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*Full Length Research Paper*

# Tissue dimensions and proportions of the stem and branch woods of *Aningeria Robusta* (A. Chev) and *Terminalia Ivorensis* (A. Chev)

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**To enhance wood economic value and effective utilization, knowledge of its properties, which impact its service behaviour, is indispensable. Fibre and vessel dimensions and tissue proportions of *Aningeria robusta* and *Terminalia ivorensis* stem wood and branch wood were compared. Stem wood recorded wider vessel lumen diameter, greater fibre and vessel proportions with less parenchyma than the branch wood. Fibre length, diameter, lumen diameter and double wall thickness were greater for*T. ivorensis* stem wood (1296.7-1508.6, 19.8-23.4, 13.3-17.3 and 6.0-6.5µm respectively) than branch wood (1046.0-1116.5, 19.2-21.2, 13.1-15.2 and 5.7-6.3µm respectively). Similarly, *A. robusta* stem wood recorded greater values (1182.9-1302.3, 22.9-23.9, 15.3-18.6 and 6.2-7.6µm respectively) than branch wood (995.1-1145.3, 20.1-22.42, 15.1-17 and 4.9-5.6µm respectively). Fibre proportions decreased up their stems (51.5-42.5%) and branches (51.2-40.0%). Their sapwood and heartwood vessel and parenchyma proportions were greater at bases than crowns. Vessel lumen diameters increased with stem height but decreased along branches. Consequently, their stem woods would have superior load-bearing capacity, be coarse-textured and produce great tear-resistant papers. Branch woods would have great density, be close-textured and suitable for product finishing and bulky paper production. Knowledge about branch wood properties would ensure proper understanding of their service performance and utilization. This would supplement their wood volumes and broadening the raw material base for the timber industry.**

**Key words:** Axial stem position, anatomical feature, branch wood, fibre length, parenchyma cell, tissue proportion, vessel lumen diameter, fibre wall thickness, wood macerate.

## INTRODUCTION

Wood anatomical features vary within-tree, including stem wood and branchwood. These include fibre dimensions, vessel lumen diameter (Zimmermann, 1978, 1983; Gartner, 1995; Mejia et al., 2003) and tissue (i.e., fibre, vessel and parenchyma) proportions (Ismail et al., 1995; Gartner et al., 1996; Longui et al., 2012). Generally, branchwood has smaller wood elements than the stem wood, which results in close-textured wood as compared to stemwood (Wilson and White, 1986).The longitudinal cells in branchwood are generally narrower in diameter and shorter in length than in stem wood (Tsoumis, 1968).For instance, longer and wider fibres were recorded for the stemwood (940±167, 22.8±4.63, 16.16±4.69, 3.34±1.18µm respect-

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ively for the fibre length, diameter, lumen width, cell wall thickness) than the branch wood (594±134, 17.81±3.53, 12.78±3.71, 2.49±0.6µm respectively) of *Ailanthus altissima* (Samariha et al*.,* 2011). Shorter fibres were also recorded for the branchwood than stemwood of *Eriotheca gracilipes* (Longui et al., 2012), and smaller branch wood than stem wood vessel lumen diameter for *Fagus sylvatica* and in *Quercus ilex* (Gasson, 1987). Haygreen and Bowyer (1996) and Joshi (2008) further reported that hardwood branches have more vessels and parenchyma with fewer fibres than the stem. In support, fewer vessels were recorded in the stemwood than the branchwood of *Acer*, which also had greater amounts of parenchyma in the branch than stem (Gurau et al*.,* 2008). Similarly, the stem of *Aigeiros tacamahaca* was with fewer vessels than the branch(Phelps et al*.,* 1982).

*A. robusta* and *T. ivorensis* are commercial timbers of great demand in the local and international markets (Lemmens, 2007; Ritcher and Dallwitz, 2009) due to their excellent performance in structural applications, especially in roofing, doorframes and furniture (Ajala and Ogunsanwo, 2011). Their branch woods have also been indicated as suitable for commercial utilization in the wood industry for products such as furniture and cabinets (Okai et al*.,* 2004). However, variations in the anatomical features (i.e., tissues, their dimensions and proportions) of the stem and branch woods of these timbers have never been studied. The anatomical features of the two hardwoods under investigation could influence their other wood properties. Fibre length influences wood load bearing capacity (Desch and Dinwoodie, 1996), Modulus of Elasticity (MOE) (Wilson and White, 1986) and the tear resistance of paper (Ademiluyi and Okeke, 1979). Fibre walls determine the bulk and tearing strength of sheets (Dadswell and Watson, 1962; Wardrop, 1969) and the toughness of wood (Schwarze, 2004;Antwi-Boasiako and Ayimasu, 2012). Similarly, wood density is affected by the diameters, wall thicknesses and lumen diameters of cells (Haygreen and Bowyer, 1996; Roque and Filho, 2007) just as fibre lumen width affects the penetration of liquids into empty spaces of the fibres and thus influences pulp beating (Emerhi, 2012). The percentage composition of the non-fibrous tissues namely, vessels, parenchyma (axial and ray), relative to that of fibres in the wood volume is very important; their presence in large quantities critically influences timber for both solid wood products and paper manufacturing (Kpikpi, 1992).Excessive parenchyma (axial and ray) will increase the wood drying rate and affect anisotropy in shrinkage, slow machine drainage and result in effluent difficulties (Klungness and Sanyer, 1981; Hua *et al.,* 1997).Differences in the fiber and vessel proportions of stem and branchwoods would likewise impact their specific gravity, machinability, mechanical properties and their fiber yield in the pulp (Hua *et al.,* 1996). Moreover, differences in tissue fractions invariably influence wood density (Kasia *et al.,* 2013). Thus, information about wood tissue dimensions and their proportions is widely regarded crucial in understanding the properties of wood and estimating its behaviour in service (Bowyer et al., 2003; Barnett and Jeronimidis 2003; Sehlstedt-persson and Olov*,* 2010) and importantly for the efficient utilization of the branchwoods of *A. robusta* and *T. ivorensis*, besides their stemwoods.

## MATERIALS AND METHOD

### Preparation of wood samples for anatomical investigations

#### (1) Conversion of wood samples

Mature trees (about 60 years) of *A. robusta* and *T. ivorensis* (14 to 15m high withstem diameters ranging from 38.5 to 61.5cm) were sampled from the Fum Headwater Forest in the Adansi North District of Ghana. Branch diameters ranged from 18 to 34 cm. Billets (1m) were removed from the base (1m from the ground), the middle (1m along half of stem), the crown (1m to branch attachment) of each stem. Along their branches, samples (1m) were also taken from the base, middle (50% branch height) and top (15cm from branch tip). Radial slabs were sampled from each billet and sections removed from the heartwood (5cm from the pith) and sapwood (5cm below the bark) regions. The required dimensions for wood sectioning (20 × 20 × 20mm) and maceration(20 × 2× 2mm) were taken from each slab.

#### (2) Wood Sectioning

Wood blocks (20mm$^3$) from each tree position were softened by soaking in cold water and in a mixture of 100ml ethanol and 100ml glycerol successively for 14 days. Sections (15µm-thick)from Transverse Section (TS),Tangential Longitudinal Section (TLS) and Radial Longitudinal Section (RLS)were made from each block (using a sliding microtome), washed in water and stained in 1% Safranin for 10 min. They were washed in water and dehydrated in increasing concentrations of ethanol (30, 50, 70, 90 and 100%) for 5min. each, covered with a mixture of 5ml clove oil and 5ml xylene for 10min. and mounted in Canada balsam on glass slides. All prepared slides were dried at 60$^0$C overnight for observation under the light microscope. Tangential vessel lumen diameter was determined from each sample (TLS) using × 40 objective lens and ×10 eyepiece. Fibre, vessel and parenchyma tissue proportions were determined from each sample (TS)using ×40 objective and ×10 eyepiece lens with a 20-point dot grid scale placed progressively at five (5) different positions. At each placement, the number of points covering any tissue was counted and calculated as a percentage of the total number of points.

### (3) Wood Maceration

Macerated tissues were made from wood strips of matchstick sizes (20 × 2× 2mm), soaked in a mixture of 50ml of 6% hydrogen peroxide and 50ml of 97% glacial acetic acid in test tubes and incubated at $60^0$C until the samples bleached white. The macerated samples were rinsed thoroughly with water and mounted in glycerol. Fibre dimensions were measured from each sample (at x10 and x40 Objective and x10 eyepiece). Terminology for description of the anatomical features followed the IAWA Committee's recommendations (Anon, 1989).

### (4) Data Analysis

ANOVA and Duncan's Multiple Range Test (DMRT) at 95 % significant level were used to test for variations in the fibre dimensions, vessel lumen diameter and tissue (fibre, vessel and parenchyma) proportions between the sapwoods and heartwoods along the stems and branches of the two timbers.

## RESULTS

### (1) Descriptive anatomy of *T. ivorensis* and *A. robusta*

Figures 1-4 show qualitative anatomical features of *T. ivorensis* and *A. robusta*. TSof *T. ivorensis* wood shows solitary vessels with radial multiples of 2, axial parenchyma predominantly paratracheal and vasicentric (Figure1).Vessels are also solitary with radial multiples of 2-4, axial parenchyma apotracheal, diffuse-in-aggregate in *A. robusta* (Figure 2). TLS shows irregularly storied rays 1-3 cells wide with tyloses occluding some vessels in *T. ivorensis. A. robusta* also has irregularly storied rays 1-3 cells wide, with multiseriate portions as wide as uniseriate portions exist (Figure 3). RLS shows body ray cells procumbent in *T. ivorensis*, with one row of square marginal cells. Body ray cells are also procumbent in *A. robusta* with mostly 2-4 rows of upright and square marginal cells, with silica bodies present in rays (Figure 4).

### (2) Dimensions of tissues for *T. ivorensis and A. robusta*

#### a) Fibre length

Fibre lengths (FLs) of the sapwoods and heartwoods of the two (2) timbers increased from the base to the middle of the stem and then decreased at their crowns (Figure 5). FLs also decreased from the base up the branches. Heartwood fibres from *T. ivorensis* stem base and middle were longer than their corresponding sapwoods, whereas the sapwood and heartwood of the crown had fibres of similar length. Sapwoods along *T. ivorensis* branch had longer fibres than their corresponding heartwoods (Figure 5). Heartwood fibres from the branch top and the stem middle had the shortest (1046.00 µm) and longest (1508.60 µm) fibres respectively in *T. ivorensis*. *A. robusta* heartwood fibres were longer than their corresponding sapwoods both in the stem and in the branch (Figure 5). Branch top sapwood and stem middle heartwood of *A. robusta* recorded the shortest and longest fibres (995.09 and 1321.49 µm respectively).

On the whole, stem wood fibres for both timbers were longer than those for the branch woods. *T. ivorensis* fibres were also longer than those of*A. robusta*, except at the branch base, where *A. robusta* had longer fibres (Figure 5). The differences in FLs between the sapwood and heartwood along the stems and branches of the two timbers were significant at $P < 0.05$ (Table 1). However, according to DMRT (Table 3), FL differences between *T. ivorensis* sapwood at the stem base, stem crown sapwood and heartwood, *A. robusta* stem sapwood and heartwood in the middle were not significant ($p<0.05$), just as those between *T. ivorensis* stem middle sapwood and heartwood. Differences between FLs of *T. ivorensis* branch base sapwood and heartwood were also not significant ($p<0.05$)likewise those between *A. robusta* branch base sapwood and heartwood, and also between *A. robusta* branch middle and top sapwoods and heartwoods.

#### b) Fibre diameter

Sapwood and heartwood fibre diameters (FDs) increased along the stems, but decreased along the branches of the 2 timbers (Figure 6). At *T. ivorensis* stem base, and from the branch base to its top, sapwood fibre diameters were wider than their corresponding heartwoods. However, at the middle and crown of stem, heartwood fibres were wider than their sapwoods. Heartwoods from the branch top and stem crown respectively had the smallest and widest fibres (19.18 µm and 23.39 µm)in *T. ivorensis* (Figure 6). However, *A. robusta* sapwood fibres were wider than their corresponding heartwood's. Its branch heart wood at the top and stem sapwood at the crown had the smallest (20.07 µm)and widest (24.79 µm)fibres respectively(Table 3; Figure 6). Fibres were also wider in *A. robusta* than in *T. ivorensis*, except the sapwood at the middle of the branch where the fibres were wider in *T. ivorensis* than *A. robusta* (Figure 6). The differences in FDs between sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A.*

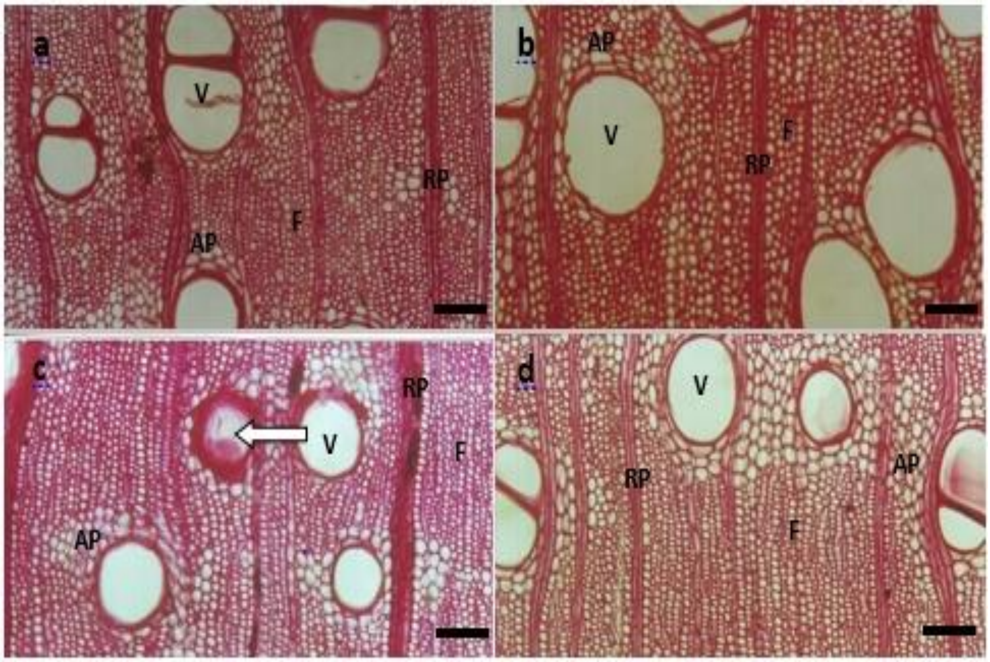


**Figure 1.** TS of *T.ivorensis* stem base heartwood (a) and sapwood (b) and branch base heartwood (c) and sapwood (d). V: vessel; F: fibre; AP: axial parenchyma; RP: ray parenchyma. Scale bar: 20 µm.

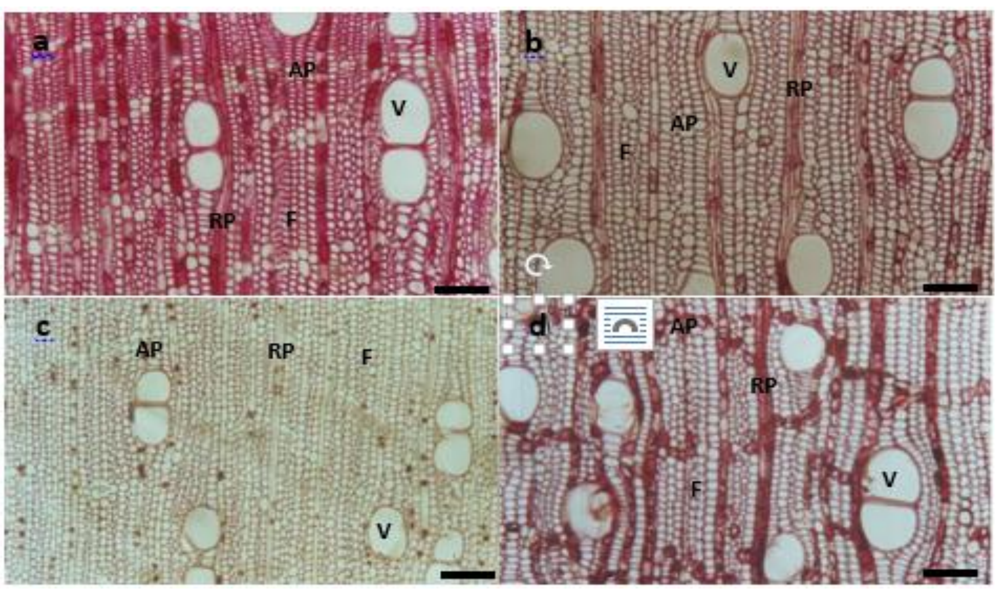


**Figure 2.** TS of *A. robusta* stem base heartwood (a) and sapwood (b) and branch base heartwood (c) and sapwood (d). V: vessel; F: fibre; AP: axial parenchyma; RP: ray parenchyma. Scale bar: 20 µm.

*robusta* were significant ($P < 0.05$) (Table 1). However, FD differences between *T. ivorensis* sapwood and heartwood at the branch top were not significant ($p<0.05$) likewise those between the sapwood and heartwood of *A. robusta* stem at the base as well as between those at the middle of the branch(Table 3).

**c) Fibre double wall thickness**

Fibre double wall thicknesses (FDWT) for *T. ivorensis* sapwood decreased up the stem, but no precise trend occurred along its branch. Those of its heartwood also decreased along the stem and along the branch (Figure

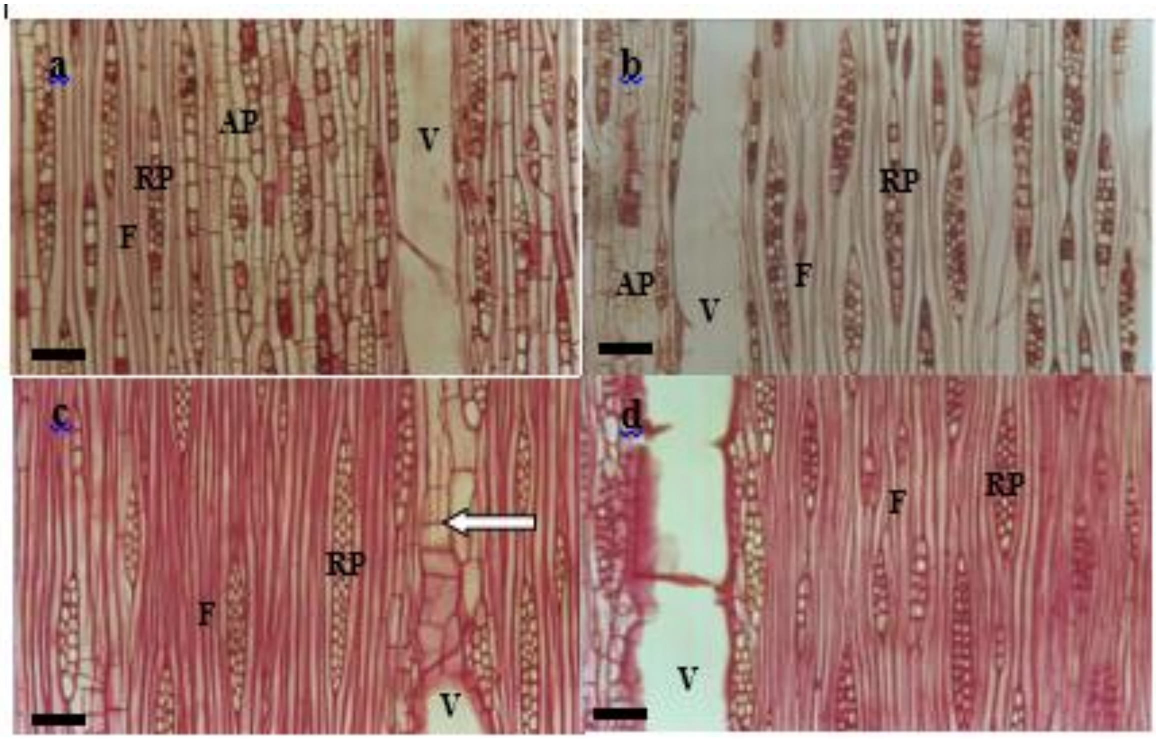


**Figure 3.** TLS of heartwood from stem base of *A. robusta* (a) and *T. ivorensis* (c) and branch base of *A. robusta* (b) and *T. ivorensis* (d). Tylosis in vessel of *T. ivorensis* (arrowed). Scale bar = 20µm.

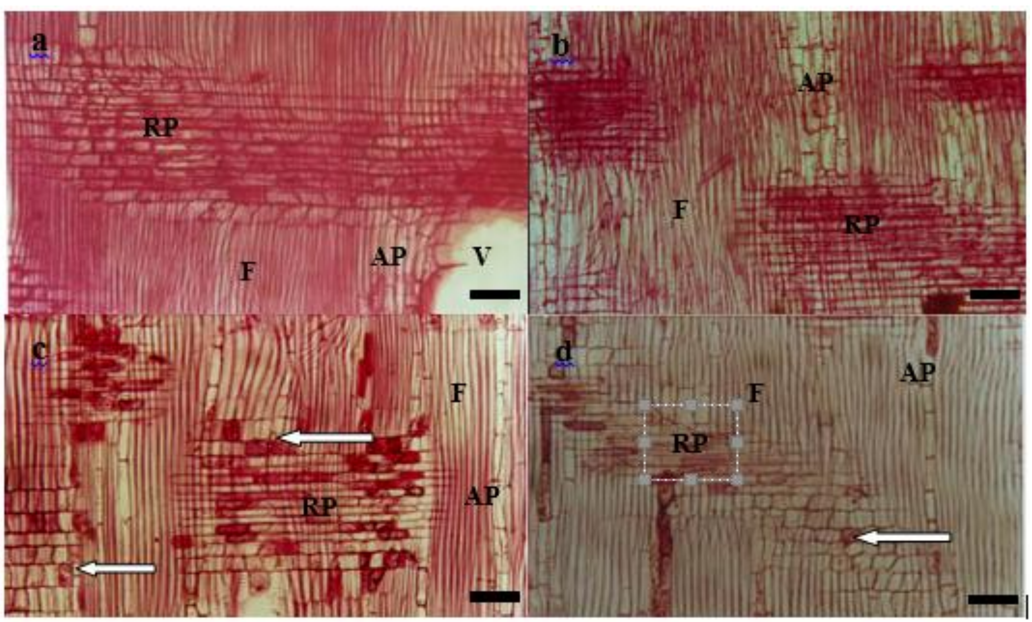


**Figure 4.** RLS of heartwoods from base of *T. ivorensis* (a) and *A. robusta* stems(c) and base of *T. ivorensis* (b) and *A. robusta* (d) branches. Silica bodies in rays of *A. robusta* (arrowed) Scale bar = 20µm

6). FDWTs for Heartwoods were also greater than for sapwoods in *T. ivorensis*. FDWTs from sapwood from middle of branch (5.69 µm) and heartwood from base of stem (6.46 µm)were the least and greatest respectively in *T. ivorensis* (Table 3; Figure 6).Similarly, *A. robusta* sapwood and heartwood FDWT decreased up the stem and also along the branch. Its stem and branch heartwood FDWT was greater than their sapwoods'. Sapwood FDWTs from top of branch (4.86 µm) and heartwood from base of stem (7.6 µm) were the least and greatest respectively. Along the stem, FDWT was greater in *A. robusta* than in*T. ivorensis,* which was the contrary along the branch (Figure 6). FDWT differences between the sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robsuta* were significant ($P < 0.05$).However there were no significant differences in FDWT ($P < 0.05$)at various parts of the stems and branches for the two timbers (Table 3).

**d) Fibre lumen diameter**

Sapwood and heartwood fibre lumen diameters (FLDs) increased with height along the stems of the 2 timbers, but decreased along their branches (Figure 6). Their sapwood fibre lumina were also wider than the heartwoods. The smallest and widest fibre lumina were from the branch heartwoods at the top and sapwoods at the base of the stem respectively. Their values were 13.09 and 17.27 µm respectively for *T. ivorensis* and 15.08 and 18.64 µm respectively for *A. robusta*. Fibre lumina were also wider in *A. robusta* than *T. ivorensis*. Differences in FLD between sapwoods and heartwoods along the stems and branches of *A. robusta* and *T. ivorensis* were significant ($p<0.05$) (Table 4) but not between *T. ivorensis* sapwood at middle of stem and *A. robusta* heartwood at base of branch and at several other areas for the two timbers.

**e) Vessel lumen diameter**

Sapwood and heartwood vessel lumen diameters(VLDs) also increased with height of the stems. However, they decreased along the branches of the two timbers. Their sapwoods had wider vessel lumina than their heartwoods (Figure 7). Branch heartwoods at the top had the narrowest lumina, while crown sapwoods of the stem had the widest in *T. ivorensis* (98.45 and 189.30 µm respectively) and*A. robusta* (79.95 and 125.45 µm respectively). Vessel lumina were also wider in *T. ivorensis* than in *A. robusta* (Figure 7).VLD differences between the sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta* were significant ($P < 0.05$) (Table 1). DMRT, however, showed that the differences were not significant ($p<0.05$) for the heartwood and sapwoods for various stem positions.

**(3) The Proportion of Tissues in *T. ivorensis* and *A. robusta***

**a) Amount of fibres**

The proportion of *T. ivorensis* sapwood fibres decreased with height along the stem (48.4-47.0%) but there were no precise trend along the branch (Figure 8). Its heartwood fibre proportion also decreased along the stem (51.5-49.8%), and along the branch (51.2-49.0%) (Figure 8). The amount of heartwood fibre was greater than that in the sapwoods of *T. ivorensis*. The sapwoods in the middle and top of the branch had the least fibre content(46%), whereas heartwood at the base of the stem had the greatest (51.5%) for *T. ivorensis.* For *A. robusta*, its fibre content of the sapwood and heartwood decreased along the stem(43.5-40.0%) and also along the branch(45.7-41.5%)(Figure 8). Fibres were also greater in the heartwoods than their corresponding sapwoods. Sapwood within the crown of the branch was the least(40%), while the heartwood at the stem base had the greatest(45.7%). *T. ivorensis* recorded more fibres than *A. robusta.* The differences between the amount of fibres in the sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta* were significant ($p<0.05$).

**b) Amount of vessels**

Vessels for the sapwood and heartwood for the 2 timbers were greater at the bases than at the crowns of the stems and branches (Figure 8). However, their sapwood vessels were more than those in their heartwoods. The least amount of vessels was recorded in the heartwoods at the bases of branch (14%) and stem (13%) for *T. ivorensis* and *A. robust* respectively. The greatest amount of vessels was found in the sapwoods of the stem crown, especially in *A. robusta* (Figure 4).Differences in the amount of vessel between sapwoods and heartwoods along the stems and branches of both timbers were significant ($p<0.05$) (Tables 2 and 4).

**c) Amount of parenchyma**

The proportion of parenchyma for *T. ivorensis* sapwood and heartwood decreased with height along the stems but without any specific trend along the branch (Table 4; Figure 8). Generally, sapwoods from the stem and branch had more parenchyma than their heartwoods. Similarly, the quantity of parenchyma for *A. robusta* sapwood decreased with height along the stem (41.5 - 35.5%) with no consistent trend along its branch(Figure 8).Its heartwood parenchyma also decreased in amount with height along the stem (41.3 - 37.4%) but increased along the branch (40.8 - 41.3%). Sapwoods had more parenchyma than their corresponding heartwoods in *A. robusta* except at the crown of the stem. The heartwood at the crown of stem had the least parenchyma(37.4%), while sapwood at its branch crown had the most (41.6%). *A. robusta* had more parenchyma than *T. ivorensis* (Figure 8). There were differences in the amount of parenchyma cells in the sapwoods and heart-woods along the stems and branches of the two timbers

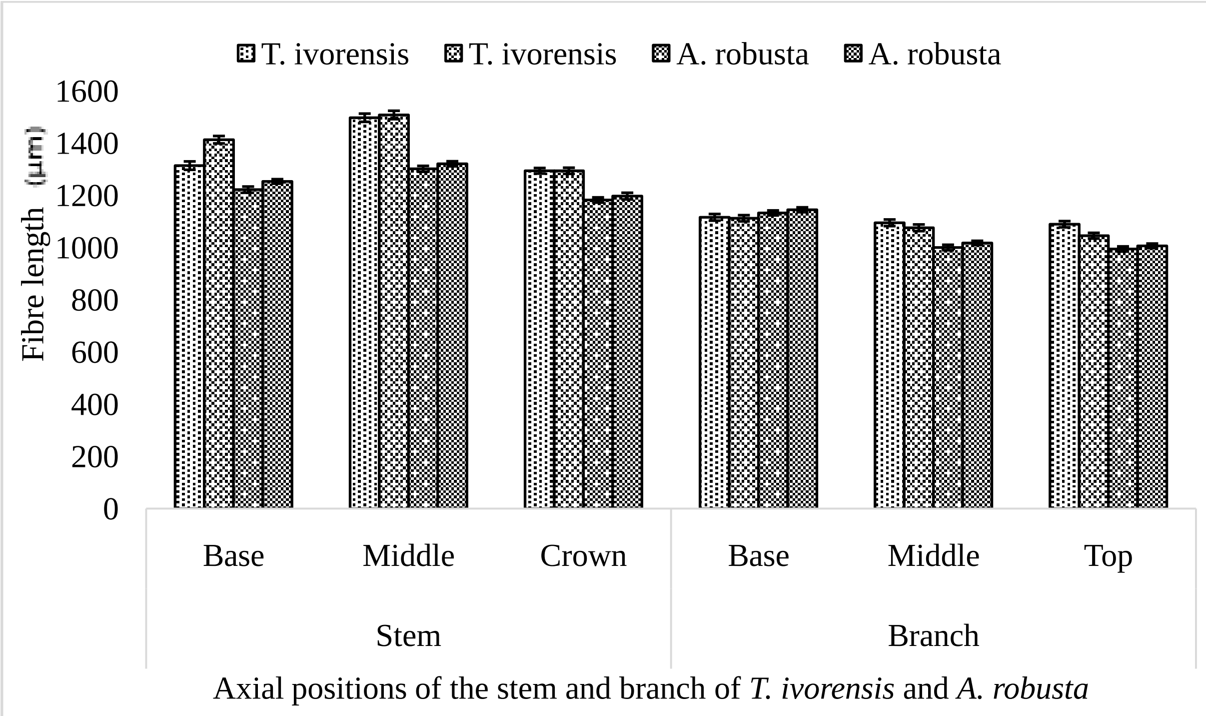


**Figure 5.** Fibre lengths of sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta.*

(Tables 2 and 4).

## DISCUSSION

### (1) Wood Anatomy of *T. ivorensis* and *A. robusta*

The anatomical features of the two timbers show that they are all porous hardwoods. In agreement with Oteng-Amoako (2002) and Lemmens (2007), silica bodies were observed in the rays of *A. robusta,* while tyloses occluded some vessels in *T. ivorensis.* Tyloses and silica greatly influence timber utilization. Silica in *A. robusta* would have a high blunting effect on saws and cutting tools (Lemmens, 2007). Chudnoff (1984) observed that while *A. robusta* was very permeable, *T. ivorensis* was highly resistant to preservative treatments due to the presence of tyloses in its vessels. The present study indicates that tyloses in *T. ivorensis* would reduce the timber's permeability and consequently resist penetration of adhesives, preservatives and pulping liquor (McIntosh, 1970; Hillis, 1972; Bierman, 1996). Their presence would also affect water movement in trees and physically impede the movement of wood-destroying organisms (Taylor *et al.*, 2002; Ali, 2011;Moore, 2011). Thus, *T. ivorensis* would be naturally resistant to bio-degraders due to the presence of tyloses.

### (2) Variations in tissue dimensions for stem and branch woods of *A. robusta* and *T. ivorensis*

#### a) Fibre length

As for the present observation for *T. ivorensis* branch, longer sapwood than heartwood fibres were earlier recorded for the stems of *Tectona grandis*, *Rhizophora racemosa* and *R. harrisonii* (Izokor and Fuwape, 2011; Emerhi, 2012). According to Ghouse and Siddiqui (1976), Jorge et al. (2000) and Amoah et al. (2012), the lengths of cambial initials usually increase with increasing cambial age from pith to periphery, resulting in longer sapwood than heartwood fibres. However, deviations could occur; longer fibres in heartwood than those in the sapwood of the base of*T. ivorensis* stem and middle as well as along *A. robusta* stem and branch could have resulted from faster growth rate (which results in shorter fibres) during wood formation at the sapwood region and the extent of the intrusive growth of the tip of fibres during their differentiation, which also results in disparities in fibre length within trees(Bailey, 1920; Wilson and White, 1986). There was an increase in fibre length from the base to the middle and decrease at the crown, as was observed by Jorge

**Table 1.** ANOVA for fibre dimensions and vessel lumen diameter for sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta.*

| Tissue dimensions | Sources of variation | Degrees of freedom | Sum of Squares | Mean Squares | F-value | P-value |
|---|---|---|---|---|---|---|
| Fibre length | Model | 23 | 104955741.687 | 4563293.117 | 164.265 | 0.000* |
| | Error | 4776 | 132677874.233 | 27780.124 | | |
| | Corrected total | 4799 | 237633615.920 | | | |
| Fibre diameter | Model | 23 | 11197.503 | 486.848 | 22.895 | 0.000* |
| | Error | 4776 | 101559.692 | 21.265 | | |
| | Corrected total | 4799 | 112757.195 | | | |
| Fibre double wall thickness | Model | 23 | 1810.569 | 78.720 | 33.041 | 0.000* |
| | Error | 4776 | 11378.849 | 2.383 | | |
| | Corrected total | 4799 | 13189.418 | | | |
| Fibre lumen diameter | Model | 23 | 8649.550 | 376.067 | 19.904 | 0.000* |
| | Error | 4776 | 90238.268 | 18.894 | | |
| | Corrected total | 4799 | 98887.818 | | | |
| Vessel lumen diameter | Model | 23 | 3526752.652 | 153337.072 | 93.747 | 0.000* |
| | Error | 4776 | 7811871.679 | 1635.652 | | |
| | Corrected total | 4799 | 11338624.331 | | | |

*Significant at P (0.000) < 0.05.

**Table 2.** ANOVA for tissue proportions for sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta.*

| Tissue proportions | Sources of variation | Degrees of freedom | Sum of Squares | Mean Squares | F-value | P-value |
|---|---|---|---|---|---|---|
| Fibre percentage | Model | 23 | 6846.990 | 297.695 | 4.415 | 0.000* |
| | Error | 576 | 38835.440 | 67.423 | | |
| | Corrected total | 599 | 45682.430 | | | |
| Vessel percentage | Model | 23 | 2624.958 | 114.129 | 2.028 | 0.003* |
| | Error | 576 | 32420.000 | 56.285 | | |
| | Corrected total | 599 | 35044.958 | | | |
| Parenchyma percentage | Model | 23 | 6549.958 | 284.781 | 3.173 | 0.000* |
| | Error | 576 | 51690.480 | 89.740 | | |
| | Corrected total | 599 | 58240.438 | | | |

*Significant difference at P (0.000) < 0.05.

(1994) and Tavares et al.(2010) for *Eucalyptus globulus*, Chauhan et al*.* (2001) for *Populus deltoides* Bartram. ex Marsh, and (Emerhi (2012) for*R. racemosa*. Similarly, Ververis (2004) noted a decrease in fibre

**Table 3.** Fibre dimensions for sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta*.

| Species/ Tree part | Axial and radial position | Fibre length* | Fibre diameter* | Fibre double wall thickness* | Fibre lumen diameter* |
|---|---|---|---|---|---|
| ***T. ivorensis* stem** | base sapwood | 1314.50$^{c}$ | 21.69$^{efg}$ | 6.22$^{def}$ | 15.47$^{defg}$ |
| | base heartwood | 1413.70$^{b}$ | 19.79$^{jk}$ | 6.46$^{bcd}$ | 13.33$^{ij}$ |
| | middle sapwood | 1497.86$^{a}$ | 21.82$^{ef}$ | 6.17$^{def}$ | 16.00$^{cdef}$ |
| | middle heartwood | 1508.60$^{a}$ | 22.40$^{cde}$ | 6.40$^{bcde}$ | 15.65$^{cdefg}$ |
| | crown sapwood | 1294.69$^{c}$ | 22.09$^{def}$ | 6.03$^{f}$ | 17.27$^{b}$ |
| | crown heartwood | 1294.69$^{c}$ | 23.39$^{bc}$ | 6.12$^{def}$ | 16.06$^{cde}$ |
| ***T. ivorensis* branch** | base sapwood | 1116.46$^{gh}$ | 21.24$^{fgh}$ | 6.08$^{ef}$ | 15.16$^{efg}$ |
| | base heartwood | 1112.75$^{gh}$ | 21.16$^{fghi}$ | 6.29$^{cdef}$ | 14.87$^{gh}$ |
| | middle sapwood | 1095.43$^{ghi}$ | 20.70$^{ghij}$ | 5.69$^{g}$ | 15.01$^{fg}$ |
| | middle heartwood | 1076.34$^{ij}$ | 20.26$^{hij}$ | 6.19$^{def}$ | 14.07$^{hi}$ |
| | top sapwood | 1089.89$^{hi}$ | 19.19$^{k}$ | 6.08$^{ef}$ | 13.11$^{j}$ |
| | top heartwood | 1046.00$^{jk}$ | 19.18$^{k}$ | 6.09$^{ef}$ | 13.09$^{j}$ |
| ***A. robusta* stem** | base sapwood | 1222.46$^{de}$ | 22.96$^{bcd}$ | 6.60$^{bc}$ | 16.36$^{bcd}$ |
| | base heartwood | 1253.89$^{d}$ | 22.89$^{bcd}$ | 7.6$^{a}$ | 15.29$^{efg}$ |
| | middle sapwood | 1302.29$^{c}$ | 23.90$^{ab}$ | 6.65$^{b}$ | 17.25$^{b}$ |
| | middle heartwood | 1321.49$^{c}$ | 23.21$^{bc}$ | 6.67$^{b}$ | 16.54$^{bcd}$ |
| | crown sapwood | 1182.86$^{f}$ | 24.79$^{a}$ | 6.15$^{def}$ | 18.64$^{a}$ |
| | crown heartwood | 1197.83$^{ef}$ | 23.60$^{b}$ | 6.34$^{bcdef}$ | 17.26$^{b}$ |
| ***A. robusta* branch** | base sapwood | 1133.20$^{g}$ | 22.42$^{cde}$ | 5.43$^{g}$ | 16.99$^{b}$ |
| | base heartwood | 1145.26$^{g}$ | 21.49$^{efg}$ | 5.56$^{g}$ | 15.93$^{cdef}$ |
| | middle sapwood | 1000.68$^{l}$ | 20.39$^{hij}$ | 5.08$^{h}$ | 15.31$^{efg}$ |
| | middle heartwood | 1018.06$^{kl}$ | 20.24$^{hij}$ | 5.12$^{h}$ | 15.12$^{efg}$ |
| | top sapwood | 995.09$^{l}$ | 20.16$^{ijk}$ | 4.86$^{h}$ | 15.30$^{efg}$ |
| | top heartwood | 1006.86$^{l}$ | 20.07$^{jk}$ | 4.99$^{h}$ | 15.08$^{efg}$ |

*NB: Means with different alphabets within a column are significantly different ($P < 0.05$).

length with height for olive and almond branches, as found currently. Panshin and de Zeeuw (1964) confirmed that the length of cells may increase with height in the stem to a maximum height and above this, it could decrease with increasing height. Consequently, longer stemwood fibres than those in branchwood supported the findings by Samariha et al. (2011) and Longui et al. (2012) for *Ailanthus altissima* and *Eriotheca gracilipes* respectively. It further substantiated Tsoumis' (1968)report that branchwood cells are shorter in length than stemwood. Moreover, the relatively longer fibres of *T. ivorensis* than *A. robusta* supports that of Richter and Dallwitz (2009) who earlier recorded shorter fibres in *A. robusta* than in *T. ivorensis.* The length of fibres is significant in wood utilization. Longer fibres overlap each other better and appropriately transfer stress from one cell to the next and consequently increase the load-bearing capacity of wood than shorter fibres (Desch and Dinwoodie, 1996).Longer fibres are also preferred in paper making tothe shorter types (Dickmann, 1975), as they would produce paper with greater tear resistance (Ademiluyi and Okeke, 1979). However, shorter fibres would result in lower Modulus of Elasticity (MOE) for wood due to the flattening of microfibrillar helices in their cell walls (Wilson and White, 1986). Consequently, longer fibres are most likely to give greater MOE and load-bearing capacity to the stemwoods, which is also expected to produce paper with greater tear resistance than branchwoods. These wood and paper properties would be particularly estimated to be the best for the heartwoods from middle of stem, which had the longest

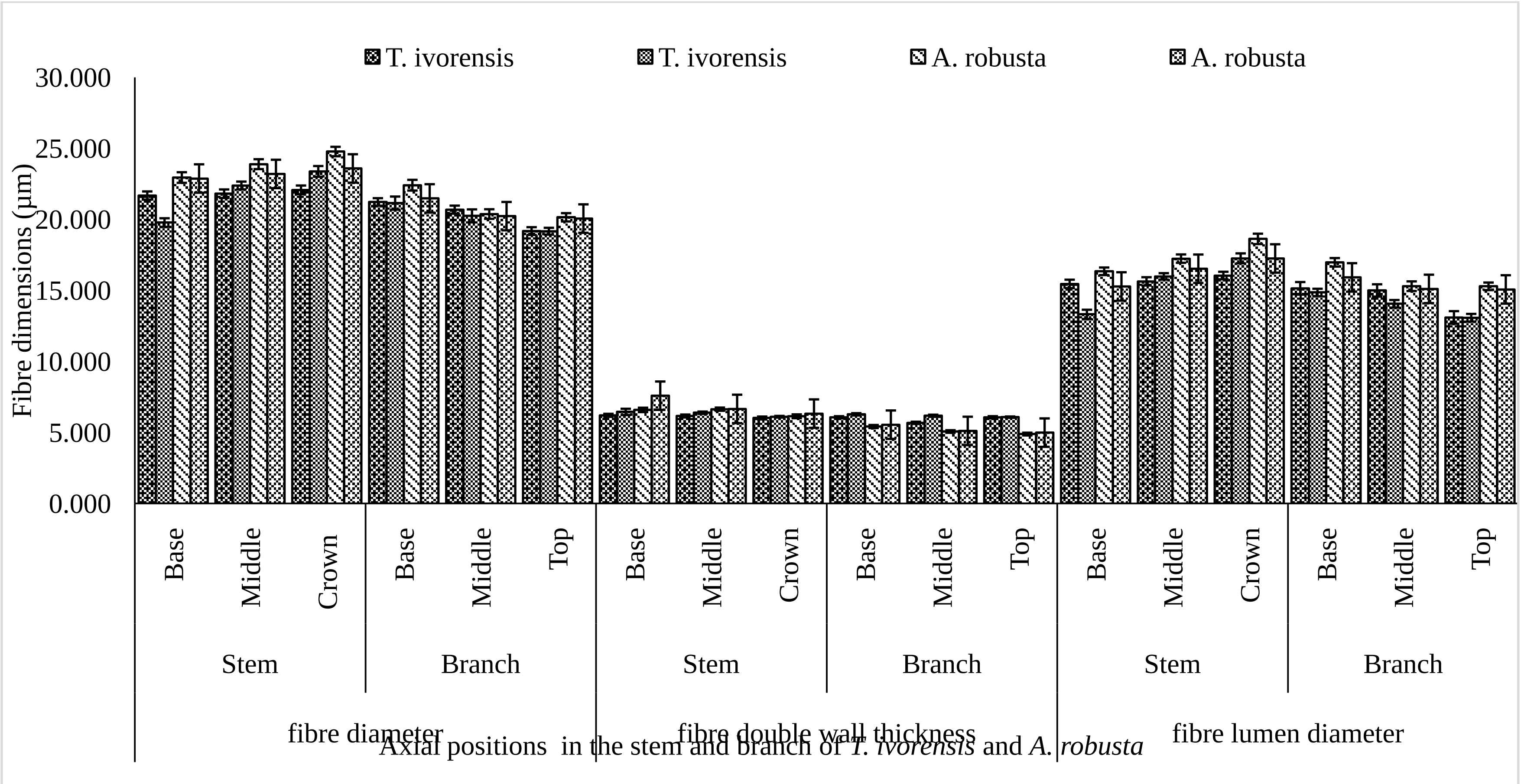


**Figure 6.** The diameter, double wall thickness and lumen diameter of fibres for the sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta.*

fibres in both timbers (1508.6 and 1321.5 µm respectively for *T. ivorensis* and *A. robusta*). The least MOE, load-bearing capacity and paper-tear resistance are predicted for*T. ivorensis* branch heartwood at the crown and *A. robusta* branch sapwood at the crown, which had the shortest fibres (i.e., 1046 and 995 µm respectively).However, both the stem and branch woods of *T. ivorensis* and *A. robusta* were medium length fibres (900-1600 µm) as was earlier established for their stemwoods by Insidewood (2004) and Lemmens (2007).Accordingly, the shorter fibres found in their branchwoods were still a characteristic of their species. This implies they are suitable for several wood products (e.g. cabinets, furniture and joinery) so as to increase wood availability for the Timber

**Table 4.** Vessel lumen diameter and tissue proportions of sapwoods and heartwoods along the stem and branch of *T. ivorensis* and *A. robusta* with Duncan's Multiple Range Test Groupings.

| Species and Tree part | Position | Vessel lumen diameter | Tissue proportion (%) | | |
|---|---|---|---|---|---|
| | | | Fibre | Vessel | Parenchyma |
| *T. ivorensis* stem | base sapwood | $150.82^{c}$ | $48.4^{abcd}$ | $16^{bcde}$ | $35.6^{abc}$ |
| | base heartwood | $122.87^{efg}$ | $51.5^{a}$ | $15^{de}$ | $33.5^{c}$ |
| | middle sapwood | $172.14^{b}$ | $47.2^{abcdef}$ | $20.5^{abc}$ | $32.3^{c}$ |
| | middle heartwood | $130.03^{de}$ | $50.0^{abc}$ | $16.7^{bcde}$ | $33.3^{c}$ |
| | crown sapwood | $189.30^{a}$ | $47.0^{abcdefg}$ | $20.9^{ab}$ | $32.1^{c}$ |
| | crown heartwood | $133.59^{d}$ | $49.8^{abc}$ | $17^{bcde}$ | $33.2^{c}$ |
| *T. ivorensis* branch | base sapwood | $120.14^{fgh}$ | $48.0^{abcde}$ | $15^{de}$ | $37^{abc}$ |
| | base heartwood | $115.82^{gh}$ | $51.2^{ab}$ | $14^{de}$ | $34.8^{bc}$ |
| | middle sapwood | $117.42^{fgh}$ | $46.0^{bcdefg}$ | $16.7^{bcde}$ | $36.8^{abc}$ |
| | middle heartwood | $112.14^{h}$ | $49.5^{abc}$ | $15^{de}$ | $35.5^{abc}$ |
| | top sapwood | $100.12^{i}$ | $46.0^{bcdefg}$ | $17^{bcde}$ | $37^{abc}$ |
| | top heartwood | $98.45^{ij}$ | $49.0^{abc}$ | $15.7^{cde}$ | $35.3^{abc}$ |
| *A. robusta* stem | base sapwood | $99.44^{i}$ | $43.5^{defghi}$ | $15^{de}$ | $41.5^{a}$ |
| | base heartwood | $87.96^{klm}$ | $45.7^{cdefgh}$ | $13^{e}$ | $41.3^{a}$ |
| | middle sapwood | $117.25^{fgh}$ | $42.9^{efghi}$ | $17^{bcde}$ | $40.1^{ab}$ |
| | middle heartwood | $100.05^{i}$ | $45.5^{cdefgh}$ | $14.5^{de}$ | $40^{ab}$ |
| | crown sapwood | $125.45^{def}$ | $42.5^{fghi}$ | $22^{a}$ | $35.5^{abc}$ |
| | crown heartwood | $122.03^{efg}$ | $44.9^{cdefghi}$ | $17.7^{abcde}$ | $37.4^{abc}$ |
| *A. robusta* branch | base sapwood | $95.46^{ijk}$ | $41.7^{fghi}$ | $17^{bcde}$ | $41.3^{a}$ |
| | base heartwood | $90.60^{jkl}$ | $43.2^{defghi}$ | $16^{bcde}$ | $40.8^{ab}$ |
| | middle sapwood | $87.99^{klm}$ | $40.9^{hi}$ | $17.7^{abcde}$ | $41.4^{a}$ |
| | middle heartwood | $82.6^{lm}$ | $42.0^{fghi}$ | $16.8^{bcde}$ | $41.2^{a}$ |
| | top sapwood | $82.16^{lm}$ | $40.0^{i}$ | $18.4^{abcd}$ | $41.6^{a}$ |
| | top heartwood | $79.95^{m}$ | $41.5^{ghi}$ | $17.2^{bcde}$ | $41.3^{a}$ |

*NB: Means with different alphabets within a column are significantly different (P < 0.05).

industry. Furthermore, branch and stemwood fibres could be blended to acquire a combination of characteristics (such as strength and bulk) in a single paper (Nandkumar, 20009; Fagbemi et al., 2014). This would make the mixture particularly suitable for applications such as newsprints and packaging (European Paper and Packaging Industries, 2016).

**b) Fibre diameter and lumen diameter**

Roszaini (2000), Kibblewhite et al. (2004) and Emerhi (2012) recorded increasing fibre diameters and fibre lumen diameters with height along the stems of*E. nitens*and *R. harrisonii*. Similarly, fibre diameter and fibre lumen diameter increased upthe stems of *T. ivorensis* and *A. robusta*. Moreover, the decrease infibre diameters and lumen diameters along their branches also confirms the findings by Ververis (2004) forolive and almond branches. Wider fibre diameter and lumen diameter forthe sapwood than those of the heartwood correspond to the findings by Emerhi (2012) for*R. harrisonii* and *R. racemosa* and Izekor and Fuwape (2011) for*T. grandis*. According to Adamopoulos and Voulgaridis (2002), Marsoem et al. (2002) and Tavares et al. (2010),greater fibre dimensions in sapwood than in heartwood is possible

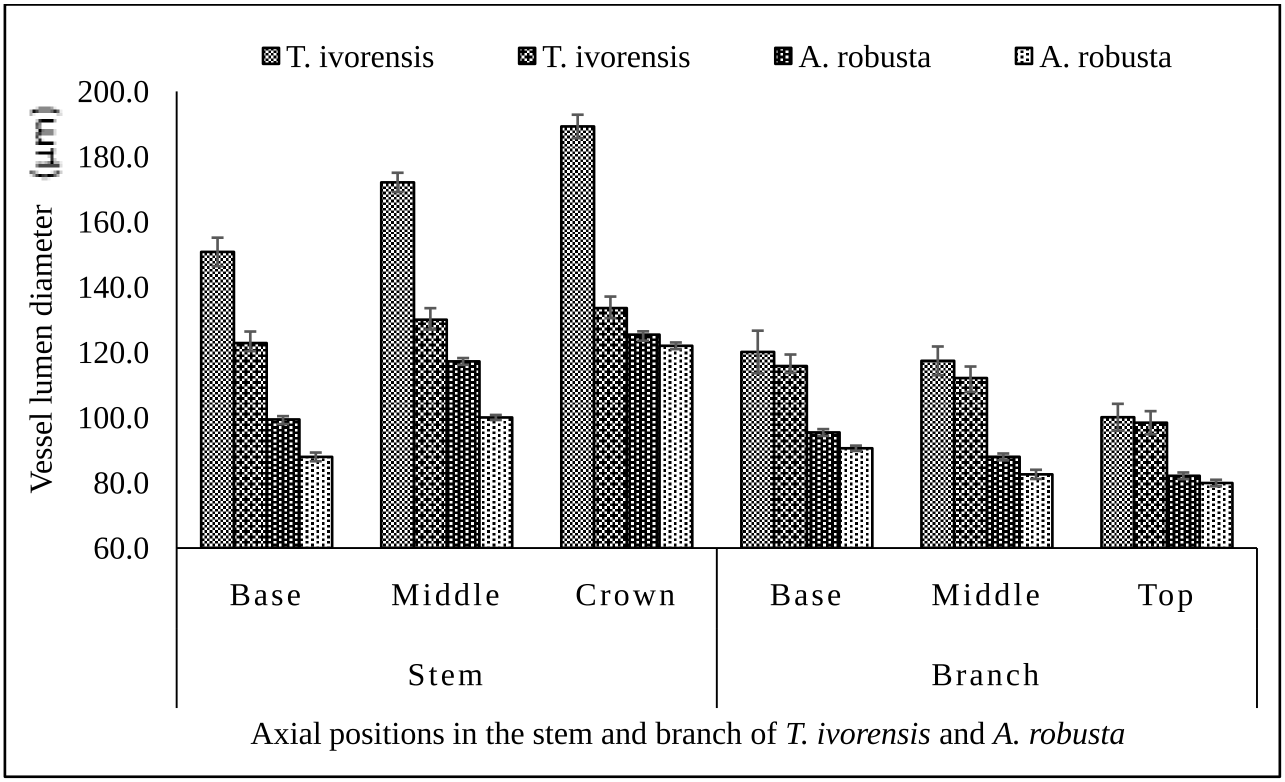


**Figure 7.** Vessel lumen diameter for sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta.*

because they generally increase from the pith to the bark of trees. However, variations in auxin content and apical activity during wood formation also influences cell diameters. Larson (1960) indicated that high auxin content in the apical meristem would result in the production of large diameter cells, while anything that reduces apical activity would result in small diameter cells. Moreover, several factors including changes in cambium as it ages, genetic controls that govern the form and growth of the tree and environmental influences (e.g. seasonal and geographical conditions or nutrient supply)cause variations in fibre dimensions and could account for the irregularities in fibre diameters between sapwood and heartwood at the middle and crown of *T. ivorensis* stems. According to Panshin and de Zeeuw (1980), the interaction of these factors makes it difficult to ascribe variability of fibre dimensions in wood or any inconsistencies to any or even to a combination of the factors. Fibre diameters for *T. ivorensis* (19.18-23.39 µm) and *A. robusta* (20.07-24.79 µm) are consistent with that for *T. ivorensis* (20.52 µm), which was recorded by (Awuku, 1979). Fibre lumen diameters were 13.09-17.27 and 15.08-18.64 µm respectively for *T. ivorensis* and *A. robusta*. Fibres with diameters 16-25 µm are medium-textured (Bolza and Keating, 1972; Panshin and de Zeeuw, 1980). This includes those of the stem and branch woods of the two timbers. However, fibre diameters and fibre lumina recorded for the branches were mostly smaller than the stems.

In support, Panshin and de Zeeuw (1964), Tsoumis (1968), Manwiller (1974), Taylor (1977), Phelps et al*.* (1982), Wilson and White (1986) andSamariha et al*.* (2011) reported that branchwood cells have narrower diameter and lumina than their corresponding stemwoods, which could result in closed-textured branchwood or difficulty during machining; such was experienced during sawing of the timbers. Widerlumen diameters from most of the stemwood portions than in the branch might result in less cell wall materials and, most likely, less density than the narrower ones in the branch. Martinez-Cabrera et al. (2009) and Rana et al. (2009) earlier reported that increased fibre lumen fraction has a negative relationship with wood density. Okai et al (2004) also recorded greater branchwood densities than stemwood for *T. ivorensis* and *A. robusta.* Larger fibre lumen widths are, however, more favourable for pulp and paper; and they are better for the beating of pulp because of the penetration of liquids into the empty spaces (Emerhi, 2012). Hence, in terms of their fibre lumina, stemwood (particularly sapwood at the crown of *A. robusta* and heartwood of *T. ivroensis* crown with the widest fibre lumina) would be better for pulp beating than wood from the crown of

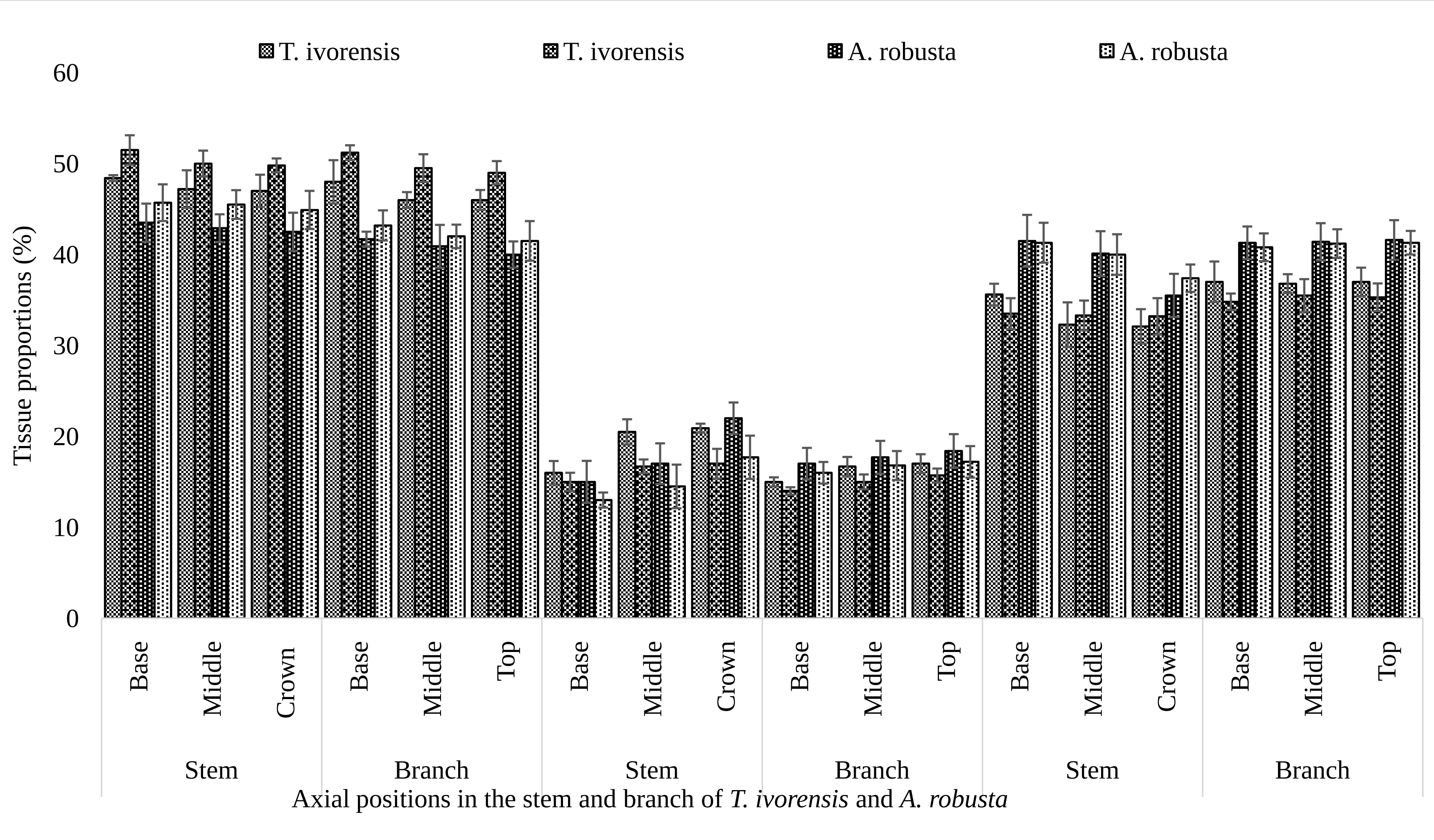


**Figure 8.** Tissue percentages of the sapwoods and heartwoods along the stems and branches of *T. ivorensis* and *A. robusta.*

branch.

#### c) Double wall thickness of fibres

The general pattern for fibre wall thickness is a decrease from the base to the top of trees (Panshin and de Zeeuw, 1964; Taylor and Wooten, 1973) as in*T. grandis* stem (Izekor and Fuwape, 2011), *Plantanus occidentalis*, *Eucalyptus citriodora* and *Acer velutinum boiss* (Voorhies and Jameson, 1969; Shashikala and Rao, 2009; Kiaei, 2011). The decreasing axial trend for the stems of the two timbers and along the branch of *A. robusta* corresponds to previous findings. For instance, Samariha et al. (2011) and Longui et al. (2012) recorded thicker fibre cell walls in the stems than branches *Ailanthus altissima* and *Eriotheca gracilipes* respectively. The greater fibre double wall thickness for heartwood than sapwood under the present investigation is divergent from the findings by Monteiro (2003) for *E. globulus*. Sudin and Wahab (2013),however, observed that younger and more actively expanding cambial wood at the sapwood region might have thinner cell walls than the older heartwood region. Moreover, cell wall growth is dependent on the accumulation of metabolic products (cellulose, hemicellulose, lignin, waxes), which increase with maturity (Fahn, 1990; Gbadamosi, 2001; Ververis, 2004). Thus, the thicker walls of the heartwood fibres than sapwoods for both timbers could result from variations in their maturity and accumulation of metabolic products. Besides, Larson (1960) expressed that wall thickness generally increases when cell diameter decreases, and that they are both related to nutrition. In consequence, sapwood, which mostly had wider cell diameters, also had thinner fibre double walls. Variations observed for fibre double wall thicknesses between the stems and branches of the two timbers would also influence their density, paper properties and natural durability. Thicker fibre walls correlate with greater wood density and they also give bulky sheets of low tensile but greater tearing strength (Dadswell and Watson, 1962; Wardrop, 1969). Wood with thicker fibre walls also withstand grazing or nibbling by bio-degraders (Schwarze, 2004;Antwi-Boasiako and Ayimasu, 2012).Even though fibre double walls were mostly greater for stemwood portions, their densities might not be greater than the branchwoods. This is because density variations depend mostly on cell wall materials, differences in ratio of cell wall to cell cavity and cell diameter (Desch and Dinwoodie, 1996;Jacobsen et al*.,* 2007; Martínez-Cabrera et al*.,* 2009).Greater cell wall materials would give greater wood density, thus, the branchwood with relatively lower fibre double wall thickness but having smaller fibres and narrower fibre lumen diameters, and as such closer textured wood than stemwood, would have more cell wall materials and greater density (Haygreen and Bowyer, 1996; Okai et al., 2004; Roque and Filho, 2007).

#### d) Vessel lumen diameter

According to Insidewood (2004), Lemmens (2007) and Richter Dallwitz (2009), vessel lumen diameters are 50-100 µm and 100-200 µm respectively for *A. robusta* and *T. ivorensis*. Broader vessel lumina were recorded for *T. ivorensis* (98.45-189.30 µm)than *A. robusta* (79.95-125.45µm). Moreover, wider vessels for sapwood than heartwood along the stems and branches of *T. ivorensis* and *A. robusta*supports previous findings:Furukawa and Hashizume (1987), Ohbayashi and Shiokura (1990), Peszlen (1994) and Bhat et al.(2001) acknowledged thatvessel lumina increased in size from inner (heartwood) to outer wood (sapwood) of trees. Zimmermann (1983), Aloni (1987), Tyree and Ewers (1991) and Carlquist (2001) reported that the lumen diameter of vessels decreased with height in timber branches and stems. Similarly, decreases in vessel lumen diameter occurred along the branches of *T. ivorensis* and *A. robusta*. Furthermore, vessel lumen diameter decreased from the base to the tip of the branches of *Anacardium excelsum, Cordia alliodora, Ficus insipida* and *Schefflera morototoni*(James et al*.*,2003).Conversely, increasing vessel lumina along the stems of *T. ivorensis* and *A. robusta* occurred against the decreasing trend reported earlierby Zimmermann(1983), Aloni(1987), Tyree and Ewers (1991) and Carlquist(2001). Modifications could be made by plants to vessel lumina, vessel composition and their distribution sin order to adjust the rates of water supply (Tyree and Zimmermann, 2002; Zanne et al*.,* 2010). Moreover, distinct mechanical-support requirements (Preston et al., 2006; Sperry et al., 2008)and different types of stem construction (McCulloh et al., 2004; McCulloh and Sperry, 2005)could result in different trends of vessel composition and distribution in timbers. Wider stemwood vessel lumina than those of branchwood recorded for the two timbers was similarly reported for *Fagus sylvatica*and *Quercus ilex* (Gasson, 1987) and in maple wood (Gurau et al., 2008).Luizon and Gasson (2012) attributed the differences to cambium ages of stem and branch woods, with older cambium age (of the stem) corresponding to wider vessel lumina.

Vessel lumen diameter is critical in moisture absorption, wood degradation and density variations (Zabel and Morrell, 1992; Kollmann and Côté, 1984; Uetimane, 2010). As the vessel lumen does not contribute to the mass and thus to the wood density (a property which is considered an indicator of strength properties), wood regions with more and larger diameters have lower resistance (Baas et al., 2004). Moreover, as Antwi-Boasiako and Ayimasu (2012) explained for fibre lumina, wide-lumen vessels would also easily absorb more moisture into their voids thereby creating conducive environment for bio-degraders, especially decay-fungi. Large vessel diameters are also unfavourable for paper-making.; they lead to problems in refining and printing processes and pose difficulties in the finishing of solid wood products (Kasia et al*.,* 2013). Subsequently, stemwoods from the crown of the stem(especially sapwoods) of the two timbers with the widest vessel lumina (189.3 and 125.5 µm respectively for *T. ivorensis* and *A. robusta*)would easily absorb moisture, be more disposed to decay and less desirable for paper making and solid products than their branchwoods (particularly heartwoods at thebranch top). *Lyctus* beetles, require wide vessel lumina (> 90 µm) that could accommodate their ovipositor to invade wood (Kollmann and Côtè, 1984). Accordingly, both the stem and branch woods of *T. ivorensis* would be generally disposed to their invasion as well asalong the stem and the branch base of *A. robusta,* which all possess vessel lumina greater than 90 µm.

**(3) Tissue proportions within the stem and branch woods of *A. robusta* and *T. ivorensis***

**a) The amount of Fibre**

Isebrands (1972) reported that fibre content generally decreases from the pith outward and from the base up thetree height. Thus, fibres would probably be greater at the base than at the crown and in heartwood than sapwood of a tree. Correspondingly, greater fibre content was recorded at the butt than the crown of *Eriotheca gracilipes* (Longui et al., 2012) as well as*T. ivorensis*, *M. excela, A. toxicaria* and *E. cylindricum* (Antwi-Boasiako and Atta-Obeng, 2009).Besides the stem, fibre proportion also decreased along the branches and was also greater in heartwood than the sapwoods for *T. ivorensis* and *A. robusta.* This trend also supports the report by Bhat et al*.* (1985), Haygreen and Bowyer (1996), Joshi (2008) and Luizon and Gasson (2012) that hardwood branches have fewer fibres than the stem. However, fibre content variations between *T. ivorensis* stem heartwoods from the middle and crown and branch heartwood at middle and top were not significantly different. Fibre proportions from *A. robusta* sapwoods from the crown of stem and base of branch, and heartwood at the middle of branch were not significantly different (P > 0.05).This indicates similar fibre yields for their pulps (Hua *et al.,* 1996) and comparable wood toughness (Longui et al*.,* 2012). To further validate the current findings, the 46-51.5% fibre proportion for *T. ivorensis* (including the stem and branch woods)isin agreement with the studies by Oteng-Amoako (2002) and Antwi-Boasiako and Atta-Obeng (2009) that*T. ivorensis* fibre content would be classified as medium (41-60%). Similarly, low to medium fibre proportion (40-45.7%) recorded for*A. robusta* is close to that of *A. altissima* ofthe same Genus(Oteng-Amoako, 2002). The branchwoods could thus be utilized as supplementary wood for these timbers.

**b) The amount of vessels**

Zimmermann (1983), Aloni (1987), Carlquist (2001) and Luizon and Gasson (2012) reported that the number of vessels increases with height in a tree.This trend existed for*T. ivorensis* and *A. robusta*. More vessels were recorded in the sapwood than the heartwood of the two timbers, which supports the observation byRao et al. (1997) and Ishiguri et al.(2009).Antwi-Boasiako and Atta-Obeng (2009)recorded more vessels in the sapwoods thanin the heartwoods of *T. ivorensis* and *E. cylindricum*. More vessels were recorded in the stem than in branch woods of *T. ivorensis* and *A. robusta*. The lowest amount of vessels were in the base of the branch of *T. ivorensis* and the stem base of *A. robusta* heartwoods, whereas the sapwoods at the stem crown of both timbers had most vessels. Haygreen and Bowyer (1996) found hardwood branches to possess more vessels than the stems. McCulloh et al. (2004), McCulloh and Sperry (2005), Preston et al. (2006) and Sperry et al. (2008) explained that trees modify the distribution of their vessels to suit different stem constructions, mechanical strength and their requirements for adequate water supply. Vessel proportions in wood affects utilization. The occurrence of several vessels together can decrease the density and strength properties of wood but increase its water absorption capacity (Luizon and Gasson, 2012).However, the abundance of vessels in wood is unfavorable for pulp production. Consequently, more stemwood vessels could contribute to reduced density and strength properties.

**c) The amount of parenchyma**

Decrease in parenchyma percentage from the base to the crown of the stems of the two timbers is in support of the earlier works by Ismail et al*.* (1995) for *Neolamarckia cadamba*. Likewise, Patel (1965) and Pate and Jeschke (1995) noted that the greatest amount of parenchyma cells is found at the base of the stems of trees. The distribution of parenchyma within a tree is dependent on their function (Zheng and Mart´ınez-Cabrera, 2013). As such, parenchyma cells, which store reserved food materials in trees are more in sapwoods than their corresponding heartwoods (Sauter and van Cleve, 1994; Pratt et al., 2007; Longui et al., 2012). To substantiate this, the sapwood regions for both timbers had greater parenchyma proportion than their respective heartwoods. Ishiguri et al. (2009) recorded more parenchyma (axial) in the sapwood than the heartwood of *Paraserianthes falcataria.* More parenchyma cells were mostly recorded for the branches than the stems of both timbers. Haygreen and Bowyer (1996) and Joshi (2008)reported that hardwood branches have more parenchyma cells than the stem. However, some few inconsistencies occurred. The greater variation in the proportions of parenchyma would adversely influence the strength properties of the branch than the stem. Since many parenchyma cells relate positively with greater mechanical fragility, thus, reduction of the mechanical resistance of wood (Luizon and Gasson, 2012). Thin cell walls and abundant parenchyma cells are expected to exhibit low density and strength properties (Sint and Hapla, 2008).However, it indicates a great tendency for the timber species for impregnation with preservatives to enhance their durability (Sint et al., 2011; 2012). The abundant presence of non-structural tissue, such as ray and axial parenchyma, may also inflict significant damage and drying defects such as splitting and cracking (Damayanti and Rulliaty, 2010), especially in the branchwoods and the sapwoods of the base of the stem of*T. ivorensis* and the sapwood and heartwood of the base of *A. robusta* stem. In general, sapwoods from the crown of the branches(especially those of *A. robusta* with the most abundant parenchyma cells) would be most fragile and susceptible to splitting and cracking during drying but it would have the greatest propensity for impregnation with chemicals. Generally, the combination of the various tissue characteristics within the individual stems and branches shows that wood from the different tree parts of both timbers would be preferred for different purposes and applications. This work has provided reliable information on the tissue dimensions and proportions of the stemwoods and branchwoods of two commercially important tropical timbers, A. *robusta* and *T. ivorensis.* These would improve their utilization, widen the raw material base for the timber industry and contribute to resolving differences in wood demand and supply as well as forest conservation.

## CONCLUSIONS

The tissue characteristics (including their dimensions and proportions) from the branch and stem woods of the timbers are general representatives of their species. Hence, both the stem and branch woods of *T. ivorensis* and *A. robusta* could suitably be utilized to reduce the over-dependence on stemwood. A mixture of the branch and stem wood fibres could provide a combination of characteristics, which would improve the properties of several wood products including the strength and bulk in a single paper. Where specific properties are required for satisfactory functioning, wood selection from any part of these tree positions (stem and branch) must be done carefully to match their end-use requirements. Stemwoods would be less dense, coarse-textured and pose more finishing problems to solid wood products. However, they would give products with greater load-bearing capacity, be favorable for pulp beating and give greater tearing-resistant papers. Branchwoods would be close-textured, have great density and be more appropriate for solid product finishing, but more difficult to saw and produce bulky papers with reduced tear resistance.

## REFERENCES

Adamopoulos S, Voulgaridis E (2002). Within tree variation in growth rate and cell dimensions in the wood of Black locust (*Robinia pseudoacacia*) IAWA. 23:191-199.

Ademiluyi EO, Okeke RE (1979). Studies on specific gravity and fibre characteristics of *Gmelina arborea* in some Nigerian plantations. Nigerian Journal of Science, 13:231-238

Ajala OO, Ogunsanwo OY (2011). Specific gravity and mechanical properties of *Aningeria robusta* wood from Nigeria. Journal of Tropical Forest Science 23(4): 389–395

Ali AC (2011). Physical-Mechanical Properties and Natural Durability of Lesser Used Wood Species from Mozambique. Faculty of Forest Sciences, Department of Forest Products Uppsala. Doctoral Thesis. 1-60

Aloni R (1987). Differentiation of vascular tissues. Annu. Rev. Plant Physiol. 38:179–204

Amoah M, Appiah-Yeboah J, Okai R (2012). Characterization of physical and mechanical properties of Branch, Stem and Root Wood of Iroko and Emire Tropical trees. Research Journal of Applied Sciences, Engineering and Technology 4(12): 1755-1761.

Anon (1989). IAWA List of Microscopic Features for Hardwood Identification. International Association of Wood Anatomist (IAWA) Bulletin 10: 219-332.

Antwi-Boasiako C, Atta-Obeng E (2009). Vessel-Fibre ratio, Specific gravity and Durability of four Ghanaian Hardwoods. Journal of Science & Technology (JUST) KNUST, Ghana, 29 (3): 8-23

Antwi-Boasiako C, Ayimasu A (2012). Inter-family variations in fibre dimensions of six tropical hardwoods in relation to pulp and paper production. Pro Ligno 8 (2): 19-36

Awuku A. (1979). Some anatomical properties of *Terminalia ivorensis.* FORIG Library. Ghana.

Baas P, Ewers FW, Davis SD, Wheeler EA (2004). Evolution of xylem physiology. In: Poole, I.; Hemsley,

a. (eds). Evolution of Plant Physiology. London: Elsevier Academic Press. 273-295

Bailey WI (1920). The cambium and its derivative tissues II. Size variations of cambial initials in gymnosperms and angiosperms. Amer. J. Bot. 7:355–367.

Barnett JR, Jeronimidis G (eds). (2003). Wood Quality and its Biological Basis. Blackwell Publishing Ltd. 1-226.

Bhat KM, Bhat KV, Dhamodaran TK (1985). Fibre Length Variation in Stem and Branches of Eleven Tropical Hardwoods; Wood and Bark Properties of Branches of Selected Tree Species growing in Kerala. KFRI, Research Report 29: 1-34

Bhat KM, Priya PB, Rugmini P (2001). Characterisation of juvenile wood in teak. Wood Sci. Tech. 34: 517–532.

Bierman CJ (1996).Handbook of pulping and papermaking. 2nd Edition. California: Academic Press Limited. 1-754

Bolza E, Keating WG (1972). African timbers: the properties, uses and Characteristics of 700 species. CSIR, Division of Building Research, Australia. 1-699.

Bowyer JL, Shmulsky R, Haygreen JG (2003).Forest products and wood science: an introduction, ed 4., Iowa State Press, Iowa, ISBN: 0813826543

Carlquist S (2001). Comparative wood anatomy: systematic, ecological and evolutionary aspects of dicotyledons wood. Berlin: Springer Verlag, 1-173

Chauhan L, Gupta S, Madhwal RC, Pandey R, Pal M (2001). Interclonal, intraclonal and within tree variation in wood properties of different clones of Populus deltoids. Indian. Forester. 127:777-784.

Chudnoff, M (1984).Tropical Timbers of the World. USDA Agriculture Handbook. No. 607. U.S. Government Printing Office, Washington, DC.

Dadswell HE, Watson AJ (1962). Influence of the morphology of wood pulp fibres on paper properties, Transactions of the Formation and Structure of Paper Symposium. Tech. Sect. B.P.B.M.A, 1-537.

Damayanti R, Rulliaty S (2010). Anatomical properties and fibre quality of five potential commercial wood species from cianjur west java. Journal of forestry research 7(1): 53-69

Desch HE, Dinwoodie JM (1996). Timber: Structure, Properties, Conversion and Use. 7th ed. Macmillan Press Ltd., London. 1-306.

Emerhi EA (2012). Variations in anatomical properties of *rhizophora racemosa* (leechm) and *rhizophora harrisonii* (G. Mey) in a Nigerian mangrove forest ecosystem. Int. J. Forest, soil and erosion, 2 (2): 89-96.

European Paper and Packaging Industries (2016). Pulping properties of hardwoods and softwood.http://www.paperonline.org/paper-making/paper-production/pulping/pulping-properties-of-hardwoods-and-softwood. [Accessed: 20th April, 2016]

Fagbemi OD, Taiwo KF, Otitoju O, Mgbachiuzor Fagbemi, Igwe CC (2014). Strength Properties of Paper from Pulp Blendof Kenaf Bark and Corn Husk: A Preliminary Study. British Journal of Applied Science & Technology, 4(28*): 4124-4129*.

Fahn A (1990).Plant anatomy, 4th ed. New York: Pergamon Press. 1-588.

Furukawa I, Hashizume H (1987). The influence of fertilization and improvement cutting on the wood quality of mature kunugi trees. Jap. Wood Association 33:443-449

Gartner BL (1995). Plant stems: Physiology and functional morphology, Academic Press, Inc. San Diego, CA. 1-440.

Gartner BL, Lei H, Milota MR (1996). Between and within-tree variation in the anatomy and specific gravity of wood in Oregon white oak (*Quercus garryana dougl*.). IAWA Journal, Vol. 17(4): 445-461

Gasson, P (1987). Automatic measurement of vessel lumen area and diameter with particular reference to pedunculate oak and common beech. IAWA Bull. 6:219–237.

Gbadamosi JO (2001).Evaluation of the structure of Pulp and Paper Industry. Nigeria Journal of Forestry, Vol. 20 (3): 45-49.

Ghouse AKM, Siddiqui FA (1976). Cell length variation in phloem fibres within the barks of some tropical fruit, *Annona squamosa, Emblica officinalis, Feronia limonia* and *Grewia asiatica*. Phytomorphology 26: 109-111.

Gurau L, Cionca M, Mansfield-Williams H, Sawyer G (2008). Comparison of the Mechanical Properties of branchwood and stemwood for three species. Wood and Fibre Science Journal 40 (4): 647-656.

Haygreen JG, Bowyer JL (1996). Forest Products and Wood Science.Third edition. Iowa State University Press, Iowa University Press. Pp.243-247.

Hillis WE (1972). Properties of eucalypt woods of importance to the pulp and paper industry. Appita J, Vol. 26 (2), pp.113-122.

Hua L, Milota MR, Gartner BL (1996). Between- and within-tree variation anatomy and specific gravity of wood in Oregon white oak (*Quercus Garryana* Dougl.). OR State University. *IAWA journal*, Vol. 17 (4), pp. 445-461.

InsideWood (2004).http://insidewood.lib.ncsu.edu/search [Accessed 19th February, 2016]

Isebrands J (1972). The proportion of wood elements within Eastern cotton wood. Wood Science (5:2), pp. 139-146

Ishiguri F, Hiraiwa T, Lizuka K, Yokota S, Priadi D, Sumiasri N, Yoshizawa N (2009). Radial variation of anatomical characteristics in *Paraserianthes falcataria* planted in indonesia. In Emerhi, E. A. (2012). Variations in anatomical properties of *Rhizophora racemosa* (leechm) and *Rhizophora harrisonii* (G. Mey) in a Nigerian mangrove forest ecosystem. *Int. J. Forest, Soil and Erosion*, Vol. 2 (2): 89-96.

Ismail J, Jusoh MZ, Mohd H, Sahri (1995). Anatomical variation in planted Kelempayan (*Neolamarckia cadamba*, Rubiaceae). IAWA Journal. Vol. 16 (3): 277-287

Izekor DN, Fuwape JA (2011). Variations in the anatomical characteristics of plantation grown *Tectona grandis* wood in Edo State, Nigeria. Arch. Appl. Sci. Res., 3 (1): 83-90

Jacobsen AL, Agenbag L, Esler KJ, Pratt RB, Ewers FW, Davis SD (2007). Xylem 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 95: 171–183.

James SA, Meinzer FC, Goldstein G, Woodruff D, Jones T, Restom T, Mejia M, Clearwater M, Campanello P (2003). Axial and radial water transport and internal water storage in tropical forest canopy trees. Oecologia, Berlin, 134:.37-45.

Jorge F (1994). Variability of anatomy in the bark of *Eucalyptus globulus* Ph.D. Thesis, Technical University of Lisbon. 1-86.

Jorge F, Quilho T, Pereira H (2000). “Variability of fiber length in wood and bark in *Eucalyptus globulus* IAWA J. 21(1), 41-48

Joshi L (2008).The anatomical studies on wood structure of trunk and branch wood of *Abies spectabilis* (D.Don.) Spach. Bulletin of the Department of Plant Resources. 30: 71-75.

Kasia Z, Butler DW, Gleason SM, Wright IJ, Westoby M (2013). Fibre wall and lumen fractions drive wood density variation across 24 Australian angiosperms AoB PLANTS,5:1-14

Kiaei M (2011). Variability of fibre length in wood and bark in *Acer velutinum boiss.* World Applied Science J. 13(5):993-995.

Kibblewhite RP, Evans R, Riddell MJC, Shelbourne CJA (2004). Changes in density and wood-fibre properties with height position in 15/16-year-old *Eucalyptus nitens* and *E. fastigata.* Appita J. 57(3): 240-247

Klungness J,Sanyer N(1981). Hardwood pulp utilization: Separation of nonfibrous oak components. TAPPI 64 (3). 109-1 13.

Kollmann FFP, Côté WA Jr. (1984). Principles of Wood Science and Technology Vol.1. New York: Springer-Verlag, 1-55

Kpikpi WM (1992). Wood structure and paper making potentials of *Ricinodendron heudelotii* and *Albizia zygia* in relation to *Gmelina arborea* in Nigerian. Journal of Botany, 5: 41-50.

Larson PR (1960). A physical consideration of spring wood summerwood transition in red pine. Forest Science 6: 110-122.

Lemmens RHMJ (2007). *Pouteria altissima* (A.Chev.) Baehni. In: Louppe, D., Oteng-Amoako, A.A. and Brink, M. (Editors). PROTA 7(1): Timbers/Bois d’œuvre 1. [CD-Rom]. PROTA, Wageningen, Netherlands. (Accessed: 4th March, 2016.

Longui EL, De Brito Garcia Silva RA, Romeiro D, De Lima IL, Monteiro S, Antônio BF, De Melo CG (2012). Root-branch anatomical investigation of *Eriotheca gracilipes* young trees: a biomechanical and ecological approach Sci. For., Piracicaba. 40 (93): 23-33,

Luizon CDL,Gasson P (2012). Anatomical comparison of original and regrowth wood from coppiced and pollarded *Poincianella pyramidalis* trees in the Caatinga of Pernambuco, Brazil. IAWA Journal. 33 (1): 63-72

Manwiller FG (1974). Fibre lengths in stems and branches of small hardwoods on Southern pine sites. Wood Sci. 7 (2): 130-134.

Marsoem SN, Haryanti E, Lukmandaru G (2002). Radial and axial variation in the fibre dimensions and cell proportion of Auri (*Acacia auriculiformis*) wood grown in the community forest. The fifth Pacific Regional Wood Anatomy Conference, Hosted by Gadjah Mada University, Yogyakarta, Indonesia, Sep. 9-14

Martínez-Cabrera HI, Jones CS, Espino S, Schenk HJ (2009). Wood anatomy and wood density in shrubs: Responses to varying aridity along transcontinental transects. American Journal of Botany96: 1388 – 1398.

McCulloh KA, Sperry JS (2005). Patterns in hydraulic architecture and their implications for transport efficiency. Tree Physiology 25: 257–267

McCulloh KA, Sperry JS, Alder FR (2004). Murray’s law and the hydraulic vs mechanical functioning of wood. Functional Ecology 18: 931–938.

McIntosh, D. C. (1970). Fiber structure and properties. In: Handbook of Pulp and Paper Technology. Britt. K.W. (ed.) Van Nostrand Reinhold Company. New York. 1-38.

Mejia M, Clearwater JSA, Meinzer FC, Goldstein G, Woodruff D, Jones T, Restom TM, Campanello P (2003). Axial and radial water transport and internal water storage in tropical forest canopy trees. Oecologia 134: 37–45.

Monteiro CMBLN (2003). Anatomical characteristics of the bark of *Eucalptus globullus.* Labill. Second rotation report on Forest Engineering. Technical University of Lisbon, Top Institute of Agronomia.

Moore J (2011).Wood properties and uses of Sitka spruce in Britain. Forestry Commission Research Report. Forestry Commission, Edinburgh 84(1): 49-60.

Nandkumar P (2009). Pulp blending and its effects on the strength properties of *pomoeacarnea* jacq. Journal of Environmental Research and Development. 3:1-4.

Ohbayashi H, Shiokura T (1990). Wood anatomical characteristics and specific gravity of growing tropical tree species in relation to growth rate. Mokuzai Gakkaishi 36: 889–893.

Okai R, Frimpong Mensah K, Yeboah D (2004). Characterization of strength properties of branchwood and stemwood of some tropical hardwood species. Wood Science and Technology 38(2): 163–171.

Oteng-Amoako AA (2002) (Ed). 100 Tropical African Timber Trees from Ghana. Tree description and wood identification with notes on Distribution, Ecology, Silviculture, Ethnobotany and Wood Uses. ISBN 9988-7943-4-7

Panshin AJ, de Zeeuw C (1964). Textbook of Wood Technology. Vol. 1. New York, U.S.A. 1-643.

Panshin AJ, de Zeeuw C (1980). Textbook of Wood Technology. Structure, Identifications, Properties, and Uses of the Commercial Woods of the United States and Canada. New York, McGraw-Hill, Inc. 1-722.

Pate JS, Jeschke WD (1995). The rope of stems in transport, storage and circulation of ions and metabolites by the whole plant In: Gartner, BL (1995). Plant stems: Physiology and Functional Morphology: 177-204

Patel RN (1965). A comparison of the anatomy of the secondary xylem in roots and stems. Holzforschung 19: 72–79

Peszlen I (1994). Influence of age on selected anatomical properties of popular clones. International Association of Wood Anatomists. 15:311-321.

Phelps JE, Isebrands JG, Jewett D (1982). Raw material quality of short-rotation, intensively cultured *Populus* clones. I. A comparison of stem and branch properties at three spacings. IAWA Bull. 3(3/4): 193-200

Pratt RB, Jacobsen AL, Ewers FW, Davis SD (2007). Relationships among xylem transport, biomechanics and storage in stems and roots of nine Rhamnaceae species of the California chaparral. New Phytologist174: 787 – 798

Preston KA, Cornwell WK, DeNoyer JL (2006). Wood density and vessel traits as distinct correlates of ecological strategy in 51 California coast range angiosperms. New Phytologist170*:* 807–818*.*

Rana R, Langenfeld-Heyser R, Finkeldey R, Polle A (2009). Functional anatomy of five endangered tropical timber wood species of the family Dipterocarpaceae. Trees Structure and Function, 23:521-529.

Rao RV, Aebischer DP, Denne L (1997). Latewood density in relation to wood fiber diameter, wall thickness, and fiber and vessel percentages in *Quercus robur* L. IAWA Journal, The Netherlands. 18: 127-138.

Rao RV, Sujatha M, Sharma SK, Sethy AK (2007). "Evaluation of anatomical properties of seven-year old plantation grown *Simarouba glauca*". J. Timber Dev. Assoc. of India. Vol. 52(3 and 4): 14-32.

Richter HG, Dallwitz MJ (2009). Commercial timbers: descriptions, illustrations, identification, and information retrieval. Version: 25th June, 2009. http://delta-intkey.com’. (Accessed: 12thMarch, 2016).

Roque RM, Tomazelo-Filho M (2007). Relationships between anatomical features and density profiles in *Gmelina arborea* applying x-ray densitometry. Cerne, outubro-dezembro, ano/vol. 13, numero 004. Universidade Federal de Lavras. Lavras, Brazil. Pp.384-392.

Roszaini AK (2000). Effect of age and height on the stem characteristics of *Calamus scipionum* (rotan semambu). Journal of Tropical Forest Products 6 (2): 190-199.

Samariha A, Kiaei M, Talaeipour M, Nemati M (2011). Anatomical structural differences between branch and trunk in *Ailanthusaltissima* wood. Indian J Sci Technol. 4: 1676–1678.

Sauter JJ, van Cleve B (1994). In Zheng, J. and Hugo Martinez-Cabrera (2013). Wood anatomical correlates with theoretical conductivity and wood density across China: Evolutionary evidence of the functional differentiation of axial and radial parenchyma. Annals of Botany. http://aob.oxfordjournals.org/content/early/2013/07/31/aob.mct153.full
(Accessed 4th May, 2014).

Schwarze FWMR (2004). Forest Pathology: Heart Rot and Wood Decay. In: Burley J, Evans J, Youngquist J (eds), Encylopedia of Forest Sciences, Elsevier Science 4., pp. 808–816.

Sehlstedt-persson M, Olov K (2010). Natural durability and phenolic content in dried Scots pine wood. BioResources 5(2), 1126-1142.

Shashikala S, Rao RV (2009). Radial and axial variation in specific gravity and anatomical properties of plantation grown *Eucalyptus citriodora* Hook. The Journal of Institute of Wood Science 19 (2): 84- 90.

Sint KM, Adamopoulos S, Koch G, Hapla F, Militz H (2012). Impregnation of Bombax ceiba and Bombax insigne wood with a methylol melamine compound. Wood Sci Technol., 47 (1): 43-58.

Sint KM, Hapla F (2008). Utilization potential of Myanmar lesser-used timber species, Forstarchiv 80: 129-131.

Sint KM, Militz H, Hapla F, Adamopoulos S (2011). Treatability and penetration indices of four Myanmar lesser-used timber species. Wood Res Slovakia 56(1): 13-22.

SperryJS, MeinzerFC, McCullohKA(2008).Safety and efficiency conflicts in hydraulic architecture: Scaling from tissues to trees. Plant, Cell & Environment31: 632–645.

Sudin M, Wahab R (2013). Variation in the decay resistance between sapwood and heartwood of *Parashorea malaanonan*. School of International Tropical Forestry, University Malaysia Sabah. Locked bag 2073, 88999 Kota Kinabalu, Sabah, Malaysia. 27-32.

Tavares F, Quilho T, Pereira H (2010). Wood and bark fiber characteristics of *Acacia melanoxylon* and comparison to*Eucalyptus globulus*. Cerne17: 61–68.

Taylor AM, Gartner BL, Morrel JJ (2002). Heartwood formation and natural durability. A review. Wood Fiber Sci 34 (4): 587-611.

Taylor FW (1977). A note on the relationship between branch- and stemwood properties of selected hardwoods growing in the mid-South. Wood Fibre 8(4):257-261

Taylor FW, Wooten TE (1973). Wood property variation of Mississippi delta hardwoods. In: Kollmann F. F. P. and Côté W. A. Jr. (1984). Principles of wood Science and technology New York: Springer-Verlag, 1-55

Tsoumis G (1968). Wood as Raw Material. 1st ed., Pergamon Press Ltd., London, 1- 276.

Tyree MT, Ewers FW (1991). The hydraulic architecture of trees and other woody plants. New Phytol. 199: 345–360.

Tyree MT, Zimmermann MH (2002). Xylem structure and the ascent of sap. Ed. 2. Springer-Verlag, Berlin.

Uetimane Jr. E (2010). Anatomy, drying behaviour and mechanical properties of lesser used wood species from Mozambique. The Swedish University of Agricultural Sciences. Department of Forest Products. Doctoral Thesis No. 2010:66. ISBN: 978-91-576-7511-8.

Ververis C, Georghiou K, Christodoulakis N, Santas P, Santas R (2004). Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. Industrial Crops and Products. 19: 245-254.

Voorhies G, Jameson DA (1969). Fibre length in southwestern Young-Growth Ponderosa Pine. For. Prod. Lab, 19(5): 52-55.

Wardrop, A.B (1969). Fibre morphology and papermaking, TAPPI J., 52(3): 396.

Wilson K, White DJB, (1986). The Anatomy of Wood: Its Diversity and Variability. Stobart and Son Ltd., London. 1-316.

Zabell RA, Morrell JJ (1992). Wood microbiology; decay and its prevention. San Diego: Academic Press Inc. 1-498

Zanne AE, Westoby M, Falster DS, Ackerly DD, Loarie SR, Arnold SJ, Coomes DA (2010). Angiosperm wood structure: Global patterns in vessel anatomy and their relation to wood density and potential conductivity. American Journal of Botany, 92, 207–215.

Zheng J, Martinez-Cabrera H (2013). Wood anatomical correlates with theoretical conductivity and wood density across China: Evolutionary evidence of the functional differentiation of axial and radial parenchyma. Annals of Botany. http://aob.oxfordjournals.org/content/early/2013/07/31/aob.mct153. (Accessed: 4th May, 2014.

Zimmermann MH (1978). Hydraulic architecture of some diffuse-porous trees. Can. J. Bot.56: 2286–2295.

Zimmermann MH (1983). Xylem structure and the ascent of sap. Springer, Berlin Heidelberg New York. 1-146.