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WOOD ANATOMY INDICES IN REVEGETATION OF DESERTIFIED AREAS

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ABSTRACT
Wood anatomy indices of Calquist (1977) namely Vulnerability and Mesomorphy of four plant species (*Gmelina arborea*, *Pentaclethra macrophylla*, *Ceiba pentandra* and *Ixora coccinea*) in Nigeria were studied to determine their adaptability to desertified areas. Temporal and permanent slides of transverse sectioned samples and macerated samples from each of the plant species were prepared and viewed under light microscope with 20 replications. Vessel density per mm^2, vessel diameter (µm) and vessel length (µm) were determined for each of the plant species as the parameters needed to calculate Vulnerability and Mesomorphy. The result showed that high Vulnerability and high Mesomorphy values were obtained in *Gmelina arborea*, *Pentaclethra macrophylla* and *Ceiba pentandra* which did not fall within the range of 0 – 2.5 and 0-199 respectively required for plant to adapt in desert areas. *Ixora coccinea* had low Vulnerability and low Mesomorphy values that were within the range. It could be concluded that *Gmelina arborea*, *Pentaclethra macrophylla* and *Ceiba pentandra* are mesophytes and cannot adapt in desertified areas. *Ixora coccinea* is xerophytic and can adapt in desert areas therefore can be used to revegetate desertified areas.

KEYWORDS: Wood Anatomy, Maceration, Mesomorphy, Vessel, Vulnerability

INTRODUCTION

One of the adverse consequences of uncontrolled exploitation of trees is desertification, a phenomenon that is both challenging and crucial to the survival of man. Desertification or desert encroachment in Tropical Africa particularly in West African sub-region is one of the menacing contemporary phenomena and indeed environmental problems facing mankind (Oladele and Iyabode, 1988). Desert encroachment is in its alarming rate in Nigeria. Experts agree that an estimated 35% of land that was cultivated 50 years ago is now desert in 11 of Nigeria's northern states (Lloyd, 1991). One of the worst affected areas is in Yobe state in northern Nigeria. Other affected areas include Borno, Bauchi, Gombe, Adamawa, Jigawa, Kano, Kastina, Zamfara, Sokoto and Kebbi states (Lloyd, 1991). The symptoms are erosion, little rainfall and drought. In addition to sustained efforts to raise tree plantations for industrial and domestic uses there is need to embark on massive forestation programs by way of tree planting exercise. Each year, government embarks on revegetation program through tree planting in desert prone areas, however such program has not yielded result as more areas are been encroached by desertification. Among other factors, the choice of plant species being used for revegetation exercise determines its success. According to Calquist (1977) plants that adapt in conditions of water stress have low vulnerability value within the range of 0 – 2.5 and mesomorphy value of less than 200. Vulnerability is a measure of the probability of cavitations and air embolisms in vessels under conditions of water stress. Vunerability of xylem to cavitations is the percentage loss of conductivity with decreasing water potential (Cochard, 1992). Low vulnerability value indicates low probability. Mesomorphy indicates the status of plants as either mesophytes or xerophytes. Plants being recommended for revegetation of desertified areas must, essentially, be able to conduct water effectively through the vessels, when subjected to water stress i.e. the probability that water conduction would be seriously impaired by cavitation and air embolisms formed in the vessels when subjected to water stress should be low (Calquist, 1977, 1985; Schultz and Matthews, 1988; Tyree and Sperry, 1989; Tognetti *et al*., 1996). There is need to determine whether the xylem of the tree is well adapted to conditions of water stress or not before it is used to revegetate desertified areas.

Gmelina arborea belongs to the family Lamiaceae. The tree attains moderate to large height up to 21m high with 2m in girth, bole tapering with slight buttresses. Bark smooth, light brown to light grey, deciduous. Wood yellowish white, soft and light (Keay, 1989). It is commonly called gmelina and white beech (English), Melina (Spanish), gamar in Bangladesh, and it has many regional names (Anon, 1994). *Gmelina arborea* is found in rain forest as well as dry deciduous forest and tolerates a wide range of conditions from sea level to 1200m elevation and annual rainfall from 750 to 5000. It grows best in climates with mean annual temperature of 21-28^{0}C (Jensen, 1995). *Gmelina arborea* originated in an area of South Africa and South Asia from Pakistan and Sri Lanka to Myanmar. It is widely planted in Southeast Asian countries (Jensen 1995). It has been planted less widely in tropical African and Latin American countries (Evans, 1982). The wood is mainly used in Nigeria as a pulping timber (Oladele, 1991; Okereke, 1962). The leaves and fruits are used as fodder in many parts of India (Lauridsen *et al*., 1995). A number of the plants parts have medicinal values. It also produces good quality honey.

Ceiba pentandra, known as Kapok tree is a tropical tree of the family Malvaceae (previously separated from the family Bombacaceae), native to Mexico, Central America and the Caribbean. The tree grows to 60-70m high, 3m in girth. The trunk and many of the larger branches are densely crowded with very large, robust simple thorns. The leaves are compound; 5 to 9 leaflets each and palm like. *Ceiba pentandra* is found in the tropical rainforests (Brunken *et al*., 2008). The plant is cultivated in Java, Philippines and Malaysia, and in South Africa. It has ethnomedical uses. The bark decoction has been used as a diuretic, aphrodisiac, and to treat headache, as well as type II diabetes (Brunken *et al*., 2008). It is also used as an additive to sane version of the hallucinogenic drink (Brunken *et al*., 2008). The seeds produce oil used locally in soap production and that can also be used as fertilizer.

Ixora coccinea belongs to the family Rubiacceae. It is a multi-branched evergreen shrub, grows 1.2-2m in height, capable of reaching up to 3.6m height. It has a rounded form, with a spread that may exceed its height. It has glossy, leathery, oblong leaves. *Ixora coccinea* is found in warm climate. It is native to tropical South-east Asia, including Southern India and Sri Lanka. It has become one of the most popular flowering shrubs in South Florida gardens and landscapes (Wikipedia, 2015). It is used in warm climate for hedges and screens, foundation plantings, massed in flowering beds, or grown in greenhouse or as a potted house plant requiring bright light. *Pentaclethra macrophylla,* the oil bean tree is the sole member of the genus occurring naturally in the humid lowlands of West Africa. It is a leguminous species (family Leguminosae), and recognized by peasant farmers in the southeast of Nigeria for its improvement properties. It has been cultivated in Nigeria since 1937 (Ladipo, 1984) and for many years in other West Africa countries where its seed is relished as food. The tree grows to about 21 meters in height and about 6m in girth (Keay, 1989). Its tree has a characteristic low branching habit and an open crown which allows substantial light under its canopy. This character accounts for the tree's use in combination with food crops on farms and particularly in home gardens in southeastern Nigeria. Stem form is usually crooked and buttressed. Some straight stemmed and less buttressed trees, which can pass for good timber, are occasionally seen in the forest. Its bark is grayish to dark reddish brown (Keay, 1989); thin and patchy with irregular flaking. *Pentaclethra macrophylla* occurs from Senegal to Angola and also to Islands of Principe and Sao Tome. This multipurpose tree is endemic to the humid and some parts of the sub-humid zone of West Africa. It does not occur in the highland although, growth can be good where rainfall is adequate and temperatures are not cooler than 18^{0}C. The natural distribution of *P. macrophylla* suggests that it is endemic to relatively acid soils. The species also tolerates water logging as in low altitudinal riverine areas of the southeast Nigeria, Togo and Cameroun. The seed serves as food to people in Nigeria and Ghana and can also be used to produce edible oil. The pod ash is used as salt substitute in Ghana. *Pentaclethra macrophylla* is planted on the fringes of compound farms mainly for its edible seed. Okafor and Fernandez (1987) described the species as a major component of agro-forestry.

This study was aimed at studying the adaptability of *Gmelina arborea, Pentaclehra macrophylla, Ceiba pentandra and Ixora coccinea* to desertified areas by determining the wood anatomy indices of Calquist (1977) of the plants, namely vulnerability and mesomorphy, in order to obtain information on if the plants could be used to revegetate desertified areas.

MATERIALS & METHODS

Collection and Preservation of Samples

Four different species of tree used for the study were variably identified based on preliminary observations on their morphological and floral characteristics as described by Keay *et al.* (1964). The tree species were *Gmelina arborea, Pentaclethra macrophylla, Ceiba pentandra and Ixora coccinea*. Samples from these four tree species were collected from Botanic Garden, University of Nigeria Nsukka. Each species were cut down and four 2-3cm thick wood discs were taken. Some of the wood discs were fixed in Formalin Acetic Acid (FAA), to prevent fungal attack.

Sectioning of Wood Samples

The wood samples were cut into sections using the sledge microtome. The thickness of the sections was 10 microns. The sections were made from one plane - the transverse section (TS). The sections from various wood samples were put in a 70% alcohol. This concentration of alcohol could equally serve as a storing medium if sectioning was not done on the same day.

Temporary Slide Preparation

For temporary slide preparation, iodine was used and prepared by dissolving 1g of iodine crystal with 2g of potassium iodide (KI) in 300ml of distilled water. The sample was mounted with 1-3 drops of iodine for identification of starch grains, which stains blue black and for identification of tissues.

Permanent Slide Preparation

The sections were separately transferred into staining jars containing safranin for 10mins. The safranin was drained off and the sections were washed 3 times with distilled water to remove excess stain. The sections were then dehydrated twice in 97% ethanol at 2 minutes internal and later in absolute alcohol for two minutes.

Counter Staining

The sections were put separately in 1% fast green for a duration of 10mins, then washed in absolute alcohol (3 times) at 2mins intervals. They were washed twice with xylene solution at 2mins intervals to clear the sections.

Maceration of Wood

The Schltze method of maceration was adopted (Kpikpi and Olatunji, 1990). In this method, chips of wood about twice the size of half a match stick were placed differently in four labeled test tubes indicating plant source. To each of the test tubes 2g of potassium chlorate ($KClO_3$) crystal and 10mls of concentrated nitric acid (conc. HNO_3) were introduced. The test tubes were then placed in test tube racks with chips left to react in the solution until they were bleached and softened. Heating was not necessary because the potassium chlorate was a very powerful oxidizing agent capable of causing instant reaction and maceration with concentrated nitric acid. At the end of the spontaneous chemical reaction, the test tubes were transferred from the racks to the oven and maintained at constant temperature of 60^0C for several hours. Excess solution was decanted from the test tubes and the softened chips washed several times with clean water to prevent further chemical reaction. The softened chips were then separately transferred into a solution composed of phenol and glycerin in well labeled specimen bottles. The solution protects the tissues from undergoing any form of decay for a reasonable period of time. The chips in the specimen bottles were shaken with glass beads. This operation allowed the tissues to fall apart. The macerated wood samples were then stained in brilliant cresyl blue in the specimen bottles. Some macerated wood samples were stained in safranine red. The stained macerated woods were mounted on slides in 30% glycerin, carefully covered with cover slip ready for the measurement of the dimension using the light microscope.

Measurement of Vessel Diameter and Vessel Length

The vessel diameter and length were measured using a KYOWA TOKYO JAPAN monocular microscope to which ocular micrometers were fitted in the eye-piece tubes. The ocular micrometer was first calibrated using a stage micrometer of 2mm range. This was done by mounting the stage micrometer stage of the microscope and 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 at x40 magnification, was noted. This was used as the conversion factor in the subsequent measurement. That is, at x40 magnifications;

15 divisions of the eyepiece micrometer graduation was equal to 0.4mm of the stage micrometer scale, *i.e.* 15 divisions = 0.4mm

Therefore, 1 division = 0.4/15 = 0.026666 = 0.0267

Determination of Vessel density

The number of vessels for each of the species was counted within 1 square millimeter. The number of vessels that fell within a square millimeter were counted and recorded. A replication of 20 was made. Meanwhile, the square millimeter was prepared by caving open a box in a graph sheet. The box was however measured and it corresponded to a square millimeter.

Calculation of Vulnerability

A replication of 20 was taken and the vulnerability of the wood specimen was evaluated using Calquist (1977) formula;

$$\text{Vulnerability} = \frac{\text{mean vessel diameter}}{\text{Mean vessel number per mm}^2}$$

Calculation of Mesomorphy

A replication of 20 was taken and the mesomorphy of the wood specimens was evaluated as stated by Calquist (1977) as thus; Mesomorphy = Vulnerability x Mean vessel length

RESULTS

Vessel Density, Vessel Diameter and Vessel Length of *Gmelina arborea, Pentaclethra macrophylla, Ceiba pentandra* and *Ixora coccinea*

Vessel density, vessel diameter and vessel length as determined for each of the plant species studied were shown in Table 1. The results showed that *Gmelina arborea* had vessel density of 7.85, vessel diameter of 203.4µm and vessel length of 378.2µm. *Pentaclethra macrophylla*, had vessel density of 16, vessel diameter of 379.8µm and vessel length of 304.6µm. *Ceiba pentandra* had vessel density of 6.8, vessel diameter of 229.2µm and vessel length of 697.8µm, while *Ixora coccinea* had vessel density of 161.9, vessel diameter of 113.4µm and vessel length of 216.8µm. The result showed that *Ixora coccinea* had the highest density of (161.9) followed by *Pentaclethra macrophylla* (16), while *Ceiba pentandra* had the least (6.8). *Pentaclethra macrophylla* had the highest value of vessel diameter (379.8µm) followed by *Ceiba pentandra* (229.2µm), while *Ixora coccinea* had the least (113.4µm). Also *Ceiba pentandra* had the highest value of vessel length (697.8µm) followed by *Gmelina arborea* (378.2µm), while *Ixora coccinea* had the least (216.8µm).

TABLE 1: Vessel density, Vessel diameter and Vessel length of *Gmelina arborea, Pentaclethra macrophylla*, *Ceiba pentandra* and *Ixora coccinea*

Plant species	Vessel density per mm^2	Vessel diameter (µm)	Vessel length (µm)
Gmelina arborea	7.85 ± 0.2835*	203.4 ± 7.982*	378.2 ± 14.19*
Pentaclethra macrophylla	16 ± 0.5758*	379.8 ± 11.15*	304.6 ± 18.35*
Ceiba pentandra	6.8 ± 0.2471*	229.2 ± 16.94*	697.8 ± 24.34*
Ixora coccinea	161.9 ± 5.660*	113.4 ± 5.462*	216.8 ± 23.88*

*****Significance at $P < 0.001$.

Vulnerability and Mesomorphy of *Gmelina arborea, Pentaclethra macrophylla, Ceiba pentandra* and *Ixora coccinea*

Vulnerability and Mesomorphy of *Gmelina arborea, Pentaclethra macrophylla* and *Ceiba pentandra* were shown in Table 2. The result showed that *Gmelina arborea, Pentaclethra macrophylla* and *Ceiba pentandra* had high Vulnerability values of 25.91, 23.74 and 33.71 respectively, while *Ixora coccinea* had low Vulnerability value of 0.6877. Similarly, *Gmelina arborea, Pentaclethra* *macrophylla* and *Ceiba pentandra* had high Mesomorphy values of 9799.162, 7230.44 and 23522.84 respectively, while *Ixora coccinea* had low Mesomorphy value of 149.09.

TABLE 2: Vulnerability and Mesomorphy of *Gmelina arborea, Pentaclethra macrophylla, Ceiba pentandra* and *Ixora coccinea*

Plant species	Vulnerability	Mesomorphy
Gmelina arborea	25.91	9799.162
Pentaclethra macrophylla	23.74	7230.44
Ceiba pentandra	33.71	23522.84
Ixora coccinea	0.6877	149.09

DISCUSSION

Many adaptations of woody plants have been identified in their stems, chief among them is the low resistance to water flow in vascular tissues (Kozlowski and Pallardy, 2002). Variations in the wood anatomy indices of Calquist (1977) of the four plant species studied showed their level of adaptability to desert conditions. According to Calquist (1977) Vulnerability values of within the range 0 – 25 indicate a high degree of safety for water conductivity under conditions of water stress, while Mesomorphy value of below 200 indicate the status of the plants as xerophytes. High Vulnerability and high Mesomorphy values were obtained in *Gmelina arborea, Pentaclethra macrophylla* and *Ceiba pentandra* which did not fall within the range of wood anatomy indices of Calquist (1977) required for plants to adapt in desert areas. This suggests that their xylems may not adapt well in a condition of water stress, because high Vulnerability indicates that there was high probability of water conduction being seriously impaired by cavitaion and air embolism if the plants were subjected to conditions of water stress. High mesomorphy values obtained in *Gmelina arborea, Pentaclethra macrophylla* and *Ceiba pentandra* also revealed that the plants were mesophytes and had no xerophytic features therefore cannot thrive in desert areas. *Ixora coccinea* had low Vulnerability and Mesomorphy values that were within the range. This suggests that its xylems may adapt well in a condition of water stress, because low Vulnerability indicates that there was low probability of water conduction being seriously impaired by cavitaion and air embolism if the plants were subjected to conditions of water stress. Low mesomorphy values obtained in *Ixora coccinea* also revealed that the plant is xerophytic in nature and implied that it can survive in desert areas. Oladele and Iyabode (1988) obtained low Mesomorphy value of 0.67 and low Vulnerability value of 196 in *Gomphrena celosioides* plant and concluded that the plant was xerophytic and could survive in desertified areas.

The efficiency of water transport system (the xylem vessels in angiosperms) can significantly affect water movements by imposing conducting constraints (Tyree and Ewers, 1991). Vessel diameter and length are positively correlated in Angiosperms (Zimmermann and Jeje, 1981), and so reduced vessel length is associated with reduced vessel transactional area in decreasing xylem conductivity in water-stressed plants. The susceptibility of xylem vessels to embolism is linked to the size and structure of their pit pores and in general, smaller vessels are less susceptible to embolism (Salleo *et al*., 1985; Sperry and Tyree, 1988; Hargrave *et al*., 1994; Lo Gullo *et al*., 1995). Desert areas are characterized with low rainfall and shortage of soil water. Humidity is as well low. These suggest that rate of transpiration would also be high. For plants to survive in desert areas they must have some modifications to adapt to the harsh environment. Plants must absorb water efficiently to be able to compensate for the shortage of water and also for the loss of water through transpiration.

Ixora coccinea had high vessel density with low vessel size. These accounted for the specie's low vulnerability and mesomorphy values - mechanisms for adaptation to water stress in drought areas. These low values suggest that air embolism could be low and hydraulic conductivity could be high, thus water could rise up to the plant. *Gmelina arborea, Pentaclethra macrophylla* and *Ceiba pentandra* lacked these properties. *Gmelina arborea, Pentaclethra macrophylla* and *Ceiba pentandra* had low vessel densities and large vessels, suggesting that air embolism could be seriously high in these plants due to shortage of water in the soil. Hydraulic conductivity could be low, thus water may not rise up to the plant. These properties implied that these plants cannot adapt under desert conditions. Whereas increased vessel diameter greatly increases water conduction efficiency by lowering friction and delivering larger volumes of water per unit time (Zimmermann, 1983; Mauseth, 1988; Ewers *et al*., 1991; Sperry, 1995), it also decreases safety and renders vessels more vulnerable to cavitation, that is, the formation of air bubbles within the conduits resulting in breakage of water columns. Conduit diameter is directly related to cavitation frequency (Sperry, 1995). Cavitation can precipitate an air embolism; the embolism spreads from element to element through the perforations on xylem walls, and the entire vessel becomes useless (Zimmermann, 1983; Mauseth, 1988; Evert, 2006). The resulting reduction in water supply to the leaves can lead to water stress and then eventually death of the plant (Sperry *et al*., 2002; Zimmermann, 1983).

CONCLUSION & RECOMMENDATION

It can be concluded from the result of this study that the probability of survival of *Gmelina arborea, Pentaclethra macrophylla* and *Ceiba pentandra* in desert areas is low. They are therefore not recommended for revegetation of desertified areas. *Ixora cocinea* can survive in desert areas, therefore is recommended for revegetation of desertified areas.

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