*Journal of Research in Forestry, Wildlife & Environment Vol. 10(1) March, 2018*
**http://www.ajol.info/index.php/jrfwe**
*jfewr ©2018 - jfewr Publications*
*E-mail:jfewr@yahoo.com*
*ISBN: 2141 – 1778*
Sadiku, 2018





# WEIGHT, POROSITY AND DIMENSIONAL MOVEMENT CLASSIFICATION OF SOME NIGERIAN TIMBERS

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## *ABSTRACT*

***Density, porosity and dimensional characteristics of selected Nigerian guinea savannah wood species were evaluated. Wood samples were collected from wood mills in Ilorin, Kwara State, Nigeria. The wood samples were cut and tested following standard procedures. The values of the densities showed statistical variations within and among wood species. Vitellaria paradoxa heartwood was most dense with value of 1147.60 kg/m$^3$ while the sapwood of Lannea welwitchii was lightest (510.90 kg/m$^3$) in weight. L. welwitchii sapwood was most porous with porosity value of 0.72 while V. paradoxa heartwood was least porous (0.26). Generally, the longitudinal shrinkage and swelling of the wood species were negligible and were not significantly different as observed for radial and volumetric movements. However, heartwood and sapwood of Syzygium guineense had the largest shrinkage and swelling values while V. paradoxa heartwood and sapwood had the least dimensional movements. The wood species were classified into weight, permeability, shrinkage and swelling classes. Based on weight, V. paradoxa was classified into very heavy weight class, Albizia zygia and Anogeisus leiocarpa were grouped as 'heavy', L. welwitchii and Irvingia gabonensis were placed into moderately light class while the other six timbers were moderately heavy. Based on permeability, V. paradoxa is refractory in nature, L. welwitchii and I. gabonensis are permeable while other seven species ranged from resistant to moderately permeable. Based on dimensional movements, V. paradoxa, A. africana, A. zygia and A. leiocarpa were characterised with small dimensional movements while the other six species had medium movements.***

**Keywords:** Weight class; Dimensional anisotropy; permeability; Refractory; Tropical hardwood

## INTRODUCTION

Wood is an anisotropic material which presents differential properties in different structural directions. The use of wood is usually restricted due to its swelling and shrinkage at different relative humidities and temperatures. The change in wood dimensions owing to variability in the moisture content of wood is of great concern in wood utilization (Boutelje, 1962). Wood tend to experience the greater part of its expansion and contraction in one particular direction. Wood movement parallel to the grain is negligible whereas expansion and contraction across the grain is significant (Wynn, 2011). The rate of expansion and contraction of wood varies from species to species and even from piece to piece (Brentuo, 2012), density, direction of measurement, relative humidity, temperature among others (Mantanis *et al.,* 1994, Hernandez 2007). The anisotropic nature of wood is very important to studies of their characteristics and is related with their moisture content. The dimensions of wood undergo variations according to the increase or decrease in moisture content. Density is the one single factor used in the determination of most properties of wood (Hoadley, 2000). It affects wood shrinkage and swelling, machinability, surface texture and micro smoothness, gluability, penetrability of fluids and gases, among others. According to Rydell (1982), high density wood tends to absorb vapour slowly compared to low density wood and there is a big difference in the moisture sorption of heartwood and sapwood.

Wood in service are generally subjected to fluctuating atmospheric humidity due to their hygroscopic nature. They swells and also shrinks continually which might cause a piece of wood not worked as designed causing millions of pounds to be spent on varnishes and paints each year to try to stop water getting into wood (Usta and Guray, 2000).

Much research has been carried out on the dimensional changes of different timber species. However, in this study, the anisotropy of both swelling and shrinkage in the longitudinal, tangential and radial directions of ten selected wood species which were; *Khaya senegalensis* (Mahogany), *Irvingia gabonensis* (Bush mango), *Albizia zygia* (Ayunre), *Anogeissus leiocarpa* (Ayin), *Afzelia africana* (Apadan), *Vitellaria paradoxa* (Emi), *Vernonia colorata* (Eriri), *Lannea welwitchii* (Opon), *Syzygium guineense* (Adere), and *Isoberlinia doka* (Babo) were evaluated. The species are mostly found in the Nigerian guinea savannah and used mostly for construction and joinery. Although, the NCP2 Code of Practice, (1973) provided information on the dimensional movement of about 53 timber species, 51 indigenous and 2 exotic species. However, only three of the wood species used for this study; *A. africana, K. senegalensis (Mahogany)* and *I. doka* were mentioned in the NCP 2 code of conduct (1973). Shrinkage and swelling were reported to be small and medium respectively for *K. senegalensis*, only shrinkage (small) was reported for *A. africana* while no information was recorded for *I. doka.* So far in literatures, data and information on the shrinkage/swelling values of the other seven species including *I. doka* were not sufficiently documented. Generating data on the shrinkage/swelling behaviour of these wood species is important to provide wood users or designers information on the wood species, their moisture content, the amount of dimensional change that should be expected so that safety values in design and construction as well as the conditions of use to put each of the species can be determine. Therefore, the main objective of this work was to determine the moisture content, density, porosity, shrinkage and swelling properties of these wood species and then classified them into weight, permeability and dimensional movement classes.

## MATERIALS AND METHODS

### Wood Collection and Preparation

The wood species used for this study are listed in Table 1. The wood were procured from wood mill in and around Ilorin, Kwara State. Experimental samples were plainned and then cut from defect-free portion of all the wood species into 20 x 20 x 60mm (radial x tangential x longitudinal) following ASTM standards. The Wood densities and porosities were determined following ASTM D 2395-93 (ASTM, 1993). While the shrinkage and swelling were determined following ASTM D 143-94 (ASTM, 1994). Five number of observations were made for each sample.

Table 1: Botanical Names, Family and Local Names of the Wood Samples

| Species | Family | Local names |
|---|---|---|
| *Lannea welwitchii* Engl. | Anacardiaceae | Opon |
| *Vitellaria paradoxa* C.F. Gaertn. | Sapotaceae | Shea butter tree, Emi |
| *Afzelia africana* Smith ex Pers | Caesalpinaceae | Apa, Apadan |
| *Albizia zygia* (DC.) Macb | Fabaceae | Ayunre |
| *Anogeissus leiocarpa (DC) Guill. & Perr.* | Combretaceae | Ayin |
| *Irvingia gabonensis* Baill. ex Lanen | Irvingiaceae | Bush mango, Oro |
| *Khaya senegalensis* (Desr.) A. Juss. | Meliaceae | Mahogany |
| *Vernonia colorata* (Willdenow) Drake | Asteraceae | Eriri |
| *Isoberlinia doka* Craib & Stapf | Caesalpinaceae | Babo |
| *Syzygium guineense* (Willd.) DC. | Myrtaceae | Adere |

### Density and Specific gravity test

For the determination of density, wood density was calculated at the green and oven dry state using the equation:

$$\text{Density} = \frac{Weight}{Volume} \quad \text{........................ Equation 1}$$

Specific gravity of the wood samples was also Carried out at the green and oven-dry state using the equation:

Specific Gravity = Density of wood/Density of water

### Determination of Moisture content

All the experimental wood samples were weighed using weighing balance; the initial weights of each wood were recorded as $w_1$. The wood was then dried in an oven at a temperature of 105±2°c until constant weight was achieved and their values were recorded as $w_2$. The moisture content of each sample was calculated using the formula: -

$$MC(\%) = \frac{\text{Initial weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100 \quad \text{.... Equation 2}$$

The porosity test was done in order to ascertain the quantity of water that can be absorbed for a given period of time. The test standard used was ASTM D 2395-93 (ASTM, 1993).

$$\text{Porosity} = 1 - \frac{g}{g_0} \times 100 \quad \text{......... Equation 3}$$

Where: 1= is the total volume of wood; $g/g_0$ = fractional volume of solid wood substance; g = bulk density and $g_0$ = specific gravity of wood substance which is put at (1.5) (FPL, 2010)

**Shrinkage and Swelling characteristics of the wood**

The shrinkage and swelling of each sample and the three orthogonal directions (longitudinal, radial and tangential) were measured. The shrinkage of the samples were measured from green to oven dry condition while swelling were measured from oven dry state to water swollen state. The following formula was used to calculate various dimensional changes:

Radial variation:

$$R_t = \frac{r_t - r_o}{r_o} \times 100 \quad \text{------------------------Equation 4}$$

Where, $R_t$ is the radial shrinkage or swelling, $r_o$ is the final radial dimension, $r_t$ is the initial radial dimension

Tangential variation:

$$T_t = \frac{t_t - t_o}{t_o} \times 100 \quad \text{----------------------Equation 5}$$

Where, $T_t$ is the tangential shrinkage or swelling, $t_o$ is the final tangential thickness, $t_t$ is the initial tangential thickness at the moment of measurement

Longitudinal variation:

$$L_t = \frac{l_t - l_o}{l_o} \times 100 \quad \text{---------------------- Equation 6}$$

Where, $L_t$ is the longitudinal shrinkage or swelling, $l_o$ is the final longitudinal dimension, $l_t$ is the initial longitudinal dimension.

**RESULT AND DISCUSSION**

**Moisture Contents, Density and Porosity of the Wood Species**

The mean values for moisture content of the wood samples are presented in Table 3. The result shows that there were variations in the species moisture content. The moisture content of all the wood samples varied from 30.48% to 129.50% for sapwood while the heartwood varied from 22.21% to 99.94% in the green state; after oven drying, the moisture content values obtained were found to ranged from 23.36% to 56.40% for sapwood and 18.17% to 49.94% for heartwood. The species with the highest moisture contents was *I. gabonensis* with the sapwood containing 129.50% moisture in the green state while the heart-wood of *V. paradoxa* had the lowest moisture content (22.21%). In the oven dry state, *I. gabonensis* sapwood had the highest moisture content of 56.40% while *V. paradoxa* heartwood had the lowest (18.11%).

There were statistical differences in the moisture content of the wood species ($p \leq 0.05$) (Table 2). However, Duncan Multiple Range Test result (Table 3) showed that the moisture content of sapwood and heartwood of *L. welwitchii* and *I. gabonensis*; *K. senegalensis; A. zygia, A. leiocarpa* and *S. guineense* sapwood and heartwood were statistically similar ($p \leq 0.05$).

Table 2: ANOVA for Density, Specific gravity, Moisture Content and Porosity of the wood species

| **Properties** | **F-values and Significance level** | |
|---|---|---|
| | **Sapwood** | **Heartwood** |
| Green density | 13.067 ** | 21.341 ** |
| Oven dry density | 22.189 ** | 93.376 ** |
| Water swollen specific gravity, | 13.260 ** | 21.358 ** |
| Oven dry specific gravity, | 21.813 ** | 91.411 ** |
| Green moisture content | 63.223 ** | 173.070 ** |
| Oven dry moisture content | 44.748 ** | 191.782 ** |
| Porosity | 21.813 ** | 91.411 ** |

** = highly significant at $p \leq 0.05$

Table 3: Influence of species and portion on wood Moisture Content and Porosity

| **Species** | **Wood Region** | **Green Moisture Content (%)** | **Oven-dry Moisture Content (%)** | **Porosity (%)** |
|---|---|---|---|---|
| *L. welwitchii* | Sapwood | $120.46 \pm 10.71^{a}$ | $54.57 \pm 2.15^{a}$ | $0.72 \pm 0.01^{a}$ |
| | Heartwood | $99.94 \pm 7.61^{a}$ | $49.94 \pm 1.93^{a}$ | $0.67 \pm 0.04^{a}$ |
| *V. paradoxa* | Sapwood | $37.97 \pm 7.39^{cd}$ | $27.38 \pm 3.94^{cd}$ | $0.38 \pm 0.07^{c}$ |
| | Heartwood | $22.21 \pm 0.76^{e}$ | $18.17 \pm 0.51^{e}$ | $0.26 \pm 0.00^{f}$ |
| *A. africana* | Sapwood | $59.71 \pm 15.05^{b}$ | $37.01 \pm 5.99^{b}$ | $0.56 \pm 0.04^{b}$ |
| | Heartwood | $31.94 \pm 1.21^{d}$ | $24.20 \pm 0.70^{d}$ | $0.39 \pm 0.03^{d}$ |
| *A. zygia* | Sapwood | $43.76 \pm 2.29^{cd}$ | $30.42 \pm 1.11^{c}$ | $0.50 \pm 0.03^{b}$ |
| | Heartwood | $42.28 \pm 2.92^{bc}$ | $29.70 \pm 1.44^{c}$ | $0.45 \pm 0.02^{c}$ |
| *A. leiocarpus* | Sapwood | $43.63 \pm 3.61^{cd}$ | $30.35 \pm 1.73^{c}$ | $0.50 \pm 0.02^{b}$ |
| | Heartwood | $40.36 \pm 0.76^{c}$ | $28.75 \pm 0.38^{c}$ | $0.36 \pm 0.02^{d}$ |
| *I. gabonensis* | Sapwood | $129.50 \pm 6.99^{a}$ | $56.40 \pm 1.31^{a}$ | $0.69 \pm 0.01^{a}$ |
| | Heartwood | $96.03 \pm 3.64^{a}$ | $48.98 \pm 0.96^{a}$ | $0.65 \pm 0.01^{a}$ |
| *K. senegalensis* | Sapwood | $30.48 \pm 0.33^{d}$ | $23.36 \pm 0.19^{d}$ | $0.50 \pm 0.01^{b}$ |
| | Heartwood | $34.26 \pm 2.07^{d}$ | $25.50 \pm 1.15^{d}$ | $0.51 \pm 0.04^{b}$ |
| *V. colorata* | Sapwood | $45.32 \pm 7.55^{c}$ | $31.07 \pm 3.48^{c}$ | $0.54 \pm 0.04^{b}$ |
| | Heartwood | $48.12 \pm 0.21^{b}$ | $32.49 \pm 0.09^{b}$ | $0.55 \pm 0.00^{b}$ |
| *I. doka* | Sapwood | $60.71 \pm 6.05^{b}$ | $37.72 \pm 2.40^{b}$ | $0.54 \pm 0.04^{b}$ |
| | Heartwood | $45.17 \pm 5.67^{bc}$ | $31.04 \pm 2.65^{bc}$ | $0.52 \pm 0.0^{b}$ |
| *S. guineense* | Sapwood | $43.62 \pm 3.81^{cd}$ | $30.34 \pm 1.86^{c}$ | $0.50 \pm 0.03^{b}$ |
| | Heartwood | $42.18 \pm 0.88^{bc}$ | $29.66 \pm 0.43^{c}$ | $0.54 \pm 0.02^{b}$ |

The values of densities observed in this study showed that the wood species varied from one region to another and from species to species. In the green state, the densities of the wood species were found to vary from 1174.10kg/m³ to 871.07kg/m³ (SW region) and from 876.90kg/m³ to 1245.20kg/m³ (HW region); with specific gravity ranging from 0.87 to 1.17 (SW region), and from 0.88 to1.25 (HW region). While in the oven-dried state, the densities varied from 429.22kg/m³ to 949.24kg/m³ (SW region) and from 510.9kg/m³ to 1147.60kg/m³ (HW region); with specific gravity ranging from 0.43 to 0.95 (SW region) and from 0.51 to 1.15 (HW region). Highest density (1245.20kg/m³) was recorded for heartwood of *V. paradoxa* while sapwood of *L. welwitchii* had the lowest density of 429.22kg/m³ for oven-dry measurements. For the porosity of the wood species, sapwood of *L. welwitchii* had the highest porosity of 0.72 while *V. paradoxa* heartwood had the lowest (0.26). The result of analysis of variance as well as mean separation showed statistical variation in the densities, specific gravities and porosities of the wood species at $p \leq 0.05$. Porosities of *L. welwitchii* and *I. gabonensis* sapwood and heartwood were statistically similar at $p \leq 0.05$, *K. senegalensis, V. colorata, I. doka and S. guineense* sapwood and heartwood also had similar porosities, while the remaining wood species differ significantly.

Results of this study are in line with the reports given by Owoyemi *et al*. (2014), Taylor *et al*. (2002) and Andres *et al.* (2015). According to these authors, high dense wood are considered to be very resistant against degradation. This in turn is connected to relatively low levels of air or water inside the wood cells as well as considerable cell wall thickness, which can constitute a natural barrier. In other words, the higher the density of a wood, the greater the resistance; also the age of wood could be responsible for its high resistance (the more the heartwood formed, the denser the wood, the higher the density). The densities of some of the wood species were comparable to some economic tropical wood species such as *Lophira lanceolata* (810 kg/m$^3$), *Bridelia ferruginea* (810 kg/m$^3$), *Parkia biglobosa* (830 kg/m$^3$), *Daniella oliveri* (640 kg/m$^3$), *Nauclea diderrichii* (660 kg/m$^3$), *Ricinodendron heudelotii* (260 kg/m$^3$), *Triplochyton scleroxylon* (420 kg/m$^3$), *Funtumia elastica* (460 kg/m$^3$), *Trilepisium madagascariense* (570 kg/m$^3$) (Ogunleye, 2014).

The heartwood of all the wood species were grouped into weigth and porosity classes (Table 5). *V. paradoxa* was grouped into very heavy class, while *A. africana, A. zygia and A. leiocarpus* were placed into "heavy" class. The moderately heavy species were *K. senegalensis, V. colorata, I. doka and S. guineense* and the moderately light classes were *L. welwitchii and I. gabonensis.* For the porosity class, *L. welwitchii and I. gabonensis* were permeable, while *V. paradoxa* was very resistance; *A. africana* and *A. leiocarpus* were resistant and *A. zygia, K. senegalensis, V. colorata, I. doka and S.* guineense were moderately permeable. *V. paradoxa* is recommended for heavy engineering construction such as bridges, water structures etc; while *A. africana, A. zygia and A. leiocarpa* are recommended for relatively heavy construction like building rafters. The moderately heavy ones are recommended for furniture making and the moderately light classes are recommended for temporary use such as scaffolds or decking.

The values for the wood porosity (Table 4) show that wood species with the highest density seemed to have the lowest porosity and vice versa. Wood permeability is mainly affected by its anatomical characteristics which influence moisture movement as well as its treat-ability (Sattar, 1990); hence, wood species with high moisture content and porosity are generally prone to attacks from bio-deteriorating agents. Therefore, the high porosity and moisture content is an advantage in the wood preservation in order to impart durability against bio-deterioration as the cells will readily absorb preservative chemicals. The more permeable, the better the treat-ability. Based on the result, the wood species heartwood only was grouped into permeability classes (Table 5), *L. welwitchii and I. gabonensis* were permeable and therefore will have good preservative treat-ability, while *V. paradoxa* is very resistant or refractory and therefore will have poor treat-ability and may require pressure treatment. *A. africana* and *A. leiocarpa* are resistant while *A. zygia, K. senegalensis, V. colorata, I. doka and S.* guineense were moderately permeable.

Table 4: Results Showing the Wood Samples Density and Specific Gravity

| Species | Wood Region | Green density (kg/m³) | Oven-dry density (kg/m³) | Green Specific Gravity | Oven-dry Specific Gravity |
|---|---|---|---|---|---|
| | Sapwood | 871.07±5.56$^{f}$ | 429.22±15.04$^{c}$ | 0.87±0.01$^{f}$ | 0.43±0.02$^{c}$ |
| *L. welwitchii* | Heartwood | 876.9±21.35$^{d}$ | 510.9±54.40$^{f}$ | 0.88±0.02$^{d}$ | 0.51±0.06$^{f}$ |
| | Sapwood | 1174.10±60.99$^{a}$ | 949.24±115.25$^{a}$ | 1.17±0.06$^{a}$ | 0.95±0.12$^{a}$ |
| *V. paradoxa* | Heartwood | 1245.2±32.90$^{a}$ | 1147.6±4.61$^{a}$ | 1.25±0.03$^{a}$ | 1.15±0.01$^{a}$ |
| | Sapwood | 1027.00±16.37$^{bcd}$ | 676.53±67.23$^{b}$ | 1.03±0.02$^{bcd}$ | 0.68±0.07$^{b}$ |
| *A. africana* | Heartwood | 1079.4±69.94$^{b}$ | 932.8±45.26$^{b}$ | 1.08±0.07$^{b}$ | 0.94±0.05$^{bc}$ |
| | Sapwood | 1078.30±75.94$^{b}$ | 774.86±48.43$^{b}$ | 1.08±0.08$^{b}$ | 0.78±0.05$^{b}$ |
| *A. zygia* | Heartwood | 1018.3±104.48$^{bc}$ | 847.4±39.10$^{c}$ | 1.02±0.11$^{bc}$ | 0.85±0.04$^{cd}$ |
| | Sapwood | 1037.30±24.08$^{bc}$ | 767.72±21.15$^{b}$ | 1.04±0.02$^{bc}$ | 0.77±0.03$^{b}$ |
| *A. leiocarpa* | Heartwood | 1209.7±40.67$^{a}$ | 984.9±25.93$^{b}$ | 1.21±0.0$^{a}$4 | 0.98±0.02$^{b}$ |
| | Sapwood | 1066.70±25.88$^{b}$ | 479.45±18.08$^{c}$ | 1.07±0.02$^{b}$ | 0.48±0.02$^{c}$ |
| *I. gabonensis* | Heartwood | 931.6±12.39$^{cd}$ | 539.2±14.62$^{f}$ | 0.93±0.01$^{cd}$ | 0.54±0.02$^{f}$ |
| | Sapwood | 968.31±14.06$^{cde}$ | 762.67±19.56$^{b}$ | 0.97±0.01$^{cde}$ | 0.76±0.02$^{b}$ |
| *K. senegalensis* | Heartwood | 898.9±20.96$^{d}$ | 761.1±58.33$^{d}$ | 0.90±0.0$^{d}$2 | 0.76±0.06$^{de}$ |
| | Sapwood | 935.80±63.08$^{ef}$ | 709.30±56.12$^{b}$ | 0.94±0.06$^{ef}$ | 0.71±0.06$^{b}$ |
| *V. colorata* | Heartwood | 940.9±4.14$^{cd}$ | 693.7±6.76$^{e}$ | 0.94±0.00$^{cd}$ | 0.70±0.01$^{e}$ |
| | Sapwood | 1093.20±37.08$^{b}$ | 714.46±59.12$^{b}$ | 1.09±0.03$^{b}$ | 0.71±0.06$^{b}$ |
| *I. doka* | Heartwood | 947.7±65.67$^{cd}$ | 737.1±11.54$^{de}$ | 0.95±0.07$^{cd}$ | 0.74±0.01$^{e}$ |
| | Sapwood | 954.16±39.91$^{de}$ | 772.64±49.33$^{b}$ | 0.96±0.04$^{de}$ | 0.77±0.05$^{b}$ |
| *S. guineense* | Heartwood | 850.8±50.10$^{d}$ | 712.9±37.92$^{de}$ | 0.85±0.05$^{d}$ | 0.71±0.04$^{e}$ |

Table 5: Weight and permeability Classification based on oven-dry measurement of the Heartwood

| Species | Weight class | Permeability |
|---|---|---|
| *L. welwitchii* | Moderately light | Permeable |
| *V. paradoxa* | Very Heavy | Very resistant |
| *A. Africana* | Heavy | Resistant |
| *A. zygia* | Heavy | Moderately permeable |
| *A. leiocarpa* | Heavy | Resistant |
| *I. gabonensis* | Moderately light | Permeable |
| *K. senegalensis* | Moderately heavy | Moderately permeable |
| *V. colorata* | Moderately heavy | Moderately permeable |
| *I. doka* | Moderately heavy | Moderately permeable |
| *S. guineense* | Moderately heavy | Moderately permeable |

Weight class based on oven-dry density of the heartwood Permeability based on porosity of the oven-dry heartwood samples

## Shrinkage and Swelling Characteristics of the Wood Species

### Dimensional shrinkage

The mean shrinkage values for the wood samples are shown in Table 7. *L. welwitchii* sapwood had the highest longitudinal shrinkage with value of 0.34 %, while the sapwood of *K. senegalensis* had the least (0.17%). Similarly, sapwood of *L. welwitchii* had the highest radial shrinkage of 4.02 % while the lowest (2.46 %) was recorded for *A. zygia* heartwood. Tangentially, both sapwood of *V. colorata* and heartwood of *S. guineense* (HW region) had the highest values of 8.50 % while the lowest value of 5.33 % was recorded for *A. zygia* heartwood. Volumetric shrinkage was highest in heartwood of *S. guineense* and lowest in *A. zygia* (HW region). Result of Analyses of Variance (Table 6) showed that the shrinkage characteristics along the three orthogonal directions and volumetric shrinkage among the species and the the wood portion from which samples were taken were statistically the same at $p \geq 0.05$. However, DMRT result (Table 7) showed that longitudinal and radial shrinkages were statistically similar. However, tangential and volumetric shrinkage were statistically different at p ≤ 0.05. Generally, when compared with some other wood species, the volumetric shrinkages of the wood species were lower than that of *Strombosia pustulata* (19.7 %), *Azadiracter indica* (19.12 %), *Streculia rhinopetala* (20.9 %), *Eribroma oblonga* (18.3 %) and *Lophira alata* (19.8 %) (Ghelmeziu, 1981) but in the same range as *Terminalia superba* (10.1 %), *Khaya ivorensis* (9.11 %), *Triplochyton scleroxylon* (9.7 %), *Mansonia altissima* (10.3 %), *Afzelia africana* (9.8 %) and *Ceiba pentandra* (10.40 %) (Akpan, 2007). The result of this work showed that tangential shrinkage is more than that of radial shrinkage where that of longitudinal shrinkage is negligible.

Table 6: Analysis of Variance for Dimensional Movement

| Orthogonal Direction | Wood Region | F-values and Significance level | |
|---|---|---|---|
| | | Shrinkage (%) | Swelling (%) |
| Longitudinal | HW | 0.942 ns | 0.941 ns |
| | SW | 0911 ns | 0.911 ns |
| Tangential | HW | 1.538 ns | 0.177 ns |
| | SW | 1.121 ns | 1.127 ns |
| Radial | HW | 0.938 ns | 0.931 ns |
| | SW | 0.422 ns | 0.372 ns |
| Volumetric | HW | 1.389 ns | 0.600 ns |
| | SW | 0.661 ns | 0.694 ns |

HW = Heartwood; SW= Sapwood; ns= not significant at p≥ 0.05

Table 7: Dimensional shrinkage characteristics

| Species | Wood region | Longitudinal (%) | Radial (%) | Tangential (%) | Volumetric (%) |
|---|---|---|---|---|---|
| *L. welwitchii* | Sapwood | 0.34±0.00$^{a}$ | 4.02±0.94$^{a}$ | 6.13±0.78$^{a}$ | 10.20±0.94$^{a}$ |
| | Heartwood | 0.34±0.00$^{a}$ | 3.12±1.12$^{a}$ | 7.92±2.26$^{ab}$ | 11.10±1.56$^{a}$ |
| *V. paradoxa* | Sapwood | 0.22±0.09$^{a}$ | 3.99±0.63$^{a}$ | 6.08±1.39$^{a}$ | 10.03±1.35$^{a}$ |
| | Heartwood | 0.28±0.10$^{a}$ | 4.09±0.71$^{a}$ | 5.33±0.29$^{b}$ | 9.46±0.72$^{a}$ |
| *A. africana* | Sapwood | 0.23±0.10$^{a}$ | 3.73±0.42$^{a}$ | 6.02±0.94$^{a}$ | 9.73±0.54$^{a}$ |
| | Heartwood | 0.23±0.10$^{a}$ | 3.90±1.00$^{a}$ | 6.03±0.57$^{ab}$ | 9.90±1.36$^{a}$ |
| *A. zygia* | Sapwood | 0.23±0.10$^{a}$ | 3.54±0.70$^{a}$ | 7.00±2.05$^{a}$ | 10.50±1.66$^{a}$ |
| | Heartwood | 0.28±0.10$^{a}$ | 2.46±0.33$^{a}$ | 5.33±0.58$^{b}$ | 7.92±0.81$^{a}$ |
| *A. leiocarpa* | Sapwood | 0.28±0.10$^{a}$ | 3.66±1.23$^{a}$ | 6.16±0.78$^{a}$ | 9.84±1.98$^{a}$ |
| | Heartwood | 0.23±0.10$^{a}$ | 3.43±1.20$^{a}$ | 6.46±1.53$^{ab}$ | 9.88±1.69$^{a}$ |
| *I. gabonensis* | Sapwood | 0.23±0.10$^{a}$ | 3.13±0.86$^{a}$ | 7.78±0.77$^{a}$ | 10.86±1.47$^{a}$ |
| | Heartwood | 0.30±0.10$^{a}$ | 3.96±0.39$^{a}$ | 7.78±1.51$^{ab}$ | 11.68±1.61$^{a}$ |
| *K. senegalensis* | Sapwood | 0.17±0.00$^{a}$ | 2.93±0.66$^{a}$ | 7.90±2.01$^{a}$ | 10.76±1.34$^{a}$ |
| | Heartwood | 0.34±0.00$^{a}$ | 3.26±0.84$^{a}$ | 7.00±2.21$^{ab}$ | 10. 33±2.85$^{a}$ |
| *V. colorata* | Sapwood | 0.28±0.10$^{a}$ | 3.74±1.30$^{a}$ | 8.05±1.50$^{a}$ | 11.73±0.86$^{a}$ |
| | Heartwood | 0.34±0.00$^{a}$ | 3.82±0.91$^{a}$ | 6.43±1.65$^{ab}$ | 10.31±2.04$^{a}$ |
| *I. doka* | Sapwood | 0.28±0.10$^{a}$ | 3.70±1.22$^{a}$ | 6.53±1.11$^{a}$ | 10.25±1.34$^{a}$ |
| | Heartwood | 0.29±0.10$^{a}$ | 3.37±1.05$^{a}$ | 6.14±1.52$^{ab}$ | 9.56±2.27$^{a}$ |
| *S. guineense* | Sapwood | 0.28±0.10$^{a}$ | 3.19±1.09$^{a}$ | 6.60±1.04$^{a}$ | 9.84±0.94$^{a}$ |
| | Heartwood | 0.23±0.10$^{a}$ | 3.47±0.84$^{a}$ | 8.50±1.62$^{a}$ | 11.89±0.99$^{a}$ |

**Dimensional swelling**

The result of the swelling characteristics follows similar trend to that of shrinkage. The swelling characteristics of the wood species varied the same way as the shrinkage characteristics. The mean longitudinal shrinkage varies from 0.17% to 0.34% for Sapwood, 0.23% to 0.34% for heartwood, the radial shrinkage varies from 2.93% to 4.02% for sapwood and 2.46% to 4.09% for heartwood, the tangential shrinkage varies from 6.02% to 8.05% for sapwood and 5.33% to 8.50% for heartwood while volumetric shrinkage varied from 9.73% to 11.73% for sapwood and 7.92% to 11.89% for heartwood (Table 8). Sapwood and heartwood of *L. welwitchii* had the highest longitudinal swelling of 0.34% while the sapwood of *K. senegalensis* had the lowest value of 0.17 %. Heartwood of *V. paradoxa* had the highest radial swelling percentage of 4.27 % while A. zygia heartwood had the lowest of 2.53%. Tangential swelling was highest (9.88%) in Heartwood of *S. guineense* while *V. Paradoxa* heartwood had the lowest tangential swelling percentages of 5.63 %. Highest volumetric swelling was recorded for *V. colorata* sapwood (12.57%), while the lowest (8.28 %) was recorded for *A. zygia* heartwood. Although no statistical variation existed in the longitudinal, radial and volumetric swelling of the wood species according to ANOVA (Table 6). However, tangential swelling of some of the species differed significantly. *L. welwitchii, A. africana, A. leiocarpa, I. gabonensis, K. senegalensis, V. colorata and I. doka* have similar tangential swelling properties (Table 7). Likewise, V. *paradoxa* and *A. zygia* were similar in their tangential swelling. Wood changes dimension when it loses moisture.

The values for dimensional characteristics observed in this study revealed that there was significant difference in the tangential and volumetric shrinkage and swelling of the wood species. Generally, some wood species were dimensionally stable and this is a favourable property for their use as raw material for composite products. Dimensional stability behaviour occurs in timber because the orientation of most of the microfibrils (S2 layer) is aligned parallel to the longitudinal axis. In the wood species used, the dimensional shrinkage varies in different orthotropic directions. When compared to some hard wood species such as *Celtis mildbraedii* (11.36 %), *Khaya ivorensis* (10.46 %), *Meliceae excelsa* (10.12 %), *Afzelia africana* (7.5 %) and *Triplocyton scleroxylon* (6.44 %) (Jamala *et al*., 2013); 9.57 %, 8.83 % and 7.74 % for the top, middle and basal portion of *Gmelina arborea* (Owoyemi *et al*., 2015). The result of the swelling is similar to that of the shrinkage characteristics. Generally, the tangential swelling is more than the radial swelling while the longitudinal swelling is negligible. Moreover, both the shrinkage and swelling in the longitudinal direction have small values compared to the radial and tangential directions. Based on the results, the species were grouped into dimensional movement classes (Table 9). *V. paradoxa, A. africana, A. zygia and I. doka* were grouped into 'small' movement class, while *L. welwitchii, A. leiocarpa, I. gabonensis, K. senegalensis, V. colorata* and *S. guineense* were grouped into 'medium' movement class. Timbers in the 'small' movement class may be utilised for outdoor application; while the medium class species may only serve indoor application where they may not be subjected to constant moisture sorption.

Table 8: Dimensional Swelling characteristics

| Species | Wood region | Longitudinal (%) | Radial (%) | Tangential (%) | Volumetric (%) |
|---|---|---|---|---|---|
| *L. welwitchii* | Sapwood | 0.34±0.00[a] | 4.19±1.02[a] | 6.53±0.88[a] | 10.76±1.03[a] |
| | Heartwood | 0.34±0.00[a] | 3.22±1.09[a] | 8.64±2.70[ab] | 11.91±1.94[a] |
| *V. paradoxa* | Sapwood | 0.22±0.10[a] | 4.16±0.69[a] | 6.49±1.59[a] | 10.58±1.52[a] |
| | Heartwood | 0.28±0.10[a] | 4.27±0.77[aa] | 5.63±0.32[b] | 9.92±0.78[a] |
| *A. africana* | Sapwood | 0.23±0.10[a] | 3.88±0.45[aa] | 6.42±1.06[a] | 10.24±0.63[a] |
| | Heartwood | 0.23±0.10[a] | 4.06±1.10[a] | 6.43±0.65[ab] | 10.43±1.48[a] |
| *A. zygia* | Sapwood | 0.23±0.10[a] | 3.67±0.75[a] | 7.56±2.37[a] | 11.17±1.94[a] |
| | Heartwood | 0.28±0.10[a] | 2.53±0.35[a] | 5.64±0.65[b] | 8.28±0.88[a] |
| *A. leiocarpa* | Sapwood | 0.28±0.10[a] | 3.81±1.32[a] | 6.57±0.88[a] | 10.37±2.16[a] |
| | Heartwood | 0.23±0.10[a] | 3.56±1.29[a] | 6.93±1.75[ab] | 10.45±1.89[a] |
| *I. gabonensis* | Sapwood | 0.23±0.10[a] | 3.24±0.92[a] | 8.44±0.90[a] | 11.60±1.62[a] |
| | Heartwood | 0.28±0.10[a] | 4.13±0.43[a] | 8.46±1.79[ab] | 12.48±1.89[a] |
| *K. senegalensis* | Sapwood | 0.17±0.00[a] | 3.02±0.70[a] | 8.61±2.38[a] | 11.53±1.67[a] |
| | Heartwood | 0.34±0.00[a] | 3.38±0.90[a] | 7.57±2.59[ab] | 10.98±3.26[a] |
| *V. colorata* | Sapwood | 0.28±0.10[a] | 3.88±1.39[a] | 8.78±1.78[a] | 12.57±1.01[a] |
| | Heartwood | 0.34±0.00[a] | 3.98±0.98[a] | 6.90±1.90[ab] | 10.52±2.84[a] |
| *I. doka* | Sapwood | 0.28±0.10[a] | 3.86±1.31[a] | 7.00±1.26[a] | 10.84±1.47[a] |
| | Heartwood | 0.29±0.10[a] | 3.50±1.12[a] | 6.56±1.74[ab] | 10.08±2.52[a] |
| *S. guineense* | Sapwood | 0.28±0.10[a] | 3.70±1.36[a] | 7.08±1.20[a] | 10.78±0.56[a] |
| | Heartwood | 0.23±0.10[a] | 3.60±0.90[a] | 9.88±2.68[a] | 11.33±5.25[a] |

Table 9: Dimensional Movement Class of the Wood Species

| Species | Dimensional Movement | | | |
|---|---|---|---|---|
| | **Shrinkage (%)** | **Class** | **Swelling (%)** | **Class** |
| *L. welwitchii* | 11.10 | Medium | 11.91 | Medium |
| *V. paradoxa* | 9.46 | Small | 9.92 | Small |
| *A. Africana* | 9.90 | Small | 10.43 | Small |
| *A. zygia* | 7.92 | Small | 8.28 | Small |
| *A. leiocarpa* | 9.88 | Small | 10.45 | Small |
| *I. gabonensis* | 11.68 | Medium | 12.48 | Medium |
| *K. senegalensis* | 10.33 | Medium | 10.98 | Medium |
| *V. colorata* | 10.31 | Medium | 10.52 | Medium |
| *I. doka* | 9.56 | Small | 10.08 | Small |
| *S. guineense* | 11.89 | Medium | 11.33 | Medium |

Movement class based on volumetric shrinkage and swelling values of the heartwood

## CONCLUSION

The densities, moisture contents, porosities and tangential shrinkages and swelling of the wood species varied significantly among species and within species of the ten wood species. Based on the density, porosity, shrinkage and swelling classification, *V. paradoxa* is recommended for heavy engineering construction such as bridges, water structures etc; while *A. africana, A. zygia and A. leiocarpa* are recommended for relatively heavy construction like building rafters. The moderately heavy ones are recommended for furniture making and the moderately light classes are recommended for temporary use such as scaffolds or decking. The more permeable a wood is, the better the treatability; therefore, *L. welwitchii and I. gabonensis* is expected to have good preservative treat-ability, while *V. paradoxa* is expected to perform poorly to preservative impregnation and may require pressure treatment. *V. paradoxa, A. africana, A. zygia and I. doka* having small dimensional movement so they may be utilised for outdoor application; while the medium class species may only serve indoor applications where they may not be subjected to varying environmental conditions.

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