

**SORPTION, WEATHERING AND ANATOMICAL PROPERTIES of *Gmelina arborea*
WOOD TREATED WITH CALCIUM CHLORIDE AND CITRIC ACID**

ORIGBO RAYMOND AYOMIDE

FWT/16/7133

SUBMITTED

TO

**THE DEPARTMENT OF FORESTRY AND WOOD TECHNOLOGY,
SCHOOL OF AGRICULTURE AND AGRICULTURAL TECHNOLOGY,
FEDERAL UNIVERSITY OF TECHNOLOGY AKURE, ONDO STATE, NIGERIA.**

**IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF
BACHELOR OF TECHNOLOGY (B.TECH) DEGREE IN FORESTRY AND WOOD
TECHNOLOGY**

MAY, 2023

CERTIFICATION

I certify that this project report titled “Sorption, Weathering and Anatomical Properties of *Gmelina arborea* Wood using Calcium chloride and Citric acid at varying curing time” is the outcome of the research carried out by **ORIGBO RAYMOND AYOMIDE**, with Matriculation Number: **FWT/16/7133** in the Department of Forestry and Wood Technology, The Federal University of Technology, Akure in partial fulfillment of the requirements for the award of Bachelor of Agricultural Technology degree (B.Agric.Tech) in Forestry and Wood Technology.

Dr. J. M. Owoyemi

Project Supervisor

DATE

Prof. A. G. Adedayo

Head of Department

DATE

DEDICATION

This work is dedicated to Almighty God, the all-knowing and my mediator for His grace, loving-kindness, and protection upon my life throughout the program and for making it turn out a huge success. This work is equally dedicated to Mr. and Mrs. J.E.R. ORIGBO.

ACKNOWLEDGEMENTS

My sincere appreciation goes to God Almighty, the all-knowing for His mercies that I have enjoyed all my life, for helping me throughout my journey in FUTA, He has been my sustenance up till today, His blessings of wisdom, knowledge and understanding resulting in all-round excellence I have today.

My profound gratitude goes to my supervisor Dr. J. M. Owoyemi, for his guidance, fatherly love and inspirational words which contributed immensely to giving me the frame of mind to complete this project.

I also want to appreciate the Head of the Department of Forestry and Wood Technology, Prof. A. G. Adedayo, Prof. M. B. Oyun and Prof. Babatunde Ajayi, and all the academic staffs of the Department for their advice and care throughout my undergraduate program. I will not forget the entire staff of Forestry and Wood Technology who has really imparted me in one way or the other. With great and sincere gratitude, I also appreciate my departmental mate (IFSA Class Dynatus “21) for their support academically

Special appreciation goes to my loving parents, Mr. and Mrs. J.E.R. Origbo for their love, prayers, moral, financial and spiritual supports towards my academic pursuit. My appreciation goes to my siblings for their encouragement and financial support throughout my stay in school. My appreciation also goes to my guardian and a mother, Mrs. G. Ojo for her encouragement and financial support during the course of my study.

ABSTRACT

The demand for timber in Nigeria is on the increase daily and wood users have majorly depend on wood from fast plantation grown wood species. The problem associated with the use of this available plantation wood species are dimensional instability which necessitate the need for properties enhancement to expand its use to serve additional functional purposes. This study assessed the physical, anatomical and durability properties of *Gmelina arborea* (*G. arborea*) wood treated with calcium chloride and citric acid with the objective to improving its basic properties. *G. arborea* tree was harvested and samples were taken longitudinally (top, middle and basal) and transverse (outer, inner and middle) directions. The samples were oven-dried at 103 ± 2 °C for 24 hours till constant weight was achieved before the selected parameters were tested. The wood samples were impregnated in a container with 30% solution concentration of Calcium chloride and Citric acid and cured for complete modification process in the oven at a temperature of 105°C at varying time regime (6 hours and 9 hours). The mean value of the absorption, weight loss due to leaching, density increment, weight percentage gain and retention of *G. arborea* wood treated with calcium chloride and citric acid were 10.91% and 17.48, 10.96% and 8.46%, 11.44% and 17.01%, 10.91% and 17.48% and 1.54% and 1.89% respectively. The results showed the samples treated with citric acid enhances dimensional stability to wood used in moisture prone environment particularly indoor construction.

.

TABLE OF CONTENTS

CERTIFICATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
1.0 INTRODUCTION	1
1.1 BACKGROUND TO THE STUDY	1
1.2 Statement of Problem	2
1.3 Objectives of the Study	3
1.4 Justification	4
1.5 Scope of the Study	5
CHAPTER TWO	6
2.0 LITERATURE REVIEW	6
2.1 Nature of Wood	6
2.2 Tree Description of <i>Gmelina arborea</i> Wood	7
2.3 <i>Gmelina arborea</i> Wood as a Raw Material Source	8
2.4 Wood and Moisture Relationship	8
2.4.1 Moisture Content of Wood	8
2.4.2 Equilibrium Moisture Content	10
2.4.3 Dimensional Changes in Wood	11

2.5 Wood Modification	11
2.5.1 Chemical Modification	12
2.5.2 Citric Acid as Modifying Agent	13
2.6 Anatomical Features	13
2.6.1 Fibres	13
2.6.2 Vessels	14
2.6.3 Rays	15
2.6.4 Anatomical Characteristics of <i>Gmelina arborea</i> Wood	15
2.7 Wood Weathering	16
2.7.1 Agents of Wood Weathering	17
2.7.2 Effects of Weathering on Wood used for Outdoor Purposes	19
2.7.3 Protection of Wood Weathering	21
3.0 METHODOLOGY	23
3.1 Study Area	23
3.1.1 Location	23
3.1.2 Climate	23
3.2 Methods	24
3.2.1 Sample Collection	24
3.2.2 Samples Preparation	25
3.2.2.1 Physical Properties Samples	25

3.2.2.1.1	Moisture Content	26
3.2.2.1.2	Density Determination	26
3.2.2.1.3	Volumetric Shrinkage	26
3.2.2.1.4	Volumetric Swelling	27
3.2.2.2	Treatment of Wood Samples	27
3.2.2.3	Curing of the Wood Samples	28
3.2.2.4	Chemical and Wood Compatibility	29
3.2.2.4.1	Wood Density Increment	29
3.2.2.4.2	Absorption	29
3.2.2.4.3	Weight Loss due to Leaching	29
3.2.2.4.4	Retention	30
3.2.2.5	Anatomical Characterization	30
3.2.2.5.1	Maceration	30
3.2.2.5.2	Sectioning	31
3.2.2.6	Anatomical Properties	31
3.2.2.6.1	Fibre Characterization	31
3.2.2.6.2	Wood Sectioning	32
3.2.2.7	Natural Weathering Test	32
3.3	Experimental Design	33
3.3.1	Experimental Model	33

3.4 Statistical Analysis	34
4.0 RESULTS AND DISCUSSION	35
4.1 RESULTS	35
4.1.1 Moisture Content Distribution	35
4.1.2 Density	37
4.1.3 Volumetric Shrinkage	40
4.1.4 Volumetric Swelling	42
4.1.5 Colour Changes	45
4.2 Chemical and Wood Compatibility	46
4.2.1 Absorption	46
4.2.2 Retention	48
4.2.3 Wood Density Increment	50
4.2.4 Percentage weight loss due to leaching of <i>Gmelina arborea</i> wood	52
4.2.5 Volumetric Swelling of <i>Gmelina arborea</i> Wood Treated with Calcium chloride and Citric acid at varying Curing Time	54
4.3 Anatomical Properties	57
4.3.1 Fibre Characterization	57
4.3.1.1 Fibre Length	57
4.3.1.2 Fibre Diameter	59
4.3.1.3 Lumen Width	61

4.3.1.4 Anatomical Properties	63
4.4 Wood Weathering	65
4.4.1 Weight Loss due to Weathering	65
4.4.2 Weathering Visual Observation	67
4.5 DISCUSSION	70
4.5.1 The Basic Properties of <i>G.arborea</i> Wood	70
4.5.2 Moisture Content Distribution	70
4.5.3 Density of <i>G.arborea</i> Wood	71
4.5.4 Volumetric Shrinkage of <i>G. arborea</i> Wood	72
4.5.5 Volumetric Swelling of <i>G. arborea</i> Wood	72
4.5.6 Weight Loss due to Leaching of <i>G. arborea</i> Wood	73
4.5.7 Dimensional Stability and Moisture Response of the Wood Treated with Citric acid and Calcium chloride	73
4.6.1 Anatomical Properties	74
4.6.1 Fibre Characterization	74
4.6.1.1 Fibre Length	74
4.6.1.2 Fibre Diameter	75
4.6.1.3 Lumen width	75
4.6 Wood Weathering of <i>G. arborea</i> Wood	76
5.0 Conclusion and Recommendations	77

5.1 Conclusion	77
5.2 Recommendation	77

List of Figures

Figure 1: Map of Ondo state showing the study area	23
Figure 2: The Descriptive Percentage Weight Loss due to Weathering of Gmelina arborea Wood	66

LIST OF TABLES

Table 4.1.1: Statistical Analysis for Moisture Content Distributor for the Different Stem Height and Lateral Positions	36
Table 4.1.2: ANOVA Table for the Moisture Content Distribution of <i>Gmelina arborea</i> Wood for different Stem Height and Lateral Positions	36
Table 4.1.3: Statistics for Green Density of <i>Gmelina arborea</i> Wood from the different Stem Height and Lateral Positions	38
Table 4.1.4: ANOVA Table for the Densities of <i>Gmelina arborea</i> Wood Obtained from the different Stem Height and Lateral Positions	39
Table 4.1.5: Volumetric Shrinkage of <i>Gmelina arborea</i> Wood from the different Stem Height and Lateral Positions	41
Table 4.1.6: ANOVA Table for Volumetric Shrinkage of <i>Gmelina arborea</i> Wood Obtained from different Stem Height and Lateral Positions	41
Table 4.1.7: Volumetric Swelling of <i>Gmelina arborea</i> Wood from the different Stem Height and Lateral Positions	44
Table 4.1.8: ANOVA Table for Volumetric Swelling of <i>Gmelina arborea</i> Wood Obtained from different Stem Height and Lateral Positions	44
4.3. 1: Fibre Length of <i>Gmelina arborea</i> wood obtained from different stem height positions	58
4.3. 2: ANOVA Table for Fibre Length of <i>Gmelina arborea</i> wood obtained different Stem Height Positions	58
4.3. 3: Fibre Diameter of <i>Gmelina arborea</i> wood obtained from different stem height positions	60
4.3.4: ANOVA Table for Fibre Diameter of <i>Gmelina arborea</i> wood obtained from different Stem Height Positions	60

4.3. 5: Lumen Width of Gmelina arborea wood obtained from different stem Height	62
4.3. 6: ANOVA Table for Lumen Width of Gmelina arborea wood obtained from different Stem Height Positions	62

List of Plates

Plate 1: The nature of wood- Wood grains	7
Plate 2: Location of water in a cell	10
Plate 3: Dimensional changes in three directions	11
Plate 4: Cracks in Wood	16
Plate 5: Wood stained with Fungi	19
Plate 6: Wood with splits and checks when exposed outdoor	20
Plate 7: Effect of Fungi on facial board	21
Plate 8: Construction method to drain off moisture	22
Plate 9: The collection and preparation of wood samples	25
Plate 10: Citric acid pure	28
Plate 11: Sample sizes for Anatomical test	30
Plate 12: Sectioning of fibres	31
Plate 13: Samples set out on the weathering panel	33
Plate 14: <i>Gmelina arborea</i> wood impregnated with citric acid at different time	45

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Wood is a fibrous material which has been used for several years for fuel, construction and serves as industrial raw materials. It is an organic and natural composite of cellulose fibers embedded in a matrix of lignin which resists compression (Riki *et al.*, 2019). The composition of wood makes it to be an outstanding material which are its versatility, inexhaustibility and being renewable (Olaoye *et al.*, 2019).

Gmelina arborea tree is a fast-growing species of family Lamiaceae varying from shrubs to moderate to large size deciduous tree. It has tremendous use in the form of ornamental and medicinal plants, avenue plantation and timber tree (Poonam, *et al.*, 2021).

The potential utility of any wood is dependent upon its basic anatomical properties (Olaoye, *et al.*, 2019). Riki *et al.*, (2019) stated that wood being a valuable raw material for pulp and paper production, the anatomical properties of wood stand out. Also, knowledge in the anatomy of wood and its fiber characteristics is essential for assessing certain properties of wood for the purpose of preservative absorption, identification, relationship to strength, seasoning, wood working and pulping properties of the wood, and thus give a guide to wood utilization in service as an engineering material (Olaoye *et al.*, 2019).

Furthermore, wood is a hygroscopic material that has the ability to absorb or desorb water in response to temperature or relative humidity of the atmosphere surrounding it (Hartley and Hamza, 2016). This nature of wood contributes to the absorption of moisture through hydrogen bonding which makes it dimensionally instable and susceptible to insect attack or decay. Rowell (1983) stated that wood polysaccharides (i.e cellulose and hemicellulose) are mainly responsible for moisture uptake and release in changing environments that result in changes in the physical

properties of wood. Apart from the formation of crack, increased roughness and dis-colouration, decay fungi occurs when wood is exposed to ground air and solar radiation and it is the most damaging component of the outdoor environment and initiates a wide variety of chemical modification on the surface of the wood (Aquino *et al.*, 2021).

These notable shortcomings of wood in service calls for properties enhancement. However, wood modification has offered an alternative approach. Wood modification is an all-encompassing term to describe the application of chemical, mechanical, physical or biological methods to alter the properties of the materials (Sandberg D, *et al.*, 2017). Therefore, Chemical modification of wood is plausible to overcome weak points of the wood material that are mainly related to moisture sensitiveness, low dimensional stability, hardness, low resistance to bio-deterioration against fungi, termites, marine borers, and low resistance to UV irradiation (Dennis and Sanberg, 2020). The present investigation focuses on the assessment of physical, weathering and anatomical properties of *Gmelina arborea* wood treated with calcium chloride and citric acid to preserve wood for outdoor purposes and guide wood users on the peculiarity of wood.

1.2 Statement of Problem

The problem of decline in the supply of wood resources from the forest create an alternatives for wood users to majorly depends on supply of wood from fast growing plantation wood species such as *Gmelina arborea*, *Tectona grandis* etc. The problem associated with the use of this available plantation wood species which are the low durability properties, dimensional instability, and low density has made it imperative to find solutions to these problems so as to achieve the desired basic properties.

Variability in the anatomical properties of these wood species affect their utilization as material for construction, furniture making, e.t.c as there is insufficient information regarding the relationship between anatomical characteristics and adsorption properties of this tree species.

Accompanying the loss of wood are the swelling and shrinking stresses set up by fluctuations in moisture, surface roughening, grain rising and the formation of small checks or cracks which affects the physical properties of wood like density and dimension, and also the anatomical properties of the wood. As a consequence, wood treatment system based on citric acid or sorbitol has emerged as a promising alternative for modification of wood species which are characterized by poor durability while improving its various properties such as hardness and UV resistance (Kurkowiak *et al.*, 2022). Therefore, chemical modification via citric acid has been proven for its improvement of dimensional stability and biological durability to improve the basic properties of the commonly available plantation grown species. This study is aimed at providing adequate information about the effect of calcium chloride and citric acid treatment on the physical, anatomical and weathering properties of plantation grown *G. arborea* wood at different curing time to ascertain its behaviour while in service.

1.3 Objectives of the Study

The general objective of this study is to assess the physical, weathering and anatomical properties of *Gmelina arborea* treated with calcium chloride and citric acid at varying curing time with the aim to improving its basic properties for specific end use.

The specific objectives are to;

1. assess the basic physical properties and anatomical characteristics of the *Gmelina arborea* wood.

2. determine the effect of calcium chloride and citric acid treatment at varying curing time on the physical properties and anatomical characteristics of *G. arborea* Wood.
3. investigate the weathering effect on treated *G. arborea* wood samples.

1.4 Justification

In recent years, there is a rise in the consumption of wood and utilization of wood for different purposes without an adequate information on the anatomical properties of wood. Riki *et al.*, (2019) stated that though many works have been carried out on the potentials of many wood species for pulp and paper production and other purposes, no detailed review on the anatomical properties have been documented to serve as the benchmark for researchers for selecting any wood material for its peculiar uses. Understanding the basic structure of wood is a key to developing new method of wood modification, basic anatomical information is also important for wood utilization. In considering the future of wood anatomy, the view is expressed that if a continuing and more effective use is to be made of wood, then wood anatomy must have a future as it plays important role in the use of wood timber resources.

G. arborea is a fast growing deciduous tree which has been introduced extensively as a fast-growing tree (Lauridesen and Kjaer, 2002), which shows a low consideration strength and durability properties. These properties are all a result of chemical degradation reactions, which can be prevented or, at least, slowed down if the cell wall chemistry is altered (Rowell *et al.*, 1983). The properties of any resource are, in general, a result of the chemistry of the components of that resource. In the case of wood, the cell wall polymers (cellulose, hemicelluloses, and lignin) are the components that, if modified, would change the properties of the resource. If the properties of the wood are modified, the performance of the modified wood would be changed. This is the basis of our chemical modification of wood which is to change its properties and improve its performance.

Furthermore, chemical modification is gaining more attention for the reduction of wood sensitivity to water, leading to an increase in durability and decrease in the dimensional instability (Rowell *et al.*, 1983).

The understanding of the effects of the method and substances used in modification and preservation of wood material on its physical, mechanical and durability process is key to the successful utilization of these commonly fast-growing tree species in service by forest-based industries.

1.5 Scope of the Study

The scope for this study is to determine the physical, durability properties, and examine the anatomical characteristics of *Gmelina arborea* wood obtained from the Department of Forestry and Wood Technology Plantation, Ondo state Nigeria. The tests carried out under physical properties are moisture content determination, volumetric shrinkage, volumetric swelling, water absorption and density determination, the anatomical investigation was carried out at the Forestry Research Institute of Nigeria (FRIN), while the natural weathering test was carried out in the Federal University of Technology Akure. Samples were selected from top, middle and base portion.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Nature of Wood

Wood is a three- dimensional, polymeric composite made up of cellulose, hemicellulose and lignin forming the cell wall and these are primarily responsible for most of the physical and chemical properties. (Rowell, 1983, 2005, Samani *et al.*, 2020). These hydroxyl groups adsorb water from humid environments which then enters the wood matrix. Since the adsorbed water is held by hydrogen bonding, wood moisture changes caused by dynamic humidity conditions results in alternate swelling and shrinkage of wood and in physical degradation, sometimes leading to mechanical failure.

Wood is one of the most important renewable bi-resources used by mankind since prehistoric days. It was used for making weapons, in constructing shelters and as fuel (Sonowal and Gogoi, 2010). Compared to other lignocellulose materials, it has better mechanical strength and materials made of wood are of better aesthetic materials. Sonowal stated that like other lignocellulose materials, wood is prone to degradation and dimensional variation on exposure to moisture, heat and biological agents like fungi, termite pose the serious threat to untreated timber and other lignocellulose materials used in various construction

Moreover, wood has been used for construction, building, furniture, decoration, and other application for years. However, as a natural material containing cellulose, hemicellulose and lignin, wood is also prone to hygro-expansion and anisotropy. It undergoes swelling and shrinkage when the equilibrium moisture content changes with the environmental conditions, wood defects such as cracks, transformation and decay which shortens the service life and value of wood products (Zhengbin *et al.*, 2019).

Wood is a hygroscopic material which loses and gains moisture as a result of changes in the humidity. It undergoes degradation when exposed to environmental conditions which is caused by ultraviolet light (UV) radiation and water (Feist and Hon 1984; Feist *et al.*, 1989). The UV radiation causes photochemical degradation mainly in the lignin polymer in the cell wall.

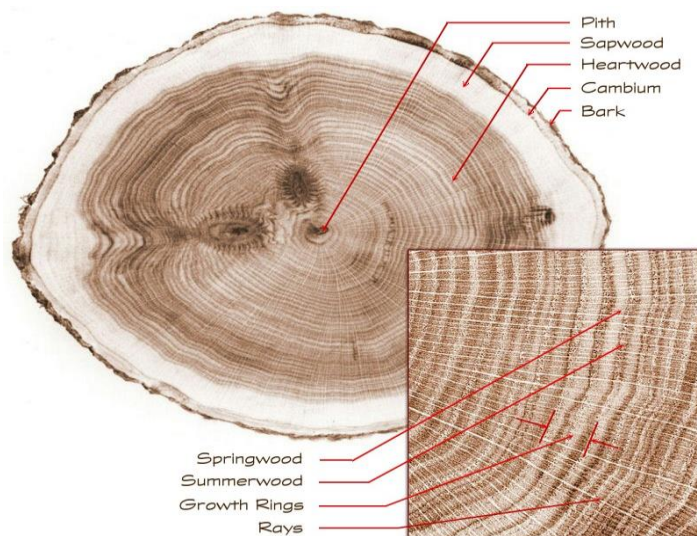


Plate 1: The nature of wood- Wood grain

2.2 Tree Description of *Gmelina arborea* Wood

Gmelina arborea is a fast-growing species of family Lamiaceae varying from shrubs to moderate to large size deciduous tree. It has tremendous use in the form of ornamental and medicinal plants, avenue plantation and timber tree. Though, it is a native of Asia, it has extensively been planted in tropical areas of Africa, Asia, Australia, America, West-indies and on several islands in Pacific ocean (Poonam, *et al.*, 2021). It is a light demanding, moderately frost hardy species and comes up well with a temperature range of 1 to 48°C and mean annual rainfall of 760 to 4500mm, grows well in soil PH ranging from 5.0 to 8.0 with preference for moist fertile alluvial with sandy loam soil (Poonam *et al.*, 2021). It is also considered as one of the classical medicinal plants due to multiple biologically active ingredients, and thus every part of the plant is utilized to treat number of diseases (Tewari, 1995; Poonam *et al.*, 2021).

The tree of *G.arborea* is approximate 40m and 140 cm in diameter. The tree form is fair too good, with 6-9m of branchless, often crooked trunk and a large, low-branched crown. The colour is dark grayish brown, branchlets, petioles, and inflorescence densely yellow-brown tomentose. The plant leaf is simple, opposite, less heart shaped, length is 10-25 cm and width is 5-18 cm. Flowers are brown in colour and arranged in pencil cymes 15-30 cm and it can appear after leaf fall. Fruit size is drupe 2.25 cm long and contains 1-4 seeds. One kg contains 700-1400 seeds (Arora and Tamrakar, 2017).

2.3 *Gmelina arborea* Wood as a Raw Material Source

The species has an extremely diverse array of uses such as in pulp and paper industry, laminated veneer lumber, wood cement composites, furniture interiors, particle board, plywood interiors, door paneling, finger jointed lumber, pallets, pencils, molding and match stick. The wood does not smoke when burned but produces high amount of ash and the wood is therefore used for charcoal production (Duke, 1983; Poonam *et al.*, 2021).

The wood is used for carving images, canoes, match manufacture, packing cases and ornamental works. It is also used for manufacture of toys and picture frames. The leaves and fruits of *G .arborea* are used as a feed stuff in India. Its fruits and leaves have been reported to contain several chemical constituents having medicinal value (Arora and Tamrakar, 2017).

2.4 Wood and Moisture Relationship

2.4.1 Moisture Content of Wood

The timber of living tree and freshly felled logs, the cell walls of the wood are always in the fully swollen condition, at fiber saturation. Therefore, no shrinkage or swelling occurs in the living tree except from hydrostatic tensions in the cell cavity water, and normal thermal expansion or changes in the fiber saturation point with temperature (Skaar, 1988). Once a fresh log or piece of lumber is

cut and exposed to the air, it will immediately begin losing free water. At this point, the wood does not contract or otherwise change in dimension since the fibers are still completely saturated with bound water. It is only once all the free water has been lost that the wood will reach what is called fiber saturation point (FSP).

The moisture can either be distributed equally in the whole log or significant moisture gradients can exist in radial or longitudinal direction. Next to the moisture differences in a single log, there can also exist significant differences of moisture content and distribution in different logs of the same wood species at the same growing conditions (Reeb, 1995).

1. Free water: water found inside the cell cavity or lumen is called free water. They are held by capillary force and are not held by any chemical reaction. Free water is not in the same thermodynamic state as liquid water. Energy is required to overcome the capillary forces. Furthermore, free water may contain chemicals altering the drying characteristics of wood.
2. Bound water: water held within the cell walls is called bound water as shown in the plate 2 below because it is tightly held by hydrogen bond. The attraction of wood for water arises from the presence of free hydroxyl (OH) groups in the cellulose, hemicelluloses and lignin molecules in the cell wall. The hydroxyl groups are negatively charged because water is a polar liquid, the free hydroxyl groups in cellulose attract and hold water by hydrogen bonding (Reeb, 1995) as shown in Plate 2.

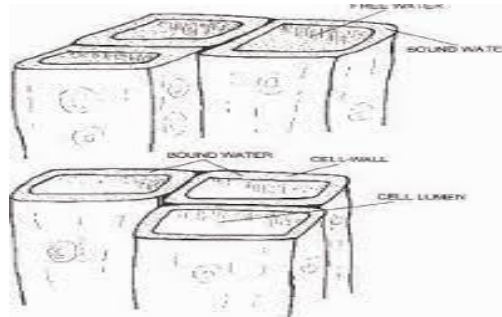


Plate 2: Location of water in a cell (Source: Division of Agricultural Sciences Oklahoma state University)

2.4.2 Equilibrium Moisture Content

Wood is a hygroscopic material, gaining moisture when the relative humidity (RH) is high, or losing moisture when the surrounding air is dry. The moisture content in wood exposed to a given temperature and RH eventually attains a constant level termed the equilibrium moisture content (EMC). When RH decreases, the capillaries are gradually emptied until Fiber Saturation Point (FSP) is reached - defined as EMC at which the cell walls are saturated with bound water, with no liquid water in the lumens. However, it was demonstrated that a loss of bound water can occur at EMC well above the FSP, with liquid water entrapped in the smallest capillaries and channels in wood. The loss of liquid water is usually complete at RH levels below 60% (Bratasz *et al.*, 2008).

Schniewind stated that the two factors which will influence E.M.C. are temperature and relative humidity. There are nevertheless several other factors which can also influence equilibrium moisture content, the reason is that, wood is a biological material with a great deal of inherent variation and finally, a factor which cannot be entirely discounted is sorption hysteresis. The word hysteresis is derived from the Greek word “hysterein”, meaning to be behind; to lag. The phenomena of sorption hysteresis manifest itself in sorption measurements on wood. Such measurements show that the equilibrium moisture content attained by a piece of wood exposed to

a constant temperature and relative humidity will be higher when equilibrium is approached by desorption than when it is approached by adsorption

2.4.3 Dimensional Changes in Wood

This increase in the outer dimensions of the cell wall results in a gross swelling of the wood material. Such swelling tends to be greater in the tangential direction, since the rays tend to have a restraining effect upon swelling in the radial direction (Kollman and cote, 1984; Simpson and Tenwolde 1999).

This shrinking and swelling can result in warping, checking and splitting of the wood, which in turn can lead to decrease in utilization of wood products, such as loosening of tool handles, gaps in flooring, or other performance problems (Winandy, 2016) as shown in Plate 3.

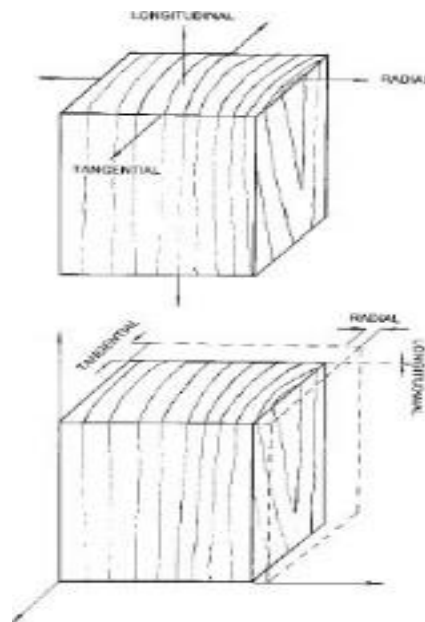


Plate 3: Dimensional changes in three directions.

2.5 Wood Modification

Wood modification aims at altering the molecular structure of the cell wall components. Wood properties can be improved considerably by converting hydrophilic OH-groups into larger more

hydrophobic groups. Dimensionally stable material is created because the cell wall itself will be in a permanently swollen state that will attract no or very little water (Homan and Jorissen, 2004). Wood modification can change important properties of the wood including biological durability, dimensional stability, hardness and UV-stability. Controlling the moisture content of the wood is a very effective way to protect timber. In many wood applications improving the dimensional stability also helps by reducing the formation of cracks and thus keeping water out of the construction (Horman and Jorissen, 2004).

The modified wood should itself be nontoxic under service conditions, and furthermore, there should be no release of any toxic substances during service, or at end of life, following disposal or recycling of the modified wood. If the modification is intended for improved resistance to biological attack, then the mode of action should be non-biocidal (Sandberg, *et al.*, 2017).

To modify wood, four main types of processes can be implemented: (1) chemical treatments; (2) thermo-hydro (TH) and thermo-hydro-mechanical (THM) treatments; (3) treatments based on biological processes; and (4) physical treatment with the use of electromagnetic irradiation or plasma (Sandberg, *et al.*, 2017).

2.5.1 Chemical Modification

Chemical modification of wood takes place when a chemical reaction of an agent occurs with the polymeric constituents of wood (lignin, hemicelluloses, or cellulose), thus resulting in the formation of a stable covalent bond between the reagent and the cell-wall polymers (Sandberg, *et al.*, 2017). It is an active modification because it results in a chemical change in the cell-wall polymers. Much is known about the modes of action of modified wood, which incorporates a combination of the following: (i) the equilibrium moisture content is lowered in modified wood, and it is harder for fungi to obtain the moisture required for decay; (ii) a physical blocking of the

entrance of decay fungi from the micro pores of the cell walls; and/or (iii) inhibition of the action of specific enzymes.

Wood acetylation reduces the number of hydroxyl groups (-OH) that can absorb moisture by hydrogen bonding to largely reduce the equilibrium moisture content and fibre saturation point. Hence, the dimensional stabilisation of wood improves with increasing weight gain, due to acetylation reaction. Other scientists favour another mechanism by modifying wood with acetic anhydride, it is observed that the dimensional stabilisation is closely related to the weight percentage gain (WPG) or bulking of the cell wall (Sandberg, *et al.*, 2017).

2.5.2 Citric Acid as Modifying Agent

Citric acid (CA) can be found naturally in fruits and vegetables, particularly citrus fruit. CA is widely used in many fields and it is used as green modifying agent and binder for wood. CA could be found naturally from a variety of fruits and vegetables, particularly citrus fruits such as oranges, tangerines, lemons, limes, and pomelos (Lee *et al.*, 2020). lemons and limes are among the citrus fruits that contain a higher concentration of CA, which amount to 8% of the dry weight of the fruits.

In wood modification, CA could be used alone or added with other reactants to enhance its effectiveness which are characterized by poor durability while improving its various properties such as hardness and UV resistance (Kurkowiak *et al.*, 2022).

2.6 Anatomical Features

2.6.1 Fibres

The term ‘fibre’ in anatomical sense refers to the sclerenchymatous fibres, compounds that are related as support to the plant. In industrial sense, it includes sclerenchymatous fibres, trachieds and vessels. The quantity and properties of fibre, affects the suitability of tree species (Ajuziogu

and Ojua, 2020). Occasionally, wood fibres will change in colour in correlation with the growing season, providing a means to distinguish the growth ring boundaries in instances where it may not be apparent in the arrangement of pores of marginal parenchyma.

The strength property of paper is a function of the fibre characteristics used. Fibre characteristics of wood have been described to vary widely and thus exert varied influences on bulk density, fibre strength, and inter-fibre bonding (Dinwoodie, 2000).

2.6.2 Vessels

When viewed from the endgrain, vessels simply appear to be holes in the wood, commonly referred to as pores. The function of the vessels is to conduct water and dissolve minerals from the roots to the higher parts of the plant and as a result, the primary cell wall is partly strengthened, or almost entirely covered with a lignified secondary wall (Riki, *et al.*, 2019).

(Kollman and cote) and (Nengi, 2004) explained that hardwood is divided into three main categories according to the arrangement of pores. In the temperate zone, it is unusual for hardwood pores to correspond to annual growing season, with larger pores forming a band or ring along the earlywood zone and it is called ring-porous. Another category common in many tropical species, occurs when the pores are distributed evenly throughout the wood. (Growth ring may still be discernible through the cell types, such as parenchyma bands, or a change of colour in wood fibres, but the largest elements, the pores will spread out and diffuse throughout the wood and this category is called the diffuse-porous. Additionally, a third, intermediate arrangement is also seen, which is sometimes difficult to define. It includes wood that has vessels that are generally evenly spaced but grade from large to small between growth rings, subtly suggesting growth boundaries. (Wood species with pores of uniform size that are arranged in weak or broken bands are considered

by some sources to be a part of this category as well.) And this intermediate category of porosity is interchangeably called either semi-diffuse porous; for simplicity, it is called semi-ring porous.

2.6.3 Rays

Found on practically every wood species, medullary rays can often time serve to provide valuable clues in the identification process. In a living tree, these cells actually run perpendicular to the rest of the wood fibres, serve to channel nutrients between the cambium, sapwood and pith. When viewed from the endgrain, rays appear as more or less straight, radial (vertical) lines spaced evenly across the wood sample. There are a number of arrangements of ray cells. Occasionally, some species will have intermittent rays that are many times wider the rest. These mega-rays are essentially a collection of normal-sized rays grouped together and appearing as one large ray. They are known as aggregate rays. In some species, the rays will flare out and get wider as they cross a growth ring boundary. These subtle characteristics is referred to as noded rays. One final characteristics of medullary rays involves examining the tangential surface of the wood. In some species, (particularly those in the tropical regions), the rays tend to align in horizontal or diagonal tiers, also referred to as stories. This pattern is called storied rays.

2.6.4 Anatomical Characteristics of *Gmelina arborea* Wood

Gmelina arborea wood have some distinct qualities which makes it special from other exotic species. These qualities include rapid growth rate for economical plantation management, longer than average fibre length, runkel ratio of less than 1, low basic density, low ash content and low chemical extractives (Dadswell et al., 1959; Dickman, 1975; Sosanwo, 1985; Fuwape, 1991; Ogunkunle and Oladele, 2008).

Kufre (2014) stated that the fibre dimensions decreases from base to top and increases from inner to outerwood while shrinkage characteristics increases from base to top and decrease from

outerwood to innerwood, and there is also a relationship between fibre properties and volumetric shrinkage. The effect of the anatomical properties is best observed in volumetric shrinkage which is caused by multiple of fibre length, fibre diameter, lumen and cell-wall thickness.

2.7 Wood Weathering

Weathering of wood can be defined as a change in appearance and surface properties of unprotected wood when exposed to outdoor weather conditions (Kropat *et al.*, 2020). In other words, it is the slow degradation of materials exposed to the weather and the degradation mechanisms depends on the type of material, but the cause is a combination of factors found in nature which are moisture, sunlight, heat/cold, chemicals, abrasion by windblown materials, and biological agents (Williams, 2005). The photo-oxidative degradation in natural weathering with UV light interacts with lignin to initiate discolouration and deterioration and it is a major drawback in the use of wood for outdoor application and the consequences of this photo-reaction in outdoor weathering of smooth wood is that the original surface becomes rough as the grain rises, the wood checks, board curps, warps, the destruction of the physical and mechanical properties, colour changes, loss of gloss and lightness (Feist, 2005; Areo *et al.*, 2019) as shown in Plate 4A and B.



Plate 4A: Cracks in wood

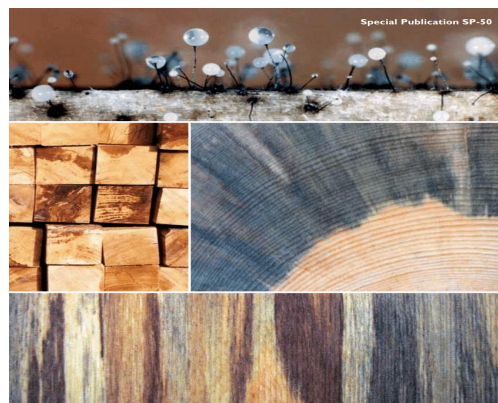


Plate 4B: Colour changes in wood

2.7.1 Agents of Wood Weathering

The delirious effect of wood weathering has been ascribed to a complex set of reactions induced by a number of factors. The weathering factors responsible for changes in the wood surface are as follow; moisture (dew, rain, snow and humidity), solar radiation (ultraviolet (UV) and infared light), temperature, and oxygen. The photon energy in solar radiation is the most damaging, initiating a wide variety of chemical changes at wood surface (Feist, 1990).

- 1. Moisture:** Water has an important role in the weathering of wood. Dimensional change caused by the wetting and drying of wood generates surface stresses that cause checking and warping of timber (Feist 1990). Water leaches photo-degraded lignin and hemicellulose fragments from weathered wood surfaces and is able to hydrolyze hemicelluloses. Water molecules swell wood thereby opening up inaccessible regions of the cell wall to degradation (Evans 2012), water vapour is taken up directly by wood by adsorption under increased relative humidities and the wood swells. Stresses are set up in the wood as it swells and shrinks because of moisture gradients between the surface and the interior. The steeper the gradient, the greater the stress, stresses are usually greatest near the surface of the wood and un-balanced stresses may result in warping and face checking (Feist, 1990). Rainwater drops can either flow down or be absorbed to the surface which depends on the wettability of material and this enhance the negative effect of biotic and abiotic degradation factors and reduce the service life of wood element.
- 2. Light:** The photochemical degradation of the exposed wood surface from sunlight occurs fairly rapidly. The initial colour of wood exposed to sunlight is a yellowing or browning that proceed to an eventual graying and these colour changes can be related to the decomposition of lignin in the surface wood cells (Feist, 1990). Photochemical reactions

in wood are initiated by UV radiation causing the formation of free radicals and the degradation of lignin and photo-oxidation of cellulose and hemicelluloses leading to wood dis-colouration. Moreover, during exposure to weathering, the polymer matrix is degraded by the action of UV rays, thereby enabling water to penetrate and reach the wood particles (Stark, 2006; Nguyen *et al.*, 2018).

3. Other factors: Although heat may not be as critical a weathering factor as UV light or water, as the temperature increases, the rate of photo-chemical or oxidative reactions increases. Freezing and thawing of absorbed water can also contribute to wood checking and abrasion or mechanical action caused by such elements as wind, sand, dirt can significantly affect the rate of surface degradation and removal of wood (Feist, 1990). Heat accelerates the chemical reactions involved in the weathering of wood and exposure of wood to low temperatures and repeated freezing and thawing can also contribute to the checking of wood

4. Fungal Decomposition: Fungi which cause discoloration and disfigurement of wood in storage and in service are generally described as staining fungi while those that grow superficial on wood are called molds. They are the most common microorganism found on weathered wood and these fungi do not decay wood, i.e. do not degrade the wood cell wall cellulose, do not reduce the strength of wood to any significant degree but they may increase the permeability of wood (Mai *et al.*, 2021).

Fungi can rapidly infect large volumes of sawn timber by means of their minute spores, which function as seeds which are blown about in the air or carried on the feet of insects, birds or animals and the way fungi cause decay is through the actions of enzymes secreted at the tips of decay hyphae and these enzymes can't reach the wood surface except there is

water movement which serves as a transport medium and without it, there can't be decay (Owoyemi *et al.*, 2008).

2.7.2 Effects of Weathering on Wood used for Outdoor Purposes

1. Discolouration/ Colour changes

The effect of colour changes on wood used for outdoor construction is mainly aesthetic problems. Exposure of wood to UV radiation for a prolonged period results mainly in surface degradation and reduction in the mechanical properties of wood due to the photo-degradation of lignin which affects the chemical constituents of the wood (Jayashri *et al.*, 2020) as shown in Plate 5A and B below. The critical role of colour change during wood weathering may suggest further investigations to see if the colour change can be used as a quality control tool for monitoring the in-service weathered wood and one of these monitoring tasks is using the colour change to predict the MOE and MOR of the weathered wood which leads to loss in the mechanical properties of wood (Nasir *et al.*, 2021).



Plate 5A: Wood stained with fungi



Plate 5B: Wood exposed to UV light

2. Physical Changes:

Weathering of wood surface caused by the combined action of light and water results in surface darkening and leads to formation of macroscopic-to-microscopic intercellular and intracellular cracks or checks and cell wall bonds near the wood surface lose their strength as shown in Plate 6 below. As weathering continues, rainwater washes out degraded portions of the wood and further

erosion takes place (Feist, 2005). Evans (2012) indicated that wood exposed to the weathering increases the checking. Check numbers and dimensions were greater in samples exposed to the full solar spectrum than in samples exposed under filters that blocked the transmission of UV, visible or infra-red radiation. Water may also accelerate surface degradation by leaching products of photo-degradation and loss in strength of wood strips during weathering (Evans and Banks, 1988; Sudiyani *et al.*, 1999; Mai *et al.*, 2021).



Plate 6: Wood with checks and splits when exposed outdoor

3. Growth of Fungi: Moisture content is probably the most important factor in determining the rate and extent of sapstain/ mold infection in wood. In softwood timber maintained in temperature conditions, fungal colonization of wood with an initial moisture content of 100-130% will take place and these fungi are early colonizer of freshly felled timber (Eaton and Hale, 1993; Mai *et al.*, 2021).

White-rot fungi degrade all the major wood components (cellulose, hemicelluloses and lignin) so that the wood becomes progressively more fragile but remains white as it decays (Owoyemi *et al.*, 2008) as shown in Plate 7A and B. The development of stain in timber and the emergence of mold on its surface are considered of great economic importance to the timber and wood preserving industries because of losses in commercial quality of the product (Mai *et al.*, 2021). The roles of

non-decay fungi is the graying of wood exposed outdoors due to the presence of melanized fungi that are relatively resistant to UV light.



Plate 7A: Effect of fungal on facial board substrate



Plate 7B: Decay fungal growth on wooden

2.7.3 Protection of Wood Weathering

1. Paint/ stain

The most common method of protecting wood from weathering is through the use of coatings. Paints contain pigments that screen wood from solar radiation and because they form a film over the wood surface they prevent surface wetting and erosion. A correctly applied and maintained paint system including a primer and at least two topcoats can greatly reduce the deleterious effects of weathering on wood (Feist 1990). Stains provide protection against weathering for 2-5 years depending on wood species and surface texture, type and quantity of stain applied to the wood and degree of exposure to the weather. Paints and to a lesser extent stains modify the appearance of wood (Evans 2012). Paints provide the most protection because they are generally opaque to the degradative effect of UV light and protect wood to varying degrees against water and paint performance may vary greatly on different wood (Mai *et al.*, 2021). Generally, the greater the pigment concentration, the greater the protection and paint gives the most protection (Feist 1990).

2. Wood Preservative

Wood preservatives mainly protect wood from damages by microorganism. The common wood preservatives can be divided into two groups: oil-borne preservatives such as creosote and water-borne preservatives. Under environmental pressure, more water-borne preservatives are developed, mainly preservatives containing copper, such as chromated copper arsenate (CCA), ammoniacal copper quat (ACQ), acid copper chromate (ACC), etc (Xie, 2005; Mai *et al.*, 2021).

3. Construction method

Construction principle that ensure long service and avoid decay in buildings include, using construction details and building designs that will keep the exterior wood dry and accelerate run-off; building with dry lumber, free of incipient decay and not exceeding the amount of mold and blue stain permitted by standard grading rules.

The first and most important thing to do once decay is discovered is to figure out where the water is coming from, check for the obvious roof and plumbing leaks, and missing or punctured flashing. Once the source of water has been shut off, remove as much decayed wood is practical and economical (Owoyemi *et al.*, 2008) as shown in Plate 8.

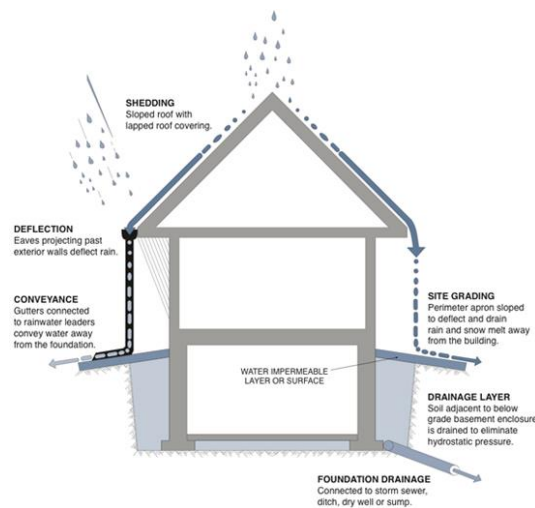


Plate 8: Construction method to drain off moisture

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

3.1.1 Location

The wood samples used were collected in the Department of Forestry and Wood Technology Plantation in Federal University of Technology Akure, Ondo state, Nigeria. The Research was conducted at the Federal University of Technology, Akure, Nigeria located on latitude $7^{\circ}29'17.27''E$ and Longitude $5^{\circ}14'6.48''N$. Akure has a land area of about 2,303 sq.km and it is situated in the western upland area within the humid region of Nigeria. The area has a general elevation of between 300-700 meters above mean sea level. Local peaks rise to 1000m; other hill structures which are less prominent rise only a few hundred meters above the general elevations (Fasinmirin and Konyeha, 2009). The anatomical research was carried out at the Wood Anatomy Laboratory at the Forestry Research Institute of Nigeria, Jericho Hill, Ibadan, Oyo state with the coordinates of 7.3911, 3.8582.

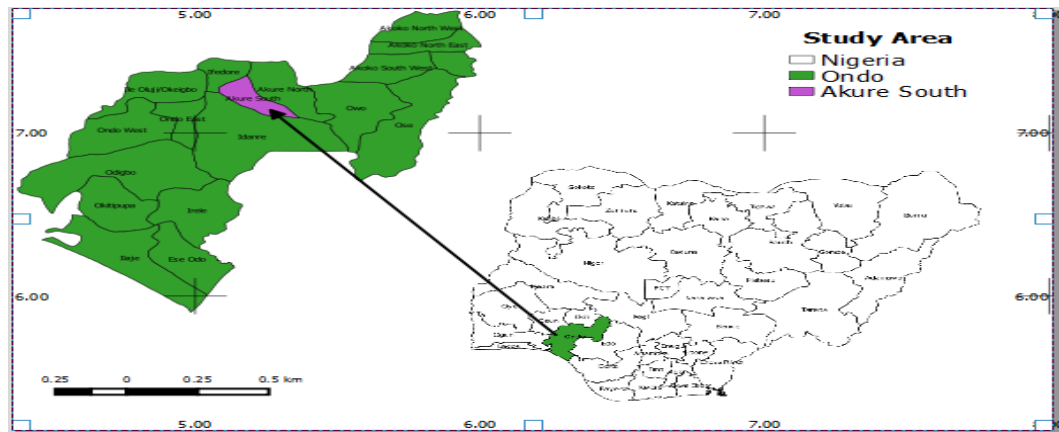


Figure 2: Map of Ondo state showing the study area

3.1.2 Climate

The climate is humid sub-tropical showing that is basically within the tropical rainforest zone which is dominated by broadleaved hardwood trees that form dense layered stands. The mean

annual temperature is about 26 °C (min. 19 °C and max. 34 °C) and rainfall of 1500 mm with bimodal rainfall pattern (Oyerinde and Osanyande, 2011).

3.2 Methods

3.2.1 Sample Collection

Gmelina arborea tree was harvested from the Forestry and Wood Technology Plantation at the Federal University of Technology Akure, Ondo state as shown in Plate 1A. The log was processed and was divided into nine equal billets from the Top, Middle and Base longitudinally according to American Society for Testing Materials (ASTM) and transversely (outer and inner) at 25%, 50% and 75% of the total stem height positions of the tree along the longitudinal axis (Plate 9B). All the samples were collected based on the standard size dimensions and were used to perform the physical, weathering and anatomical test as shown in (Plate 9D, E and F).



Plate 9: The collection and preparation of wood samples; A: *G. arborea* tree harvesting using chain saw B: Conversion of billets with circular saw C: Conditioning of wood D,E and F: Converted defect free wood samples

3.2.2 Samples Preparation

3.2.2.1 Physical Properties Samples

The billets were processed into samples of dimension 20 x 20 x 60 mm. The sample was weighed to determine the initial weight and the dimensions (length, breadth and height) was taken and recorded respectively. Afterward, these samples were oven-dried at a constant temperature of 103 ± 2 °C for over 24 hours until they attained a constant weight and the oven-dried weight and dimensions were taken respectively. The samples were soaked for 24, 48 and 72 hours and at each soaking interval the weight and the volume of the wood were measured.

3.2.2.1.1 Moisture Content

The wood samples were weighed on the weighing balance to know the initial weight (Wg) and final weight (Wo) before and after drying. Moisture content of the wood samples were calculated using the following formula according to ASTM D4442-16

$$MC(\%) = \left(\frac{Wg - Wo}{Wo} \right) \times 100 \dots\dots\dots \text{(Equation 1)}$$

Where; MC= Moisture Content, Wg = weight of green samples (g), Wo = weight of oven-dried samples (g)

3.2.2.1.2 Density Determination

The mass and volume of the sample after oven drying were used to determine the density of the wood sample according to ASTM D2395-14el using the following formula:

$$Density = \left(\frac{M}{V} \right) kg/m^3 \dots\dots\dots \text{(Equation 2)}$$

Where; D = Density, M = Mass of the oven dried sample (g), V = Volume of oven-dried samples (mm³)

3.2.2.1.3 Volumetric Shrinkage

Volumetric shrinkage was determined by recording the volume of the wood samples at the green stage, also at the end of the drying period. Test wood sample of 20 x 20 x 60 mm was used for percentage shrinkage as suggested in BS 373 (1989). The initial volume of the samples (L x B x H) was taken at the green stage using the venier caliper and at the end of the drying process. The final volume attained was measured. The volumetric shrinkage of the samples was estimated as;

$$Vs(\%) = \frac{D_1 - D_2}{D_1} \times 100 \dots\dots\dots \text{(Equation 3)}$$

Where; VS= Volumetric Shrinkage %, D₁ = Green Dimensions (mm), D₂ = Final Dimension after oven dry (mm)

3.2.2.1.4 Volumetric Swelling

The volumetric Swelling of *Gmelina aborea* wood was determined by taking the oven dried dimensions of the wood, soak in water for 24, 48 and 72 hours respectively and take the final Dimensions. Formula that will be used is;

$$VS (\%) = \frac{D_2 - D_1}{D_1} \times 100 \dots\dots\dots \text{(Equation 4)}$$

Where VS = Volumetric Shrinkage %, D_1 = Oven dried Dimensions (mm), D_2 = Final Dimension after soaking in water (mm)

3.2.2.2 Treatment of Wood Samples

The *G. arborea* wood samples were treated with citric acid and calcium chloride as shown in Plate 3A. The acid used was in salt and the dissolving ratio was 30% of both Calcium chloride and Citirc acid diluted with 70% distilled water (Plate 10B). The oven-dried samples of *Gmelina arborea* wood were impregnated for 24 hours in a solution concentration of Calcium chloride and Citric acid as shown in Plate 10C, D and E below.



Plate 10: A: Citric acid pure B: preparation of the chemicals into solution C: Dipping of the wood samples in prepared citric acid D: Dipping of the wood samples in prepared calcium chloride E: Dipping of the weathering samples in the prepared chemical solution

3.2.2.3 Curing of the Wood Samples

The withdrawn samples were wrapped in an aluminum foil in the oven for the curing (Modification) process (Plate 4A). The curing in the oven was carried out at a temperature of 105 °C at varying time (6 hours and 9 hours) while the un-treated samples was dried at 100 °C to a constant weight were maintained for comparison. There was a reaction on the wood samples treated with citric acid which changed the colour of the wood samples whitish. All the modified samples were conditioned at atmospheric room conditions for a day prior to testing for properties.

3.2.2.4 Chemical and Wood Compatibility

3.2.2.4.1 Wood Density Increment

The density increment of the treated wood sample was determined according to ASTM D239514el using the formula

$$\text{Density Increment (DI)} = \frac{D_1 - D_0}{D_0} \times 100 \dots \text{Equation 5}$$

Where D₁ is the oven dried density of the treated wood samples while the D₀ is the oven dried density of the untreated samples.

3.2.2.4.2 Absorption

The rate of chemical uptake during the treatment of *Gmelina arborea* wood samples were calculated using the formula:

$$\text{Absorption (\%)} = \frac{T_3 - T_2}{T_2} \times 100 \dots \text{Equation 7}$$

Where T₃ is weight of the samples after treatment while T₂ is the weight of the samples before treatment.

3.2.2.4.3 Weight Loss due to Leaching

The weight loss of the wood samples due to leaching after repeated cycles of water soaking (24, 48, 72) hours was determined on samples of dimension 20 mm x 20 mm x 60 mm. This was carried out according to Rowell (2005), and was estimated using the following formula:

$$\text{Weight Loss (\%)} = \frac{W_i - W_f}{W_i} \times 100 \dots \text{Equation 8}$$

Where;

W_i is the oven dried weight; W_f is the oven dried weight (g) after 72 hours of soaking.

3.2.2.4.4 Retention

Retention of the chemical in the treated samples was calculated using (ASTM D281):

$$\text{Retention (\%)} = \frac{G \times C}{V} \times 100 \dots \dots \dots \text{Equation 9}$$

Where G is the (T2 – T1) the amount of treating solution absorbed by the wood specimen (g); T1 is the initial weight of the wood specimen before treatment; T2 is the weight of the wood samples immediately after treatment and wiping; C is the quantity of the solution in 100 g of treating solution and V is the volume of the wood samples (cm³).

3.2.2.5 Anatomical Characterization

3.2.2.5.1 Maceration

For this test samples size of 20 x 20 x 20 mm were collected from *Gmelina arborea* wood that were used for this study from along the longitudinal position (Bottom, middle and top) in the stem height position (Plate 11A). The strands collected from each sample were macerated as shown in Plate 3B and after maceration, they were washed and measured under the microscope (Plate 11C and D).



Plate 11: A: sample size for anatomical test B: chipped fibres C: Maceration of fibres D: Measurement of fibres under the microscope

3.2.2.5.2 Sectioning

For this test samples size of 20 x 20 x 20 mm were collected from *Gmelina arborea* wood that were used for this study from along the longitudinal position (Bottom, middle and top) in the stem height position. Each sample was later sectioned on a sliding microtome, each section was about 20 micrometre thick and was measured under the microscope for different observation as shown in Plate 12A and B.

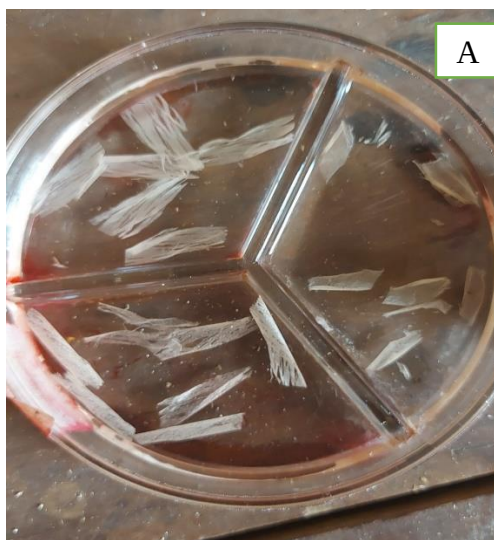


Plate 12A: Sectioning of fibres

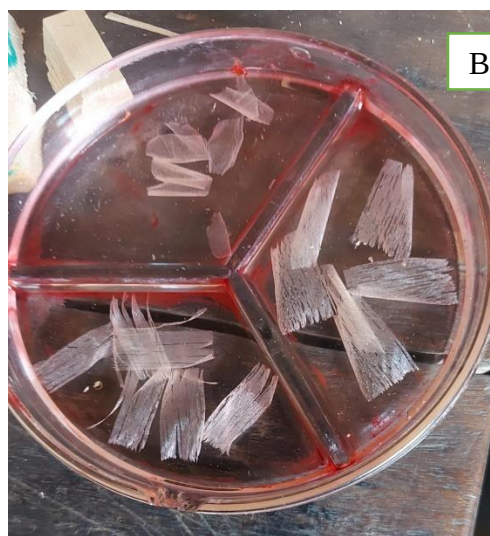


Plate 12B: sectioning on sliding microtome

3.2.2.6 Anatomical Properties

3.2.2.6.1 Fibre Characterization

Samples were prepared into silvers of about 1 cm x 2 mm x 2 mm and put in test tubes for maceration in equal volume of glacial acetic acid (ethanoic acid) and hydrogen peroxide (1:1). The solution was put in the oven for 2 hours at temperature of about 100⁰C for maceration. After this the resultant solution was agitated in order to separate it into individual fibres. Using a stage micrometer mounted on a zeiss light microscope (Standard 25) under x80 magnification, random samples of macerated fibres were mounted on slides and measured. Fifteen (15) fibres were measured from each representative sample slide, following the approach by Jorge (1999). The

microscopy was performed in accordance with the ASTM D1413-48 of 1983 and ASTM D1413-61 procedure of 2007. The fibre length, fibre diameter and lumen diameter were measured using a stage micrometer and an eye piece micrometer.

3.2.2.6.2 Wood Sectioning

Sections were prepared from three well oriented planes vis-à-vis, transverse (T.S), radial longitudinal sections (R.L.S) and tangential longitudinal sections (T.L.S) respectively, using a microtome slicing machine according to the procedure used by (Gills, *et al.*, 1984). Sections were washed with distilled water and covered with safranin stain for two minutes after which the sections were later washed with distilled water until the water becomes colourless. Dehydration was done by passing the wood sections through a series of bath increasing concentrations of ethanol (30%, 50%, 70% and 90%) which replaced water. This facilitated easy lifting of sections during mounting. The specimens were later covered with clove oil for 1 hour in order to drive off alcohol. The sections were placed on a clean slide, excess clove oil was drained off using filter paper, a slight amount of Canada balsam (a mounting medium and a synthetic substance) was added while the slide was covered with a cover glass and air bubbles were removed by applying heat gently and were subjected and view under microscope to observe and capture the section characteristics of the wood. The vascular diameter of the wood was then measured under the microscope.

3.2.2.7 Natural Weathering Test

For this test, samples sizes of 20 x 75 x 300mm were collected from *Gmelina arborea* wood and those dimensions were used for this study. These specimens were subjected to natural weathering test. Each wood sample, both the treated and the un-treated wood samples were placed on the weathering panel as they were exposed to ultraviolet radiation and rainfall for the duration of 12

weeks to assess the weathering effects it will have on the treated and un-treated wood samples as shown in Plate 13. The level of deterioration was recorded weekly by taking pictures of the samples to determine the colour changes of the wood samples.



Plate 13: Samples set out on the weathering panel

3.3 Experimental Design

The experimental layout was RCBD with factors consisting of 2 treatments and the varying curing time (6 hours and 9 hours). Each treatment was replicated 5 times.

3.3.1 Experimental Model

The model for this experiment is 2 x 2 factorial in RCBD $Y_{ijk} = Y + A_i + B_i + (AB)_{ij} + \sum_{ijk}$

Where Y_{ijk} = Individual observation

Y = General mean

A_i = Two Curing time (6 and 9 hours)

B_i = Two treatment (Calcium chloride and Citric acid)

$(AB)_{ij}$ = Effect of interaction AB

$\sum_{ijk}$ = Experimental error

3.4 Statistical Analysis

The data obtained was analyzed using the Analysis of Variance (ANOVA) and descriptive statistics with the aid of Statistical Package for Social Science (SPSS). Graphical representation was carried out using the Microsoft Excel sheet.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Moisture Content Distribution

The moisture content distribution of the *Gmelina arborea* wood obtained from different stem height and lateral positions for this study revealed that wood obtained from the bottom stem height position has the highest mean moisture content ($37.30 \pm 3.90\%$) with the outer wood moisture content ($39.99 \pm 4.98\%$) higher than that of the middle ($36.14 \pm 2.14\%$) lateral position, and the least in the wood with moisture content is the wood obtained from the inner position ($35.76 \pm 3.19\%$), followed by wood obtained from the middle stem height position ($30.91 \pm 6.82\%$) with the outer wood moisture content ($37.19 \pm 4.94\%$) higher than that of the inner ($28.24 \pm 7.31\%$) and the lateral position with the least moisture content is the middle ($27.31 \pm 3.22\%$), while wood obtained from the top stem height position has the least mean moisture content ($19.02 \pm 4.70\%$), with the outer wood moisture content ($21.64 \pm 6.78\%$) also higher than that of the middle ($18.17 \pm 3.06\%$), and the lateral position with the least moisture content is that of the inner ($17.25 \pm 2.89\%$). From the foregoing, it can be observed that the moisture content of *Gmelina arborea* wood reduces along the stem height position from the base to the top and decreases laterally across the stem as you move inwards from the outer wood to the inner wood.

The analysis of variance for the moisture content of *Gmelina arborea* wood obtained from the different stem height and lateral positions; it can be observed that there is a significant difference (i.e. $P < 0.05$) between the moisture contents of wood obtained from different stem height positions with $F_{(2, 32)} = 60.57$, and no significant difference between the moisture contents of wood obtained laterally across the stem, i.e. the outer, middle and inner positions with $F_{(1, 32)} = 7.889$.

Table 4.1.1: Statistical Analysis for Moisture Content Distributor for the Different Stem Height and Lateral Positions

STEM HEIGHT POSITION	LATERAL POSITION	MOISTURE CONTENT(%)	AVERAGE
BASE	OUTER	39.99±4.98	37.30±3.90
	MIDDLE	36.14±2.14	
	INNER	35.76±3.19	
MIDDLE	OUTER	37.19±4.94	30.91±6.82
	MIDDLE	27.31±3.22	
	INNER	28.24±7.31	
TOP	OUTER	21.64±6.78	19.02±4.69
	MIDDLE	18.17±3.06	
	INNER	17.25±2.89	

Values are means±SD; Values in the same column for each stem height position with the same superscript are not significantly different from each other

Table 4.1.2: ANOVA Table for the Moisture Content Distribution of *Gmelina arborea* Wood for different Stem Height and Lateral Positions

Source	Type III Sum of Squares	df	Mean Square	F	P	Sig.
Samples	2580.447	2	1290.223	60.572	.000	*
Lateral Position	336.083	2	168.041	7.889	.001	*
samples *	70.237	4	17.559	.824	.518	Ns
Lateral Position						
Error	766.824	36	21.301			
Total	3753.591	44				

4.1.2 Density

The descriptive statistics of the densities of the *Gmelina arborea* wood obtained from the different stem height and lateral positions for this study is shown in Table 4.1.3. It can be observed that wood obtained from the middle stem height position has the highest mean density ($454.20 \pm 42.95 \text{ kg/m}^3$) with the outer wood density ($492.87 \pm 33.17 \text{ kg/m}^3$) higher than that of the middle ($448.50 \pm 24.79 \text{ kg/m}^3$) and the least is the inner wood with ($421.22 \pm 38.39 \text{ kg/m}^3$) from the lateral position, followed by wood obtained from the top stem height position ($446.64 \pm 21.99 \text{ kg/m}^3$) with the highest which is the outer wood density ($465.35 \pm 20.43 \text{ kg/m}^3$) higher than that of the middle ($438.82 \pm 15.09 \text{ kg/m}^3$) and the least of the lateral position which is the inner wood density ($435.76 \pm 19.65 \text{ kg/m}^3$), while wood obtained from the base which is the lowest mean density ($417.78 \pm 33.99 \text{ kg/m}^3$), with the outer wood density ($451.38 \pm 7.94 \text{ kg/m}^3$) higher than the middle ($427.32 \pm 7.73 \text{ kg/m}^3$), while the lowest of the lateral position is the inner wood density ($374.64 \pm 8.38 \text{ kg/m}^3$).

The analysis of variance for the densities of *Gmelina arborea* wood obtained from the different stem height and lateral positions; from this, it can be observed that there is a significance difference (i.e. $P < 0.05$) between the densities of wood obtained from the different stem heights of top, middle and base positions with $F_{(2, 32)} = 11.294$ and $P = 0.000$. Also, there is a significance difference (i.e. $P < 0.05$) between the densities of wood obtained laterally across the stem, i.e. the outer, middle and inner positions with $F_{(1, 32)} = 26.946$ and $P = 0.000$.

Table 4.1.3: Statistics for Green Density of *Gmelina aborea* Wood from the different Stem Height and Lateral Positions

STEM HEIGHT POSITIONS	LATERAL POSITIONS	GREEN DENSITY (kg/m³)	AVERAGE
Bottom	Inner	374.64±8.38	417.78±33.99
	Middle	427.32±7.73	
	Outer	451.38±7.94	
Middle	Inner	421.22±38.39	454.20±42.95
	Middle	448.50±24.79	
	Outer	492.87±33.17	
Top	Inner	435.76±19.65	446.64±21.99
	Middle	438.82±15.09	
	Outer	465.35±20.43	

Table 4.1.4: ANOVA Table for the Densities of *Gmelina arborea* Wood Obtained from the different Stem Height and Lateral Positions

Sources of Variation	Sum of Squares	Df	Mean Square	F	P	Sig
Stem Height Position	11080.257	2	5540.128	11.294	0.000	*
Lateral Position	26435.246	2	13217.623	26.946	0.000	*
samples * Lateral Position	4694.954	4	1173.739	2.393	0.069	Ns
Error	17659.045	36	490.529			
Total	59869.502	44				

* = Values less than 0.05 are significant, ns = Not significant

4.1.3 Volumetric Shrinkage

The descriptive statistics showed that wood obtained from the base stem height position has the highest volumetric shrinkage ($8.19 \pm 1.99\%$) with the outer wood volumetric shrinkage ($9.25 \pm 0.67\%$) higher than that of the middle wood ($8.50 \pm 2.32\%$), and the lowest shrinkage of the lateral position is the inner wood with ($6.83 \pm 2.03\%$), followed by wood obtained from the middle stem height position ($8.04 \pm 1.30\%$) with the middle wood ($8.50 \pm 1.23\%$) lateral position higher than that of the outer ($8.28 \pm 1.60\%$), while the wood with lowest shrinkage of the lateral position is the inner wood ($7.34 \pm 0.97\%$). Nevertheless, wood obtained from the top stem height position has the least mean volumetric shrinkage ($6.31 \pm 2.81\%$), in this case, the outer wood volumetric shrinkage ($8.87 \pm 0.54\%$) is higher than that of the inner ($5.86 \pm 3.23\%$) lateral position. However, the middle wood ($4.20 \pm 1.69\%$) has the lowest shrinkage of the lateral position. From the foregoing, it can be observed that the volumetric shrinkage of *Gmelina arborea* wood decreases along the stem height from the base to the top and also that the outer wood had a higher shrinkage than the inner wood, except in some cases where the middle wood had a higher shrinkage laterally across the stem.

The analysis of variance for the volumetric shrinkage of *Gmelina arborea* wood obtained from the different stem height and lateral positions; it can be observed that there is a significant difference (i.e. $P < 0.05$) between the volumetric shrinkage of wood obtained from the different stem heights of top, middle and base positions with $F_{(2, 32)} = 5.125$ and $P = 0.011$. Also, there is a significant difference (i.e. $P < 0.05$) between the volumetric shrinkage of wood obtained laterally across the stem, i.e. the outer, middle and inner positions with $F_{(1, 32)} = 6.017$ and $P = 0.006$.

Table 4.1.5: Volumetric Shrinkage of *Gmelina arborea* Wood from the different Stem Height and Lateral Positions

STEM HEIGHT POSITION	LATERAL	VOLUMETRIC	
	POSITION	SHRINKAGE	AVERAGE
Bottom	Inner	6.83±2.03	
	Middle	8.50±2.32	8.19±1.99
	Outer	9.25±0.67	
Middle	Inner	7.34±0.97	
	Middle	8.50±1.23	8.04±1.30
	Outer	8.28±1.60	
Top	Inner	5.86±3.23	
	Middle	4.20±1.69	6.31±2.81
	Outer	8.87±0.54	

Values are means±SD; Values in the same column for each stem height position with the same superscript are not significantly different from each other

Table 4.1.6: ANOVA Table for Volumetric Shrinkage of *Gmelina arborea* Wood Obtained from different Stem Height and Lateral Positions

Sources of Variation	Type III Sum of				P	Sig
	Squares	Df	Mean Square	F		
Stem Height Position	32.712	2	16.356	5.125	0.011	*
Lateral Position	38.406	2	19.203	6.017	0.006	*
samples * Lateral Position	37.011	4	9.253	2.899	0.035	*
Error	114.900	36	3.192			
Total	223.029	44				

*= Values less than 0.05 are significant, ns = Not significant

4.1.4 Volumetric Swelling

The volumetric swelling of the *Gmelina arborea* wood obtained from the different stem height and lateral positions for this study after different soaking times of after 24hrs, 48hrs and 72hrs in water revealed that there is an increase in the volumetric swelling of the *Gmelina arborea* wood obtained along the stem height positions and across the lateral positions with increasing soaking times. In terms of the stem height position, wood obtained from the base stem height position has the highest mean volumetric swelling with range of 4.64 ± 1.17 to 7.53 ± 0.95 , followed by wood obtained from the middle stem height position with range of 3.87 ± 1.15 to 7.63 ± 1.18 , while wood from the top stem height position exhibited the least volumetric swelling with range of 3.67 ± 1.41 to 7.65 ± 1.34 across the different soaking times of 24hrs, 48hrs and 72hrs respectively. On the other hand for wood obtained from the lateral positions, the volumetric swelling did not seem to follow any definite pattern across the different soaking times; for the bottom stem height position, the wood obtained from the middle lateral position had a higher volumetric shrinkage with range 4.19 ± 0.61 to 7.92 ± 0.94 than the outer wood with range 5.93 ± 0.87 to 7.77 ± 0.54 and the least of the lateral position with the lowest volumetric swelling is the inner wood with range of 3.80 ± 0.69 to 6.91 ± 1.11 . Moreover, wood obtained from the middle stem height position, the middle lateral position had the highest volumetric swelling with range 4.19 ± 1.21 to 7.63 ± 1.35 than the inner wood with range 4.03 ± 1.43 to 7.59 ± 1.27 and the least lateral position is the outer wood with range 3.87 ± 1.15 to 6.69 ± 0.84 . The trend reversed for wood obtained from the top stem height position with the outer wood having a higher volumetric swelling with range 4.44 ± 1.37 to 8.33 ± 0.95 than the inner wood with range 3.40 ± 0.86 to 7.46 ± 0.90 and the lateral position with the lowest volumetric swelling is the middle wood with range 3.16 ± 1.79 to 7.16 ± 1.91 across the different soaking times of 24hrs, 48hrs and 72hrs respectively.

The result of the analysis of variance for the volumetric swelling of *Gmelina arborea* wood obtained from the different stem height and lateral positions under different time durations of soaking in water is shown in the Table 8 below. It can be observed that there is no significant difference (i.e. $P>0.05$) between the volumetric swelling of wood obtained from the different stem heights of top, middle and base positions with $F_{(2, 32)} = 0.104$ and $P = 0.901$, also, there is no significant difference (i.e. $P>0.05$) between the volumetric swelling of wood obtained laterally across the stem, i.e. the outer, middle and inner positions with $F_{(1, 32)} = 2.688$ and $P = 0.073$. However, there is a significant difference (i.e. $P<0.05$) in the observed mean volumetric swelling of the wood stem height position and lateral positions considering the three cycles duration of the repeated water soaking with $F_{(2, 32)} = 106.815$ and $P = 0.000$.

Table 4.1.7: Volumetric Swelling of *Gmelina arborea* Wood from the different Stem Height and Lateral Positions

STEM HEIGHT POSITION	LATERAL POSITION	VS (24hrs)	AVERAGE	VS (48hrs)	AVERAGE	VS(72hrs)	AVERAGE
BOTTOM	INNER	3.80±0.69		5.10±0.77		6.91±1.11	
	MIDDLE	4.19±0.61	4.64±1.17	6.18±0.53	5.74±0.83	7.92±0.94	7.53±0.95
	OUTER	5.93±0.87		5.93±0.87		7.77±0.54	
MIDDLE		4.03±1.43		6.60±1.20		7.59±1.27	
	INNER	4.19±1.21	3.87±1.15	6.85±1.25	6.53±1.16	7.63±1.35	7.63±1.18
	MIDDLE	3.87±1.15		6.16±1.18		6.69±0.84	
TOP	OUTER	3.40±0.86		6.33±0.91		7.46±0.90	
	INNER	3.16±1.79	3.67±1.41	6.27±1.75	6.72±1.33	7.16±1.91	7.65±1.34
	MIDDLE	4.44±1.37		7.56±0.98		8.33±0.95	
	OUTER						

Values are means±SD; Values in the same column for each stem height position with the same superscript are not significantly different from each other

Table 4.1.8 ANOVA Table for Volumetric Swelling of *Gmelina arborea* Wood Obtained from different Stem Height and Lateral Positions

Sources of Variation	Sum of Squares	Df	Mean Square	F	P	Sig
STEM HEIGHT POSITION	0.269	2	0.134	0.104	0.901	Ns
Lateral POSITION	6.920	2	3.460	2.688	0.073	Ns
Time	274.928	2	137.464	106.815	0.000	*
STEM HEIGHT POSITION * TIME	16.730	4	4.183	3.250	0.015	
LATERAL POSITION * TIME	2.625	4	0.656	0.510	0.729	
STEM HEIGHT * LATERAL POSITION * TIME	4.341	8	0.543	0.422	0.906	
ERROR	138.989	108	1.287			
TOTAL	469.337	134				

*= Values less than 0.05 are significant, ns = Not significant

4.1.5 Colour Changes

The modification that occurred after the impregnation of the wood samples with citric acid and cured in the oven at a constant temperature of 105 °C at varying times of 6 and 9 hours impacted significant colour changes as the colour of the samples turns whitish as the curing time increases as shown in Plate 14.



Control



Cured for 9 hours



Control



Cured for 9 hours

Plate 14: *Gmelina arborea* wood samples impregnated with citric acid and cured at different time

4.2 Chemical and Wood Compatibility

4.2.1 Absorption

The descriptive statistics below shows the chemical absorption rate of *Gmelina arborea* wood treated with calcium chloride and citric acid at varying time. Table 4.2.1 showed that wood treated with the citric acid has the highest absorption rate value of 17.48 ± 5.15 % than the wood treated with calcium chloride with absorption value of 10.91 ± 6.11 %. For the wood samples treated with calcium chloride and cured for 6 hours has the highest absorption value of 12.08 ± 6.75 % than the ones cured for 9 hours with the absorption value of 9.75 ± 5.76 %. Likewise, for the wood treated with citric acid and cured for 6 hours has the highest absorption value of 17.84 ± 3.71 % while the lowest absorption value of 17.11 ± 6.60 % was recorded for 9 hours cured samples.

Analysis of Variance (ANOVA) for chemical absorption rate presented on Table 4.2.2 revealed that there was a significant difference (i.e. $P < 0.05$) between the treatments used which is the calcium chloride and citric acid with $F_{(1, 20)} = 7.537$ and $P = 0.012$. Moreover, there was no significant difference ($P > 0.05$) in the curing time and the interaction of the treatments and the curing time with $F_{(1, 20)} = 0.409$ and $P = 0.503$, and $F_{(1, 20)} = 0.111$ and $P = 0.742$ respectively.

Table 4.2. 1: Absorption rate of *Gmelina arborea* Wood treated with calcium chloride and citric acid at varying curing time

TREATMENT	CURING TIME	ABSORPTION	AVERAGE
Calcium	6 hours	12.08±6.75	10.91±6.11
	9 hours	9.75±5.76	
Citric	6 hours	17.84±3.71	17.48±5.15
	9 hours	17.11±6.60	

Values are means±SD; Values in the same column for each treatment with the same superscript are not significantly different from each other

Table 4.2. 2: ANOVA Table for absorption of *Gmelina arborea* Wood treated with calcium chloride and citric acid

Source	Type III Sum of Squares	Df	Mean Square	F	P	Sig
Treatments	258.282	1	258.282	7.537	0.012	*
Curing	14.024	1	14.024	0.409	0.530	Ns
Treatments * Curing	3.815	1	3.815	0.111	0.742	Ns
Error	685.334	20	34.267			
Total	961.455	23				

*= Values less than 0.05 are significant, ns = Not significant

4.2.2 Retention

The descriptive statistics below shows the retention of the chemical treatment in the *Gmelina arborea* wood cured at varying time. Table 4.2.3 showed that the wood treated with citric acid has the highest retention rate value of $1.89 \pm 0.31 \text{ kg/m}^3$ than the wood treated with calcium chloride with retention rate value of $1.54 \pm 0.50 \text{ kg/m}^3$. For the wood samples treated with calcium chloride and cured for 9 hours has the highest retention capacity value of $1.65 \pm 0.65 \text{ kg/m}^3$ than the ones cured for 6 hours with the retention value of $1.43 \pm 0.31 \text{ kg/m}^3$. Likewise, the wood samples treated with citric acid and were cured for 9 hours has the highest retention capacity value of $1.98 \pm 0.26 \text{ kg/m}^3$, while the lowest retention value of $1.79 \pm 0.35 \text{ kg/m}^3$ was recorded for 6 hours cured samples.

Analysis of Variance (ANOVA) for chemical retention rate presented on Table 4.2.4 revealed that there was no significant difference (i.e. $P > 0.05$) between the treatments used which is the calcium chloride and citric acid with $F_{(1, 20)} = 3.952$ and $P = 0.061$. Moreover, there was no significant difference ($P > 0.05$) in the curing time and the interaction of the treatments and the curing time with $F_{(1, 20)} = 1.410$ and $P = 0.249$, and $F_{(1, 20)} = 0.006$ and $P = 0.940$ respectively.

Table 4.2. 3: Retention rate of *Gmelina arborea* wood treated with calcium chloride and citric acid at varying curing time

TREATMENTS	CURING TIME	RETENTION (kg/m ³)	AVERAGE
Calcium	6 hours	1.43±0.31	1.54±0.50
	9 hours	1.65±0.65	
Citric	6 hours	1.79±0.35	1.89±0.31
	9 hours	1.98±0.26	

Values are means±SD; Values in the same column for each treatment with the same superscript are not significantly different from each other

Table 4.2. 4: ANOVA Table for retention of *Gmelina arborea* wood treated with calcium chloride and citric acid

Source	Type III Sum of Squares	Df	Mean Square	F	P	Sig
Treatment	0.721	1	0.721	3.952	0.061	Ns
Curing	0.257	1	0.257	1.410	0.249	Ns
Samples * Curing	0.001	1	0.001	0.006	0.940	Ns
Error	3.648	20	0.182			
Total	4.628	23				

*= Values less than 0.05 are significant, ns = Not significant

4.2.3 Wood Density Increment

The descriptive statistics below shows the mean density increment values of *Gmelina arborea* wood treated with Calcium chloride and Citric acid cured at varying time. Table 4.2.5 showed that the wood treated with calcium chloride has a lower DI value of 11.44 ± 5.47 % than the wood treated with citric acid with DI value of 17.01 ± 4.58 %. For the samples cured at 6 hours and dipped in a 30 % calcium chloride has the highest DI value of 11.90 ± 6.13 % than the one cured at 9 hours with the DI value of 10.98 ± 5.26 %. Likewise, the wood treated with citric acid and cured at 9 hours has the highest DI value of 18.01 ± 5.69 % than the samples cured at 6 hours with the DI value of 16.00 ± 3.37 %.

Analysis of Variance (ANOVA) for density increment presented on Table 4.2.6 revealed that there was a significant difference (i.e. $P < 0.05$) between the treatments used which is the calcium chloride and citric acid with $F_{(1, 20)} = 6.813$ and $P = 0.017$. Moreover, there was no significant difference ($P > 0.05$) in the curing time and the interaction of the treatments and the curing time with $F_{(1, 20)} = 0.066$ and $P = 0.800$, and $F_{(1, 20)} = 0.473$ and $P = 0.500$ respectively.

Table 4.2. 5: Wood Density Increment of *Gmelina arborea* wood treated with calcium chloride and citric acid at varying curing time

TREATMENT	CURING TIME	DENSITY	AVERAGE
		INCREMENT (%)	
Calcium	6 hours	11.90±6.13	11.44±5.47
	9 hours	10.98±5.26	
Citric	6 hours	16.00±3.37	17.01±4.58
	9 hours	18.01±5.69	

Values are means±SD; Values in the same column for each treatment with the same superscript are not significantly different from each other

Table 4.2. 6: ANOVA Table for Density Increment of *Gmelina arborea* wood treated with calcium chloride and citric acid

Source	Type III Sum of				P	Sig
	Squares	Df	Mean Square	F		
Samples	186.079	1	186.079	6.813	0.017	*
Curing	1.804	1	1.804	0.066	0.800	Ns
Samples * Curing	12.916	1	12.916	0.473	0.500	Ns
Error	546.230	20	27.311			
Total	747.029	23				

*= Values less than 0.05 are significant, ns = Not significant

4.2.4 Percentage weight loss due to leaching of *Gmelina arborea* wood

The mean values for percentage weight loss (PWL) due to leaching of *Gmelina arborea* wood treated with calcium chloride and citric acid at varying curing time. The descriptive analysis below showed that the wood samples treated with calcium chloride has the highest percentage weight loss value of 10.96 ± 4.15 % than the wood treated with citric acid with the value of 8.46 ± 3.49 %. The wood samples cured for 9 hours and treated with calcium chloride has the highest average PWL value of 11.90 % than the ones cured for 6 hours with the average value of 10.23 %. Likewise, the wood samples treated with the citric acid and cured for 9 hours has the highest average PWL value of 9.50 % than the wood cured for 6 hours with the value of 7.42 %, while the least mean value of PWL (4.23 ± 0.84 %) was recorded for the untreated samples (control).

Analysis of Variance (ANOVA) for percentage weight loss due to leaching presented on Table 4.2.8 revealed that there was a significant difference (i.e. $P < 0.05$) between the treatments used which is the calcium chloride and citric acid. Moreover, there was no significant difference at ($P > 0.05$) in the curing time at ($P > 0.05$) and the interaction of the treatments and the curing time

Table 4.2. 7: Percentage Weight Loss due to Leaching of *Gmelina arborea* Wood treated with calcium chloride and citric acid at varying curing time

Treatment	Curing Time	Weight Loss (%)	AVERAGE
calcium chloride	6 hours	10.02±3.47	10.96±4.15
	9 hours	11.90±4.87	
citric acid	6 hours	7.42±3.41	8.46±3.49
	9 hours	9.50±3.54	
Control		6.60±11.31	6.60±11.31

Values are means±SD; Values in the same column for each treatment with the same superscript are not significantly different from each other

Table 4.2. 8: ANOVA Table for Percentage Weight Loss due to Leaching of *Gmelina arborea* wood treated with calcium chloride and citric acid

Source	Type III Sum of Squares	Df	Mean Square	F	P	Sig.
Treatment	278.087	2	139.043	4.418	0.021	*
Curing Time	.629	1	0.629	0.020	0.889	Ns
Treatment * curing Time	90.729	2	45.365	1.442	0.252	Ns
Error	944.081	30	31.469			
Total	1313.525	35				

*= (P<0.05) are significant, ns = Not significant (P>0.05)

4.2.5 Volumetric Swelling of *Gmelina arborea* Wood Treated with Calcium chloride and Citric acid at varying Curing Time

The volumetric swelling of *G. arborea* wood treated with calcium chloride and citric acid cured at varying time in Table 4.2.9 showed that the mean VSW of the wood samples treated with the calcium chloride with value of 15.65 ± 1.43 % is higher than the wood treated with citric acid with VSW value of 14.08 ± 0.91 %. After the prolonged immersion of the treated and untreated samples in water for 24, 48 and 72 hours, the untreated (control) has the highest VSW value of 15.75 ± 3.10 %. Furthermore, the samples treated with calcium chloride and cured for 9 hours has the highest VSW value of 15.96 ± 1.64 % than the one cured for 6 hours with the VSW value of 15.34 ± 1.15 %. However, the wood samples treated with citric acid and cured for 6 hours has the highest VSW value of 14.14 ± 1.04 %, while the least value of 14.02 ± 0.79 % was recorded for samples cured for 9 hours. Moreover, there was a significant difference (i.e. $P < 0.05$) in the VSW of the *G. arborea* wood treated with calcium chloride and citric acid and cured at different times.

Analysis of variance (ANOVA) presented in Table 4.3.0 revealed that there was a significant difference at $P < 0.05$ in the treatment, curing time but there was no significant difference at $P > 0.05$ in the soaking time. Moreover, there was no significant difference at $P > 0.05$ in the interaction in the treatment, curing time and soaking time.

Table 4.2. 9: Volumetric Swelling of *Gmelina arborea* wood treated with calcium chloride and citric acid at varying curing time

Treatment	Time	Curing Time	Volumetric Swelling (%)	Average
Calcium	24 hours	6 hours	14.66±1.09	15.65±1.43
		9 hours	15.24±1.60	
	48 hours	6 hours	15.28±1.03	
		9 hours	15.92±1.60	
	72 hours	6 hours	16.09±1.03	
		9 hours	16.71±1.65	
	6 hours 9 hours		15.34±1.15 15.96±1.64	
Citric	24 hours	6 hours	13.55±0.78	14.08±0.91
		9 hours	13.35±0.58	
	48 hours	6 hours	14.08±0.95	
		9 hours	13.96±0.56	
	72 hours	6 hours	14.79±1.11	
		9 hours	14.75±0.54	
	6 hours 9 hours		14.14±1.04 14.02±0.79	
Control	24 hours		14.46±2.76	15.75±3.10
	48 hours		15.81±3.11	
	72 hours		16.96±3.42	

Values are means±SD; Values in the same column for each treatment with the same superscript are not significantly different from each other

Table 4.3.0: ANOVA Table for Volumetric Swelling of *Gmelina arborea* wood treated with calcium chloride and citric acid

Source	Type III Sum	Df	Mean	F	P	Sig.
	of Squares		Square			
Treatment	44.285	2	22.143	8.066	0.001	*
Time	48.707	2	24.353	8.871	0.000	*
Curing Time	4.441	1	4.441	1.618	0.207	Ns
Treatment * Time	2.532	4	.633	.231	0.921	Ns
Treatment* Curing	25.612	2	12.806	4.665	0.012	*
Time * Curing	.131	2	.065	.024	0.976	Ns
Treatment * Time * Curing	.708	4	.177	.065	0.992	Ns
Error	247.069	90	2.745			
Total	373.486	107				

*= Values less than 0.05 are significant, ns = Not significant

4.3 Anatomical Properties

4.3.1 Fibre Characterization

4.3.1.1 Fibre Length

The fibre length of the *Gmelina arborea* wood from the different stem height positions with different treatment for this study, as well as which stem height position and treatments are significantly different from each other with respect to their fibre length; it can be observed that the wood treated with calcium chloride has the highest mean fibre length (1.08 ± 0.33 mm) with the top stem fibre length (1.27 ± 0.34 mm) higher than that of the middle (1.12 ± 0.24 mm), while the base stem height (0.85 ± 0.27 mm) position has the least fibre length, followed by wood samples treated with citric acid (1.08 ± 0.25 mm), having the same pattern with the wood treated with calcium chloride. The top having the highest fibre length (1.23 ± 0.24 mm), then the middle (1.06 ± 0.25 mm), while the base (0.96 ± 0.18 mm) has the lowest fibre length with respect to the stem height position, while the untreated samples (control) has the lowest mean fibre length (1.06 ± 0.29 mm), following a different pattern from what is observed with the treated samples with the top (1.11 ± 0.37 mm), followed by the base portion (1.06 ± 0.30 mm), while the middle has the least mean fibre length with respect to the stem height position.

It can be observed that there was no significant difference (i.e. $P > 0.05$) between the fibre length of wood and the treatment with $F_{(2, 126)} = 0.127$ and $P = 0.881$ as shown in Table 3.3.2. However, there was a significant difference (i.e. $P < 0.05$) between the fibre length of wood obtained from the different stem heights of top, middle and base positions with $F_{(2, 126)} = 9.011$ and $P = 0.000$. Moreover, there was no significant difference in the interaction of the treatment and the stem height position with $F_{(4, 126)} = 2.112$ and $P = 0.083$

4.3. 1: Fibre Length of *Gmelina arborea* wood obtained from different stem height positions

TREATMENT	STEM HEIGHT		AVERAGE
	POSITION	FIBRE LENGTH (mm)	
Control	Bottom	1.06±0.30	1.06±0.29
	Middle	1.01±0.19	
	Top	1.11±0.37	
Calcium	Bottom	0.85±0.27	1.08±0.33
	Middle	1.12±0.24	
	Top	1.27±0.34	
Citric	Bottom	0.96±0.18	1.08±0.25
	Middle	1.06±0.25	
	Top	1.23±0.24	

Values are means±SD; Values in the same column for each stem height position with the same superscript are not significantly different from each other

4.3. 2: ANOVA Table for Fibre Length of *Gmelina arborea* wood obtained different Stem Height Positions

Source	Type III Sum					Sig.
	of Squares	df	Mean Square	F	P	
Treatment	0.020	2	0.010	0.127	0.881	Ns
Stem Height Position	1.385	2	0.692	9.011	0.000	*
Treatment * Stem Height Position	0.649	4	0.162	2.112	0.083	Ns
Error	9.681	126	0.077			
Total	11.734	134				

*= Values less than 0.05 are significant, ns = Not significant

4.3.1.2 Fibre Diameter

The descriptive statistics of the fibre diameter of the *Gmelina arborea* wood in Table 4.3.3 below showed that wood obtained from the different stem height positions treated with calcium chloride and citric acid to determine the influence of the treatment on the fibre diameter, as well as which stem height and treatment are significantly different from each other with respect to their fibre diameter. It can be observed that wood treated with citric acid has the highest mean fibre diameter ($31.80 \pm 10.92 \mu\text{m}$) with the base stem height fibre diameter ($33.76 \pm 12.95 \mu\text{m}$) higher than the top ($31.66 \pm 10.64 \mu\text{m}$), while the middle stem height has the lowest mean fibre diameter ($29.98 \pm 9.29 \mu\text{m}$), followed by wood treated with the calcium chloride ($31.50 \pm 7.49 \mu\text{m}$), however, the trend seemed to have reverse with the top stem height position ($33.68 \pm 5.66 \mu\text{m}$) having the highest mean fibre diameter, then the middle position ($33.43 \pm 6.20 \mu\text{m}$), while the base stem height has the lowest mean fibre diameter ($27.38 \pm 8.87 \mu\text{m}$). on the other hand, the untreated wood (control) has the least mean fibre diameter ($27.77 \pm 6.90 \mu\text{m}$), with the base stem height ($28.89 \pm 9.11 \mu\text{m}$) having the highest mean fibre diameter, then the middle position ($28.05 \pm 3.64 \mu\text{m}$), while the top stem height ($26.37 \pm 7.07 \mu\text{m}$) has the lowest mean fibre diameter. From the foregoing, it can be observed that the fibre diameter distribution of the *Gmelina arborea* wood along the stem height from the base to the top, did not follow any linear pattern.

It can be observed that there was a significance difference (i.e. $P < 0.05$) between the fibre diameter and the different treatment with $F_{(2, 126)} = 3.074$ and $P = 0.050$. However, no significant difference (i.e. $P > 0.05$) between the fibre diameter obtained from the different stem height positions and the interaction of the treatment and the different stem height position with $F_{(2, 126)} = 0.056$ and $P = 0.946$; $F_{(4, 126)} = 1.799$ and $P = 0.133$ respectively.

4.3. 3: Fibre Diameter of *Gmelina arborea* wood obtained from different stem height positions

TREATMENT	STEM HEIGHT	FIBRE DIAMETER	
	POSITION	(μm)	AVERAGE
Control	Bottom	28.89 $\pm$ 9.11	27.77 $\pm$ 6.90
	Middle	28.05 $\pm$ 3.46	
	Top	26.37 $\pm$ 7.07	
Calcium	Bottom	27.38 $\pm$ 8.87	31.50 $\pm$ 7.49
	Middle	33.43 $\pm$ 6.20	
	Top	33.68 $\pm$ 5.66	
Citric	Bottom	33.76 $\pm$ 12.95	31.80 $\pm$ 10.92
	Middle	29.98 $\pm$ 9.29	
	Top	31.66 $\pm$ 10.64	

Values are means $\pm$ SD; Values in the same column for each stem height position with the same superscript are not significantly different from each other

4.3.4: ANOVA Table for Fibre Diameter of *Gmelina arborea* wood obtained from different Stem Height Positions

Sources	Type III Sum of Squares	df	Mean Square	F	P	Sig.
Treatment	453.301	2	226.650	3.074	0.050	*
Stem Height Position	8.208	2	4.104	0.056	0.946	Ns
Treatment * Stem Height Position	530.447	4	132.612	1.799	0.133	Ns
Error	9288.942	126	73.722			
Total	10280.898	134				

*= Values less than 0.05 are significant, ns = Not significant

4.3.1.3 Lumen Width

Table 4.3.5 shows the Statistical Analysis of the lumen width of the *Gmelina arborea* wood obtained from the different stem height and different treatment, as well as which stem height and treatment are significantly different from each other with respect to their lumen width. It can be observed that wood treated with the calcium chloride has the highest lumen width ($24.52 \pm 17.68 \mu\text{m}$), with the base stem height lumen width ($30.91 \pm 28.93 \mu\text{m}$) higher than the middle ($22.68 \pm 6.49 \mu\text{m}$), while the top stem height ($19.99 \pm 5.88 \mu\text{m}$) has the least lumen width, followed by wood treated with the citric acid ($21.39 \pm 8.86 \mu\text{m}$), having the same pattern with the wood treated with calcium chloride. The base ($23.77 \pm 9.19 \mu\text{m}$) having the highest lumen width, then the middle portion ($20.74 \pm 8.74 \mu\text{m}$), while the top ($19.65 \pm 8.73 \mu\text{m}$) has the lowest lumen width with respect to the stem height positions, while the untreated wood samples (control) has the least mean lumen width ($17.69 \pm 6.56 \mu\text{m}$), following a different pattern from what is observed with the treated samples with the top ($18.73 \pm 5.65 \mu\text{m}$) having the highest lumen width, followed by that of the base ($17.22 \pm 8.85 \mu\text{m}$), while the middle stem position ($17.13 \pm 4.82 \mu\text{m}$) has the least mean lumen width with respect to the stem height position. From the foregoing, it can be observed that the lumen width of the *Gmelina arborea* did not seem follow any definite pattern with respect across the three stem height positions.

The analysis of variance for the lumen width of *Gmelina arborea* wood obtained from the different stem height and different treatment below showed that there was a significant difference (i.e. $P < 0.05$) in the treatments with $F_{(2, 126)} = 3.686$ and $P = 0.028$. However, there was no significant difference (i.e. $P > 0.05$) between the lumen width of wood obtained from the different stem heights positions with $F_{(2, 126)} = 1.846$ and $P = 0.162$. Also there is no significant difference (i.e. $P > 0.05$) in the interaction of the treatment and the stem height positions with $F_{(4, 126)} = 1.059$ and $P = 0.380$.

4.3. 5: Lumen Width of *Gmelina arborea* wood obtained from different stem Height

TREATMENT	STEM HEIGHT		AVERAGE
	POSITION	LUMEN WIDTH (μm)	
Control	Bottom	17.22±8.85	17.69±6.56
	Middle	17.13±4.82	
	Top	18.73±5.65	
Calcium	Bottom	30.91±28.93	24.52±17.68
	Middle	22.68±6.49	
	Top	19.99±5.88	
Citric	Bottom	23.77±9.19	21.39±8.86
	Middle	20.74±8.74	
	Top	19.65±8.73	

Values are means±SD; Values in the same column for each stem height position with the same superscript are not significantly different from each other

4.3. 6: ANOVA Table for Lumen Width of *Gmelina arborea* wood obtained from different Stem Height Positions

Sources	Type III Sum of Squares	df	Mean Square	F	P	Sig.
Treatment	1052.567	2	526.284	3.686	0.028	*
Stem Height Position	527.107	2	263.553	1.846	0.162	Ns
Treatment * Stem Height Position	604.676	4	151.169	1.059	0.380	Ns
Error	17989.413	126	142.773			
Total	20173.763	134				

*= Values less than 0.05 are significant, ns = Not significant

4.3.1.4 Anatomical Properties

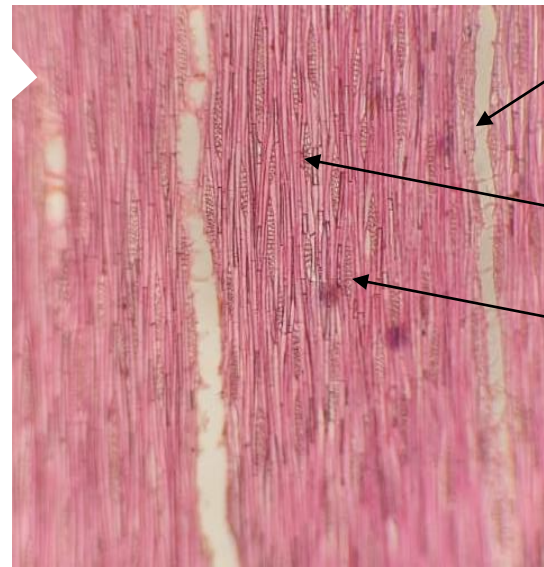
Tranverse section of *Gmelina arborea*



Control (un-treated)

Vessels

Rays

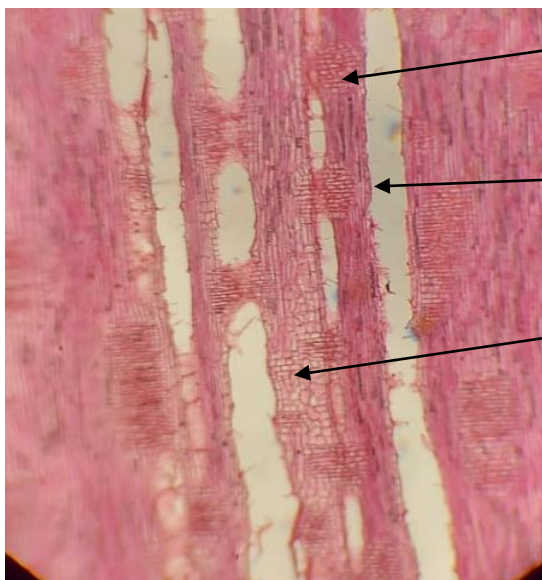


control (Tangential section)

Vessel

Ray

Fibres

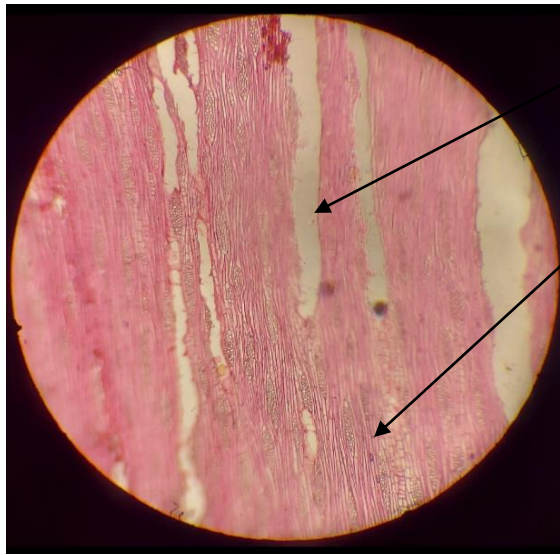


Control radial section of *Gmelina arborea*

Rays

Vessel

Axial Parenchyma



Calcium chloride tranverse section

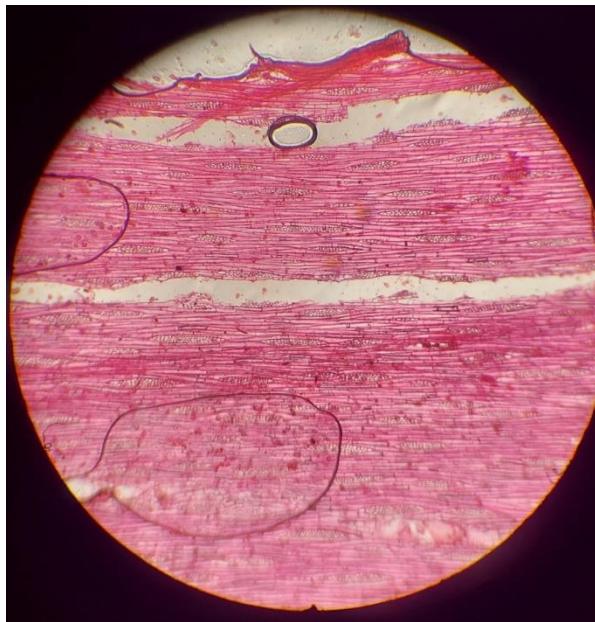
Vessels

Axial

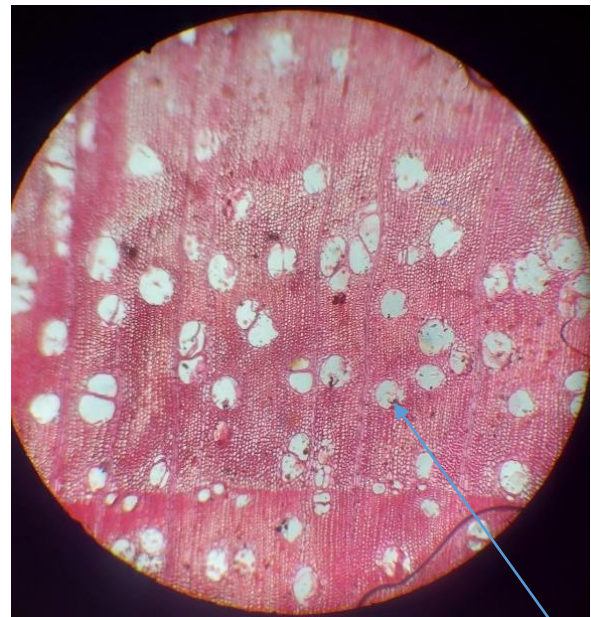
Parenchyma



calcium chloride tranverse



Citric acid tangential section



citric acid tranverse section

Vessels

4.4 Wood Weathering

4.4.1 Weight Loss due to Weathering

Figure 2 below shows the graphical representation of weight loss due to weathering of *Gmelina arborea* wood treated with calcium chloride and citric acid and cured for 6 and 9 hours. From the figure below, the results showed that the untreated wood samples (control) has the highest mean weight loss value of 5.86 %, while the wood treated with calcium chloride has the highest mean value of 4.31 % than the wood treated with citric acid with 4.24 % as seen in Figure 1. The wood samples treated with calcium chloride and cured for 9 hours has the highest average weight loss value of 6.03 % than the ones cured for 6 hours with the weight loss value of 2.60 %. However, the wood treated with citric acid did not seem to follow the linear pattern of the wood treated with calcium chloride. It was observed that the wood cured for 6 hours with weight loss value of 4.49 % is higher than the ones cured for 9 hours with weight loss value of 3.99 %.

Analysis of Variance (ANOVA) presented in Table 4.4.1 revealed that there was no significant difference at (i.e. $P > 0.05$) in the treatment with $F_{(2, 20)} = 1.846$ and $P = 0.184$. Also, there was no significant difference in the curing time and the interaction of the treatment and the curing time with $F_{(1, 20)} = 2.222$ and $P = 0.152$; $F_{(1, 20)} = 3.986$ and $P = 0.060$ respectively.

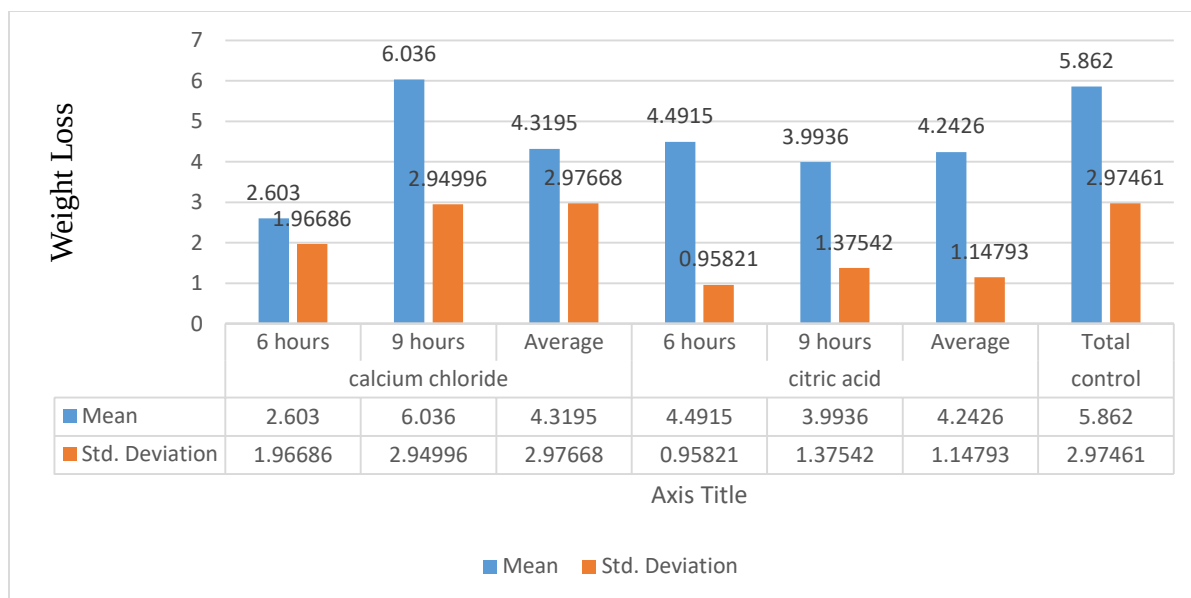


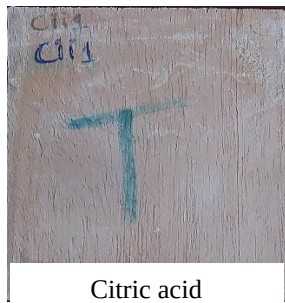
Figure 3: The Descriptive Percentage Weight Loss due to Weathering of *Gmelina arborea* Wood

Table 4.4.1: ANOVA Table for Percentage Weight Loss due to Weathering of *Gmelina arborea* wood treated with Calcium chloride and Citric acid at varying curing time

Source	Type III Sum					Sig.
	of Squares	df	Mean Square	F	P	
Treatment	17.889	2	8.945	1.846	0.184	Ns
Curing	10.768	1	10.768	2.222	0.152	Ns
Treatment * Curing	19.315	1	19.315	3.986	0.060	Ns
Error	96.916	20	4.846			
Total	137.026	24				

*= Values less than 0.05 are significant, ns = Not significant

4.4.2 Weathering Visual Observation



Citric acid

Week 1



Calcium chloride



Control



Week 2



Week 3



Week 4





Week 5



Week 6



Week 7



Week 8



Week 9



Week 10



Week 11



Week 12

4.5 DISCUSSION

4.5.1 The Basic Properties of *G.arborea* Wood

Wood is a natural material with inherent properties that make it useful for a variety of applications. In addition to its application, it has an excellent physical and aesthetic properties, good relationship between weight and strength and it can be easily processed. The basic property of wood is very important in research in guiding end users on the peculiarity of wood. Moreover, with its renewable and eco-friendly nature, it has been used widely for many applications including light and heavy weight constructions.

4.5.2 Moisture Content Distribution

Wood is a hygroscopic material that absorbs water and the moisture content distribution of a wood is a very important physical property of any woody plant. The moisture content of a wood will determine the method of sawing, drying and final use of the wood. The finding of this study revealed that wood obtained from the base portion along the stem height has higher moisture content, then the middle and the top has the lowest overall mean moisture content distribution. Moreover, laterally, the wood moisture content distribution increases from the inner wood portion to the outer wood. The moisture variation along the *Gmelina arborea* stem corroborates with the work of Owoyemi *et al.*, (2015) states that variation in the moisture content along the *Gmelina arborea* bole may be due to the nature of moisture passageways or wood structures. The different size of vessels along the tree stem may be a good reason for the moisture variation. Moreover, the variation in moisture variation may help in reducing drying defect like splits and cracks. This is a condition where there is a tendency for the outer layer of the wood to dry faster than the interior one.

The ANOVA findings also showed that there is a statistically difference between the moisture content distributions along the stem height and the lateral positions of *Gmelina arborea* wood and

this is in agreement with the suggestion of Reeb (1995) that moisture can either be distributed equally in the whole log or significant moisture gradients can exist in radial or longitudinal direction. Next to the moisture differences in a single log, there can also exist significant differences of moisture content and distribution in different logs of the same wood species at the same growing conditions.

4.5.3 Density of *G.arborea* Wood

Wood density is a property of wood that has a significant effect on the other properties of wood; dimensional stability, strength and durability. In addition, it provides an estimation of the amount of cell wall material and therefore influences many factors such as drying time, strength property, physical property, swelling, shrinkage and many other properties (Wiemann *et al.*, 2009; Owoyemi *et al.*, 2018). In this study, it was examined that along the stem height position, the density of the wood is greater at the middle portion, followed closely by the top portion with the base portion having the lowest value in terms of density and this is not in consonance with the work of Owoyemi and Akinwamide, (2020) that the basic density of *Borassus aethiopium* ranged from the top core portion to bottom dermal portion, which maybe as a result of lower age trees used in their study. Moreover, it increases laterally from the inner wood to the outer wood from the result and this agrees with the findings of Chave, (2006) that the outer part of the tree tends to have higher density than the inner part close to the pit.

There was significant difference in the density variation of *G. arborea* wood along and across the stem height position and this corroborate with the findings of Owoyemi *et al.* (2012) that density variation exists and because wood species belong to the same family does not necessarily mean they will have similar or closely related density.

4.5.4 Volumetric Shrinkage of *G. arborea* Wood

Volumetric shrinkage is very important in cases whereby the wood will be used for constructional purposes. However, wood is susceptible to dimensional changes by reduced volumetric shrinkage, swelling and water absorption. The findings of this study revealed that wood obtained from the base portion has the highest percentage of volumetric shrinkage, followed by the middle portion and the top has the lowest percentage of volumetric shrinkage and this disagree with the findings of Okon (2014) that states volumetric shrinkage increase from base to the top and from innerwood outward to outerwood. The outer portion of the wood has a higher percentage of volumetric shrinkage with the exception of the middle part of the wood whereby the middle portion has a greater value than the outer and then the innerwood. This agrees with the work of Owoyemi *et al.*, (2015) that the volumetric shrinkage was greater for the outer portion than the inner portion of the bole. Moreover, the result is the same compared with the volumetric shrinkage of normal timber producing trees such as *Leucaena leucocephala* whose base has more volumetric shrinkage closely followed by the middle portion and the top having the lowest mean value for volumetric shrinkage according to the work of Owoyemi *et al.*, (2017).

4.5.5 Volumetric Swelling of *G. arborea* Wood

Volumetric swelling is a very important characteristics of wood property. It reflects how much of water or liquid substances the wood will take in, thereby increasing its original weight and volume; this requires wood modification especially wood that will be exposed for outdoor construction. The findings of this result revealed that the untreated wood samples has the highest volumetric swelling and the wood samples treated with citric acid has the lowest value of the volumetric swelling and this corroborates the work of Samani *et al.*, (2020) that wood treated with citric acid performed better than untreated samples resulting in better anti-swelling efficiency and

dimensional stability. Furthermore, it might be due to the presence of resins which results in lower WPG.

4.5.6 Weight Loss due to Leaching of *G. arborea* Wood

The amount of weight loss determines how fast a wood will deteriorate particularly when exposed to weathering. Resistance and dimensional stability are a critical determinant of life span of tree species. After the continuous soaking of the *G. arborea* wood samples in water for 24, 48 and 72 hours to ascertain its response to weathering when used for outdoor applications, the estimated results for the percentage weight loss due to leaching revealed that wood treated with calcium chloride has the highest percentage of weight loss due to leaching than the wood treated with citric acid. From my findings, citric acid performed better in reducing the weight loss due to leaching and this corroborates with the work of Owoyemi *et al.*, (2013) that dimensional change can be reduced by treating wood with chemicals to replace the hydroxyl groups with other hydrophobic functional groups of modifying agents.

4.5.7 Dimensional Stability and Moisture Response of the Wood Treated with Citric acid and Calcium chloride

Chemical modification offers a non-biocidal alternative to protect wood against decay fungi, and wood destroying organisms, while simultaneously improving its various properties to make it suitable for specific end uses. Dimensional stability is a commonly targeted property for improvement through wood modification. The anti-swelling efficient (ASE) as a measure of the dimensional stability of *G. arborea* wood treated with calcium chloride and citric acid at different curing time was evaluated through this study which confirmed generally, the wood samples treated with citric acid and cured for 9 hours showed some extent of reduction in the dimensional instability due to the reaction in the wood structure which is more complex, so a significant

leaching stable bulking effect is initiated (Kurkowiak *et al.*, 2022). Kurkowiak *et al.*, (2022) reported in their work that dry curing of citric acid impregnated wood at both tested temperatures resulted in a comparable modification efficiency (WPG) and cell wall bulking and that specimens subjected to higher curing temperature have achieved a higher fixation of the impregnation chemicals.

4.6.1 Anatomical Properties

4.6.1 Fibre Characterization

4.6.1.1 Fibre Length

The result of this study showed the fibre length of the *Gmelina arborea* wood obtained from the different stem height and the treatment are significantly different from each other for this study. From my findings, it can be observed that there was no significant difference in the treatments used and the stem height positions for the fibre length of the *Gmelina arborea* wood. Moreover, it was observed that the fibre length of *Gmelina arborea* was higher for the top, followed by base while the middle has the least fibre length and this corroborate with the work of Emerhi (2012), where the mean value of fibre length obtained in the longitudinal position of *R. racemosa* species ranged from top to base and the middle with the least fibre length. The inconsistency in the fibre length in the longitudinal direction and the differences in the fibre length associated with increase in height could be mainly due to the differences in the juvenile and matured wood.

The mean result obtained for the fibre length ranged from 0.85-1.27 mm and this was lesser than the *Gmelina arborea* fibre length reported by Olayanu *et al.*, (2022) and his findings state that it might be as a result of site growth, climatic condition, age of the trees studied, and the portion along the bole from which the samples were collected.

4.6.1.2 Fibre Diameter

In this study, the fibre diameter of *Gmelina arborea* wood obtained from different stem height and the treatment are significantly different from each other for this study. From my findings, it can be observed that there was no significant difference in the interaction of the treatment and the different stem height position between the fibre diameter. However, the fibre diameter distribution along the stem height decrease from the base to the top for the control which corroborate the work of Fathi (2014) on oil palm which stated that the fibre diameter gradually decreased from the bottom end to the top of the trunk. In comparison with hardwood species, it ranged from 26.37-33.76 μm which is found to be suitable for quality pulp and paper production (Olayanu *et al.*, 2022).

4.6.1.3 Lumen width

The density of timber is a function of both cell wall thickness and lumen diameter and there exists a correlation between strength and density of timber (Dinwoodie, 2000). In this study, the lumen width of *Gmelina arborea* wood obtained from different stem height and the treatment are significantly differently from each other for this study. From my findings, it can be observed that there was no significant difference in the interaction of the treatment and the different stem height position. The study shows that the average lumen width for the treated did not seem to follow the same pattern of the lumen width along the stem height position. It can be observed that the lumen width decreased along the longitudinal position from the base to the top while the control seems to be different with the top higher than the base, while the middle has the least lumen width; this variation in the lumen width corroborate with the findings of Emerhi (2014) that the variation in the lumen width in both at the radial and longitudinal position can be attributed to the increase in cell size and physiological development of the wood as the tree grows in girth.

4.6 Wood Weathering of *G. arborea* Wood

Wood as an organic material is highly susceptible to damage by deteriorating agents; the most common of these are degradation by fungi, termites and other abiotic factors particularly wood exposed to outdoor construction. In order to prevent damages to wood by these agents, wood must be subjected to preservative treatment which can prevent or limit to the barest minimum the effects of these bio-deteriorating agents. From my findings, it can be observed that there was no significant difference in the treatments used. The estimated results of the percentage weight loss is higher in the untreated wood samples than the treated samples exposed to weathering and this corroborate with the findings of Mantanis and Lykidis (2015) that chemical modification (wood furfurylation) leads to a high protection against bio-deterioration by fungi, bacteria, while it increases the hardness, lowers the equilibrium moisture content, and improves largely the dimensional stability of wood. Moreover, from my observation, there was some sort of colour changes in the wood samples exposed outdoor, from yellowing after 6 weeks exposure then eventually to greying for both the treated and untreated after a prolonged exposure to weathering and this corroborate with the results of Mantanis and Lykidis (2015) that all treated decks appeared to exhibit extensive greying effects on their surfaces after prolonged exposure to outdoor weathering.

CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusion

Gmelina arborea wood classified as low density showed considerable improvement in its sorption, strength, durability properties revealing its treatability capacity. The wood showed the capacity to absorb moisture which makes it earn a great potential to absorb and retain preservatives. Therefore, the rate of uptake shows that the *G. arborea* wood samples retained considerable amount of the chemical. Moreover, citric acid performed best and the curing time of 9 hours results in a higher modification efficiency and cell wall bulking. The results showed that citric acid treatment provided essential protection to wood used in moisture prone environment. This established the possibility of using citric acid as a chemical in wood modification and further helps in the property enhancement of the wood for wood users that depend on the fast growing plantation wood species. However, the durability assessment showed that wood treated with citric acid and calcium chloride will not be suitable for used in a prolonged outdoor construction. Hence, this necessitate the need to incorporate substance with inherent properties of proffering essential fixation of the treatment. Nevertheless, the anatomical characteristics of both the treated and untreated *G. arborea* showed no significant difference. This revealed that the treatment do not offer significant modification on the properties of *G. arborea* wood with citric acid and calcium chloride.

5.2 Recommendation

Arising from this study, the following recommendations were made;

1. Further work on the chemical retention and fixation should be carried out to guarantee utilization for external applications and maximize the full potential of *G. arborea* wood treated with citric acid.

2. For acceptability, it is highly essential to popularize the use of other eco-friendly chemicals in the modification of less durable wood.
3. To enhance the aesthetic value of wood citric acid treatment can be considered as it offers significant colour modification of the wood samples.

References

- Ajuziogu, G. and Ojua, E. (2020). Comparative Anatomical Studies on the Wood and Bast Fibres of *Gmelina arborea*. Corpus ID: 222219993.
- Aquino V.B., Bertolini M.S., Galvio C.A., Almeida T.H., Almeida D.H., Lahr F.A. and Christoforo A.L. (2021). Effect of Artificial Weathering on Physical and Mechanical Properties of Wood. DOI: 10.1590/1806-908820210000034
- Areo, O.S., Omole, O.A., and Adejoba, O.R. (2019). Mechanical Properties of Photodegraded Wood of Nigerian Grown *Gmelina Arborea*. International Journal of Applied Research and Technology. Vol, 8, No 3.
- Arora, C. and Tamrakar, V. (2017). *Gmelina arborea*: Chemical Constituents, Pharmacological activities and applications. *Journal of Phytomedicine*, 9(4), 528-542.
- Bratasz, L., Kozłowski, R., Kozłowska, A. and Rachwał, B. (2008). Sorption of Moisture and Dimensional Changes of Wood species used in Historic Objects. *European Journal of Wood and Wood Products*, 70, 445-451.
- Chave, J. (2006). Measuring Wood Density for Tropical Forest Trees a Field Manual. PAN-AMAZONIA project. Universite Paul Sabatier 31000 Toulouse, France, pp1-6.
- Dennis, J. and Sandberg, D. (2020). A review of Wood Modification Globally- Updated Findings from COST FP1407. DOI: 10.37947/ipbe.2020.vol1.1
- Dinwoodie, J.M. (2000). Timber- Its Nature and Behaviour. E & FN Spon, Taylor & Group, London and NY.
- Emerhi, E.A. (2012). Variations in Anatomical Properties of *Rhizophora racemosa* (Leechm) and *Rhizophora harrisonii* (G.mey) in a Nigerian Mangrove Forest Ecosystem. *International Journal of Forest, soil and Erosion*, ISSN: 2251-6387, 2(2): 89-96.

- Evans, P. (2012). Weathering of Wood and Wood Composites. Handbook of wood chemistry and Wood Composites, pp: 151-216, DOI: 10.1201/b12487-10.
- Fathi, L. (2014). Structural and Mechanical Properties of the Wood from Coconut palms, Oil palms and date palms. *Iran Journal of Scientific and Industrial Research*. 6(1), 59-66.
- Feist, W.C., Rowell, R.M. and Ellis, W.D. (1989). Moisture Sorption and Accelerated Weathering of Acetylated and Methacrylated Aspen. *Forest Product Laboratory*.
- Feist, W.C. (1990). Outdoor Wood Weathering and Protection. *Forest Product Laboratory*, WI- 53705-2398.
- Hartley, I.D., and Hamza, M.F. (2016). Wood: Moisture Content, Hygroscopicity and Sorption. PP(1-7). DOI:10.1016/B978-0-12-803581-8.02219-0
- Homan, W.J. and Jorissen, A.J.M. (2004). Wood Modification Development. *Heron*, 49(4).
- Jayashri, G., Pankaj, A. and Shakti, C. (2020). Changes in colour and mechanical properties of wood propylene composites on natural weathering. Indian Council of Forestry Research and Education. Vol 22, no 3, pp 325-334.
- Kropat, M., Hubbe, M. A., & Laleicke, F. (2020). Natural, accelerated, and simulated weathering of wood: A review. *BioResources*, 15(4), 9998.
- Kufre, O. (2014). Relationship between fibre Dimensional Characteristics and Shrinkage Behaviour in a 25 year old *Gmelina arborea* in Oluwa Forest Reserve, South-west Nigeria. *Advances in Applied Science Research*. (65), pp:50-57
- Kurkowiak, K., Hentges, D., Dumarcay, S. and Militz, H. (2022). Understanding the mode of action of Sorbitol and Citric acid in Wood. Proceedings of the Tenth European Conference on Wood Modification

- Lauridsen, E.B. and Kjaer, E.D. (2002). Provenance Research in *Gmelina arborea* Linn., Roxb. A Summary of Results from the Three Decades of Research and a Discussion of How to Use Them. *International Forestry Review*, 4, 20-29.
- Mai T.H., Tang T.K., Hong. and Yen N.T. (2021). The Effect of Weathering on Wood and its Protection. *Journal of Forestry Science and Technology*, No 11.
- Mantanis, G.I. and Lykidis, C. (2015). Evaluation of Weathering of Furfurylated Wood Decks after a 3-year Outdoor Exposure in Greece. DOI: 10.5552/drind.2015.1425. 66(2): 115-122.
- Nasir, V., Fathi, H., Fallah, A., Kazemirad, S., Sassani, F., & Antov, P. (2021). Prediction of mechanical properties of artificially weathered wood by color change and machine learning. *Materials*, 14(21), 6314.
- Nengi, S.S. (2004). Wood Science and Technology. Applied Forestry Series No.2. International Book Distributors, Dehra Dun, India. pp 249.
- Nguyen, V.D., Nguyen, T.T., Zhang, A., Hao, J. and Wang, W. (2018). Effect of three Species on UV Weathering of Wood-Flour –HDPE Composites. Northeast Forestry University. <https://doi.org/10.1007/s11676-019-00890-4>.
- Ogunkunle, A.T.J. and Oladele, F.A. (2008). Structural Dimension and Paper making Potentials of Wood in some Nigerian Ficus L. (moraceae). *Advances in Natural and applied sciences*, 5(2): 10-15.
- Okon, K.E. (2014). Variations in Specific Gravity and Shrinkage in Wood of 25-year-old *Gmelina arborea* in Oluwa Forest Reserve, South-West Nigeria, *Archives of Applied Science Research* 6(4): 271-276.
- Olaoye K.O., Okanlawon F. B. and Fayanjuola A.I. (2019). Selected Anatomical Properties of *Boscia angustifolia* Wood. Federal College of Forestry, Forestry Research Institute of Nigeria. Doi: 10.19044/esj.2019.v15n12p11 [URL:http://dx.doi.org/10.19044/esj.2019.v15n12p11](http://dx.doi.org/10.19044/esj.2019.v15n12p11)

- Olayanu, C.M., Majekobaje, A.R., Adeyemo, S.M. and Omole, A.O. (2022). Anatomical Characterization of *Blighia sapida* K. Koenig Wood explains its Potential Utilization. PRO LIGNO. ISSN: 2069-7430. Vol. 18(3).
- Owoyemi, J.M, Kayode, J.O, and Olaniran, O.S. (2008). Decay Fungi Infestation of Wood Structures in Building. Forest and Forest Products, pp 283-285.
- Owoyemi, J.M., Olufemi, B. and Olaniyan, M.O. (2012). Fungicidal Effect of Chromated Copper Arsenate and Cashew Nut Shell Extract applied on *Ceiba pentandra* Wood. *Nigeria Journal of Mycology*, 4: 22-29.
- Owoyemi, J.M., Olaniran, O.S. and Aliyu, D.I. (2013). Effect of Density on the Natural Resistance of Ten selected Nigerian Wood species to subterranean Termites, PRO LIGNO. 9(4): 32-40.
- Owoyemi, J.M., Oyedele, O.O. and Aladejana, J.T. (2015). Assessment of Dimensional Stability of *Gmelina arborea* Wood using Modified Green House Dryer. pp. 11-20, Vol. 11(2).
- Owoyemi, J.M., Olumuyiwa, A.O. and Oyeleye, I.O. (2017). Sorption and Strength Properties of Thermally Modified Plantation Grown *Leucaena leucocephala* (Lam) Wood using Paraffin Wax. *American Journal of Material Science*, 7(3): 53-58.
- Owoyemi, J.M., Adamolekun, O.R. and Aladejana, J.T. (2018). Assessment of Hygroscopic Characteristics of *Hevea brasiliensis* Wood. *International Journal of Agriculture and Environmental Research*. 4(1): 78-91. ISSN: 2455-6939.
- Owoyemi, J.M. and Akinwamide, T.O. (2020). Assessment of Density and Anatomical Properties of Nigerian Grown *Cocos nucifera* Wood. *Applied Tropical Agriculture*. 25(1): 148-154.
- Poonam S., Anchal R., Neha S.P., Ashok K. (2021). Tree Improvement Breeding and Biotechnology of *Gmelina arborea* Roxb India Forester, 147(11): 1075-1082. DOI: 10.36808/if/2021/v147i11/154156
- Reeb, J. (1995). Wood and Moisture relationships. <https://extension.oregonstate.edu/catalog>

- Riki, J.T.B., Sotannde, O.A., and Oluwadare, A.O. (2019). Anatomical and Chemical Properties of Wood and their Practical Implications in Pulp and Paper Production. *Journal of Forestry, Wildlife & Environment*. ISBN: 2141-1778, Vol. 11(3).
- Rowell, R.M. (1983). Chemical Modification of Wood. USDA, Forest Service, Forest Product Laboratory. DOI: 10.3139/9783446442504.022
- Samani, A., Hom, S., Bhoru, Y.U. and Ganguly, S. (2020). Dimensional Stability of Wood Modified by Citric acid. *Indian Forester*, 146(5): 455-458. DOI:10.36808/if/2020/v146i5/147218
- Sandberg, D., Kutnar, A., and Mantanis, G.I. (2017). Wood Modification Technologies – A review. *iForest – Biogeosciences and Forestry*, 10(6): 895-908. DOI: 10.3882/ifor2380-010
- Simpson, W. and TenWolde, A. (1999). Physical Properties and Moisture relation of Wood. *Forest Product Laboratory*, PP: 3, 1-3.
- Skaar, C. (1988). The Equilibrium Moisture Content of Five Lesser Utilized Species of Ghana Contrasted with Three European Species. *Open Journal of Composite Material*, Vol 12(2). <https://doi.org/10.1007/978-3-642-73683-4>
- Sonowal, J. and Gogoi, P.K. (2010). Dimensional Stability, Thermal Degradation and Termite Resistant Studies of Chemically Treated Wood. *International Journal of Chemistry*, 2(2). DOI:10.5539/ijc.v2n2p218
- Williams, R. S. (2005). Weathering of wood. *Handbook of wood chemistry and wood composites*, 7, 139-185.
- Winandy, J.E. (2016). Relating Wood Chemistry and Strength: Part 2. Fundamental Relationships between Changes in wood Chemistry and Strength of Wood.
- Zhengbin, H., Zhenyu, W., Lijie, Q., Jing, Q. and Songlin, Y. (2019). Modeling and Simulation of heat-mass transfer and its application in Wood Thermal Modification. Vol. 13. 102213.

Appendices



A: Weighing of wood samples B: soaking of wood samples C: wood samples after 72 hours of soaking.