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ASSESSMENT OF HYGROSCOPIC CHARACTERISTICS OF *Hevea brasiliensis* WOOD

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ABSTRACT

Wood behave differently under different environment, the knowledge of the hygroscopic nature of wood is a key factor when selecting wood for a particular. This study assessed the hygroscopic behavior of *Hevea brasiliensis* wood. Void volume; Percentage volumetric swelling in the tangential, radial and longitudinal direction; and percentage volumetric swelling were used to assess the response of the selected wood when loosing moisture. Samples were obtained longitudinally, transversely and dried in the oven at 103 ± 2^{o}C for laboratory experiment. The mean values for moisture content in green *Hevea brasiliensis* wood were 49.74 %, 51.14 % and 54.36 % for top, middle and bottom portion respectively along the tree while 51.77 %, 50.02 % and 53.45 % was recorded for outer, middle and inner portions respectively across the tree. The values obtained for volumetric shrinkage and swelling were higher at the top part of *H. brasiliensis*. It was also observed that the longitudinal shrinkage was negligible while tangential direction showed the highest shrinkage among the wood direction. The result obtained showed clarification on the wood density of *hevea brasiliensis* based on the position and portion of the wood species and the variation in moisture content, void volume, volumetric shrinkage and swelling were also revealed. This will provide information in the process of drying *hevea brasiliensis* wood to ensure better wood quality devoid of defects.

Keywords: Shrinkage; Swelling; Void volume; Moisture content; Tangential direction

1. INTRODUCTION

Wood is an engineering material with the ability to take in or give off moisture in the form of vapor in response to changes in the temperature and the humidity of the surrounding atmosphere (Akpan 1999, Capon and Brain 2005). As wood dries below the fiber saturation point (25-30 %), it begins to shrink and become stiffer. Wood in service shrinks and swells as it loses and gains

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moisture from the air, under typical indoor conditions, wood contains 5 to 12 % moisture (Christiansen 1990).

According to Gan *et al.*, (1997), the drying rate expressed as percentage moisture content lost per unit time (day) is an important parameter closely related to energy consumption and economic feasibility of the process which also determines the quality of drying. Other parameters such as absence of collapse, discolouration, timber deformation, cracks, case-hardening and the resultant decrease in mechanical strength properties directly affects marketing of the product (Ogunsanwo, Amao-Onidundu, 2011).

All physical and mechanical properties of wood are greatly affected by the fluctuations in the quantity of water present in wood. In using wood as a raw material (Akpan 1999), it is therefore essential to evaluate the behaviour of *H. basiliensis* when loosing or gaining moisture. These physical properties must be considered in wood selection for construction. The mechanical properties of wood used for any construction contributed greatly to the strength and durability of the finish products (Innes 1996). The knowledge of physical properties relating to wood moisture is required to make appropriate selection and preventing construction failures. Therefore, this study examined the hygroscopic nature of *Hevea brasiliensis* wood species.

2. MATERIAL AND METHODS

2.1 The study area

The study was carried out in Ondo State, Nigeria: While *H. brasiliensis* trees was freshly felled at Ode-Irele, the laboratory work was carried out at the Federal University of Technology, Akure on the longitude of $7^{0}18^{1}$E and latitude of $5^{0}08^{1}$N.

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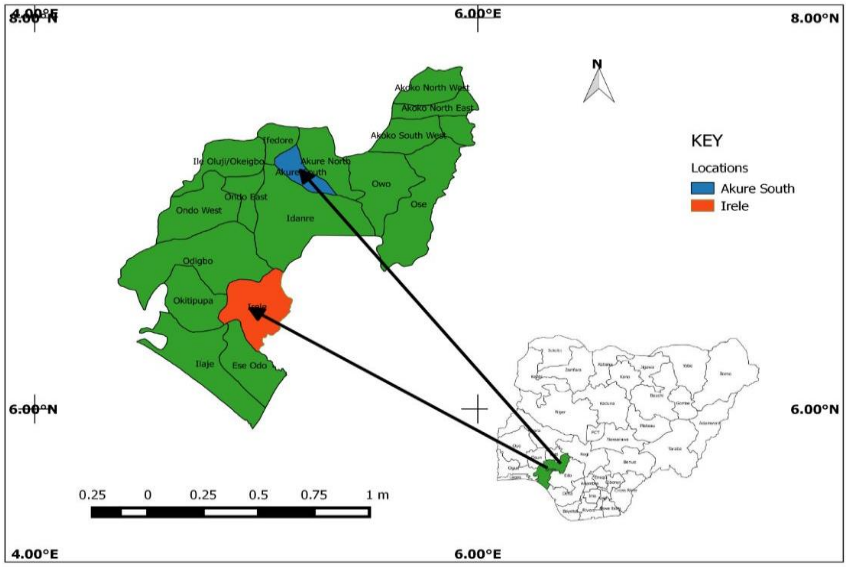

Fig. 1: Map of Ondo State showing the study areas

2.2 Material Preparation

Three stands of 65-year old *Hevea brasiliensis* trees were felled from Akinjoye farm, Legbogbo Village, Ode Irele, Ondo State, Nigeria from an old rubber plantation, flitched and evacuated. Ten sample size of 25 × 75 × 450 mm from three different trees were selected from three sampling heights of 25 %, 50 % and 75 % (the top, middle and basal parts). Another five specimens size of 20 × 20 × 60 mm were selected from the outer, middle and inner parts of the trees that were cut from the top, middle and base; dried in the oven for 24 hrs at 103 ± 2°C until the weight was constant and the following tests were carried out:.

2.3 Moisture content

The initial moisture content of samples from the freshly felled *Hevea brasiliensis* trees was determined by taking the green weight (w_1) of the samples before drying and after drying (w_2) using:

$$MC\% = \frac{W_1 - W_2}{W_2} \qquad (1)$$

2.4 Density

The variation in the wood density along and across the bole was determined using:

$$Density\ (kg/m^3) = \frac{Mass}{Volume} \quad (2)$$

2.5 Volumetric shrinkage

The reduction in wood size as a result of moisture loss during was determined using:

$$Tgs = \frac{Dt-dt}{Dt} \times 100 \quad (3)$$

$$Rds = \frac{Dr-dr}{Dr} \times 100 \quad (4)$$

$$Lgs = \frac{Dl-dl}{Dl} \times 100 \quad (5)$$

Volumetric shrinkage of the green sample was determined using:

$$Volumentric\ Shrinkage = \frac{D_1 - D_0}{D_0} \times 100 \quad (6)$$

2.6 Volume swelling

The volumetric swelling depicting the change in the volume when soaked was carried out after soaking the oven-dry samples in water for 24 hrs using:

$$Volumetric\ swelling = \left(\frac{\text{Final thickness} - \text{Initial thickness}}{Initial\ thickness}\right) \times 100 \quad (7)$$

2.7 Void volume

Void volume which is the expression of the amount of liquid preservatives the wood can absorb during preservative treatment was calculated using (Simpson 2000):

$$Void\ volume\ \% = 1 - \frac{Dry\ specific\ gravity}{1.50} \times 100 \quad (8)$$

2.8 Experimental design and Data analysis

The experimental design used for this study was two factor (3×3) factorial experiments in a Completely Randomized Design (CRD). Data collected was subjected to descriptive and graphical data presentation, while statistical analysis was carried out using Statistical Package for Social Science (SPSS). The effect of treatment was analyzed using Analysis of Variance (ANOVA) to determine relationship among moisture content, density, swelling and shrinkage of the wood samples. Follow up test was carried out using Duncan Multiple Range Test (DMRT) to test for the significant differences among the levels.

3. RESULTS AND DISCUSSIONS

3.1 Initial moisture content variation in *Hevea brasiliensis* wood

The mean values for moisture content of freshly felled *Hevea brasiliensis* wood in Fig. 2 showed 49.74 %, 51.14 % and 54.36 % for top, middle and basal areas respectively along the tree while 51.77 %, 50.02 % and 53.45 % was recorded for outer, middle and inner portions respectively across the tree. Analysis of variance carried out at 5 % probability level to test for significant differences of moisture content in the direction of cut of *Hevea brasiliensis* in Table 1 showed that there were no significant differences in the distribution of moisture content in the longitudinal axis and transverse direction of *Hevea brasiliensis* wood. Also, the interactions between longitudinal axis and transverse axis were not significant. The mean value for initial moisture content of freshly felled *H. brasiliensis* wood along the tree was 51.74 %, while for across was 51.75 %. This showed that the initial moisture for freshly felled *H. brasiliensis* was 51.45 %.

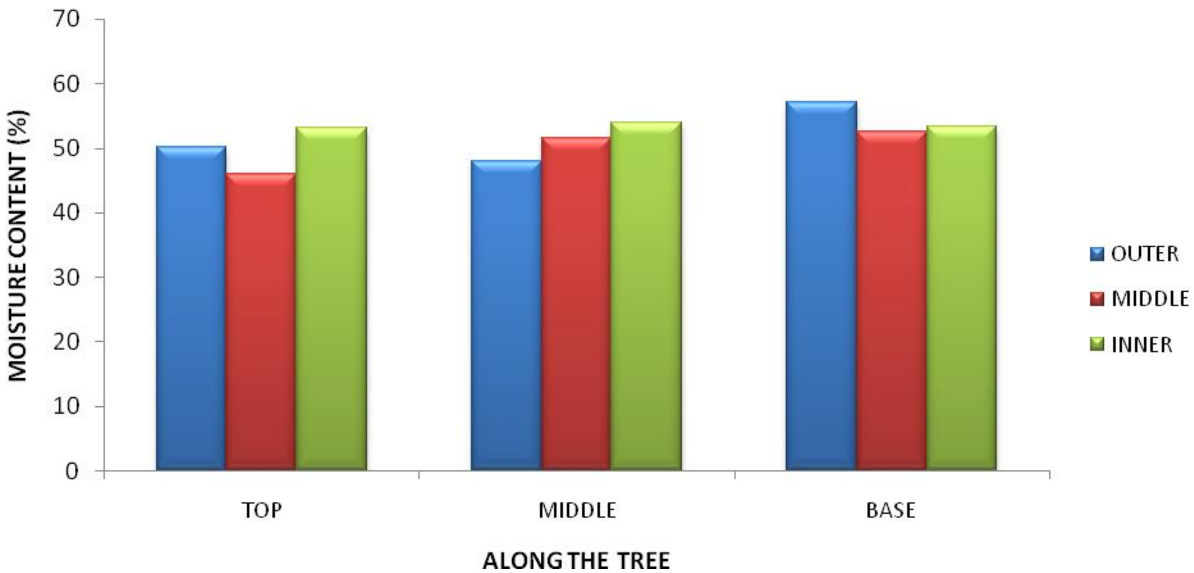

Fig. 2: Moisture content along and across *Hevea brasiliensis* wood

Table 1: Analysis of Variance of Effect of Location and Portion on Percentage Moisture Content

Source of Variation	Df	Sum of Squares	Mean Square	F-cal
Longitudinal	2	504.84	252.42	1.364^{ns}
Transverse	2	264.55	132.27	0.715^{ns}
Longitudinal * Transverse	4	582.57	145.64	0.787^{ns}
Error	126	23324.50	185.12	
Total	134	24676.46		

ns: not significant (P>0.05)

The study showed that there was a concentration of moisture in the bottom portion of *Hevea brasiliensis* tree than at the middle and the top, the top portion of *Hevea brasiliensis* had the least. The heaviness of the wood may be as a result of water occupying more than half of the weight of the green rubber wood, it could also be as a function of the higher volume of woody tissues at the bottom, the conical feature of the tree, and that water will move from the area of higher concentration to low area. This could affect transportation cost as less number of logs could be evacuated per truck load. This was in consonance with the works of Llach (1971), Moya *et al.*, (2009); Moya and Munoz (2010) that moisture content increase from the bottom to the top of a tree.

The difference in the moisture content distribution from top to the bottom is caused by water requirement for physiological processes at different heights (Zobel and Van 1989). Also, the initial moisture content across the *H. brasiliensis* wood showed that moisture content was higher in the inner portion than both in the middle and outer wood. Higher value of moisture content with the inner wood confirms the hypothesis that initial moisture content increases with increasing heartwood area in cross section. Higher moisture content value in the inner wood than the outer wood is less common in many other species (Zobel and Sprague 1998). Although it also occurred in *Gmelina arborea, Cedreta odorata, Acacia mangium* and *Acacia auriculiformis* [Yamamoto *et al.*, (2003), Ofori and Breutu (2005), Moya and Munoz (2008)]. However, for temperate species, initial moisture content of outer wood is usually higher than the inner wood especially in species with lower specific gravity and in soft wood (Skaar 1972). Another characteristic that led to increased high initial moisture content was the amount of juvenile wood in the samples. Juvenile wood with thinner cell walls and larger lumens leads to higher moisture content, which is not affected by distance from pith, because the same void spaces exist across the section (Zobel and Sprague 1998). This was shown by Butterfield *et al* (1993) who studied the anatomical features of *Vochysia guatemalensis* and determined that wood density, diameter of vessels, and pore frequency were stable across the distance from the pith and in heartwood and sapwood.

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3.2 Density variation in *H. brasiliensis* wood

The result of the mean values for density variation in green *H. brasiliensis* wood presented in Fig. 3 showed 638.85 kg/m^3, 580.48 kg/ m^3 and 573.95 kg/m^3 respectively for the top, middle and bottom, also 609.46 kg/m^3, 595.60 kg/m^3 and 588.21 kg/m^3 was recorded for outer, middle and inner portion respectively.

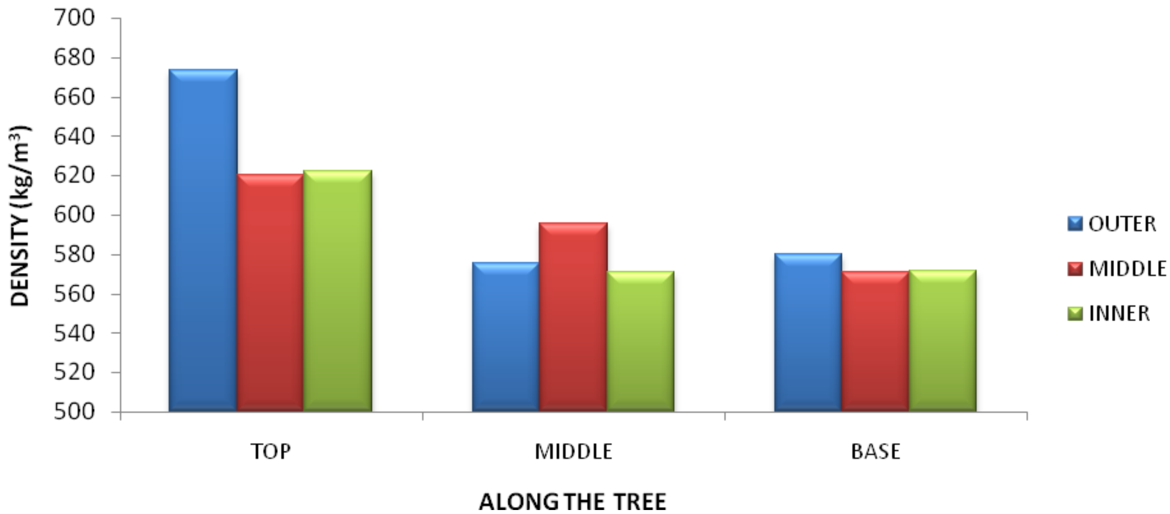

Fig. 3: Density along and across *Hevea Brasiliensis* wood

Wood density provides an estimation of the amount of cell wall material and therefore influences many factors such as the drying time, strength property, physical property, swelling, shrinkage and many other properties (Wiemann et al. 2009). Density influences the moisture holding capacity of the wood as more porous wood, less woody tissue per unit volume meant more space for moisture vice-versa. The overall mean density of *Hevea brasiliensis* was found to be 598 kg/m^3, which tallied with the general classification of wood densities by Ruwanpathirana (2014), and Owoyemi *et al*, (2013) as medium density wood (500-640 kg/m^3 at 12 % MC). *Hevea brasiliensis* compared favorably with some economic trees commonly used for construction in Nigeria. Examples of these tree species according to Desch (1996) and Akpan (2010) include *Eribroma ablonga* (670kg/m^3), *Khaya ivorensis* (485kg/m^3), *Chlorophora excelsa* (660kg/m^3), *Mitragyna ciliata* (560 kg/m^3), *Tectona grandis* (660 kg/m^3), *Triplochiton scleroxylon* (368kg/m^3), *Mansonia altissima* (615 kg/m^3), *Terminalia ivorensis* (550 kg/m^3), and *Terminalia superba* (580 kg/m^3). Thus, *Hevea brasiliensis* wood will be a promising tree species for utilization after tapping process.

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3.3 Volumetric shrinkage and swelling of *Hevea brasiliensis* wood

The mean values for volumetric shrinkage of *H. brasiliensis* wood presented in Table 2 ranged from 5.29 to 10.34 % for the top tree portion, 6.65 to 7.62 % middle portion and 6.91 to 7.32 for bottom of the wood while volumetric swelling ranged from 6.26 to 9.56 % for the top, 7.25 to 8.92 % for the middle and 6.48 to 7.17 % for the bottom portion. Table 3 showed the percentage shrinkage of *H. brasiliensis* wood at different wood directions. The table showed that longitudinal direction showed a negligible shrinkage ranged from 0.211 to 0.753 % for the different wood position. Tangential direction showed the highest shrinkage ranged from 1.448 to 4.330 % for all the directions. Analysis of variance was carried out at 5 % probability level to test for differences of volumetric shrinkage and swelling in the direction of cut of *Hevea brasiliensis* wood showed in Table 4 and 5. The result showed that, there were no significant differences in volumetric shrinkage and swelling in the longitudinal axis and transverse direction of *H. brasiliensis* wood. However, the mean values of the dimensional volumetric shrinkage in Fig. 4 showed that the tangential direction has a higher level of shrinkage than the radial direction while longitudinal direction had the least shrinkage which is negligible with the following mean values: T=3.22, R=2.81 and L=0.40 respectively.

Table 2: Volumetric shrinkage and swelling along and across *Hevea brasiliensis* wood

ALONG	ACROSS	MEAN SHRINKAGE (%)	MEAN SWELLING (%)
TOP	OUTER	10.34±11.9	9.56±11.52
	MIDDLE	5.29±1.54	6.26±1.93
	INNER	7.93±1.84	6.92±1.97
MIDDLE	OUTER	7.62±4.24	8.92±5.92
	MIDDLE	7.52±3.11	7.25±0.98
	INNER	6.65±1.38	7.61±1.40
BOTTOM	OUTER	6.97±2.13	7.17±2.34
	MIDDLE	6.91±1.15	6.99±0.95
	INNER	7.32±2.14	6.48±2.40

The number before “±” denotes mean values of three replicate and the number after “±” denotes standard error

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Table 3: Shrinkage values of *Hevea brasiliensis* wood at different positions and directions

Girth	Direction	Top (%)	Middle (%)	Bottom (%)
Outer	**Tangential**	3.852±3.13	1.448±4.88	2.228±4.03
	Radial	3.088±1.70	1.241±4.91	4.258±2.94
	Longitudinal	0.439±0.27	0.211±0.38	0.515±0.37
Middle	**Tangential**	3.317±2.68	3.656±2.02	3.091±1.56
	Radial	0.533±5.00	3.762±2.50	3.317±1.54
	Longitudinal	0.339±0.30	0.262±0.38	0.616±0.79
Inner	**Tangential**	4.330±1.71	3.148±1.56	3.847±2.46
	Radial	3.509±2.62	2.735±2.05	2.854±1.78
	Longitudinal	0.227±0.77	0.243±.039	0.753±0.54

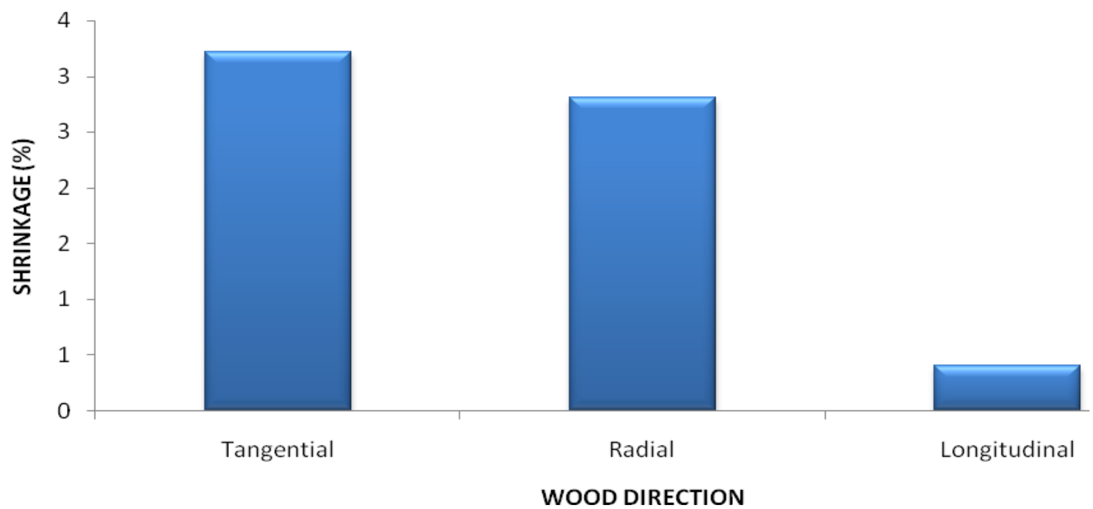

Fig. 4: Dimensional shrinkage in Rubber Wood

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Table 4: Analysis of Variance on Percentage Shrinkage of *H. brasiliensis* wood directions

Source of Variation	Df	Sum of Squares	Mean Square	F-cal
Longitudinal	2	15.32	7.66	0.368^{ns}
Transverse	2	68.26	34.13	1.639^{ns}
Longitudinal * Transverse	4	132.78	33.20	1.594^{ns}
Error	126	2623.28	20.82	
Total	134	2839.64		

ns: not significant (P<0.05)

Table 5: Analysis of Variance on *H. brasiliensis* wood Percentage Swelling of directions of cut

Source of Variation	Df	Sum of Squares	Mean Square	F-cal
Longitudinal	2	25.68	12.84	0.607^{ns}
Transverse	2	80.62	40.31	1.906^{ns}
Longitudinal * Transverse	4	37.96	9.49	0.449^{ns}
Error	126	2664.22	21.15	
Total	134	2808.48		

ns: not significant (P<0.05)

The longitudinal shrinkage from green to oven dry condition and swelling is negligible; these observations are in consonant with the work of Akpan (2007). The pattern of variation showed that both the vertical axis and the radial plane are alike. Volumetric shrinkage and swelling increased from base to top and from inner wood outward to outer wood. This agrees with the previous reports of Bekta and Guler (2001), Panshin and de Zeeuw (1980), Onyekwelu et al. (2006) and Rigatto (2004). The inner wood has less shrinkage and increase from inner wood to the outer wood. This situation may be due to the presence of greater amount of extractives in the inner wood which tend to inhibit normal shrinkage by bulking the amorphous regions in the cell wall substance. However, as the moisture content in the wood samples reduces from green to dry condition, the volumetric shrinkage increases. This scientific concept is explained by the fact that wood begins to shrink only when it is below fibre saturation point (FSP) which varies from 25 to 30 %. The shrinkage finally ceases when the wood is completely dried, at < 10 % M.C. The volumetric shrinkage and swelling properties are affected by several wood factors, such as the heartwood to sapwood ratio and the fibrillar angle on the S2 layer (Haygreen, Bowyer 1998). Lowe (1981) reported similar shrinkage behavior in *Azadirachta indica.*

3.4 Effect of Wood Location and Portion on the void volume

Analysis of variance was carried out at 5 % probability level to test for significant differences of the void volume in the direction of cut of *Hevea brasiliensis* wood (Table 6). The result showed that, there was significant difference in the void volume of the longitudinal axis of *Hevea brasiliensis* wood but transverse direction showed no significant difference. Also, the interactions between longitudinal axis and transverse axis were not significant at 5 % probability level. The mean values showed the void volume to be 43.0 %, 39.0 % and 38.0 % at the top, middle and bottom respectively, which showed that the percentage of the void volume is highest at the top compared to the middle and bottom. Result of the Duncan Multiple Range test in Table 7 showed that the top portion of the wood had the highest void volume of 43.0 %.

Table 6: Analysis of Variance of Effect of Location and Portion on the void volume

Source of Variation	Df	Sum of Squares	Mean Square	F-cal
Longitudinal	2	510.73	255.363	10.986*
Transverse	2	46.533	23.267	1.001^{ns}
Longitudinal * Transverse	4	100.736	25.184	1.083^{ns}
Error	126	2929.008	23.246	
Total	134	207351.332		

*: significant (P<0.05), ns: not significant (P>0.05)

Table 7: Duncan Multiple Range Test (DMRT) along the length of *Hevea brasiliensis* wood

Location	Void Volume (%)
Top	43.0^{a}
Middle	39.0^{b}
Bottom	38.0^{b}
SE±	**0.02**

Means in the same column having the same superscripts are not significantly different at 5 % probability level (Duncan Multiple Test at P=0.05)

The percentage of the void volume recorded for the *Hevea brasiliensis* wood corresponds with the wood density i.e. a medium density of 598 kg/m^3. The density of wood species is usually influenced by the percentage of void present in the wood. The percentage of voids recorded for the *Hevea brasiliensis* wood were similar to those reported for other hardwood species by Stamm

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(1964); Petty (1971) and Wangard (1969). Void volume is an indication of capacity of wood to absorb preservatives during treatment. This result showed that *H. brasiliensis* is treatable with either water-borne or oil-borne preservatives to prolong the serviceable life.

4. CONCLUSIONS

This study has shown that moisture content, density, void volume shrinkage and swelling properties varied in *Hevea brasiliensis* wood longitudinally from base to top and transversely from inner wood to outer wood, hence the need to properly monitor the process of drying to ensure better wood quality devoid of defects. Variations in moisture content, shrinkage and swelling was minimal along and across the bole of the species as they decreased gradually from base through the middle to the top, but, density and void volume increased gradually through the bottom to the top. Tangential and radial shrinkage was inconsistent along the tree but there was a great difference between tangential and radial shrinkage across the tree. The percentage of void volume of *Hevea brasiliensis* wood will make it to absorb a good amount of preservative chemical that will prolong the durability of the wood species.

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