ECOLOGICAL AND FUNCTIONAL COMPARISON OF WOOD ANATOMY ON SOME TREE GENERA IN THE SOUTHERN NIGERIA

VIRGINUS OKWUDILI AYOGU, EBERE UGWUNWA NJOKU, ANTHONY NWEZE
UNIVERSITY OF NIGERIA
NIGERIA

ABSTRACT

This work aimed at utilizing wood anatomical traits to assess the compatibility or suitability of 9 species in the families where they belong since the earlier classification depended only on morphological characters and also to possibly deduce the permeability of their vessel lumen during wood treatment with preservatives of equal or different viscosity. Comparative stem anatomy of tree taxa *Antiaris toxicaria* Lesch. (Moraceae), *Ficus exasperate* Vahl. (Moraceae)*, Milicia excelsa* Welw. (Moraceae), *Dacryodes klaineana* Lam. (Burseraceae) *Canarium schweinfurthii* Engl. (Burseraceae), *Dacryodes edulis* Lam. (Burseraceae), *Erythrophleum suaveolens* Taub. (Fabaceae), *Pelthophorum pterocarpum* De Cand. (Fabaceae), *Pterocarpus soyauxii* Taub. (Fabaceae) was studied.
Observations on the transverse, radial-longitudinal and tangential-longitudinal sections showed that there were vast variations and few similarities in the vessel, axial parenchyma, ray cell and storied fibre distributions within and across families. Variations across the three ecological zones were found. The highest vessel diameter occurred in *C. schwenfortii* with 222.84μm (Burseraceae) followed by *F. Exasperate* with 196.42 μm (Moraceae) and *P. pterocarpum* with 187.23 μm (Fabaceae) across the three ecological zones. Vessel diameters were in direct proportion with the amount of rainfall while vessel frequencies were in negative proportion with the amount of rainfall across the ecological zones. Qualitative properties were not significantly affected by either temperature or rainfall.

KEYWORDS: Wood anatomy, taxonomy, vessel lumen sizes, wood treatment, Moraceae, Burseraceae, Fabaceae.

INTRODUCTION

Plant systematics has always drawn its backbone from the comparative study of plant morphology and anatomy. Anatomical characteristics are considered unavoidable when

the relationships among higher plants are elucidated. The internal structures of the plants have added a lot in understanding the relationship between the taxa (Wafaa 2005, Hammadi 2002, Al-Rubaie 2002, Lafta 2005, Al-Edany 2005). Plant anatomy is the branch of botany dealing with the anatomical and histological structure of various parts of plant organs. The comparative study of plant structure, morphology, and anatomy has always been the backbone of plant systematics. Anatomical characteristics are important evidence when elucidating the relationships among higher plants (Priya and Hari 2021). Functionally, Vessel elements and tracheids play a crucial role in the transport of water from roots to leaves (Carlquist 2001). Wood anatomical studies frequently provide several quantitative details of these cells, such as vessel diameter, vessel density, vessel element length, and tracheid length (Alexander et al. 2013). Tracheary elements have been studied by plant anatomists for many years and provide valuable information to a wide range of wood related study fields, ranging from wood identification and palaeobotany to plant ecology and physiology (Tyree and Zimmermann, 2002, Fonti et al. 2010, Pittermann 2010, Gasson 2011, Choat et al. 2011). Conduit parameters may not only provide additional structural information, but also valuable insight into hydraulic functionality and ecological trait (Schweingruber et al 2006, Fichtler and Worbes 2012). Enormous economic loss has been greatly experienced due to degradation by termite and fungi (Ajuziogu et al. 2018) Wood treatment is therefore imperative for the mitigation of this loss (Tsoumis 1991; Chunsheng et al. 2021; Kalleshwaraswamy et al. 2022). Nowadays, along with other branches, anatomy is also essential to validate and understand many aspects of plant biology, including the ecological and molecular ends of the spectrum (Priya and Hari 2021). The weakness of comparative wood anatomy lay in its separation from knowledge of ecology, habit and other relevant information (Calquist 2012). However, coupled with the relegation of ecological anatomy of small separate account in a handful of their familial summaries by Metcalfe and Chalk (1950) and Gregory (1994), as stated by Calquist (2012), the earliest plant taxonomy depended only on morphological characters for the delimitation of taxa. Comparative and functional wood anatomy as meant here investigated relationship within and across genera and within and across ecological zones. Also, quantitatively and qualitatively, it investigated how the variabilities in xylem anatomy of these genera are related to plant function, growth, and environment. There is an enormous diversity of xylem anatomy that can be spotted through the use of microscope. Moreover, wood anatomical features represent a natural store house for plant functioning and growth-environment relationships with inter and intra-annual resolution (Fonti et al. 2010).

In fact, as can be found in the earlywood or latewood, xylem cells may be localized at a certain position within a given annual growth ring, which is linked to the time of their formation. The xylem anatomical structures are influenced during their development by internal and external factors, and mal-adjusted xylem structure may even be responsible for tree mortality. Quantitative wood anatomy capitalizes on the xylem anatomical structures mostly fixed in the stems once the cells are mature, and often focuses on a small number of cell types such as conduits (vessels and tracheids), parenchyma (axial and radial), and fibres (Carrer et al. 2015; Pellizzari et al. 2016; Georg et al. 2016).

It is therefore, a course for concern that plant anatomy is highly and progressively marginalized among biology courses in the university (Cutler et al. 2008). One of the ways to

reduce the decline is to promote an awareness of the wider value of the study of plant structure as it allows researchers to conceptually integrate the structure of organism and function. It further helps to reveal the relationship between structure, function, taxonomy and ecology (Sebastian et al. 2022).

This work is aimed at comparing the anatomical variables of stem for proper taxonomic placement and to deduce the treatability of wood with regard to the measured vessel pore sizes.

MATERIAL AND METHODS

Replicates of five samples of stems of each of the nine species namely: *Antiaris oxicaria, Ficus exasperata, Milicia excelsa* - (Moraceae), *Dacryodes klaineana, Canarium schweinfurthii, Dacryodes edulis* - (Burseraceae) and *Erythrophleum suaveolens, Pelthophorump terocarpum, Pterocarpus soyauxii* - (Fabaceae) were collected from five different locations in each of the three ecological zones (Nsukka - Southern Guinea Savanna, Awka- Southern Derived Savannah, Obio/Akpo - Fresh Water Swamp Forest, in the Southern Nigeria making a total of 45 samples from each zone and 135 samples from the three zones. Nsukka lies at 6.86^{o}N, 7.39^{o}Eand is described as the transition woodland or low free Savannah. The area has 1051 mm rainfall annually with an average temperature of about (27.3^{o}C). Nsukka lies on the Udi Hill at an elevation of 1300 feet (396 m), altitude 455 m (Chinago 2015). Awka in Anambra State, Nigeria, lies at 6.22°N,7.08°E, with an annual rainfall of 1828 mm and an average temperature of 26.5°C (Okereke *et al.,* 2016). Obio/Akpo in Rivers State lies at 4.87°N, 7.01°E with an annual rainfall of 2708 mm and an average temperature of 25.8°C. It is located in the Fresh Water Swamp Forest (Adoki 2012).

These samples were put in polythene bags to keep their cells and tissues in the active cellular state from the point of collection to the Plant Anatomy Laboratory University of Nigeria, Nsukka. Small blocks 1-2 cm, cut out from the mature stem from the nine woody species werefixed in formalin acetic alcohol (FAA) separately in a well labelled glass jars. This solution contained 90 ml of 70% ethanol, 5ml of glacial acetic acid and 5 ml of formaldehyde. This preserved the blocks, and their cell contents for a long period as well as softening the blocks for easy sectioning with the microtome (Nwosu 2006).

Preparation of the slides
The method of Runsin (1999) was adopted, where sections were embedded in Parowax and subsequently dehydrated through a series of alcohol and finally cleared in xylene solution. Sections were stained in 1% aqueous Safranine 'O' for 5 min. The Safranine was drained off and the materials were rinsed with three changes of distilled water. Sections were counter stained with 1% fast green solution for 2 min, drained off and then rinsed with two changes of absolute alcohol. The sections were then cleared with pure xylene for 5 min and finally mounted on Canada balsam and sealed off with cover slips.

After the aforementioned procedures, wood samples were sectioned with a Reichert (Heidelberg) sledge microtome in three planes of sections and sections were examined under an Olympus (CHBS) model XSZ-107BN-Japan Biological Microscope at various magnifications: X40, X100 and X400.The ocular micrometer was first calibrated using a stage micrometer

placed on the stage of the microscope by aligning its zero mark with that of the ocular. The number of units of the ocular which aligns with a given unit of the stage micrometer, in a given magnification was noted. The values obtained were used after conversion in all the readings. Ten vessel lumen diameters were measured on each field of view and the mean taken. Vessel frequency/density was determined by counting the number of vessel in five fields of view on each slide and the mean recorded.

The data obtained from the anatomical parameters were subjected to One-way Analysis of variance (ANOVA) and Duncan's new multiple range test (DNMRT) to compare their means and for multiple separations of means respectively ($p \leq 0.05$).

RESULTS AND DISCUSSION

Observations on transverse sections (TS)

On the TS of the woods, vessels in the three species of Moraceae were present in solitary and radial multiples (Fig. 1). In Burseraceae, vessels were predominantly solitary in the three taxa while in Fabaceae, vessels in solitary and radial multiples were present. The highest vessel diameter occurred in *C. schwenfortii* with 222.84μm (Burseraceae) followed by *F. Exasperate* with 196.42 μm (Moraceae) and *P. pterocarpum* with 187.23 μm (Fabaceae) across the three ecological zones.
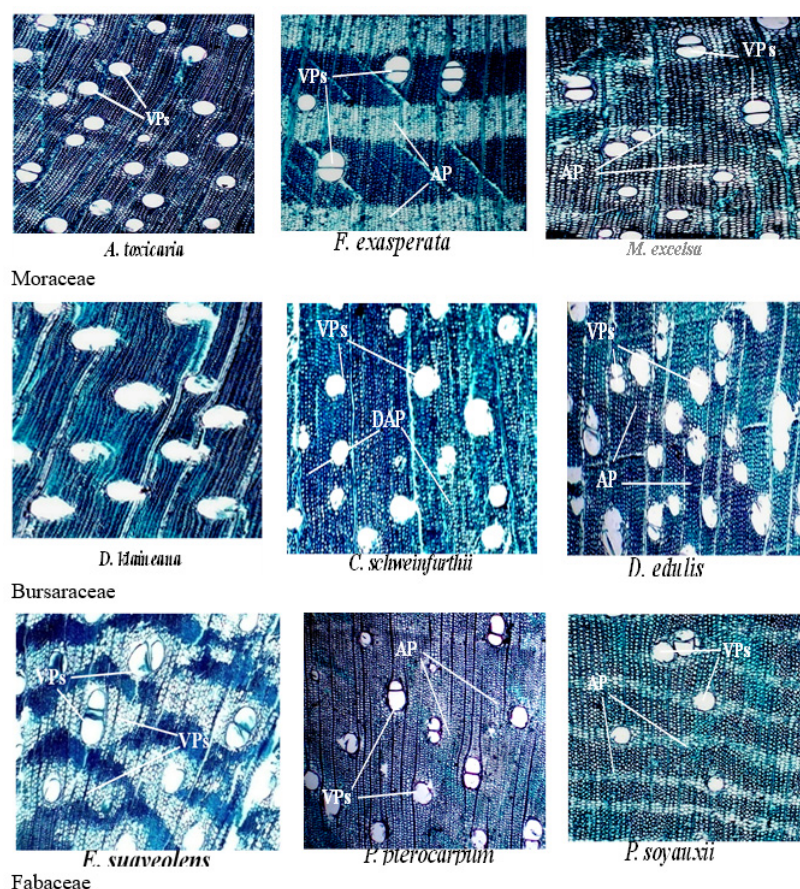

Fig. 1: Transverse section of woodsof the nine species showing vessels in solitary and radial multiples, axial parenchyma and ray cells. AP - axial parenchyma, VPs -vessel pores., DAP -diffuse axial parenchyma.

In Moraceae, *A toxicaria* had scanty type of paratracheal axial parenchyma *F. exasperata* had banded type of paratracheal while *M. excelsa* had a combination of aliform and banded types of paratracheal axial parenchyma. In Burseraceae, diffuse apotracheal was present in all the three taxa while in Fabaceae, *E. suaveolens* had a combination of aliform and vasicentric types, scanty type in *P. pterocarpum* (plate 1h) and banded type in *P. soyauxii*.

The ray cells were present in the radial direction in all the nine taxa of the three families. The three taxa of Moraceae, Burseraceae and Fabaceae had diffused porous wood within the growth or annual rings. No starch granules were observed in *E. suaveolens* but were observed in *P. pterocarpum* and *P. soyauxii*. No starch granules in Burseraceae but scantly present in Moraceae.

Observations on tangential-longitudinal sections (TLS)

In Moraceae, *A. toxicaria* and *M. excelsa* had biseriate rays being predominant while multiseriate was predominant in *F. exasperata* (Fig. 2). In Burseraceae, the three taxa had uni-, bi- and multiseriate rays but biseriate was predominant. The ray cells were nonstoried in all the taxa of Burseraceae. In Fabaceae, uni-, bi- and multiseriate rays were present. Multiseriate rays were predominant in *E. suaveolens*, uniseriate rayswere predominant in *P. pterocarpum* and biseriate ray were predominant in *P. soyauxii*.
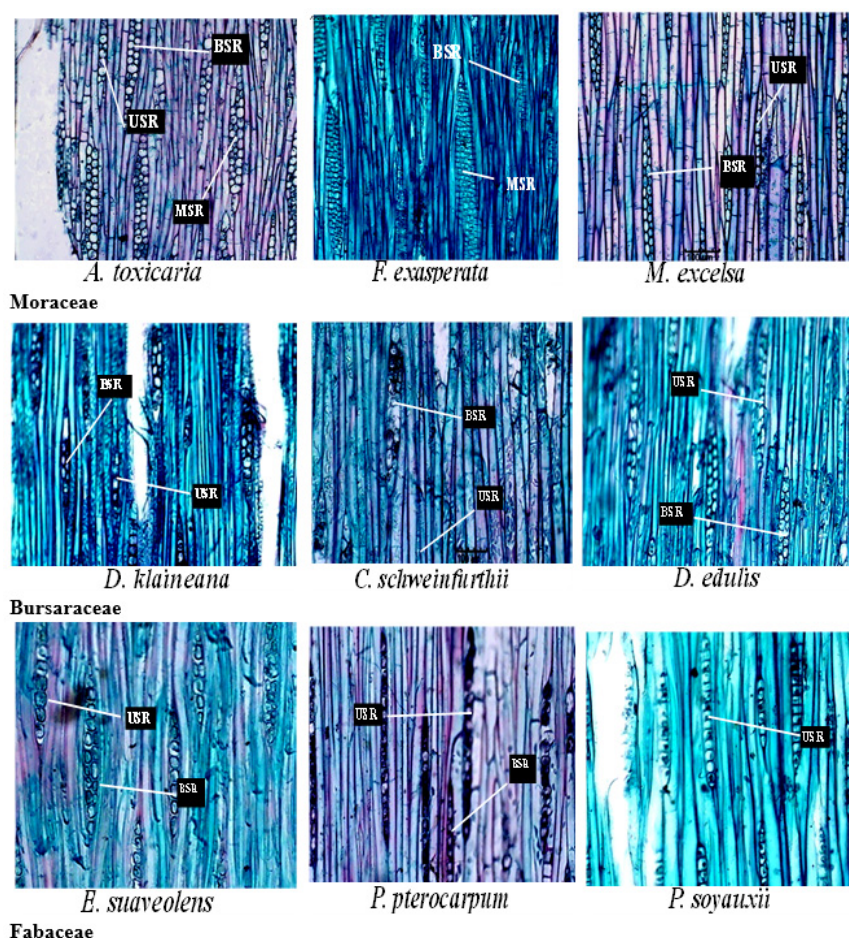

Fig. 2: Tangential-longitudinal sections of wood of the nine taxa. USR- uniseriate ray, BSR- biseriate ray and MSR- multiseriate ray.

Observations on radial-longitudinal sections (RLS)

Procumbent and upright ray cells were present almost in equal proportion in all the three taxa ofMoraceae. *D. klaineana* and *D. edulis* of Burseraceae had both upright and procumbent raysbut upright rays were predominant in *C. schweinfurthii*. Both upright and procumbent rays were present in Fabaceae. *P. Pterocarpum*was predominantly procumbent (Fig. 3).
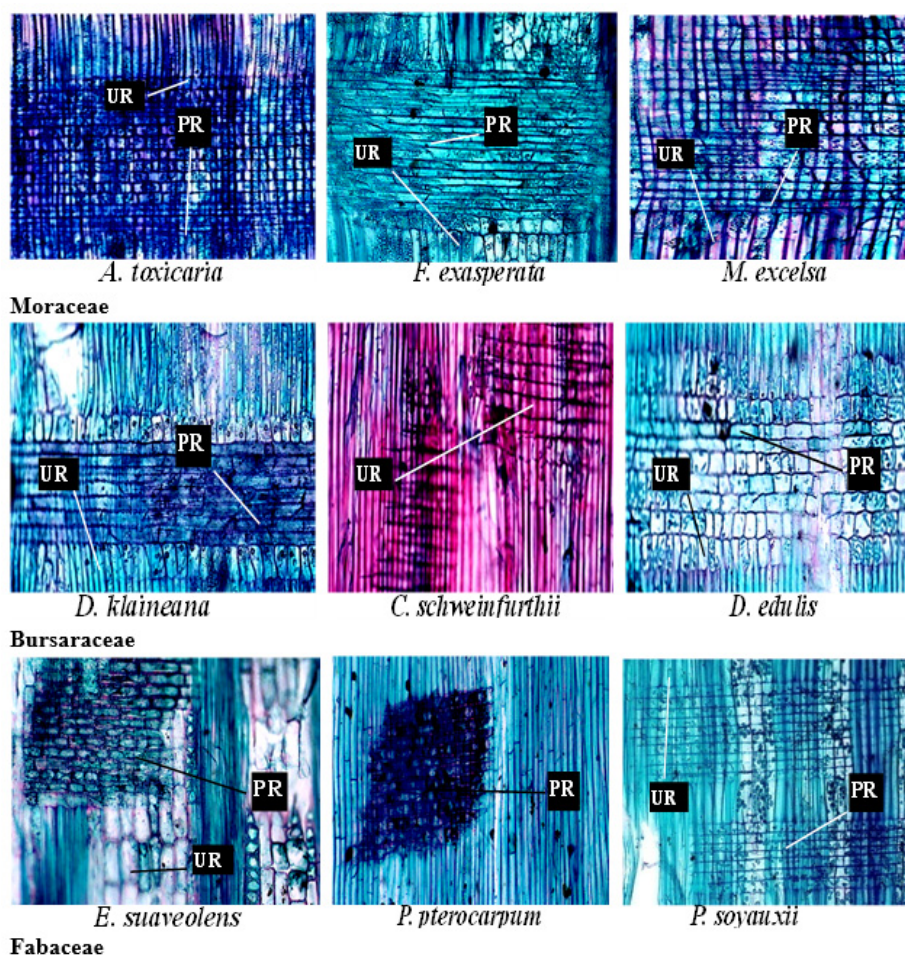

Fig. 3: Radial-longitudinal sections of wood of the nine taxa UR- upright rays, PR- procumbent rays.

Vessel grouping occurred in various patterns, which include vessel cluster, radial multiples and tangential multiples. The change of these grouping patterns between interspecific and intraspecific is frequently associated with a particular ecological, environmental or stressful condition. Larger number of vessel groupings occurred in the species from drier zone (Von Arx *et al.,* 2013; Mirwas*et al.,* 2019). For some species, the degree of vessel grouping is higher with stressful condition (Trifilo *et al.,* 2014). This work is in conformity with the works of the above two authors. Across the three ecological zones, the species in Moraceae have vessels in solitary and radial multiples but the groupings decreased from the Southern Guinea Savannah through Derived Savannah to Fresh Water Swamp Forest (Figs.4 and 5). Though, vessel groupings occurred in Burseraceae and Fabaceae, it decreased in intensity than that of the Moraceae. Functionally, the genera in Moraceae will be more hydraulically efficient and can withstand

the effects caused by embolism than those of the Burseraceae and Fabaceae. This was in conformity with the work of Sano et al. (2008) who opined that grouped vessels can withstand the effects caused by embolism or cavitations as other vessels will take up the hydraulic functions when some break down. This mostly applies to growing plants.

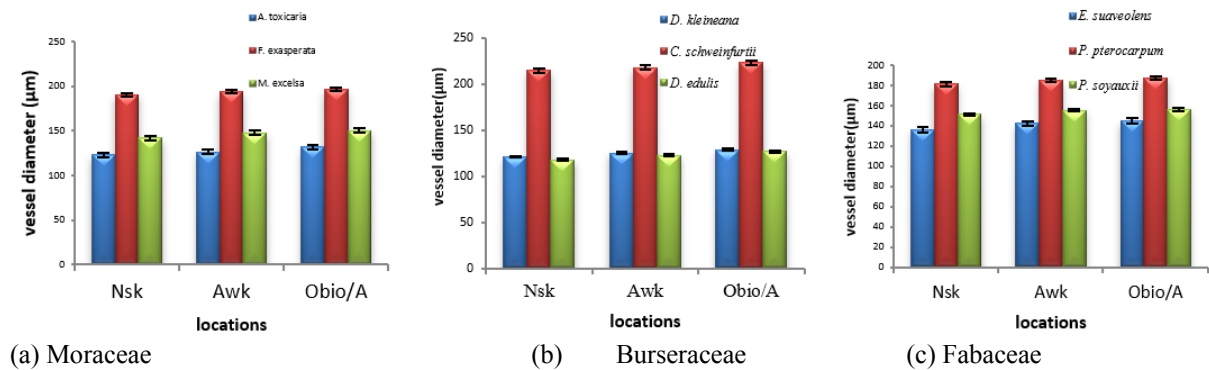(a) Moraceae   (b) Burseraceae   (c) Fabaceae

Fig. 4: Comparison of vessel diameters of the three families within and across three locations with significant differences across genera and across locations, increasing from Nsukka to Obio/Akpo(p ≤ 0.05).

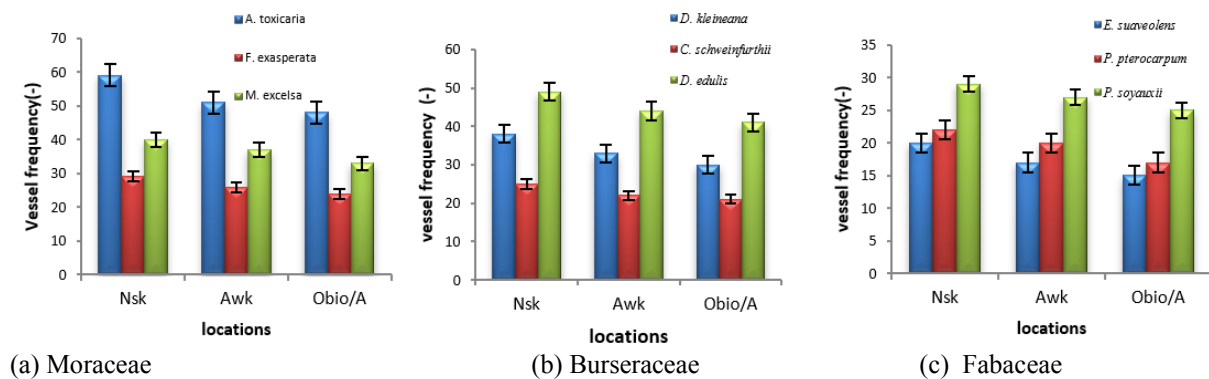(a) Moraceae   (b) Burseraceae   (c) Fabaceae

Fig. 5: Comparison of vessel frequency within and across families and across locations with significant differences across genera and across location in a decreasing order from Nsukka to Obio/Akpo (p ≤ 0.05).

On the vessel diameter, the results showed that variation in vessel diameter was influenced by environmental factors. Annual rainfall was in direct proportion to the vessel diameter. Higher temperature negatively affected the vessel diameter but positively affected the vessel frequency across the three locations. This conforms to Schreiber et al. (2015). They are well adapted to respond and adjust to environmental change through the process known as phenotypic plasticity (Nicotra et al. 2010; Urliet al. 2023).

In Moraceae, *F. exasperata* showed the widest vessel diameter followed by *M. excelsa* and *A. toxicaria,* in the increasing order from the Southern Guinea Savannah through the Southern Derived Savannah to Fresh Water Swamp Forest. In the same vein, in Burseraceae, *C. schweinfurthii* had the widest vessel diameter followed by *D. klaineana* and *D. edulis.* In Fabaceae, *P. pterocarpum* had the widest vessel diameter followed by *P. Soyauxii*and *E. suaveolens.* The decreasing order of hydraulic conductivity and vulnerability to cavitation in

all the genera across the three families were as follows, *C. schweinfurthii, F. exasperata, P. pterocarpum, P. soyauxii, M. excelsa, E. suaveolens, A. toxicaria, D. klaineana* and *D. edulis*.

This is in agreement with Mario et al. (2009) who stated that vessel sizes determine the relative hydraulic conductivity and vulnerability to cavitation and therefore, plants with wider vessel would be more vulnerable to cavitation and air embolism than the one with narrower vessels. If Hagen-Poiseuille equation $K = \pi r4\ 8l\eta$ is applied, where: *K* - conductivity, *l* - length of vessel member, *r* - radius of vessel lumen diameter, η - viscosity (Newman 1976), it can be deduced that the treatability rate on these woods will be in the order as listed above based on the vessel diameter and the viscosity of the preservatives that may be used.

Different types of axial parenchyma were observed within and across families while in some genera, axial parenchyma was totally absent (Fig. 1). This was in line with the work of Calquist (2001), who reported that there are many of the angiosperm woods in which axial parenchyma was absent or very scanty e.g. Burseraceae, Amborallaceae and Trochodendraceae. According to him, one reason for the scanty may be that in those families, upright ray cells were predominant and rays were close to each other. Therefore, upright rays may serve as a kind of substitute for axial parenchyma. This therefore, conformed to the observation made on radial longitudinal sections of wood in Burseraceae where the upright ray cells were predominant but virtually lack axial parenchyma in their transverse section (Fig. 1). In conifers, axial parenchyma is nearly irrelevant because of the margo-torus structure of the tracheid pit that is effective in minimizing cavitation. Unlike the angiosperms, embolism or cavitation is removed by the transfer of solute or photosyntate into the vessels from the axial parenchyma (Hacke et al. 2016). This follows in this work that the genera in Moraceae and Fabaceae will be more resistant to cavitations or embolism than the genera in Burseraceae even though those in Burseraceae have another resistant mechanism offered by the upright ray cells; the resistance offered by the axial parenchyma is more effective than the one offered by the ray cells.

The woods in all the genera were diffuse porous. This functionally meant that all the genera under study were more mechanically improved than other relatively high xylem/vessel area ratio of ring porous angiosperm woods, which conforms to Uwe et al. (2006) who stated that the relative low xylem/vessel area ratio for diffuse-porous angiosperm trees shields the plant from mechanical vulnerability. Ecologically, the vessel sizes/ diameter of angiosperm wood were in direct proportion with the soil water availability or high rainfall and in the reverse proportion with high temperature, while vessel frequency was inversely related to the higher rainfall or soil water but in direct proportion to higher temperature. It therefore, follows that diffuse porosity increases from the Guinea Savannah through the Southern Derived Savannah to the Fresh Water Swamp Forest.

CONCLUSIONS

Some authors have reported that plants were initially classified only on the morphological characters that they shared in common. This has led to changes, grouping and regrouping that keep taking place endlessly. This work therefore further exposed the weakness and

shortcoming that arose as a result of employing only morphological characters in the delimitation of taxa. It showed that some taxa were actually supposed to be grouped together under one family while some should be separated from their families and regrouped. For example, if classification should be made based on the axial parenchyma, all the taxa in the Moraceae should not be together because they do not share the same type of axial parenchyma. Likewise, in Fabaceae. The taxa in Burseraceae are actually suitable to be in one family because they all have the same type of axial parenchyma. By compatibility, based on the axial parenchyma, *F. exasperata* and *P. soyauxii* should be grouped together as both shared banded paratracheal type of axial parenchyma. *M. excelsa* of Moraceae shared the aliform type of axial parenchyma with *E. suaveolens* of Fabaceae. *A. toxicaria* in Moraceae shared the scanty type of axial parenchyma with *P. Pterocarpum* in Fabaceae. More so, vessel grouping in Moraceae, Burseraceae and Fabaceae were justified as the taxa in each of the families shared the same type of vessel grouping. On the TLS, classification based on the ray type should have *A. toxicaria* and *M. excelsa* grouped with the three taxa in Burseraceae and *P. soyauxii* in Fabaceae as they have ray cells predominantly biseriate while *F. exasperata* in Moraceae and *E. suaveolens* in Fabaceae should be grouped together, both having multiseriate rays. *P. pterocarpum* and *P. soyauxii* being in one family is justified as both of them have uniseriate ray cells. Ecological factors (Rainfall and temperature) affected the quantitative variable such as the vessel diameter and frequency because they changed across ecological zones. As the rainfall increased from Nsukka through Awka to Obio/Akpo, vessel diameters also increased. However, vessel frequency was in the inverse order with temperature. Meanwhile, these factors did not affect the qualitative variables (vessel grouping, ray types and axial parenchyma) within species across zones irrespective of the phenotypic plasticity of plant.

Therefore, the modern method of plant classification should not depend only on the morphological method for proper and reliable delimitation of taxa. Further studies can be conducted using the measured vessel diameters to estimate the rate of wood treatability by applying Hagen-Poiseuille equation since the permeability of preservatives in wood is majorly dependent on the vessel diameter.

REFERENCES

1. Al-Edany T.Y. (2005). Comparative anatomical study of some species of the family verbenaceae in Iraq, Basrah Journal of Agriculture Science, 18(1)35-51.
2. Alexander, S., Matthias, K., Zohreh, K. and Steven, J. (2013). How to quantify conduits in wood. Frontier Plant Science 4: 56
3. Al-Rubaie I.M., (2002). Comparative anatomical study of some species of Malvaceae in Iraq, Journal of Basrah Researches, 28: 90-109.
4. Adoki, A. (2012). Quality survey of some locations in the Niger Delta area. Journal of Applied Science and Environmental Management, 16:125-134.
5. Ajuziogu, G.C, Onyeke, C.C. Ayogu, V.O., Asuzu, C.U., Urama, D. C. and Odoh, N.V. (2018). Treatability indices of some plant species of Fabaceae in Nigeria. Wood Research 63 (6):971-978

6. Carlquist, S. (2001). Comparative wood anatomy. (2nd ed.). Springer-Verlag, Heidelberg, Germany. 157pp.

7. Carlquist, S. (2012). Fibre dimorphism: cell type diversification as an evolutionary strategy in angiosperm woods. Botanical Journal of the Linnean Society, 174: 44-67.

8. Carrer, M., von Arx, G., Castagnieri, D. and Petit, G. (2015). Distilling environmental information from time series of conduit size: the standardization issue and its relation to allometric and hydraulic constraints. Tree Physiology, 35: 27–33.

9. Chinago, A.B. (2015). Climatological review of Enugu rainfall from 1916-2012 and its implication. Global Journal of Science Frontier Research, 15:111-180.

10. Choat B., Jansen S., Brodribb T.J., Cochard H., Delzon S., Bhaskar R., et al. (2012). Global convergence in the vulnerability of forests to drought. Nature 491, 752–755

11. Chunsheng, W., Michael, D., Ulyshen, D., Chunjie, S., Zhijian, Z., Yi Zhang, Y., Yuanqiu, L., and Geoff, G.W. (2021). Stronger effects of termites than microbes on wood decomposition in a subtropical forest, Forest Ecology and Management, 493:119-263.

12. Cutler, D.F Botha, T. and Stevenson, D.W (2008). Plant anatomy: an applied approach. Annals of Botany,102(3): 481–482.

13. Fichtler E., Worbes M. (2012). Wood anatomical variables in tropical trees and their relation to site conditions and individual tree morphology. IAWA Journal. 33, 119–140

14. Fonti, P., von Arx, G., García-González, I., Eilmann, B., Sass-Klaassen, U., and Gärtner, H., (2010). Studying global change through investigation of the plastic responses of xylem anatomy in tree rings. New Phytology, 185: 42–53.

15. Gasson, P. (2011). How precise can wood identification be? Wood anatomy's role in support of the legal timber trade, especially cites. IAWA Journal. 32: 137–154

16. Georg, V.A., Alan, C., Angela, L.P., Katarina, C. and Marco, C. (2016). Quantitative wood anatomy- practical guidelines. Frontiers in Plant Science,7:781-796.

17. Hacke, U.G., Spicer, R., Schreiber, S.G., and Plavcová, L. (2016). An ecophysiological and developmental perspective on variation in vessel diameter. Plant Cell Environ. 40: 831–845.

18. Hammadi, K.J. Al-Mayah A.A. and Al-Rubaie, I.M. (2002). Comparative anatomical study of some genera of Polygonaceae in Iraq. Journal of Basrah Researches, 28:90-109.

19. Hajek, P., Leuschner, C., Herte, I.D., Delzon, S., and Schuldt, B. (2014). Trade-offs between xylem hydraulic properties, wood anatomy and yield in Populus. Tree Physiol. 34: 744–756.

20. Kotowska, M.M., Hertel, D., Rajab, Y.A., Barus, H., and Schuldt, B. (2015). Patterns in hydraulic architecture from roots to branches in six tropical tree species from cacao agroforestry and their relation to wood density and stem growth. Frontiers in Plant Science. 6:191.

21. Lafta A.H., Al-Saadi S.A. and Al-Edany T.Y., (2005). Taxonomic significance of anatomical characters of different species of the family Chenopodiaceae in Iraq, Basrah Journal of Science 23(1) 59-73.

22. Larjavaara, M. and Muller-Landau, H.C. (2010). Rethinking the value of high wood density. Functional Ecology, 24:701–705.

23. Metcalfe, C.R. and Chalk, L. (1950). Anatomy of the Dicotyledons. Volume 2. Clarendon Press. Oxford, UK. 245pp.

24. Mirwas M.Q., Ashley B.M. and Sage, L.D. (2019). Environmental factors influencing plant vascular system and water regulation. *Plants 8*(3), 65.

25. Nicotra, A.B., Atkin, O.K., Bonser, S.P., Davidson, A.M., Finnegan, E.J. and Mathesius, U. (2010). Plant phenotypic plasticity in a changing climate. Trends in Plant Science, 15: 684–692.

26. Nwosu, M.O. (2006). Preparation of botanical slides. In: Inyang, N.M., Nwosu, M.O. and Ivoke, N. (Eds.). A Manual of Laboratory Techniques in Biology. University of Nigeria, Nsukka Press, Nigeria, pp.131-162.

27. Okereke, N. C., Mbaekwe, E.I., Nnabude, P. C., Ekwealor, K.U., Nwonumara, G.U., Iroka, C.F. and Ukpaka, G. C. (2016). Comparative evaluation of the species richness and diverdity of three parallel forest ecosystems in Southeasthern Nigeria. Journal of Agriculture and Ecology Research International, 8(4): 1-12.

28. Pellizzari, E., Camarero, J. J., Gazol, A., Sangüesa-Barreda, G. and Carrer, M. (2016). Wood anatomy and carbon-isotope discrimination support long-term hydraulic deterioration as a major cause of drought-induced dieback. Global Change Biology, 22: 2125–2137.

29. Priya, C. and Hari, N. (2021). A review on anatomical methods in plant systematics, Plant Archives,21(1): 1417-1424.

30. Runsin, S.E. (1999). Plant microtechnique and microscopy. Annals of Botany, 86(3):322-328.

31. Sano, Y., Ohta, T. and Jansen, S. (2008). The distribution and structure of pits between vessels and imperforate tracheary elements in angiosperm woods. International Journal of Wood Anatomists Journal, 29: 1 – 15.

32. Schweingruber F., Börner A. and Schulze E. (2006). Atlas of woody plant stems – evolution, structure, and environmental modification. Heidelberg, Berlin: Springer

33. Schreiber, S.G., Uwe, G.H and Andreas, H. (2015). Variation in vessel diameters across a climate gradient: insight from a reciprocal transplant experiment with a widespread boreal tree. Functional Ecology, 29:1392-1401.

34. Sebastian, S., Mark, F., Jonathan, M., Suanna, L. Julie, P. and Karan, L.B. (2022). The botanical education extinction and the fall of plant awareness, Ecology and Evolution 12(7).

35. Trifilò, P., Barbera, P.M., Raimondo, F., Nardini, A. and Gullo, M.A.L. (2014). Coping with drought-induced xylem cavitation: coordination of embolism repair and ionic effects in three Mediterranean evergreens. Tree Physiology, 34:109–122.

36. Tsoumis, G., 1991: Science and technology of wood structure, property, utilization. Chapman and Hall. London, 494 pp.

37. Tyree, M.T. and Zimmermann, M.H. (2002). Xylem structure and the ascent of sap. 2nd Edn Berlin, Heidelberg, New York: Springer-Verlag

38. Urli, M., Porté, A.J., Cochard, H., Guengant, Y., Burlett, R. and Delzon, S. (2013). Xylem embolism threshold for catastrophic hydraulic failure in angiosperm trees. Tree Physiology,33: 672–683.

39. Uwe, G.H., John, S.S., James, K.W. and Laura, C. (2006). Scaling of angiosperm xylem structure with safety and efficiency. Tree Physiology, 26: 689 – 701.

40. Von Arx, G., Kueffer, C. and Fonti, P. (2013) Quantifying plasticity in vessel grouping-added value from the image analysis tool ROXAS. IAWA Journal, 34:433–445.

41. Wafaa, K.T. (2005). Modern trend in plant taxonomy. Asian Journal of Plant Science, 4(2):184-202.

VIRGINUS OKWUDILI AYOGU, EBERE UGWUNWA NJOKU*, ANTHONY NWEZE
UNIVERSITY OF NIGERIA
DEPARTMENT OF PLANT SCIENCE AND BIOTECHNOLOGY
NSUKKA, ENUGU
NIGERIA
*Corresponding author: Ebere.njoku@unn.end.ng