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Assessment of Wood Vessel Characterization in Some Nigerian Trees

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ABSTRACT

Twenty Nigerian trees namely *Triplochiton scleroxylon* (Obeche), *Pterocarpus osun* (Osun), *Mansonia altisima* (Mansonia), *Spondias mombin* (Iyeye), *Milicia excelsa* (Iroko), *Terminalia superba* (Afara), *Khaya senegalensis* (Oganwo), *Entandrophragma cylindricum* (Ijebo), *Cedrela odorata*, *Cordia alliodora* (Omo), *Enatandrophragama angolense* (Sapele), *Nauclea diderrichii* (Opepe), *Alstonia boonei* (Ahun), *Gmelina arborea* (Gmelina), *Vitex doniana*, *Tetrapleural tetaptera*, *Pericopsis elata* (Afromosia), *Hildegardia barteri* (Okurugbedu), *Ficus exasperata*, and *Afzelia africana* (Apa) were investigated for vessels within their stem and root regions. Wood samples collected from stem and root using an increment borer were sectioned into about 20 µm thick on a Reichert microtome sliding machine. Microscopic investigations of wood samples were performed using an Olympus (CH series) light microscope at 80 ×. Results showed that vessel traits, arrangement and distribution that were uniquely exhibited in the stem of each wood species were greatly similar to those in the root regions. However, quantitative analysis revealed that sizes and values of vessel parameters within the stem varied greatly from the root region in all the wood species. Within the stem region, vessel diameter was highest in *Milicia excelsa* (276.40 ±29.57 µm) but lowest in *Mansonia altissima* (93.71 ±15.53 µm). Values of vessel diameter (185.26 ±51.88 µm), vessel density (6.07 ±5.02 V/mm^2) and vessel group index (1.52 ±0.52) were higher in the stem than in the root among a greater number of trees studied. Vessel traits among investigated varied from species to species, and therefore cannot be generalized as they are species dependent, or influenced upon response of trees to environmental factors. Hence, Discrepancies in wood moisture content, rate and period of seasoning, wood processing and workability properties are an indication of sizes, arrangement and distribution of vessels within and among the trees.

Keywords: Vessels; stem; roots; arrangement; regions; utilization

Introduction

A living tree is made up of two main regions, the shoot and the roots. The roots are the subterranean structures responsible for water and mineral nutrient uptake, mechanical anchoring of the shoot, and storage of biochemicals, while the shoot supports the leaves, it also transports nutrients and water to various parts of the tree. Both tree regions are interconnected, hence several qualitative characteristics of the root xylem in certain species have been observed to be similar to the xylem within stems (Marcati *et al*., 2014). Nevertheless, some differences such as wider and longer vessel element, lower ray frequency and wider rays (Machado and Angyalossy, 1997) in wood cells have been found between the stem and root wood. Right from the root system to the leaf region, the efficiency of a tree's hydraulic system is primarily a function of

the quantity, diameter, and length of the xylem vessels (conduits). Interestingly, and because xylem is dynamic, an instantaneous alteration of the conduits during response of trees to water availability or scarcity can lead to spatial constraints that result in clear allocation of cell types in both stems and roots (Pratt *et al*., 2007; Pfautsch *et al*., 2016) This is because the sizes of the vessels (including other wood cells), their distribution and arrangement are basically formed to meet the needs of the living tree. Hence there is no property of wood (physical, mechanical, chemical, biological, or technological) that is not formed to accomplish the functions of conduction, mechanical support and storage of biochemicals (Alex, 2000). These functions and features are heritable can express the adaptive nature of the woody species to environmental stresses and can also determine the quality of a timber as every wood species exhibits its own distinct properties, applications, and potentials that are significantly important in both plant and human domains (Carlquist, 2012; Maiti and Rodriguez, 2015)

There are many good quality wood species in Nigeria, but most anatomical studies on Nigerian trees have dealt with only stem wood without paying much attention to the root wood, whereas useful and relevant anatomical information about a tree species is also stored in the root wood. As such, tree felling might be discouraged during the quest for identification and utilization potentials of tree species if anatomical information retrieved from the root wood can mirror the common microstructures of its trunk. Investigating functional characteristics of plants has added much to the understanding of ecosystem structure, functioning and responses to environmental factors (Baraloto *et al.* 2010)

Therefore, examining wood cells both above and below ground level can unveil species diversity in wood strategies which is due to varied xylem anatomical configurations that serve as functional adjustments to fluctuations in water availability and other environmental conditions within and above the soil. Thus, this study intends to compare the vessels of root and stem wood of the selected trees with a view to bringing to the fore the patterns of functional distribution of wood conduits that in turn also influences wood utilization.

Materials and Methods

Stem and root wood from twenty (20) matured trees namely *Triplochiton scleroxylon* (Obeche), *Pterocarpus osun* (Osun), *Mansonia altisima* (Mansonia), *Spondias mombin* (Iyeye), *Milicia excelsa* (Iroko), *Terminalia superba* (Afara), *Khaya senegalensis* (Oganwo), *Entandrophragma cylindricum* (Ijebo), *Cedrela odorata*, *Cordia alliodora* (Omo), *Enatandrophragama angolense* (Sapele), *Nauclea diderrichii* (Opepe), *Alstonia boonei* (Ahun), *Gmelina arborea* (Gmelina), *Vitex doniana*, *Tetrapleural tetaptera*, *Pericopsis elata* (Afromosia), *Hildegardia barteri* (Okurugbedu), *Ficus exasperata*, and *Afzelia africana* (Apa) were investigated for vessels. Stem wood samples were collected from the inner and outer tree using an increment borer of diameter 12 mm and length 28 cm at the tree breast height of 1.35 m (Rahman, *et al*, 2004; Luchi *et al.* 2005; Rodrigues *et al*, 2011; and Marcati *et al*, 2014) in order to produce a resultant cube of about 1cm x 1cm x 1cm. Root wood samples were obtained from the lateral root of each mature tree at a radius of about 100 cm to the trunk following Stokke (1986) using the increment borer as also obtained for the stem region.

Sectioning of wood samples for microscopic investigations was performed using a Reichert microtome sliding machine on which samples were sectioned into three planes, namely transverse section (Tr. sec), tangential longitudinal section (TLS) and radial longitudinal section (RLS) of about 20 µm thick. Simple staining was done using a Safranin stain before dehydrating by passing wood sections through a series of bath of increasing concentrations (30%,

50%, 70% and 90%) of ethanol to replace water. Clearing of specimens was done in a vegetable oil, precisely coconut oil (Adeniyi *et al*. 2016); sections were subsequently mounted on a microscopic slide using Canada balsam and covered with a cover glass slip. Microscopic investigations of wood samples were performed using an Olympus (CH series) light microscope at 40 × (where necessary) and 80 × magnifications. Measuring of vessels was done at the transverse and tangential sections, and twenty (20) observations were made for each tree while each tree species was replicated four (4) times. The experiment was designed in 2 x 2 x 20 factorial in randomized complete block design (RCBD): two regions (stem and root), two portions (outer and inner portions), and twenty tree species. Analysis of variance (ANOVA) using R software (R Core Team, 2017) was used to investigate the extent of variations among the wood cell parameters.

Results and Discussions

Qualitative Description

Vessel arrangement and composition that were uniquely exhibited by each wood species in the root regions were greatly similar to those within the stem regions. This indicates that the root region of each wood species had common anatomical characteristics of the stem region in terms of cell composition, arrangement and distribution. This is also a hint that the root wood could be used in wood diagnosis of the main stem without having to destroy the whole tree during wood anatomical investigation about wood identification and tree utilization potentials. Intervascular pits were either simple and alternate in the wood species except in *Spondias mombin, Pterocarpus osun, Terminnalia superba, Nauclea diderrichii, Gmelina arborea, Astonia boonei* and *Tetrapleural. Tetraptera* where inter vascular pits were vestured.

***Triplochiton sceleroxylon* (Obeche):** Vessels in *T. sceleroxylon* were diffuse, mostly solitary but radial multiples of three and pore pairs were also observed at the two regions (stem and root). Tyloses were found in some vessels.

***Pterocarpus osun* (Osun):** Vessels in *P. osun* were diffuse and mostly solitary, and radial multiples of 2-3 were present at the two regions (stem and root). Gum deposits were present inner root.

***Mansonia altissima* (Mansonia):** Vessels in *M. altissima* were mostly oval (less oval in the stem) and predominantly in pore pairs in both stem and root regions. There were also solitary and diffuse, but also in clusters in the stem region.

***Spondias mombin* (Iyeye):** Vessels in *S. mombin* were diffuse, mostly in pore pairs, in radial multiples of three to four, and also in clusters in both stem and root. Tyloses were present inside the vessels but were abundant at the inner portions of stem.

***Terminalia superba* (Afara):** Vessels in *T. superba* were mostly oval, diffuse, solitary and mostly in radial multiples of 2-3 at the two regions (stem and root).

***Khaya senegalensis* (Oganwo):** Vessels in *K. senegalensis* were diffuse, solitary, in pore pairs and radial multiples of 3 to 4 in both root wood and stem wood. Gum deposits were present in vessels of inner root and inner stem regions.

***Entandrophragma cylindricum* (Ijebo):** Vessels in *E. cylindricum* were diffuse, solitary, in pore pairs and in radial multiples of 3; pore clusters were also observed. Vessels were arranged in a diagonal manner in both stem and root wood. Gum deposits were present in the inner portion of the wood species.

***Cordia alliodora* (Omo):** Vessels in *C. alliodora* were diffuse, solitary, in pore pairs and mostly in clusters in both stem and root, and were of two distinct diameter classes within the two regions. Tyloses were present inside the vessels at the inner

stem and root regions; sclerotic tyloses found in the root region vessels.

***Entandrophragma angolense* (Sapele):** Vessels within the stem and root of *E. angolense* were arranged in a diagonal manner, diffuse, mostly solitary but radial multiples of three and pore pairs were also observed. Vessels were also polygonal and filled with coloured deposits especially in the inner stem.

***Alstonia boonei* (Ahun):** Vessels in *A. boonei* were angular, diffuse, mostly in pore pairs, in radial multiples of three to four, and also in clusters in both stem and root.

***Gmelina arborea* (Gmelina):** Vessels in *G. arborea* were mostly solitary and ring porous in both stem and root regions. Tyloses were found inside many stem vessels, but not observed inside root wood.

***Vitex doniana*:** Vessels in *V. doniana* were polygonal, diffuse, solitary, oval; vessels were mostly in radial multiples of 2 -3, and were arranged in a tangential manner in both stem and rood wood; pore clusters were also observed.

***Tetrapleural tetaptera* (Aridan):** Vessels in *T. tetraptera* were diffuse, solitary, in pore pairs and sometimes in radial multiples of three, and were arranged in a diagonal manner in both stem and root wood. Some vessels were filled with gum deposits, intervascular pits were small and vestured.

***Pericopsis elata* (Afromosia):** Vessels in *P. elata* were diffuse, mostly in pore pairs, in radial multiples of three to four, and also in clusters in both stem and root. Yellowish deposits were observed inside some vessels at the inner portion of stem and root regions.

***Ficus exasperata*:** Vessels in *F. exasperata* were diffuse, oval, mostly solitary, pore pairs and radial multiples of three present at the two regions (stem and root). Vessels in the inner stem were filled tyloses, but rare or absent in the root region.

***Afzelia africana* (Apa):** Vessels in *A. africana* were exclusively solitary, radial multiples of three was observed. The pores were filled with yellow deposits at the inner portions of both stem and root regions.

***Milicia excelsa* (Iroko):** Vessels in *M. excelsa* were mostly solitary and diffuse within the stem and root, and tyloses were found in the inner wood vessels.

***Nauclea diderrichii* (Opepe):** Vessels in *N. diderrichii* were mostly solitary, ring porous and oval in both stem and root regions. Yellow deposits were present in the vessels from the inner portion of the stem, but not observed in the inner portion of the root region.

***Hildegardia bateri*:** Vessels in *H. barteri*were semi-ring porous, and exclusively solitary.

Cedrela odorata: Vessels in *Cedrela odorata* were not arranged in specific pattern. Vessels were mostly solitary, semi-ring porous and with pore pairs and radial multiples of three.

Quantitative Analysis

Mean Tangential Diameter (MTD)

Results shows that within the stem region, values of mean tangential diameter (MTD) ranged from 74.42 µm in *M. altissima* to 328.9 µm in *Milicia excelsa*. Table 2 shows that *Milicia excelsa* had the highest mean vessel diameter of 276.40 ±29.57 µm, while *Mansonia altissima* had the least vessel diameter of 93.71 ±15.53 µm. Within the root wood region, values of mean tangential diameter (MTD) ranged from 65.00 µm in *Pericopsis elata* to 272.04 µm in *Cedrela odorata*. Table 2 shows that *Cedrela odorata* had the highest mean vessel diameter of 228.22 ±25.34 µm, while *Pericopsis elata* had the least vessel diameter of 95.30 ±26.1 µm.

Figure 1 shows that vessel diameter was wider at the outer portion than the inner portion in a greater number of trees in this study, when the means were

pooled together, Similarly, Govina *et al.*, (2021) found vessel dimension higher in the sapwood than that of the heartwood. Also, MTD at the stem region was 185.26±51.88 µm, while 64.04 ±43.08 µm was recorded as MTD for the root region. Figure 1therefore reveals that MTD was higher in the stem region than in the root region among most of the trees. Table 2 indicates that there were significant differences in MTD among the twenty trees. it also shows that there was a significant difference in MTD between the stem and root regions which was also depended on the tree species.

Basically, as stated by Ayensu and Bentum (1974) and IAWA (1989) vessels are moderately small if MTD is between 50 µm to 100 µm, medium-sized if it is between 100 µm to 200 µm, large or moderately large if MTD is between 200 µm to 300 µm and very large if MTD is between 300 µm to 400 µm. Hence, vessels were moderately small in *M. altissima*, medium-sized in all the wood species except in *H. barteri, V. doniana, A. africana, F. exasperata, P. osun, S. mombin* and *M. excelsa* in which vessels were either large or moderately large.

Instances of wider pores in the stem than in the root region had been reported on certain wood species (Gartner, 1996; Stevenson and Mauseth, 2004). On the other hand, wider vessels in root wood had also been reported by Cutler (1976); Alder *et al*. (1996); Ewers *et al*. (1997); McElrone *et al*. (2004) and Machado *et al*. (2007). Although narrower vessels in the root region can impose high conducting resistance, such a phenomenon (low conductance) provides safety during drought and can make the tree root less vulnerable to cavitations resulting from gas bubbles formation which in turn has considerable adverse consequences such as canopy dieback or whole plat mortality (Tyree and Sperry, 1989: Psaras and Sofroniou, 2004a: Psaras and Sofroniou, 2004; Jacobsen *et al*., 2007; Cai and Tyree, 2010). It may not be strange that root vessels in most tree species were narrow, this might be for functional adaptation especially with respect to conductive safety as transport of sap and liquid materials become safer when the vessels are narrow.

However, wider pores within the stem region are faced with the challenge of stressed-induced cavitation but instances of wider vessels in the stem region of some Nigeria hardwood species might be essential as water or nutrients can be conducted more efficiently through a long distance along the tree with little resistance (Tyree and Sperry, 1989; Psaras and Sofroniou, 2004; Jacobsen *et al*., 2007; Machado *et al*., 2007; Cai and Tyree, 2010; Pramod and Rao, 2012). Therefore, evolvement of wide or narrow vessels in regions where they occur in trees can be species dependent, or influenced by edaphic features or response of trees to environmental factors all which dictate allocation of tree resources to its organs, particularly to the root and shoot regions. Moreover, instances of wider vessels in trees where they were recorded might signal more access to water for the tree species, while narrower pores might indicate restricted access to water upon which adaptive adjustment is made by trees, and indication that xylem in plants is not static.

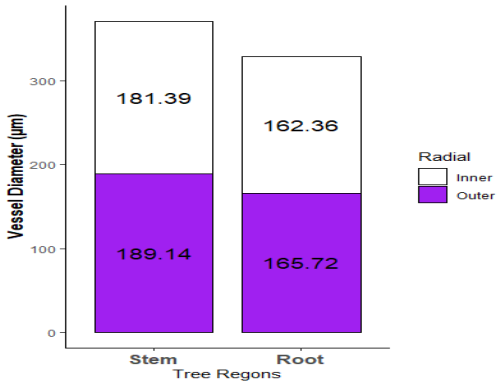


Figure 1: Aggregate values of vessel diameter in stems and roots of all the tree species

Vessel Density (VD)

Vessel density (VD) which measured number of pores per unit area (vessel frequency) within the stem region was highest (Figure 2) in *Mansonia altissima* (21.58±10.58 v/mm^2), while the lowest VD within the stem region was recorded in *Milicia excelsa* (2.06±0.22 v/mm^2). Within the root region, the highest vessel density was observed in *S. mombin* (12.11±2.29 v/mm^2), while the lowest vessel density was found in *Milicia excelsa* (1.77±0.26 v/mm^2).

Among the trees, Figure 2 shows that vessel density was slightly higher at the inner portion than the outer portion in a greater number of trees in this study when the means were pooled together, although there was no significant difference as shown in Table 2. Govina *et al*. (2021) also reported a higher vessel density in the inner wood (heartwood) than in the outer wood (sapwood) in certain wood species. Pooled means between stem and root regions among the trees revealed that values of VD at the stem region was 6.07±5.02, while 5.38 ±2.92 was recorded as VD in the root region. Figure 2 reveals that VD was higher in the stem region than in the root region among most of the trees, and Table 3 indicates that there was a significant difference in VD between the stem and root regions. Between-tree VD values were also significant among the twenty trees as shown in Table 3. It is interesting to note that all the members of the Meliaceae family (*E. angolense*, *E. cylindrical*, *C. odorata* and *K. senegalensis*) had higher VD in the root region (Table 1). Higher vessel density observed at the stem region than at the root in many trees in this study was also reported by Gartner (1995) on some hardwood and softwood species. It was observed that vessel density (VD) was lower in trees that possessed wider vessels, this was confirmed by a negative correlation (R= 0.77, $p<0.05$) that was recorded between VD and MTD (mean vessel diameter) among the wood species. Hence, VD was higher either in root or stem wood wherein narrower pores or vessels occurred. This phenomenon was observed and evident in *Mansonia altissima* which possessed the highest frequency of vessels, but had the smallest vessel diameter (MTD); this report was also supported by Pramod and Rao (2012) on certain wood species. Hydraulic conductivity has been closely linked with vessel frequency (Tyree and Zimmermann, 2002; Fichtler and Worbes, 2012). Incidence of higher number of vessels per unit area in some trees prevents shortfalls of sap and nutrients resulting from inefficient transportation water due to high resistance to flow. This is because more pores are available for conduction in case of failure resulting from cavitation.

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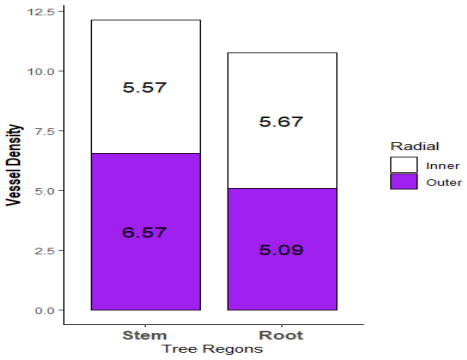


Figure 2: Aggregate values of vessel density in stems and roots among the tree species

Vessel Length (VL)

Within the stem region results showed that *Alstonia boonei* had the highest mean vessel length of 0.78 ±0.08 mm, while *Pterocarpus osun* had the least vessel length of 0.21 ±0.05 mm. Within the root region, *Alstonia boonei* had the highest vessel length of 0.71 ±0.18 mm, while *Milicia excelsa* had the least vessel length of 0.17 ±0.02 mm. Wide vessels were said to be longer than narrow vessels (Dickison, 2000), but trees with wider vessels in this study such as *M. excelsa* had shorter vessel length than some trees with narrower vessels. This may indicate that vessel length is a function of type of tree species, environmental factors, such as precipitation as stated by Carrillo *et al*. (2013). Table 2 shows that there were significant differences in VL among the trees and were influenced by the species, but there was no significant difference in VL between the stem and root regions among the trees as can also be seen in Figure 3.

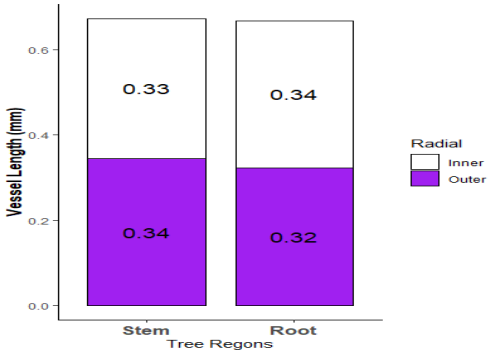


Figure 3: Aggregate values of vessel length in stems and roots among the tree species

Vessel Group Index (VGI)

Values of vessel group index (VGI) which measured vessel grouping and number of solitary vessels in trees within the stem wood among the wood species ranged from 1.04±0.03 in *N. diderrichii* to 10.88±2.69 in *A. boonei*. Table 1 showed that within the stem region *A. boonei* had the highest vessel grouping, while *N. diderrichii* had the least VGI. Within the root wood among the species, values of vessel group index (VGI) ranged from 1.05±0.04 in *N. diderrichii* to 10.41±1.11 in *A. boonei*. Table 2 showed that *A. boonei* had the highest VGI, while *N. diderrichii* had the least vessel grouping in the root region (Figure 4). A negative correlation of 0.55 was recorded between vessel diameter and vessel grouping within the root region among the wood species. This confirmed

that within the root region, some trees with wider vessels appeared to be more solitary and less grouping, but no correlation of such was observed in the stem region. It appeared therefore that trees with narrow vessels (e.g *P. elata* and *Mansonia altissima*) possessed high vessel groupings of pore pairs, clusters or / and radial multiples which are strategic to enhance conduction efficiency. More pores in terms of vessel density and vessel grouping are ways to strengthen sap conduction in trees like *P. alata* and *Mansonia altissima* in which conduction can be drastically low on the account of narrow vessels. On the other hand, the long distance through which water has to be moved along the stem from the root region can be the reason why some wood species with wider vessels at the stem also advantageously developed more vessel grouping than the root region (for example *Milicia excelsa*). In order to boost conduction during the attendant cavitation resulting from such a task via very wide pores, alternative conduits through pore pairs, radial multiples and pore clusters must be provided in case some vessels are hampered or disrupted by embolism (Carlquist, 1984) ensuing from limited water and drier environment (Dickison, 2000). Thus, the level of vessel grouping could depend on size of vessels and also on crash or malfunction in functional vessels during water conduction.

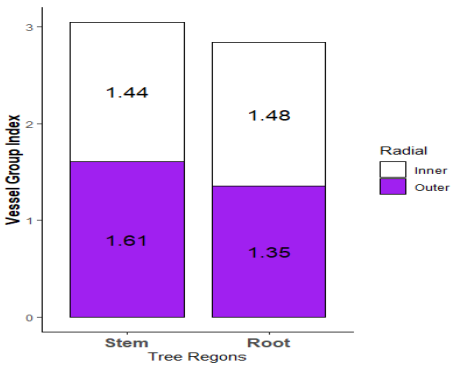


Figure 4: Aggregate values of vessel groupings in stems and roots among the tree species

Table 1: Average values of vessel parameters in wood species

Species	MTD (µm) Mean ± SD		VL (mm) Mean ± SD		VD (v/mm^2) Mean ± SD		VGI Mean ± SD	
	Stem	Root	Stem	Root	Stem	Root	Stem	Root
E. angolense	192 ±23.4	168.18 ±22	0.36 ±0.06	0.34 ±0.06	4.25 ±0.71	5.79 ±1.12*	1.25 ±0.12	1.23 ±0.07
T. sceleroxylon	171 ±20.7**	134 ±15.7	0.28 ±0.02	0.28 ±0.03	3.85 ±0.63	2.59 ±0.24	1.77 ±0.29*	1.11 ±0.08
M. excelsa	276.40 ±29.57***	199.37 ±11.20	0.22 ±0.10	0.17 ±0.02	2.06 ±0.31	1.77 ±0.26	1.28 ±0.08	1.23 ±0.11
P. elata	108 ±10.40	95.30 ±26.1	0.27 ±0.02*	0.24 ±0.02	12.55 ±0.96**	10.59 ±1.67	2.03 ±0.01	2.23 ±0.23*
S. mombin	215.14 ±45.93***	139.98 ±20.86	0.30 ±0.08	0.35 ±0.06	6.73 ±2.46	12.11 ±2.29***	1.58 ±0.42	1.93 ±0.49*

P. osun	206.20 ±48.92***	128.43 ±25.91	0.21 ±0.05	0.21 ±0.04	3.44 ±0.89	3.70 ±0.1.70	1.44 ±0.17*	1.32 ±0.20
F. exasperata	203.75 ±46.76	195.18 ±45.03	0.27 ±0.05	0.28 ±0.06	3.60 ±0.56*	2.89 ±0.98	1.51 ±0.15*	1.34 ±0.16
T. tetraptera	174.51 ± 25.31	194.48 ±24	0.32 ±0.04	0.36 ±0.06	5.09 ±0.65	4.82 ±0.83	1.21 ±0.15	1.14 ±0.06
K. senegalensis	191.18 ±22.95	205.30 ±21.02	0.36 ±0.05	0.38 ±0.06	6.39 ±0.56	6.95 ±1.74	1.54 ±0.1	1.66 ±0.23
C. alliodora	120.95 ±23.85	111.77 ±17.74	0.27* ±0.15	0.17 ±0.02	10.88 ±2.69	10.41 ±1.11	1.96 ±0.27	1.81 ±0.22
A. africana	205.86 ±36.60	196.87 ±33.27	0.28 ±0.05	0.26 ±0.03	3.33 ±0.37	3.26 ±0.32	1.46 ±0.16	1.35 ±0.11
A. boonei	130 ±25.90	141.00 ±19.30	0.78 ±0.08	0.71 ±0.18	2.39 ±0.63	2.53 ±0.42	10.88 ±2.69	10.41 ±1.11
T. superba	196.08 ±33.04**	149.22 ±17.66	0.33 ±0.08	0.40 ±0.09	2.58 ±0.63	3.17 ±0.43**	1.34 ±0.16	1.37 ±0.13
N. diderrichii	198.63 ±38.26	185.84 ±34.02	0.53 ±0.10	0.50 ±0.04	5.34 ±1.11	7.26** ±0.68	1.04 ±0.03	1.05 ±0.04
G. arborea	184.25 ±26.50	166.23 ±26.96	0.24 ±0.10	0.28 ±0.06	5.59 ±0.93	6.28 ±1.72	1.11 ±0.05	1.16 ±0.03
V. doniana	254.48 ±35.61***	189.96 ± 27.73	0.33 ±0.07	0.32 ±0.07	5.45 ±0.55j	5.41 ±1.45	1.43 ±0.07***	1.27 ±0.12
C. odorata	169.13 ±20.88	228.22 ±25.34***	0.28 ±0.04	0.33 ±0.05*	2.19 ±0.51	3.75 ±1.02	1.19 ±0.09	1.29 ±0.16
E. cylindricum	197.37 ±26.25	177.97 ±19.73	0.46 ±0.08	0.50 ±0.07	4.94 ±0.82	7.50 ±1.34*	1.23 ±0.08	1.20 ±0.09
Mansonia altissima	93.71 ±15.53	94.49 ±12.03	0.34 ±0.04	0.32 ±0.03	21.58 ±10.58***	10.85 ±1.56	1.98 ±0.10***	1.46 ±0.14
H. barteri	207.02 ± 23.58**	160.56 ±25.88	0.28 ±0.04	0.28 ±0.03	2.22 ±0.76	2.99 ±1.13	1.20 ±0.23	1.45 ±0.24*

***= significant at P<0.05**

Table 2: The results of Analysis of variance for vessel parameters among tree species.

Variables	Sources of Variation	DF	F value	Pr(>F)
Mtd	Radial (Outer and Inner)	1	3.22	0.07 ns
	Species	19	27.80	< 0.001 ***
	Regions (Stem and Root)	1	46.86	0.003**
	Regions*Species	19	6.67	< 0.001 ***
	Radial*Region	1	0.60	0.43 ns
Vl	Radial (Outer and Inner)	1	0.17	0.68 ns
	Species	19	57.45	< 0.001***
	Regions (Stem and Root)	1	0.13	0.72 ns
	Regions *Species	19	2.11	0.005 **

	Radial*Region	1	8.54	0.003**
Vd	Radial (Outer and Inner)	1	0.17	0.68 ns
	Species	19	50.48	< 0.001***
	Regions (Stem and Root)	1	0.55	< 0.001***
	Radial*Region	1	8.54	0.004**
	Regions *Species	19	19.73	< 0.001
Vgi	Radial (Outer and Inner)	1	0.60	0.44 ns
	Species	19	23.99	< 0.001***
	Regions (Stem and Root)	1	9.36	0.002 **
	Species*Regions	19	3.60	< 0.001***
	Radial*Region	1	42.22	4.666e-10***
Residual		240		
Total		319		

***= significant at P<0.05; ns= not significant at P>0.05**

Relationship between Variables and Wood Utilization

Effect of differences in pore sizes among the wood species investigated in this study will also bring about variation in wood texture. Bigger-vessel wood species are expected to be coarser than wood species with narrower numerous pores. These findings also are supported by previous studies on some wood species by Stamm (1931), Kemp (1957); Chen and Tang (1991); Hur and Kang (1997); Ofori and Brentuo (2005); Fogg and Choong (2007); Toong *et al*. (2014 and Jang *et al*. (2019). In view of this, texture will be coarse in trees like *M. excelsa, H.* barteri and V. *doniana* in which pores were large, while narrow and numerous pores in *Mansonia altissima* will enhance a smooth-textured surface which does not require special attention before finishing. However, more numerous pores in *M. altissima* will likely slow down the rate of drying owing to smaller vessel diameter as also stated by Eloy *et al* (2020) on certain study. Yet, initial moisture content is expected to reduce in wood species in which narrow vessels were recorded in this study.

Comparatively, wood species with expected lower initial content based on their narrow pores include *P. elata*, *M. altissima* and *C. alliodora*, although lower permeability is expected in wood species with small pores. Moreover, tyloses in *M. excelsa, F. exasperata, T. sceleroxylon, S. mombin, C. alliodora* (can be sclerotic), *G. arborea,* including gum or deposits in *N. diderrichii, P. osun, Khaya senegalensis***,** *E. cylindricum*, *E. angolense*, *T. tetraptera*, *P. elata* and *A. africana* can render their wood more resistant to bio-deteriorating agents. Yet, such cell inclusions (tyloses, gum or deposits) can hinder constant flow of liquid in vessels that are clogged by them thereby causing low liquid uptake and even slow down seasoning processes. Consequently, the presence of tyloses had been found to obstruct chemical preservatives in G. arborea (Olaniran *et al*. 2022). However, presence of tyloses and deposits in vessels can render these wood species more resistant to bio-deteriorating agents. Therefore, discrepancies in wood moisture content, rate and period of seasoning (and the attendant level of defects), wood processing, wood luster and texture, wood gluability, wood workability and wood nailing properties are an indication of sizes, arrangement and distribution of vessels within the trees.

Conclusion

The results from this study have shown that within a tree, qualitative features of the root wood had several common anatomical characteristics of the stem wood. Similarities in anatomical features between the root and stem regions will be advantageous during the process of wood

identification and determination of wood quality. This is because wood diagnostic method could be undertaken using the root wood without destruction of the whole tree.

There is divergence of wood cell composition, arrangement, distribution and sizes among the Nigerian hardwood species based on inherent characteristics that are uniquely exhibited in individual genera and families; and secondly, on the account of habitat and ecological niche.

There are clear variations on the account of quantitative analysis of cells between stem wood and root wood of the tree species. As such, higher or lower values of vessel diameter, vessel grouping, vessel density and vessel length recorded in the root or stem wood depend on the species and environmental factors, and therefore cannot be generalized.

Vessel group index (VGI) and vessel density, wherever they are reinforced in a tree are essential to provide alternative conduits in case of vessel malfunctions during cavitation (formation of bubbles by reason of big conduits) that results in embolism (air blockage) especially in stems in which water is transported through a long distance.

Discrepancies in wood moisture content, rate and period of seasoning (and the attendant level of defects), wood processing, wood luster and texture, wood gluability, wood workability and wood nailing properties are an indication of sizes, arrangement and distribution of vessels within tree xylem.

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