosberg Grown in the South-western, Nigeria. *Trends in Applied Sciences Research*. 2020; 15:226-234.

[13] Sundqvist B. Colour changes and acid formation in wood. Ph.D. Thesis. Division of Wood Material Science; 2004.

[14] Regis BM. Chapter 2: Structure of Wood. From Wood handbook—Wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463 p. 1999.

[15] Taylor AM, Cooper PA. The effect of pre harvesting girding on selected properties of red maple and eastern larch wood. *Fiber sci.* 2002; 34(2): 212-220.
[16] Sotannde AO, Anguruwa GT, Ishaya D. Wood Quality Study of 9-Year Old Plantation Grown *Khaya senegalensis* in Sudano-Sahelian Environment of Borno State Nigeria. *Journal of Forestry Research and Management*. 2015; 12: 95-112
[17] Taylor AM, Gartner BL, Morrell JI. *Heartwood formation and natural durability: A review*. Department of Wood Science and Engineering Oregon State University Corvallis, OR 97331(Received April 2002). pp. 586-611.
[18] Philips EWJ. The inclination of the fibrils in the cell wall and its relation to the compression strength of timber. *Empire Forestry J.* 1941; 20: 74-78.
[19] Sotannde OA, Riki JTB. Wood Quality Studies of Some Wood Species in Sudano-Sahelian Environment of Borno State, Nigeria. *Journal of Research in Forestry, Wildlife & Environment*. 2019; 11(3) 8-19.
[20] Kityo PW and Plumptre RA. *The Uganda timber user's handbook: A guide to better timber use*. Commonwealth Secretariat, London, UK, 1997.
[21] Appiah-Kubi E, Kankam CK, Adom-Asamoah MA. *Bending and Modulus of Elasticity Properties Of 10 Lesser-Used Timber Species In Ghana.* CSIR-Forestry Research Institute of Ghana; 2012, pp. 23.
[22] Quartey GA. Anatomical Properties of Three Lesser Utilised Ghanaian Hardwood Species. *Materials Sciences and Applications.* 2015; 6: 1111-1120.
[23] Akachuku AE. *Agric. Research Bulletin*, Vol. 1 No. 2, University of Ibadan, Nigeria, 1980, pp. 5-6.
[24] Fuwape JA, Fabiyi JS. Variation in strength properties of plantation grown *Nauclea diderichii* wood. *Journal of Tropical Forest Products*. 2003; 9(1): 45-53.
[25] Izekor DN, Fuwape JA, Oluyege AO. Effects of density on variations in the mechanical properties of plantation grown Tectona grandis wood. *Archives of Applied Science Research*. 2010; 2(6): 113-120.
[26] Sotannde OA, Oluyege AO, Adeogun PF, Maina SB. Variation in Wood Density, Grain Orientation and Anisotropic Shrinkage of Plantation Grown *Azadirachta indica. Journal of Applied Sciences Research*. 2010 6(11): 1857.
[27] Riki JTB, Adeyemo SM, Majekobaje AR, Oyelere AT, Oluwadare AO. Density variation in axial and radial positions of Caribbean Pine (*Pinus caribaea* Morelet) grown in Afaka, Nigeria. *J. Agric. & Envir*. 2019; 15(2): 163-171.
[28] Larson PR. *Wood Formation and the Concept of Wood Technology*; New York: MacGraw Hill Book, 1969, vol. 1.
[29] Zobel BJ Van Buijtenen JP. *Wood variation its causes and control*; Berlin: Springer-Verlag, 1989, pp. 354-358.
[30] Oyagade AO, Fasulu SA. Physical and mechanical properties of *Trilepisium madagascariensis* and *Funtumia elastica* wood. *J. of Trop. For. Sci.* 2005; 17(2): 258-264.
[31] Kiaei M, Bakhshi R. Radial variations of wood different properties in *Diospyros lotus*. *Forest Systems*. 2014; 23(1): 171-177.
[32] Akpan M. Olufemi B. Quantitative studies on density of neem (*Azadirachta indica* A.Juss) wood for utilization as timber in northeastern Nigeria. University of District Columbia UDC630*33/.35/669, 2007 pp. 1-7.
[33] Jacobsen AL, Agenbag L, Esler KJ, Pratt RB, Ewers FW, Davis SD. Wood density, biomechanics and anatomical traits correlate with water stress in 17 evergreen shrub species of the Mediterranean-type climate region of South Africa. *Journal of Ecology*. 2007; 95: 171–183.
[34] Hugo IMC, Cynthia SJ, Susana E. Schenk HJ. Wood anatomy and wood density in shrubs: Responses to varying aridity along transcontinental transects. *American Journal of Botany*. 2009; 96: 1388-1398. doi:10.3732/ajb. 0800237.
[35] Barker DA, Philips OL, Laurance WF, Pitman NCA, Almeida S, Arroyo L, et al. Do species traits determined patterns of wood production in Amazonian forests? *Biogeosciences.* 2009;6: 297-307.
[36] Okon KE. Variations in specific gravity and shrinkage in wood of 25 – year old *Gmelina arborea* in Oluwa forest reserve, south west Nigeria. *Archives of Applied Science Research.* 2014; 6(4): 271-276.
[37] Noah AS, Abiola JK, Ayeni OD, Bamidele OD. Comparative Assessment of selected Acoustic Properties of Talking Drums Made from Wood of *Gmelina arborea* (Roxb) and *Brachystegia eurycoma* (Harms). *Journal of Multidisciplinary Engineering Science and Technology (JMEST)*. 2012; 1(5): 22-27.
[38] Ogunbajo AB, Adigun MA, Alaboru FO. Sustainability and stress properties of selected hardwood timber section in Lagos, Nigeria. *Ideal Journal of Engineering and Applied Sciences.* 2016; 2(1): 21-27.
[39] Aguma Q, Ogunsanwo OY. Selected Physical and Mechanical Properties of Stem and Branch Woods of *Khaya grandifolia.* M.S. Thesis, University of Ibadan, Nigeria, 2015.
[40] Emerhi EA, David-Sarogoro N. Spatial and volumetric shrinkage of *Terminalia catappa* (linn) wood in Bunu Tai, Rivers state, Nigeria. *Gsj.* 2019; 7(8): 951.
[41] Kumar, B.M. Physical and mechanical properties of three agroforestry tree species from Kerala, India. *Journal of Tropical Agriculture*. 2006; 44 (1-2): 23-30.
[42] Bodig J, Jayne BA. *Mechanics of wood and wood composites.* Florida: Krieger Publishing Company; 1993 ISBN-13: 9780894647772. 736.
[43] Schniewind AP. Concise Encyclopedia of Wood and Wood-based materials. Pergamon Press, 1989, pp. 248.
[44] Rijsdijk JF, Laming PB. *Physical and related properties of 145 timbers. Information for practice*; Netherlands: Kluwer Academic Publisher, 1994.
[45] Panshin AJ, de Zeeuw C. *Textbook of Wood Technology.* 5th ed. MacGraw-Hill Book Company; 1980, pp. 722.
[46] Kollman FPP, Cote WA. *Principles of Wood Science and* Technology; Berlin: Springer-Verlag, 1986, pp 592.
[47] Harte A. *Introduction to timber as an engineering material.* ICE Manual of Construction Materials, Institution of Civil Engineers, 2009. doi: 10.1680/mocm.00000.0001
[48] Josue J. Some wood properties of *Xylia xylocarpa* planted in Sabah. *Sepilok Bulletin*. 2004; 1: 1-15.