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Specific Gravity and Shrinkage Characteristics of Stem and Branch woods of *Khaya grandifoliola* (Welw.) C. DC

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Abstract

Specific gravity and shrinkage characteristics of stem and branch woods of *Khaya grandifoliola* were investigated to assess the pattern of variations along and across the main bole and along the branch woods. Wood samples were collected from *Khaya grandifoliola* in the Department of Forest Resources Management, University of Ibadan, Nigeria. The tree was sectioned into main boles, primary branch wood and secondary branch wood. Fifty centimeter (50cm) length bolts were obtained from the base 10, middle 50 and top 90% of the tree height, two (2) primary and four (4) secondary branch woods. Bolts from the main bole were partitioned into inner wood, middle wood and outer wood. Central planks were also obtained from the bolts of primary and secondary branch woods which were further converted into test samples. Data obtained were analysed using descriptive statistics and ANOVA. The mean value of specific gravity of stem wood was 0.74. Primary branch woods had mean value of 0.79 while Secondary branch woods had mean value of 0.77. The mean values for tangential shrinkage, radial shrinkage and volumetric shrinkage of stem wood were 8.64%, 4.53% and13.33% respectively. The Primary branch woods had mean values of 9.40% for tangential shrinkage, 4.21 for radial shrinkage and 13.61% for volumetric shrinkage. Secondary branch woods had mean of 9.70% for tangential shrinkage, 4.51% for radial shrinkage and 14.15% for volumetric shrinkage. Variation pattern was inconsistent in specific gravity along the vertical axis and radial zones of the main bole. Variation pattern was inconsistent in radial shrinkage along the vertical axis of stem woods. Branch woods had higher specific gravity than stem woods. Variation pattern was inconsistent in radial shrinkage along the vertical axis of stem woods. In primary branch woods, the least volumetric shrinkage was at the top, while secondary branch woods had the lowest shrinkage at the base. Branch wood can be used as substitute for stem wood and therefore should be treated as such in conversion and utilization schemes. Physical and Strength properties of other branch woods should be determined to find out whether they can be used as a structural raw material for furniture and other wood products.

Key words: Physical properties, radial shrinkage, specific gravity, tangential shrinkage, utilization, variation, volumetric shrinkage.

1. INTRODUCTION

The high demand for stem wood has made the cost of purchasing furniture very high and difficult to afford. However, there are branch wood which when put into maximum use will keep the furniture manufacturers in business. Currently, the uses of branch wood in Nigeria are for firewood and charcoal burning. Some are even left in the forest to rot because the properties and maximum uses are not known to most wood users. The use of branch wood in the market will increase the resource base and make more raw materials available to the timber industry while taking some amount of pressure off the stem wood (Queen *et al.,* 2019). However, successful expansion of the timber industry through increased branch wood utilization will depend on adequate knowledge of their physical properties.

Several initiatives have been made to find out the wood properties of *S. macrophylla* between natural and monoculture plantation and the wood properties of branch woods of *Khaya ivorensis*. But no attempt has been made to determine the specific gravity and shrinkage characteristics of stem and branch woods of *Khaya grandifoliola.* A number of studies have reported the distribution, pattern of wood physical properties and their influencing factors on regional scale. However, these studies generally focus on density and ignore other wood properties. Since the growth and development of plants are affected by the combined effect of various wood properties, consideration of only wood density is insufficient. Moreover, most of these studies were performed in regions of Europe and America which have quite different species composition compared with Nigeria. Physical properties of wood are very important consideration in selecting wood for numerous uses, such as furniture manufacturing, cabinet manufacturing, construction of frame, bridge, building structures, sporting goods, measuring instruments, musical instruments, particle boards, decorative surfaces, insulating media etc. The physical properties of wood, as one of the basic elements in wood traits evaluation, are the main criteria when determining the usage of wood (Bowyer *et al.,* 2007). Therefore, understanding the variations pattern and determinants of wood physical properties will provide benefits for forestry management and also provide guidance for wood application and forest tree breeding. These properties can change with tree species and life form, for example, softwoods are usually not compact and softer, while hardwoods are denser and harder (Robert, 2010 and Carlquist 2001). Moreover, these wood properties can be affected by climate, soil and other site conditions due to the close connection between wood physical, mechanical properties and plant growth (Swenson *et al.,* 2007 and Quesada *et al.,* 2012). Therefore, a comprehensive assessment of wood physical properties and the pattern in

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which these properties vary, and the driving factors are of great importance.

In this study, specific gravity and shrinkage characteristic of stem and branch woods of *Khaya grandifoliola* have been evaluated.

2. MATERIALS AND METHODS

2.1 Sourcing of Materials

Species for the study were obtained from the Department of Forest Resources Management, University of Ibadan, Nigeria. The experiment was conducted at normal room temperature (27±2^{0}C). Forest Resources Management lies between latitude 7°27′29″ and 07°26′55.87″ North and longitude 3°53′43.81″ and 3°53′54.62″ East (Adeyemi and Adesoye, 2012).

2.2 Sampling Strategy

Fifty two years old *Khaya grandifoliola* tree with a height of 40 m and bole diameter of 120 cm was sectioned into main boles, primary branch woods and secondary branch woods. Fifty centimeter (50 cm) length bolts were obtained from the base, middle and top of the stem wood (stem wood), two (2) primary branch woods and four (4) secondary branch woods, which gave a total of 21 bolts. Bolts from the main bole were partitioned into inner wood, middlewood and outerwood. Central planks were also obtained from the bolts of primary and secondary branch woods which were further converted into test samples.

Plate 1: 52 year old *Khaya grandifoliola* tree sampled for the study before it was cut down

Plate 2: Researcher examining sample specimen during cross-cutting

2.3 Sample Preparation for Physical Properties.

Wood samples of 20×20×50 cm were obtained from each central plank of *Khaya grandifoliola* stem and branch woods. Ten (10) clear specimens were selected from each zone, for selected physical properties evaluation. This gave a total of 90 samples from the stem, 60 samples from the two primary branch woods and 120 samples from the four secondary branch woods.

Plate 3: Central planks where the samples were obtained

Plate 4: Test Samples converted into different dimensions

The test samples were conditioned to 12% moisture content in a controlled laboratory as used by Ogunsanwo and Onilude, (2000).

2.4 Physical Properties Tests

Specific gravity (SG) was obtained by removing cubes of 20 × 20 ×20 mm from the upper part of each of the test specimens. They were subjected to a gravimetric procedure developed by Smith (1954) in which specimen were completely saturated with water by boiling. Each cube was removed from water, blotted to remove excess water, weighed and oven-dried to a constant weight at 103°C. Specific gravity was determined using the formula:

$$G = \frac{1}{\frac{Ws-Wo}{Wo} + \frac{1}{1.53}}$$

Where G = Specific gravity

WS = Saturated weight of wood

WO = Oven dry weight of wood

1.53 = Constant developed by (Stamm, 1929) as the actual weight of wood substance.

Test specimens of 20 mm x 20 mm x 60 mm were prepared for the determination of percentage shrinkage; they were properly aligned and denoted 'T' and 'R' for Tangential and Radial planes respectively. They were soaked in water for 72hrs in order to get them conditioned to moisture above Fibre Saturation Point (FSP). Specimens were removed one after the other; their dimensions in wet condition were taken to the nearest millimeter. Percentage shrinkages along the two planes were measured after specimens have been oven-dried as

$$S = \frac{D_S - D_O}{D_S} X100 \qquad (1)$$

Where: $_S$ = shrinkage %

D_S = dimension at saturated condition

D_O = dimension of oven dry condition

$$VS = S_R + S_T \qquad (2)$$

Where: VS = Volumetric shrinkage

S_R = Radial shrinkage

S_T = Tangential shrinkage

This is in accordance with approximations done by Dinwoodie, (1989).

Plate 5: Combination machine used for conversion of wood samples into dimensions

2.5 Experimental Design

The experimental design adopted for the main bole was a two factor split plot with the main plot arranged in a CRD with five replications. In this design, the main factor was longitudinal variations (Base, Middle and Top) while the sub-factor (B) was the radial zones (Inner, Middle and Outer) which was allotted on the main bole. Completely Randomised Design was used for the branches. Data obtained from the experiment were analysed using both inferential and descriptive analysis.

3. RESULTS

3.1 Specific Gravity

The mean specific gravity recorded along the vertical axis of the main bole was 0.74. This value ranged between 0.79 at the top and 0.73 at the base (Table 1). While along the Radial axis, the mean ranged from 0.69 in the outerwood to

0.79 in the middlewood. The mean specific gravity value recorded along the vertical axis of secondary branch woods was 0.77 with values ranging from 0.75 to 0.8 (Table 1). The primary branch woods recorded mean specific gravity of 0.79 which ranged from 0.76 to 0.84 (Table 1).

Table 1: Mean Specific Gravty of *Khaya grandifoliola* stem wood, primary and secondary branch wood in Relation to Height and Positions in the tree

Wood Properties	Wood Types	Sampling Height (%)			
		Base (10%)	Middle (50%)	Top (90%)	Mean± SD
Specific gravity	Outerwood	0.70 ± 0 .06[b]	0.65 ± 0 .06[b]	0.74 ± 0.03[b]	0.69 ± 0.05
	Middlewood	0.80 ± 0 .02[a]	0.71 ± 0 .07[a]	0.85 ± 0.10[a]	0.79 ± 0.06
	Innerwood	0.70 ± 0 .10[a]	0.78 ± 0.07[a]	0 .77 ± 0.05[a]	0.75 ± 0.07
Pooled Mean		0.73 ± 0.06	0.7 ± 0.07	0.79±.0.06	0.74 ± 0.06
	Primary branch wood	0.84 ± 0.92[a]	0.78 ± 0.88[a]	0.76 ± 0.87[a]	0.79 ± 0.89
	Secondary branch wood	0.8 ± 0.89[b]	0.75 ± 0.87[a]	0.75 ± 0.87[a]	0.77 ± 0.88

Values in the same column with the same letter do not differ significantly (*P*=0

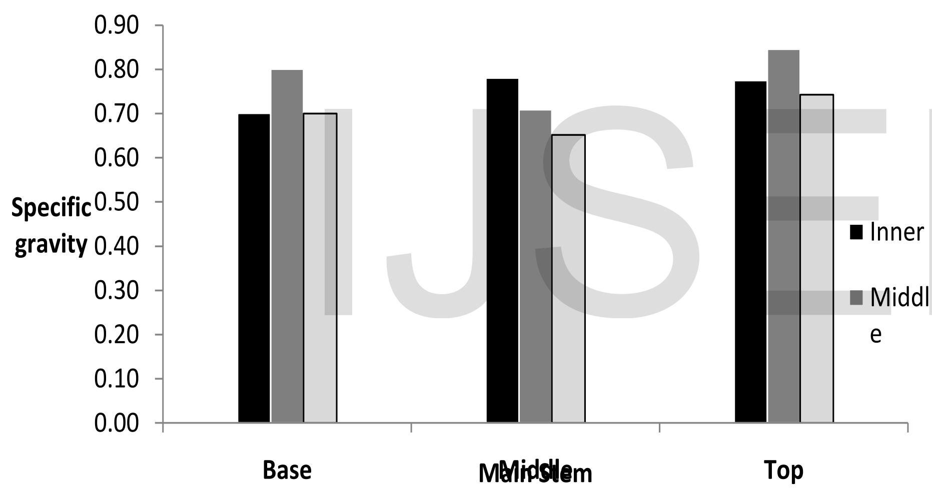

Fig 1: Variations in specific gravity of wood samples of *Khaya grandifoliola*

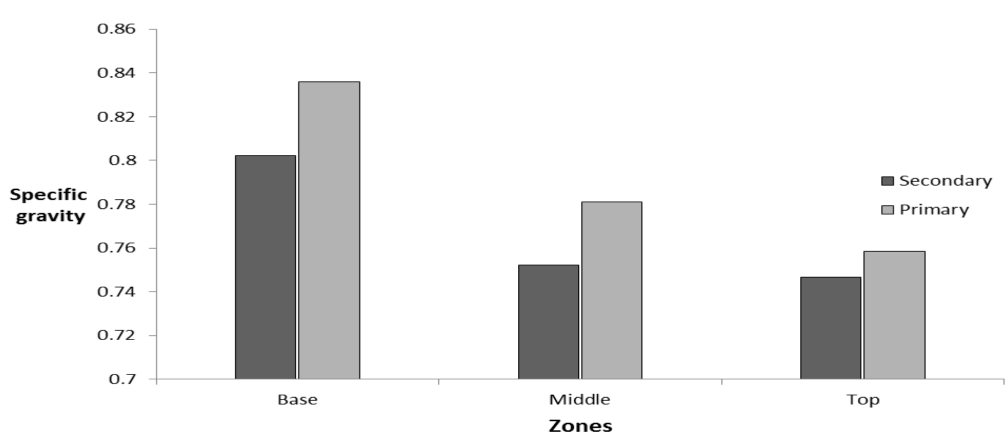

Fig 2: Variations in Specific gravity primary and secondary branchwoods of *Khaya grandifoliola* along the vertical axis.

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3.2 Tangential Shrinkage

The mean tangential shrinkage values obtained was 8.64%. This value ranged from 8.29% at the base to 8.99% at the top. While along the radial axis, tangential shrinkage ranged from 8.47% in the innerwood to 8.78% in the outerwood (Table 2). Secondary branch woods recorded mean values of 9.70% with the values ranging from 9.3% to 10% (Table 2). The primary branches recorded mean Tangential Shrinkage of 9.40%. The values ranged from 8.85% at the top to 10.28% at the middle (Table 2).

Table 2: Mean Tangential Shrinkage of *Khaya grandifoliola* stem wood, primary and secondary branch wood in Relation to Height and Positions in the tree

Wood Properties	Wood Types	Sampling Height (%)			
		Base (10%)	Middle (50%)	Top (90%)	Mean± SD
Tangential Shrinkage	Outerwood	8.22 ± 2.87^b	9.38 ± 3.06^a	8.73 ± 2.95^a	8.78±2.96
	Middlewood	8.58 ± 2.93^a	8.45 ± 2.91^{ab}	8.98 ± 2.99^a	8.67±2.94
	Innerwood	8.07 ± 2.84^a	8.08 ± 2.84^a	9.25 ± 3.04^a	8.47±2.91
Pooled Mean		8.29 ± 2.88	8.64 ± 2.94	8.99 ± 2.99	8.64±2.94
	Primary branch wood	9.47 ± 3.08^b	10.48 ± 3.21^b	8.45 ± 2.91^a	9.4 ± 3.07
	Secondary branch wood	9.36 ± 3.06^b	10.0 ± 3.16^{ab}	9.74 ± 3.12^a	9.7 ± 3.11

Values in the same column with the same letter do not differ significantly (*P*=0

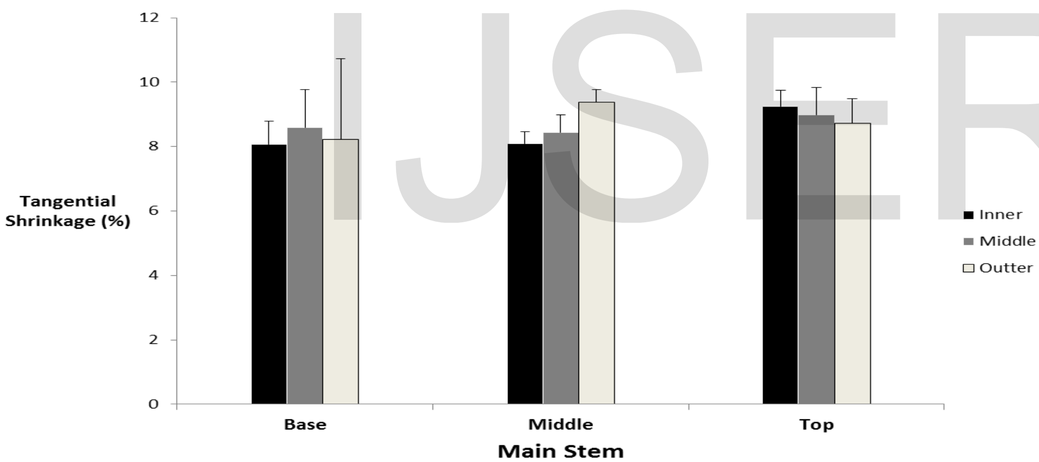

Fig 3: Variations in tangential shrinkage of wood samples of *Khaya grandifoliola*

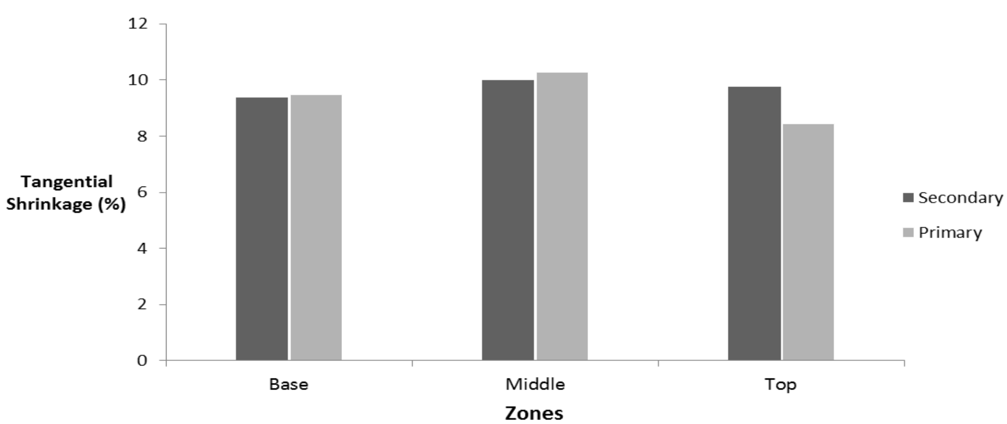

Fig 4: Variation patterns in tangential shrinkage along the vertical axis of primary and secondary branches

3.3 Radial Shrinkage

The result obtained indicates that radial shrinkage had mean values of 4.53%. The values obtained from the vertical axis were 4.59% at the base, 4.31% at the top and 4.70% at the middle (Table 3). While along the radial zones, radial shrinkage decreased from 4.99% in the outerwood to 4.05% in the middlewood and 4.56% in the innerwood (Table 2). Secondary branch woods recorded mean of value of 4.51%. The values ranged from 3.96% at the base, to 4.8% at the middle while primary branch woods recorded mean values of 4.21%. The values ranged from 3.74% in the base to 4.56% at the top (Table 3).

Table 3: Mean Radial Shrinkage of *Khaya grandifoliola* stem wood, primary and secondary branch wood in Relation to Height and Positions in the tree

Wood Properties	Wood Types	Sampling Height (%)			
		Base (10%)	Middle (50%)	Top (90%)	Mean± SD
Radial Shrinkage	Outerwood	4.71 ± 2.17[a]	5.08 ± 2.25[a]	5.18 ± 2.28[a]	4.99 ± 2.23
	Middlewood	4.66 ± 2.16[a]	4.00 ± 2.00[a]	3.50 ± 1.87[a]	4.05 ± 2.01
	Innerwood	4.41 ± 2.10[a]	5.02 ± 2.24[ab]	4.24 ± 2.06[a]	4.56 ± 2.13
Pooled Mean		4.59 ± 2.14	4.70±2.16	4.31±2.07	4.53±2.12
	Primary branch wood	3.74 ± 1.93[ab]	4.31 ± 2.08[a]	4.56 ± 2.14[a]	4.21 ± 2.05
	Secondary branch wood	3.96 ± 1.99[a]	4.8 ± 2.19[a]	4.75 ± 2.18[a]	4.51 ± 2.12

Values in the same column with the same letter do not differ significantly (*P*=0

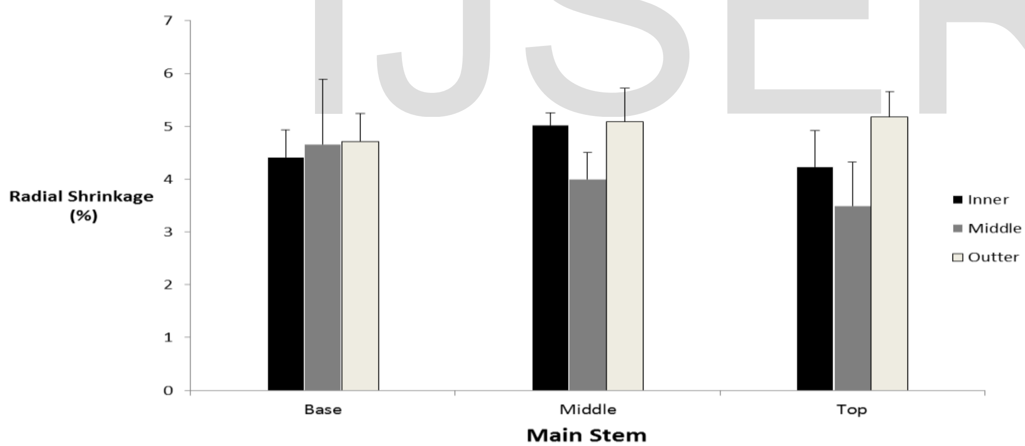

Fig 5: Variation patterns in Radial shrinkage of wood samples of *Khaya grandifoliola*

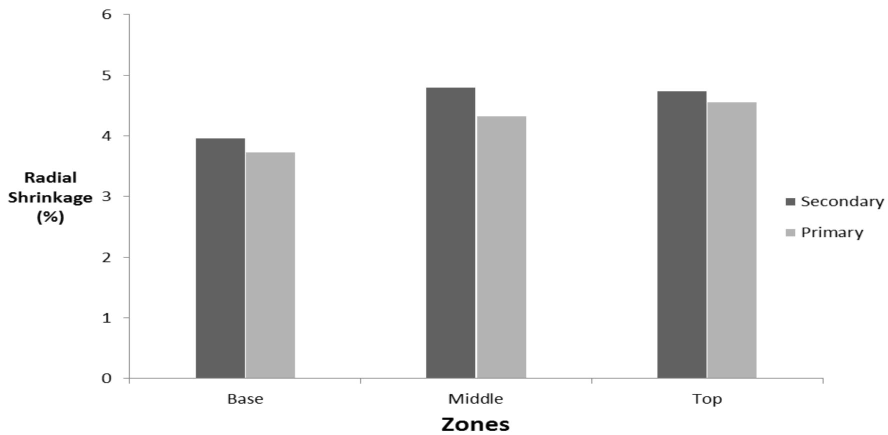

Fig 6: Variation patterns in Radial shrinkage of wood samples of *Khaya grandifoliola alon*g the vertical axis

3.4 Volumetric Shrinkage

Volumetric Shrinkage recorded mean values of 13.13%. Along the vertical axis, the values ranged from 12.89% in the base to 13.33% in the middle (Table 4). While along the radial zones, the value ranged from 12.72% in the middlewood to 13.77% in the outerwood (Table 4). The mean volumetric shrinkage for Secondary branch woods was 14.15% with values ranging from 13.32% to 14.81% (Table 4). Primary branch woods recorded mean values of 13.61%. The values ranched from 13.01% at the top, to 14.61% at the middle (Table 4).

Table 4: Mean Volumetric Shrinkage of *Khaya grandifoliola* stem wood, primary and secondary branch wood in Relation to Height and Positions in the tree

Wood Properties	Wood Types	Sampling Height (%)			
		Base (10%)	Middle (50%)	Top (90%)	Mean± SD
Volumetric Shrinkage	Outerwood	12.94 ± 3.60[a]	14.46 ± 3.80	13.91 ± 3.73[a]	13.77 ± 3.71
	Middlewood	13.24 ± 3.64[a]	12.45 ± 3.53[a]	12.48 ± 3.53[a]	12.72±3.57
	Innerwood	12.48 ± 3.53[a]	13.09 ± 3.62[a]	13.09 ± 3.62[a]	12.89 ± 3.59
Pooled Mean		12.89 ± 3.59	13.33 ± 3.65	13.16 ± 3.63	13.13 ± 3.62
	Primary branch wood	13.21 ± 3.63[a]	14.61 ± 3.82[ab]	13.01 ± 3.61[a]	13.61 ± 3.69
	Secondary branch wood	14.32 ± 3.78[a]	14.81 ± 3.85[a]	13.32 ± 3.65[a]	14.15 ± 3.76

Values in the same column with the same letter do not differ significantly (*P*=0

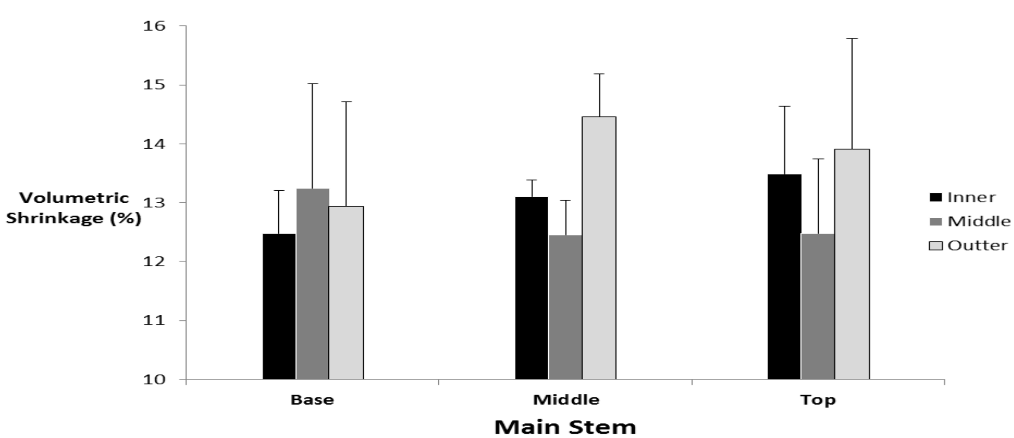

Fig 7: Variations in volumetric shrinkage of wood samples of *Khaya grandifoliola*

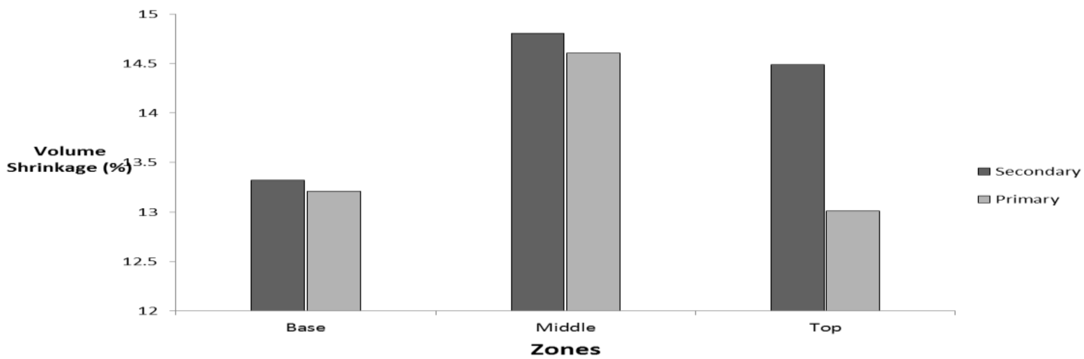

Fig 8: Variations in Volumetric shrinkage of primary and secondary branchwoods *Khaya grandifoliola along* the vertical axis

4. DISCUSSION

The pattern of variation was inconsistent in specific gravity along the vertical axis of the stem wood (Table 1). It decreased from the top to the middle (Table 1). There was also inconsistent variation pattern in specific gravity along the radial zones (fig 1). This pattern of variation is in line with radial variations in specific gravity described by Panshin and deZeeuw (1980). The pattern of variations showed that specific gravity increased from the top to the base (Fig 1). Specific gravity is similar to density and is an excellent index of the amount of wood substance contained in a piece of wood; it is a good index of mechanical properties as long as the wood is clear, straight grained, and free from defects. It is important to note that the higher the value of the specific gravity of the wood, the *greater* the strength properties (Green *et al*., 2003). Wood specific gravity varies within the same species growing in different geographic locations and even varies within the same tree from pith to bark and at different heights. The radial trend in specific gravity may be explained by the transition between juvenile wood and mature wood, age, site factors, nutrient, environment, silvicultural control and wood type. For instance, Bao *et al.* (2001) observed considerable differences in most wood properties (including specific gravity) between plantation-grown juvenile wood and mature wood, and between naturally-grown juvenile wood and mature wood. Based on their findings, Bao *et al.* (2001) argued that "wood properties of plantation-grown trees greatly depends on juvenile wood content, and can thus be manipulated effectively through varying rotation age". Generally, the longer the rotation age, the lower the juvenile wood content and superior the wood properties. Apart from genetic factors, higher growth rates are often resulting from improved site, nutrient, environmental conditions and intense silvicultural control. Branch woods had higher specific gravity than stem woods (Fig 2). Branch wood is generally higher in specific gravity than stem wood (Fegel 1941; Kollmann and Côté 1968; Tsoumis 1968. Stephen *et al* (2014) also reported values similar for *Khaya ivorensis.* He reported that the branch woods of *Khaya ivorensis* had basic density of 0.92% and 0.98% respectively.

Pattern of variation along the vertical axis of the stem wood indicates that tangential shrinkage increased from the base to top (Table 2, Fig 3). While along the radial zones, tangential shrinkage decreased from outerwood to the innerwood (Fig 3). The pattern of variation in primary and secondary branch woods indicates that tangential shrinkage was inconsistent (fig 4). This variations pattern agrees with proceeding findings by (Mottonnen & Loustarinen, 2006; Seralde, 2006). Izekor & Fuwape (2009) reported gradual increase in tangential and radial shrinkage of plantation grown teak from butt log to the Crown Point and this subsequently has a linear relationship with specific gravity. Wood with high specific gravity has proportionally more cell wall or less lumen, and tends to shrink or swell more (Walker, 1993). These differences according to Desch and Dinwoodie (1996) are as a result of restricting effect of the rays on the radial plane, the difference in the degree of lignifications between the radial and tangential walls, the difference in microfibrillar angle between the two walls and the increase in thickness of the lamella in the tangential direction in relation with that in the radial direction. Akpan (2007), obtained a mean of 12.65% along the tangential axis of neem (Azadiractha indica), grown in Sahel Savanna. While for neem grown in the sudan Savanna and Guinea Savanna he obtained a mean tangential shrinkage of 12.88% and 12.69% respectively. Movement in the horizontal direction is greater than in longitudinal direction. Both primary and secondary branch woods had means that correlates with that of the stem wood.

The result obtained in this study, indicates that; along the vertical axis of the main bole (stem wood), radial shrinkage was high in the base, became higher at the middle and it later decreased at the top, giving an inconsistent pattern of variation (Fig 5, Table 3). While along the radial zone, radial shrinkage increased from the middlewood to the outerwood, giving an indication of inconsistency in pattern of variation (Fig 5). This is in agreement with the previous published findings by Ogunsanwo and Onilude, (2000), Mottonen and Laustarinen, (2006). Radial Shrinkage was observed to be twice lesser than the tangential shrinkage. This may have occurred as a result of some physiological activities in the wood cells. Poku *et al* (2001) reported a significant difference between radial and tangential shrinkage on lesser used hardwood species in Ghana. According to Kiaei and Samariha (2011), variation of shrinkage in different direction is due to the cell low structure and physical organisation of cellulose chain molecules within the cell walls. Malan and Arbuthno (1995) also pointed out that microfibril angle of S_2 layer is an important factor that affects shrinkage. According to Kiaei and Samariha (2011), variation of shrinkage in different direction is due to the cell low structure and physical organisation of cellulose chain molecules within the cell walls. Radial shrinkage in primary branch woods increased form base to top while radial variation was inconsistent in secondary branch woods. Radial shrinkage increased from the base through the top to the middle (Fig 6). Both primary and secondary branch woods had means that correlates with that of the main stem (Table 3). Radial shrinkage was also observed to be lesser than tangential shrinkage. This may also have occurred as result of the wood type and physiological activities in the wood cells.

Volumetric shrinkage increased from the base to the middle along the vertical axis of the stem wood (Table 4). The innerwood of the study samples had less shrinkage and increased from innerwood to middle wood (Fig 7). This situation may be as a result of greater amount of extractives that are present in the innerwood which inhibits normal shrinkage by bulking the amorphous region in the cellwall substance. Guler *et al*, (2007), reported similar shrinkage behaviour of *Azadirachta indica*. He stated that volumetric shrinkage increased from the base to the middle and then decreased towards the top in both heartwood and sapwood. The volumetric shrinkage and swelling properties are affected by several wood factors, such as the heartwood to sapwood ratio of fibrillar angle in the S_2 layer (Bekt and Guler 2001). Variations pattern along vertical axis of the branch woods shows that the secondary branch woods had higher volumetric shrinkage than primary branch woods (Fig 8). Volumetric shrinkage was highest and in the middle in both primary and secondary branch woods. In primary branch woods, the least volumetric shrinkage was at the top, while secondary branch woods had the lowest shrinkage at the base (Fig 8). This indicates that branch woods are closely related in terms of volumetric shrinkage. The variation pattern in the branch woods could also be related to factors like heartwood to sapwood ratio of fribriller angle in the S_2 layer (Bekt and Guler 2001).

5. CONCLUSION AND RECOMMENDATION

The study has showed that specific gravity increased from the middle to the top along the vertical axis of the stem wood. There was also inconsistent variation pattern in specific gravity along the radial zones. Specific gravity decreased from the outerwood to the middlewood along the radial zones. It was observed that Specific gravity in primary and secondary branch woods generally increased from the base to top. Tangential shrinkage increased from the base to top of the stem wood. While along the radial zones, tangential shrinkage decreased from outerwood to innerwood. Tangential shrinkage was inconsistent in primary branch woods. It increased from the top, through the base to the middle. While in secondary branch woods, tangential shrinkage increased from base through the top, to the middle. Radial shrinkage decreased from the top through the base to the middle of the stem wood. Along the radial zone, radial shrinkage increased from the middlewood to the outerwood giving an indication of inconsistency in pattern of variation in the main bole. The pattern of variation showed that radial shrinkage increased along the tree bole (vertical axis) from base through the mid log to the top in all the primary and secondary branch woods. Volumetric shrinkage increased from the base to the middle along the vertical axis of the stem wood. The innerwood of the study samples had less shrinkage and decreased from innerwood to middlewood. Volumetric shrinkage in both primary and secondary branch woods, increased from the top, through the base, to the middle. This study has shown that *Khaya grandifoliola stem* wood possesses a variable specific gravity of 0.69 to 0.79. Secondary branch woods possess a variable specific gravity of 0.75 to 0.8. Primary branch woods possess a variable specific gravity of 0.76 to 0.84 which falls within the range of wood considered to be heavy wood. *Khaya grandifoliola* is a heavy wood. This study recommends that the stem and branch woods of *Khaya grandifoliola* be used as structural materials such as beams, columns and other support work that requires high strength wood. *Khaya grandifoliola* branch woods should be used by the local furniture makers and carpenters to produce furniture, windows, doors, carbinets, where appearance and dimensional stability are important. Physical and Strength properties of other branch woods should be determined to find out whether they can be used as a structural raw material for furniture and other wood products. Given the variation found in the limited tree samples of this study, further analysis should be done with larger samples from different provenances and planting zones.

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