WOOD PROPERTIES OF TAPPED RUBBER TREE (*Hevea brasiliensis* Muell. Arg.) IN AGBARHA, DELTA STATE, NIGERIA.

BY

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ABSTRACT

Hevea brasiliensis, a major source of natural rubber is an important source of timber in Nigeria as senescence occurs. However, duration of latex collection is known to affect *Hevea brasiliensis* wood formation and consequently, the wood properties. Knowledge on wood properties of tapped rubber tree in Nigeria which would enhance its sustainable exploitation as timber is limited. Therefore, the physical, anatomical, mechanical and chemical properties of tapped *Hevea brasiliensis* were investigated.

A rubber plantationwith information on years of tapping (YoT)was purposively selected from Agbarha, South-South, Nigeria. Five trees fromeach of 5, 10, 15 and 20 YoT were harvested. One billet each (60 cm long) was taken from the base and top of the bole of each tree and partitioned into innerwood, middlewood and outerwood. These were further processed into standard dimensions for determination of wood properties. Using a 4 x 2 x 3 factorial arrangement in a completely randomised design, experiments were carried out to determine physical [Specific Gravity (SG),Volumetric Shrinkage (VS, %)]; anatomical [Fibre Length (mm),Cell Wall Thickness (CWT,µm)]; mechanical [Maximum Compressive Strength parallel to grain (MCS//,Nmm^{-2}), Modulus of Elasticity (MoE,Nmm^{-2}), Modulus of Rupture (MoR,Nmm^{-2})] and chemical [Lignin Content (%), Ash Content (AC, %)] properties using standard procedures. Data obtained were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

Physical and mechanical properties were not significantly different. Mean SG was 0.6±0.01 across tapping age while VS was highest (11.4±0.7,YoT_{10}) and least (9.5±0.5,YoT_{15}). Fibre length increased from 1.4±0.02 (YoT_5) to 1.5±0.02 (YoT_{20}) while, CWT increased from 4.3±0.1(YoT_5) to 4.7±0.1 (YoT_{20}). The MCS// ranged from 69.4±2.8 (YoT_5) to 77.9±1.7 (YoT_{15}) while,MoE varied from 12459.7±789.8 (YoT_{10}) to 14155.3±657.9 (YoT_{20}).The MoR was highest (438.8±2.9,YoT_{10}) and least(422.2±2.9,YoT_5).Lignin Content varied from 21.4 (YoT_{10}) to 23.8 (YoT_{15})while, AC ranged from0.28 (YoT_5) to 0.36 (YoT_{10}). The SG was higher at the top (0.6±0.04) than the base (0.5±0.05), but VS decreased from base (10.9±0.4) to top (9.5±0.3). Fibre Length and CWT at the base and top were 1.43±0.01;4.23±0.1 and 1.50±0.02;4.78±0.1, respectively. The MCS// increased from the base (67.4±1.0) to the top (82.4±0.9). The MoE and MoR increased from the base (10897±345.8;421.2±1.8) to the top (15540±419.8; 438.6±2.1). Lignin content varied from the base (22.3±0.5) to the top (22.8±0.5) while, AC was 0.3±0.01 at the base and top. The SG was 0.6±0.01 from innerwood to outerwood while, VS decreased from 10.3±0.6 (innerwood) to 10.2±0.3 (outerwood). Fibre length did not differ (1.5±0.01) for innerwood, middlewood and outerwood. The CWT increased from innerwood (4.4±0.1) to outerwood (4.6±0.1). The MCS// and MoE were highest at innerwood (75.3±1.7; 13738.0±676.4) and least at outerwood (74.2±1.6; 12841.6±514.9) while, MoR varied from innerwood (428.9±2.9) to outerwood (430.6±2.8). Lignin content increased from innerwood (20.4±0.4) to outerwood (24.8±0.5) while, AC ranged from 0.3±0.01 in the innerwood to 0.4±0.01 in the middlewood.

Tapping duration had no negative impact on physical, anatomical, mechanical and chemical properties of tapped*Hevea brasiliensis*. Senescent *Hevea brasiliensis* may be used as timber.

Keywords: *Hevea brasiliensis,* Tapping duration, Maximum compressive strength, Volumetric shrinkage

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DEDICATION

This work is dedicated to God, the source of all wisdom and knowledge and to all who inspire to know and are doing everything possible to achieve knowledge.

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CERTIFICATION

I certify that this work was carried out by **IghoyivwiONAKPOMA** under my supervision in the Department of Forest Production and Products, Faculty of Renewable Natural Resources, University of Ibadan, Ibadan, Nigeria.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Wood is a natural productthat has been part of our life and has been in use throughout the world from year to year. This is due to its several advantages (versatility and applicability) andmakes wood a more superior material resource over other materials for structural and other uses (Ogunsanwo, 2001).

Despite the myriads of opportunities present with respect to the number of species potentially available for use, efforts are concentrated on very few species which are today facing the trend of extinction. It has been reported that there are over 600 wood species available for use in the tropical forest of which only about 56 representing just below 10% are currently being exploited for use. There is need therefore to have a paradigm shift so as to save the choice species which are currently on the spot, exploit other species and increase the scope of tropical tree/wood utilisation and hence expand the frontiers of wood utilisation research in Nigeria and other parts of the globe.

There have been efforts at utilising other species termed lesser-used species (LUS) and lesser known species such as reports of Poku *et al.*(2001), Ajala (2005), Ogunsanwo and Terziev (2010), Ajala and Ogunsanwo (2011), Ogunsanwo and Ojo (2011).

Apart from the lesser used species gotten mostly from the forest whose utilisation and application is on the increase, some agricultural tree plantations are also becoming relevant in the supply of industrial wood and fibres. These tree crops are often established for other purposes other than its timber for example, fruit and related use. These tree crops often outlive their primary purpose after several years of exploitation. They are sometimes employed in agroforestry systems and thus play a significant part in the supply of domestic wood fuel to local people than for industrial use (FAO, 2001). Rubber wood falls within this particular position as the tree is an agricultural crop while the timber obtained falls under the scope of forestry. Rubber wood has firmly reputed itself as a major source in the supply of timbers in South East Asia in the wood industry within a period of about 10 years to produce furniture and other furniture components. Hong (1995a) described the usage of rubber wood in Malaysia as "*a success story" –* rising from a valueless timber to one which is in great demand by the wood based industry.

Hevea brasiliensis (Muell. Arg.) generally referred to as rubber tree or para rubber is native to Brazil(Amazon forest) from which it extended to be widely established as a plantation in 20 countries around the globe for the latex production with countries in South Eastern Asia as leading producers (Teoh *et al.* 2011). In the year 1999, the size of established rubber plantation majorly for the production of latex worldwide was recorded to be about 7.2 million hectares. Out of these, more than 80% are located in Southeast Asia while three of these countries viz Indonesia, Malaysia and Thailand are responsible for the establishment of about 70% of the total rubber plantation worldwide (or 5.2 million ha) (FAO, 1999). Until the late of 1980's Malaysia was number one globally in terms ofrubber producer. After this period, Indonesia overtook Malaysia as the largest rubber cultivator in the world with Malaysia down to third and Thailand in between as the second largest grower of rubber globally (Shigematsu *et al.,* 2011; Balsiger *et al.,* 2000). Nigeria has a total of 225,000 hectares of rubber plantation which is about 70% of the total acreage in Africa (FAO, 1999).

Over the years, rubber wood has turn out to be an essential source of wood supply for the wood business in the tropics especially in Malaysia. Before now, latex has been the most important product from the rubber plantations and efforts were channelled towards increasing the latex yield (Mohd Izham, 2001). Scarcity of choice timber species as a result of the depletion of tropical forests, has turned attention towards using rubber wood as a different source for the supply of timber. Now, rubber wood is widely planted in Malaysia not just for the production of latex but also for timber production (Tuberman, 2007). The fact that rubberwood is an offshoot from rubber plantations grown majorly for the production of latex and the undemanding site requirements needed for growth of rubber may be responsible forthe availability of rubber wood in large quantities (Killmann and Hong, 2000). Rubberwood becomes available from agricultural plantations when latex yield has declined after 25 to 30 years and replanting is ready to be carried out in the plantations. The wood produced at this stage may have grown into a mature timber with height ranging from 20 to 30 m with a clear trunk (free of branches) of 3 to 10 m above ground length and diameter ranging from 30 to 50 cm (Balsiger *et al.,* 2000; Lim *et al.,* 2003).

The importance of rubberwood has increased in South East Asia as a raw material for sawmills. Rubberwood has good woodworking properties and as a result has supplemented the use of other natural choice wood as raw materials for various end products in the furniture industry. It has become an established means of income in the South Eastern Asia, most especially Malaysia and Indonesia, as wood from rubber is already being shipped to other countries. The production of rubber wood in the wood industry started with sawn wood processing, majorly for export to countries like India and Sri Lanka who have an historical backgroundof using rubber wood for timber, due to the scarcity of timber and high population. In Thailand, the economic boom in rubberwood exploitation started some years back and leading to establishment of several small and medium scale sawmills to the wood business (Ratnasingam *et al*., 2011). Furthermore, the Nigerian government and its populace have not been updated with this growing acceptability of this species and their perception has not been satisfactory towards rubber wood utilisation.

That rubber wood comes from a plantation as a by-product and its relatively low cost gives it certain advantages over traditional timbers and other lesser used timber species from the natural forest (FAO, 2001). The cost of production per cubic meter of rubber wood is only about 30percent when compared with *Shorea* spp despite its low recovery rate. Rubber wood is of medium density with Lee (1982) reporting its air-dry density as 560–650 kgm^{-3}. It can be used for varied applications as it possesses good timber and woodworking properties (FAO, 2001).

The use of rubber wood has a great potential in contributing meaningfully to the Nigerian economy if its use is maximized. A report by Killmann and Hong (2000) has shown that the earning from export of rubber wood in Malaysia rose from about US$74.2 million in 1991 to US$683.3 million in 1998. Nigeria has to harness this resource well enough as it will not only be beneficial to the gross domestic product of the nation but will also contribute to reduction in the deforestation of the dwindling natural forest resources as its wood could well be used as an alternative to the choice timber species.

1.2 Statement of Problems

Generally, the demand for wood and wood products has intensified and will continue to increase due to its versatility for a wide range of use as well as population increase, change in status and taste. However, the supply of wood has not matched the demand due to shortage of wood. This has virtually led to increasing deforestation, land encroachment and excessive timber harvest so as to meet the increasing demand of the populace.

The increase in demand for choice wood species has led to scarcity of these wood species. This increasing scarcity has led to calls for in-depth research into the wood properties of LUS so as to increase the knowledge base as well as the utilization potentials of these species in order to achieve sustainability in of wood and wood products. Some of these lesser known species include agricultural tree crops such as wood from oil palm, coconut, mango, cashew and rubber, whose primary purpose was for the production of fruits and latex. After a period of time, their productivity reduces as they begin to approach senescence. These trees are mostly left on farm lands where they occupy useful space of lands or they are used as fuel wood, thereby contributing to the environmental challenge currently facing the world.

Researchers such as Whitmore and Sayer (1992) have identified utilisation of wood as a major problem facing wood industries. This is a result of dearth of quality and up to date information on the technical properties of wood as noted by Chowdhury *et al.* (2005) who opined that there is an apparent lack of information on wood mechanical properties of most plantation grown trees. Poor knowledge towards the use of rubber wood has not improved the usage of this wood in Nigeria. The need for information on wood properties is very important as it is strongly linked to effective utilisation. Unfortunately, this is the problem faced in Nigeria as information on technical properties of rubber wood is grossly lacking and this has led to it being used only as fuel wood in rural communities.

1.3 Objectives

The main objective of this study is to determine the effect of tapping periods on selected properties of Rubber wood (*Hevea brasiliensis* Muell. Arg.) with a view to maximizing its utilization potential as a substitute for choice wood species in Nigeria. The specific objectives are to;

i. determine the effect of tapping age on the physical properties of rubberwood
ii. determine the effect of tapping age on the anatomical characteristics of rubberwood
iii. evaluate the effect of tapping age on the mechanical properties of rubberwood
iv. assess the effect of tapping age on the chemical composition of rubberwood.
v. determine the utilisation potential of rubberwood

1.4 Justification

Rubberwood plantations are found in various locations in Nigeria most especially the sounthern region. They were established to supply raw materials for the production of rubbers within and outside the country. According to Omo-Ikerodah *et al.* (2011) and Binang *et al.*(2017), it has been estimated that there are about 18 million hectares (ha) of land suitable for cultivation of natural rubber in Nigeria out of which only about 247,000 ha is under rubber. However, there has been a decline in the rubber utilization locally and decline in export due to oil boom. These has resulted in abandoning of several hectares of rubber plantation. Several researchers such asHong (2005b) and Ratnasingam *et al*.(2011)have shown that rubber wood could be an important source of timber production for sawmills.

The demand for wood and wood products is increasing and has virtually exceeded supply. To meet this increasing demand for wood, increasing quantities for the supply of world's requirement including Nigeria will be gotten from new sources such as tropical and semi-tropical forests, as well as from plantations (Emerhi, 1992). The current concern is whether this future demand can be met sustainably. Rubber wood from rubber as a plantation species has complemented supply from other sources to address wood supply in several countries in Asia. This to an extent will ensure adequate supply of wood to wood-based industries on a sustainable basis and thus, meet the growing challenge of wood scarcity.

Researches have shown that rubber wood can be seen as a viable alternative for many timber products as it has good timber and woodworking properties which makes it fit for a wide range of usages (Killmann and Hong, 2000). The lack of in-depth knowledge about their properties has hampered the adequate utilization of these woody species. More efficient utilization which will be heralded by the gathering of data on the technical properties of wood is germane in dousing the tension mounted by expanding wood scarcity and maintaining the sustainability of the tropical ecosystem. Knowledge of wood properties such as the physical, anatomical, mechanical and chemical properties is germane to evaluating the utilization status of wood. Most wood dealers of Nigerian hardwoods have mostly depended on indigenous knowledge which is based on years of experience in the use of certain species, but possesses little or no information on the technical wood properties. A systematic approach is therefore needed to bring to light utilisation of the lesser-used wood species.
Rubber plantations are majorly cultivated for the production of latex and the process by which latex is collected causes injury to the tree (Kainulainen, 2007). This process may have effect on log quality as the tree is placed under stress and the trees will react accordingly by producing cells capable of cushioning the effect of the stress. Every wood species has its own way of responding to the stress by

stimulating physiological reactions to the injury. For instance, in the new wood that grows around the edges of the wounded area,traumatic resin ducts are also formed in it, sealing by phenolic substances in the medullary rays, as well as in tangential series of parenchyma cells and by extensive deposition of tylose of the vessels in some other tree species (Metzler and Hecht, 2014). As bark damage continues to increase, the timber quality is invariably affected due to the formation of callus(Metzler and Hecht, 2014)**.** Many of the effects of cambial wounding are not realized for many years after an injury occurs. Hence there is a need to study the effect of continuous tapping as it affects the properties of the wood produced from rubber during these periods.

Woodproperties of the same tree differ from top to thebase as well as from pith towards the bark which have an effect on how the wood behaves when used. The age of a tree also has an effecton the properties of wood (Chowdhury *et al.,* 2005). Thus, it is necessary to be informed ontapping duration, sampling height and radial position and how they affect theproperties of rubber wood. Thestudy on the effect of tapping duration, height and radial position on the physical, anatomical, mechanical and chemical properties of rubberwood is imperative for its proper uses.

Research on anatomical, strength and chemical properties of rubber wood in South East Asia has been documented by Naji*et al.* (2011), Zaki *et al.* (2012), Majumdar *et al.* (2014), Naji *et al.* (2014). However research in rubber wood in Nigeria has not matched what is being obtained in these other countries with respect to wood properties as many researches have been focused on the latex from the rubber tree and also a handful on the oil from rubber seed. Tembe *et al.* (2010) however studied the variations in fibre length of rubberwood grown in South Eastern Nigeria. Ogunsanwo *et al.* (2001) also investigated the strength properties of tapped rubber wood. However both studies did not consider the effect of tapping period on wood characteristics. Presently in Nigeria, there is paucity of information on the properties of rubber tree grown as dictated by tapping period. This study therefore seeks to investigate the effect of tapping period on the properties of plantation grown rubberwood in Nigeria.

1.5 Scope of the Study

The scope of this research was to characterize the properties of *Hevea brasilliensis* wood with different tapping periods. This was achieved by determining the chemical, anatomical, physical, mechanical characteristics of the wood. The wood samples from top and base positions of the tree were used as well as the radial position i.e. innerwood, middlewood and outerwood.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Wood as a material resource

Wood is a product from the forest used for diverse purposesthroughout the world. Of all the available resources gotten from the forest availablein most countries of the world, wood is the most essential of them all. This is so because of its versatile usage and applicability that makes it a suitable raw material for many industrial and constructional end-uses (Ogunsanwo, 2001). Despite the development of other material products e.g steel, plastic and concrete, wood and wood based products are still in high demand (Ojo, 2016). Thus, wood is put to various uses such as production of pulp and paper, ply and particle boards, match sticks, pencil etc. Wood is also used in the production of electrical poles, furniture and even as a source of fuel. However, the use to which wood is put depends mainly on the technical performance of the wood. Variations in wood properties are noticeable in terms of density, strength, vigour, grain and durability. As a result of these variations present in wood characters, exploitation of tropical wood species had to be selective and narrowed down to only those species that are strong and durable. These include*Afzelia Africana,Khaya ivorensis,Milicia excelsa, Nauclea diderrichii, Triplochiton scleroxylon etc.*

2.2 Lesser known species (LKS)

Due to the upsurge in the demand for wood products and subsequent decline in supplies of traditional timber species around the world, there have been calls to introduce lesser-used species (LUS) to complement the traditional species. The exploitation and utilisation of LUS is being promoted so as to extend the species base of the wood industry and to reduce the increasing pressure on the forest due to unsustainable harvesting patterns of the ever reducing highly sought species mostly in developing countries. Also as prices of these highly sought timber increases, there will be a resultant decrease in the quality and quantity of this timber. Sustainable forest management can be achieved through greater use of lesser used species and efficient utilization of the tropical forest (Poku *et al.,* 2001).

Apart from the lesser used species whose application is on the increase, some "non-forestry" tree plantations planted and grown by the agricultural sector rather than the forestry sector are also becoming relevant in the supply of industrial wood and fibres. These tree crops which are often established for other purpose other than its timber for example fruit and related use. These tree crops often outlive their primary purpose after several years of exploitation. They are oftentimes incorporated into the agroforestry systems, which are usually of greater value to indigenous people for the supply of household wood fuel than for commercialpurpose (FAO, 2001).

2.3 Biology of *Hevea brasiliensis*

Hevea brasiliensis (rubber tree) is native to Brazil (the Amazon forest) and is establishedand utilised for the production of latex, which is a raw material used to manufacture natural rubber. Rubber plantations are now being planted in many parts of the world due to its commercial value. The total area of rubber plantations globally is more than 9 million hectares with Asia being a major location for rubber plantation. About three countries stand out as major producers of rubber in 2010 namely Indonesia, Thailand, and Malaysia with 86, 48, and 71 % *Hevea brasiliensis* plantation respectively and totaling more than 6 million hectares (Jalani and Ramli, 2003; Shigematsu *et al.,* 2011 and Humberto *et al.,* 2015)

Before the advent of crude oil exploration Nigeria was a leading producer of natural rubber. It was the largest producer of the rubber in Africa and sixth largest in the world, contributing about 3 percent of global output between 1957 and 1960 (Purseglove, 1987). However, production declined progressively for several decades and has only been recently stabilized such that the country is now estimated to produce about 90,000 metric tons per annum (Omo-Ikerodah *et al.,* 2011; Binang *et al.,* 2017). Olayide and Olatunbosun (1992) and Giroh *et al.* (2013) credited the decline in production to ageing plantations, difficulty in land acquisition as a result of competition resulting in establishment of plantations in marginal areas, poor agronomic practices, shortage and high cost of labour, poor rubber prices, and inadequate storage facilities. It is estimated that there are about 18 million hectares (ha) of land suitable for cultivation of natural rubber in Nigeria out of which only about 247,000 ha is under rubber (Omo-Ikerodah *et al.,* 2011; Binang *et al.,* 2017).

Hevea brasilliensis cultivation and processing are important aspects of the socio-economic life of the people of the Niger Delta region of Nigeria. The region could be described as the rubber-belt of the country where extensive plantations of the tree crop are found (Binang *et al.,* 2017). Rubber cultivation is labour intensive and is therefore capable of creating employment opportunities and contributing to Nigeria's external trade (Aigbekaen *et al.,* 2000). Cultivation of rubber tree in Nigeria is being expanded to sub-optimal areas including Taraba and Kaduna States in recent times so as to meet the growing demand for natural rubber, facilitate crop diversification in traditional rubber-growing areas and upgrade the living standards in non-traditional rubber growing areas (Binang *et al.,* 2017).

Rubber grows over a wide range of conditions. The optimal climatic conditions for rubber tree are average rainfall of 2000 mm with 125-150 annual rainy days that is evenly distributed with no severe dry season; mean monthly temperature of 25-28ºC; high atmospheric humidity averaging about 80%, with moderate wind, and bright sunshine also averaging about 2000 hours in a year which is about six hours a day in all months. The rainfall requirement depends on its distribution, length of dry season and water retention capacity of the soil. Under favourable soil conditions, rubber could tolerate a dry season of 4-5 months, during which less than 100 mm of rain is received within this period, or 2-3 months with rainfall less than 50 mm. Extreme weather conditions (long and intense dry spells and heavy rains) can greatly reduce harvesting intensity through a reduction in latex production within this period (Binang *et al.,* 2017).

2.3.1 General Description of *Hevea brasiliensis*

Hevea brasiliensis is a tough, fast-growing, straight tree with often straight bole and an open leafy crown. The bark is typically grey in colour with white patches and fairly smooth. The bark of the trunk is the part from where latex is harvested. In the natural forest, the tree height may increase to over 40 m with an average life cycle of more than 100 years. However, those grown in plantation rarely exceed 25-30 m in height because of the effect of tapping (latex collection process) on the tree leading to growth reduction (Webster and Paardekooper, 1989). Moreover, after 30years when latex yiels seems to have declined economically, the trees are harvested and the land replanted thereafter. The young plants show typical growth pattern of alternating periods of rapid elongation and consolidation. The tree is deciduous thus the occurrence of annual leaf fall during dry seasons while refoliation and flowering follows after this period (during rainy season). The leaves are arranged in storey or groups. From each storey, a cluster of spirally arranged, trifoliate glabrous leaves is produced. The petioles are long, usually about 15 cm, with extra floral nectaries present in the region of insertion of the leaflets (Premakumari and Saraswathyamma, 2000). The trees develop a whole root system made up of strong tap root and extensive lateral roots and this comprises about 15 percent of the total dry weight of the mature rubber tree. The wood of the rubber tree is light varying from white to cream with the sapwood not easily differentiated from the heartwood (Humberto *et al.,* 2015)

Plate2.1:*Hevea brasiliensis* seeds

2.4 Wood Injury

Trees are commonly wounded as a result of impacts, abrasions and scrapes which lead to broken branches. Animal damage, insect attack, fire, crown and basal injury arising from storms and other natural hazards as well as from human activity etc. are other forms through which a tree is wounded. (Clatterbuck, 2017; Smith, 2015). Tapping of a tree especially in *Hevea* is a latex collecting activity that wounds the trees. The impact it has and the way it responds is often being misunderstood. Wounds damage trees usually by breaking the bark of the tree and damaging the phloem or inner bark and sometimes both the phloem and xylem or wood which are the food and water conducting tissues in plants. This exposes the inner part of the tree to both micro and macro organisms, particularly bacteria, fungi and insects that may infect and cause wood discoloration and decay of the wood. In living trees, wounding often introduces infection that leads to decay of wood (Schwarze, 2008; Shortle and Dudzik, 2012)

Trees respond to stem injuries in the short term through the production of materials for wound closure. This process may have effect on log quality as the tree is placed under stress. The trees react accordingly by producing cells capable of cushioning the effect of the stress. Each species have its own way is responding to the stress by initiating physiological reactions to the injury. For instance, the formation of traumatic resin ducts in the new growth of wood around the boundaries of the injury (barrier zone), sealing by phenolic substances in the medullary rays, as well as in tangential series of parenchyma cells and by extensive deposition of tylose of the vessels in some other tree species which are internal (Metzler and Hecht, 2014). At the same time, trees also respond internally to stem injury through a coordinated approach for limiting damage to it by walling off the healthy tissue (Shigo, 1984, Smith, 1988 and Dujesieften and Liese, 2011). Exudates are also released by the trees externally to seal of the affected areas. These exudates appear as water insoluble resin in softwood and gums in tropical species while it comes out as latex in rubberwood (lange, 1998). Many of the effects of cambial wounding are not realized until many years after an injury occurs.

When a tree gets wounded, the injured tissue is not repaired and does not heal like other living things do. This leads us to say that trees do not heal but only seal up the affected areas (Clatterbuck, 2017). Shigo (1984) led an innovative research project that developed an idea called ‘compartmentalization’ which is used to explain the natural basis for pattern of wood reaction in living trees to injury. He stated that compartmentalization process has been part of the life of forest trees from time immemorial and that compartmentalization is a boundary setting process that restricts the loss of normal tissue function and the range at which infection introduced by wounding through the “walling off” of injured and infected tissue thereby isolating the older, damaged tissue with the gradual development of new, healthy tissue. (Clatterbuck, 2017 and Smith, 2015). Following wounding, physiological responses that occur is the compartmentalization of boundaries. The most immediate border is formed by cavitation, plugging, and tylosis of tracheary elements. Norton (1998) reported compartmentalisation to be in two-stages. Firstly, the tissues present at the time and site of injury changes chemical produced to restrict the effect of the injury. This is achieved through production and accumulation of antimicrobial materials that impede the increase in area of disease causing organisms that may develop after wounding or it may be achieved through development of plugs including tyloses that reduces loss of water from impaired xylem cells. Xylem and ray parenchyma adjust to stress metabolism and produce phenols and waterproofing lipids in a area most frequently referred to as a reaction zone (Shigo, 1984; Schwarze, 2008 and Smith, 2015). Secondly, chemical and anatomical restrictions are formed after the infection by plant pathogens, as the living cambium develops a protective tissue between the tissues that were present at the time of wounding and the new tissues formed after wounding to isolate or separate the infected wood on the inside from the healthy wood. Compartmentalization process of wound closure may to an extent restore continuity of the vascular cambium, sapwood, and phloem along the stem circumference. A proper understanding of the compartmentalisation process is necessary for drawing conclusions on the effect of tapping on rubberwood

Tapping is known to activate latex metabolism and reports have shown a negative correlation exists between latex production and production of wood biomass (Norton, 1998 and Annamalainathan *et al*., 2001). Tapping is carried out on a small portion of the stem, which brings to mind the question on the actual effect the affected areas will have on wood properties. Silpi *et al*.(2006) found tapping to impact radial tree growth as growth rate was reduced drastically when tapping resumes hence there is the possibility of the tree responding to the effect of tapping and thus impacting the wood properties.

2.5 Variation in wood

2.5.1 Radial Variation in Wood

Generally, variation in wood properties across radial position of wood can be classified into a few patterns, which show that they either increase from the pith to the bark or decrease towards the bark. Panshin and Dezeeuw, (1980), as cited by Ojo (2016) summarized the radial trend in specific gravity as follows:-

Type 1: specific gravity of wood increase from pith to bark.

Type 2: specific gravity of wood is high at the pith, decrease outwards for the a few years and then increase to a maximum at the bark.

Type 3: Specific gravity increase near the pith, maintains a relatively constant value, or sometimes the specific gravity may even decrease in the last formed growth next to bark.

Type 4: Specific gravity of wood exhibit a general decrease from pith to bark

2.5.2 Axial Variations in wood properties

Trees also differ in axial variation i.e. from top to bottom or the other way round. Wood properties may increase or decrease from top to bottom. However, Panshin and Dezeeuw (1980), as cited by Ojo (2016) propounded a general pattern of axial variations in the following order:

(a) Decreasing uniformly from base to top.

(b) Increasing uniformly from base to top

(c) Increasing in the stem from base to top in a non-uniform pattern.

2.5.3 Age/physiological Variation in wood properties

Wood properties also vary as the tree increases in age

2.6 Anatomical characteristics of wood

The anatomical characteristics of wood include the cellular structures that are present in the wood and can only be analysed with the aid of a microscope. Wood is built of individual units called cells. These cells are either tube like with blunted or pointed ends or brick shaped. They may be empty or may contain various kinds of solid or semi-solid substance. These cells differ in shape and size between tree species and when viewed from transverse, radial and tangential sections (Umar, 2015). The different patterns of distribution in terms of arrangement of the microstructures and the dimensions of component cells contribute to variations observed in wood properties (Awoyemi, 1997). Certain factors such as ecological and site conditions, management practices, inherent individual gene, and age of the trees growing in a plantation affect these cells during their formative period (Zobel and Van Buijtenen, 1989). These cells come together and form the anatomical structures such as the vessels, fibres, parenchyma and wood rays. These wood elements play a major role in determining the structure and properties of wood. Results from researches have shown that cell proportion determines to a large extent the end use properties of wood (Onilude and Ifju, 1992; FRIN, 1992 and Umar, 2015). Hardwoods consist mainly of three different of cells. These incluepointed ends or needle-like cells (fibres), hollow or pipe-like cells (vessels elements)and prismatic shape cells (parenchyma cells). Softwoods possess relatively long tracheids which perform the functions of both fibres and vessels. Thus softwood has no vessel elements and this makes it a more desirable species for the production of pulp and paper.

2.6.1 Vessel

In living trees, vessels serve as the channels for transporting sap within the tree trunk. They are trachery element of the hardwood specialized in conduction of water and mineral salts. When studied from the transverse direction, vessels simply look as if there are holes in the wood. Vessels elements are the biggest type of cells, and when compared with other hardwood cell types. They can be observed singly oftentimes with the naked eye without any sort of magnification while the others can't. The major form of differentiation of hardwoods from softwoods is the presence of vesselelements, or pores, that are found only in hardwoods. Vessel elements differ in size, number and spacing from earlywood to latewood, from pith to bark, from tree to tree, from one location to another and from one species to another. Pores that are ≤ 100µm can be classified as small, between 100 < 200µm as medium while ≥ 200µm are classified as large (Desch and Dinwoodie*,* 1996). Vessels are composed of vessel elements connected end to end through perforation plates in a continuous tube-like structure of about 200-650µm in length (Desch and Dinwoodie*,* 1996; Ahmed and Chun, 2009). Vessels constitute about 15-40% of the total volume of hardwood species. The distribution of pores over the transverse section depends relatively on the tree species and can either be diffused porous where there is an abrupt change is size or semi ring- porous or ring-porous where it is concentrated in ring-like structures. Vessels morphology influence some utilisation attributes of wood such as absorption and retention of preservative. Ahmed and Chun (2009) related the longitudinal pathway of fluid in wood to the vessel diameter, length, frequency and inter-vessel pit size and number. Trees with wider vessels may not be suitable for the paper manufacture and solid-wood products as it could result to vessel picking. Reports have found large vessel size and high frequency to have adverseeffect on wood quality (Ahmed and Chun, 2009; Zobel and van Buijtenen 1989).

Onilude and Ifju (1992) observed that increase in proportion of vessels per unit area leads to decrease in density of wood and other strength related properties and Akachuku (1983) supported the view that there is linked decrease in wood density to increase in vessel proportion, furthermore stated that the fibre thickness increase correspondingly density may not decrease.

2.6.2 Fibres

Fibre is the primary structure responsible for the strength of wood. The rigidity of many wood depend on fibre content and this determine the value of specie for many end uses (FAO, 1990). Fibres possess thicker walls than other cells found in the wood hence they are able to perform their function of providing strength and rigidity to the wood (Panshin and Dezeeuw, 1980; Desch and Dinwoodie, 1996). Haygreen and Bowyer (1989), explained that the higher the proportion of thick-walled fibres, the higher the strength. Fibre proportion in wood varies from one position to the other (Desch, 1988; Panshin, 1994). According to Taylor (1973), there is a slight increase in fibre proportion from pith to bark. Since fibres are the major source of pulp, the proportion of fibre as well as its characteristics determines the suitability of species for pulp wood and fibre board production.

Fibres in hardwoods are elongated cells with thick walls and small lumen diameters. The fibres length ranged from 600-2300µm, 10-30µm in diameter with wall thickness varying within thin to very thick wall, narrow lumen and pointed ends. The side walls basically have simple pits which are slit-like in nature and facilitate lateral fluid movement from among the xylem elements. Fibres often account for between 4% to 50% volume of tropical hardwood and are mainly responsible for mechanical support of the tree (Desch and Dinwoodie, 1996; Okoh, 2014). Hardwood fibres are produced from derivatives of cambial fusiform initials and undergo significant elongation by the cell tip intrusive growth prior to secondary cell wall deposition. This intrusive elongation of the fibre tip is particularly important when the fibres are derived from a storied cambium. Fibres play a passive role in water and sap conduction in trees stem as this function is performed chiefly by the vessels. In wood industries especially the paper industry, fibre length and the extent of overlapping of the fibres as well as joining of fibres to one another is given great attention. Fibre length affects the properties of fibre products such as strength, surface, and bonding. For many purposes, long fibres are more desirable than short ones particularly in paper production. In addition to fibre length, thickness of the fibre cell wall also plays an important role in the utilization of wood. Wood fibres with thick walls and small lumen give increased specific weight, while wide lumen and thin walls decreases it.

The percentage of the stem cross-sectional area that fibres occupy depends both on the position in the stem also on the species. Generally, fibre length increases from pith to bark and from base to top (Zobel and Van Bujitenen, 1989; Veenin *et al*., 2005; Jorge *et al.*, 2000; Izekor and Fuwape 2011). In addition to fibre length, fibre diameter and lumen width was observed in different hardwood species to also increase from pith to bark. For instance, Quilho *et al.* (2006) on *Eucalyptus grandis,*Naji*et al.*(2011) *Hevea brasiliensis*, and Okon (2014) in *Gmelina arborea*.Fibres having thin walls and large lumina are found near the stem centre and thick walls and small lumina near the stem periphery. The density of a wood is largely dependent on fibre wall thickness (Wiedenhoeft, 2010). According to Panshin and de Zeeuw (1980), if the fibres are thick walled then the density tends to be high. On the other hand, if they are thin walled, the density will be low. Fibres are particularly important in the determination of density, since their small cross sections allow a greater number of them to be massed in a small place.

2.6.3 Pit

The walls of the xylem elements have minute openings through which fluid from one element reach the adjacent ones. These minute openings are called pits. Hardwood pits have diameters between 3 and 12µm and the aperture elongated. The pits differ considerably in distribution and shape; they may be scalariform, opposite, alternate; and alternate polygonal. Pit may be simple, bordered or semi-bordered due to the presence or absence of the overarching cell wall. Bordered pits are usually found between vessels, semi-bordered pit pairs are found between vessel and parenchyma cells; simple pit pair is found between parenchyma cells (Desch and Dinwoodie, 1996). Pits provide one of the main pathways for the liquid flow between cells. The structure and distribution of pits affect the penetration and subsequent distribution of fluid in wood (Desch and Dinwoodie*,* 1996).

2.6.4 Ray and axial parenchyma

Parenchyma cells are small, thin-walled, longitudinal cells that functions as food storage. These cells are sparse in softwoods especially the axial parenchyma but are often quite significant in hardwoods. Axial parenchymas are arranged longitudinally in either brick-shaped or square shaped cells with thin wall, small lumen and numerous simple pits in their walls. They constitute about 10-50% of the woody tissues of tropical hardwoods and are responsible for the axial transport and storage of photosynthetic products. Ray parenchymas are brick-shaped, radially arranged cells with thin wall, small lumen and numerous simple pits in their walls. The cells are aggregated into ribbon-like shapes of one to 30 or more cells wide. In some hardwoods, the ray cells occur in two distinct sizes with the larger cells enclosing the central smaller cells. Ray parenchymas constitute between 10-25% of the tropical hardwood in volume and are responsible for the transport and storage of food in the radial direction (Desch and Dinwoodie, 1996). There are two basic types of parenchyma namely; paratracheal and apotracheal. The paratracheal parenchyma makes contact or closely associated with the pores or vessel elements. They are thin walled with large simple pits while apotracheal parenchymas are separated from pores by fibres or rays are thick walled with smaller pits. Parenchyma functions mainly in the storage of nutrient and is also capable of mobilizing the nutrients again when needed. The abundance of parenchyma influences properties such as drying behaviours of wood, because it shrinks differently from fibres (Saravanan *et al.,* 2013).

2.6.5 Rays

Rays are found practically on every wood species (both hardwood and soft wood). They often times serve to provide valuable information in the identifying wood. Ray cells are ribbon shaped strands of tissue extending across the grains. They constitute about 18% of total volume of wood in hardwood. Ray cells run at right angles to the rest of the wood fibres, and act as a link between the pith, sapwood and cambiumfor passage of plant nutrients. When viewed under a microscope, ray width can be described by the number of cells across the ray. Wood species with the thinnest rays are uniseriate (one cell wide) or biseriate (two cells wide) while others may possess well over a dozen cells. Uniseriate rays are mostly found in softwoods while multi seriate rays are found mostly in hardwoods.

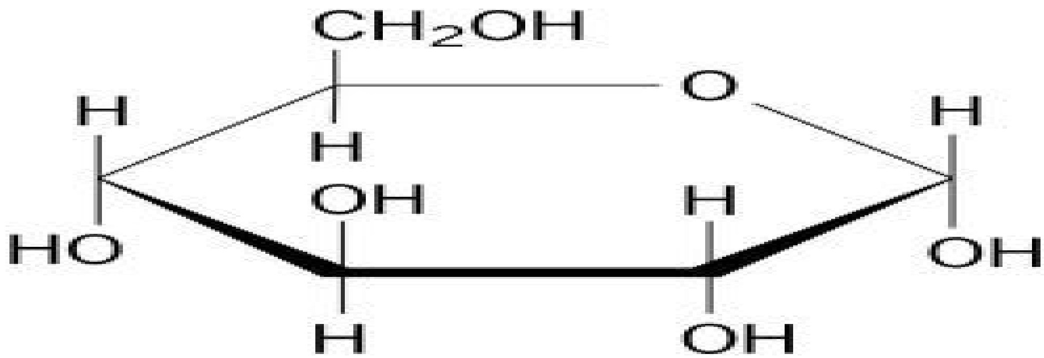
Certain end uses of wood are determined by the proportion of ray parenchyma present. For instance Kollman and dan Cote (1968) stated that the presence of broad rays in a wood is an indication of possibility of timber splitting readily in the radial direction. Rays also affects the drying behaviours and dimensional shrinkage of wood. Shrinkage differences along the structural planes of wood have been identified to be linked to what is known as ray parenchyma restraint theory (Petric and Scukanec, 1975; Dinwoodie, 1989).

2.7 Chemical characterisation of wood

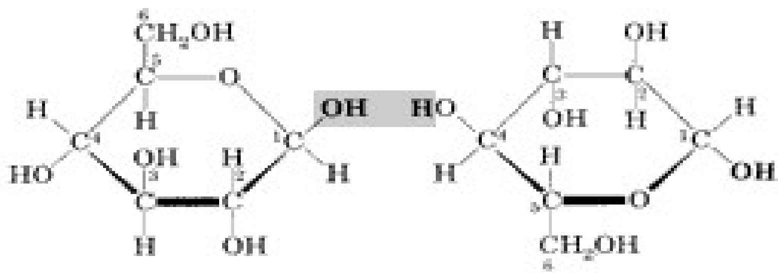
Chemical composition of wood varies with respect to the part of the tree, wood type, ecological locations, soil conditions as well as age of the tree. Through many years of research, average values have been decided for the chemical composition of wood. Wood generally is made up of carbon (C), hydrogen (H) and oxygen (O) as its major constituents with carbon composing about 50% of the wood, with oxygen next on 44% and hydrogen having 6% including small amounts of several metallic ions (Adedeji, 2016). The elements react together to form associated structural polymers that are highly polymerised (cellulose, hemicelluloses, and lignin) which makes up the cell wall. The amount of cellulose, hemicelluloses, and ligninas well as extravtives present in woods varies. The cellulose content have been found to be between (40–45 %), hemicellulose (25-35 %), Lignin (18-25 %) while the extractive content (4-10 %). This variation may be as a result of wood type(softwood or hardwood), species and ecological location. The Cellulose, hemicellulose, and lignincombine to form thread-like materials called microfibrils which are interwoven together in strata to form a mat leading to wall formation of individual wood cells that constitutes the building block of wood. Cellulose and hemicellulose serve as the reinforcing material for the cell wall. While cellulose and hemicellulose give the wood its strength, the lignin is responsible for the stiffness possessed by the cells. Hemicelluloses and lignin are the matrix and building materials in the secondary cell wall layer. Lignin (18-35%) is the primary component of the middle lamella cementing the wood cells together. Extractives are compound of diverse chemical composition that are also present in the wood cell wall. Wood extractives(usually 4-10%) are made up of food reserves, enzymes, metabolic products. They are deposited during the development and growth of the cell wall.Extractives are found majorly in the heartwood region. These materials add certain characteristics to certain wood species which are smell and colour, durability and susceptibility to bio-deteriorating agents and impermeability (Oluyege, 2007). They may sometimes help in identification of wood.

2.7.1Cellulose

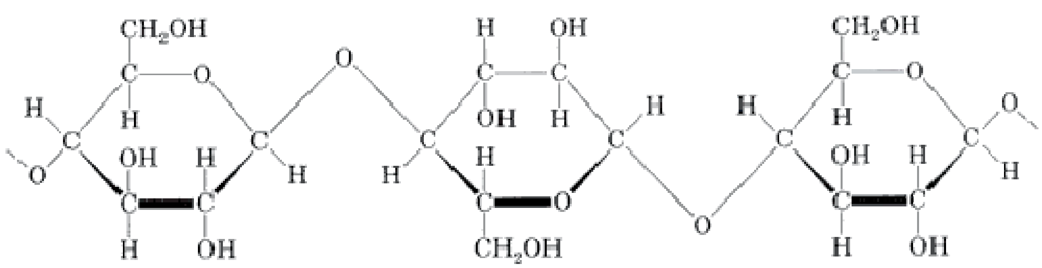
Cellulose is a long chain polymer of linked sugar molecules that give wood its remarkable strength. Photosynthesis is the process by which water and CO_2 are combined with sunlight as catalyst to form glucose and other simple sugars with oxygen as by-product. The amount of cellulose decreasese from base to top (Harmean *et al.,* 2014; Riyaphan *et al.,* 2015). Cellulose is manufactured directly from units of glucose (Figure 2.1a) then, in a complicated process. The glucose is chemically modified through the removal of a molecule of water from each unit yielding an anhydride of glucose ($C_6H_{10}O_5$-glucose anhydride) (Figure 2.1b). Glucose anhydride units are next linked end-to-end to form a long chain polymer, cellulose $(C_6H_{10}O_5)n$, where n, the degree of polymerization equal to 5000-10000 (Figure 2.1c). Glucose and formation of cellulose are presented thus:



Glucose molecule – (a)



Juxtaposition and removal of water molecules from glucose – (b)



Glucose anhydride linking to form cellulose – (c)

Figure 2.1: Pathway of cellulose formation from glucose units: (a) – (c) Adapted from Senese, 2010

2.7.2 Hemicellulose

Hemicelluloses are polysaccharides in plant cell walls that have beta-(1->4)-linked backbones with an equatorial configuration. Hemicellulose is formed from sugar molecules other than glucose and these may include xyloglucans, xylans, mannans and glucomannans. The detailed structure of the hemicelluloses and their abundance vary widely between different species and cell types. Hemicellulose also contributes to solidification of the cell wall by interacting with cellulose and sometimes with lignin (Scheller and Ulvskor, 2010). The monosaccharide units are linked by 1-3, 1-6 and 1-4 glycosidic bonds, to form polymers having a degree of polymerization usually lower than 200 (Figure 2.2).

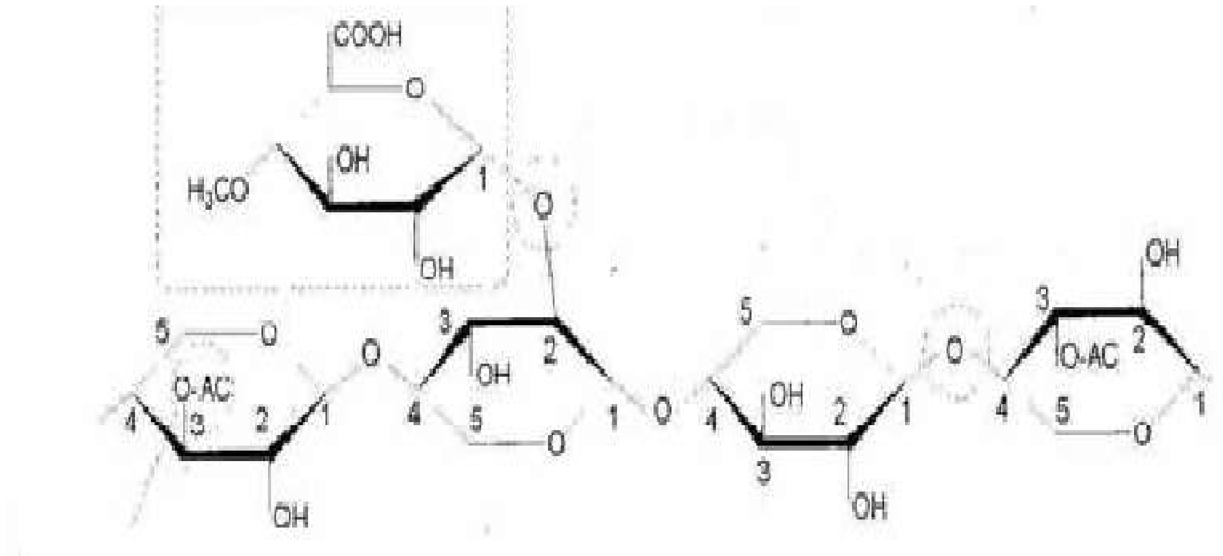


Figure 2.2: Schematic representation of hemicellulose (Adapted from Vignali, 2011).

2.7.3 Lignin

Lignin refers generally to a large group of aromatic polymers deposited predominantly in the walls of secondarily thickened cells, which makes them stiff and impervious. This helps to protect the cellulose and hemicellulose from microbial degradation as well as pathogens and insects thus making the cell wall decay resistant. The amount of lignin present in the cell wall can be increasd upon by various stress conditions both biotic and abiotic. This may be as a result of pathogen infection, metabolic stress, wounding and perturbations in cell wall structure (Boerjan *et al.*, 2003; Cano-Delgado *et al.,* 2003; Ralph *et al.*, 2004; Tronchet *et al.*, 2010). Lignin content increases from base to top (Zaki *et al.,* 2012; Riyaphan *et al*., 2015)

Lignin is a polymeric material composed of phenylpropanoid units derived from three cinnamyl alcohols (monolignols): *p*-coumaryl, coniferyl, and sinapyl alcohols (Figure 2.3). The oxidative coupling between monolignols can result in the formation of several different interunit linkages (Figure 2.4).

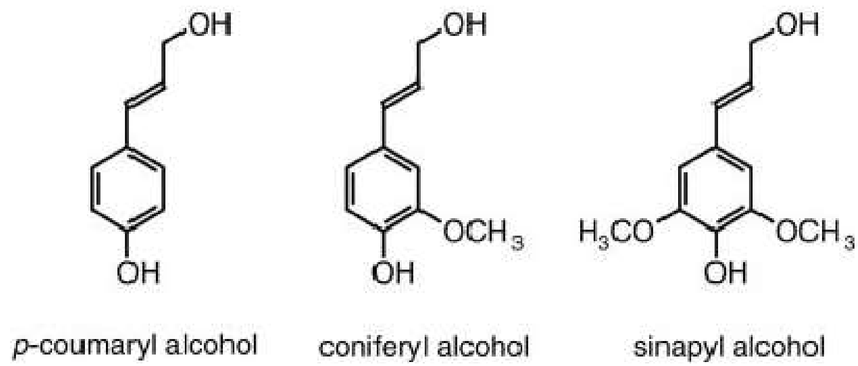


Figure 2.3a: Major monolignols found in "natural" plant lignins (adapted from Hatfield and Vermerris, 2001)

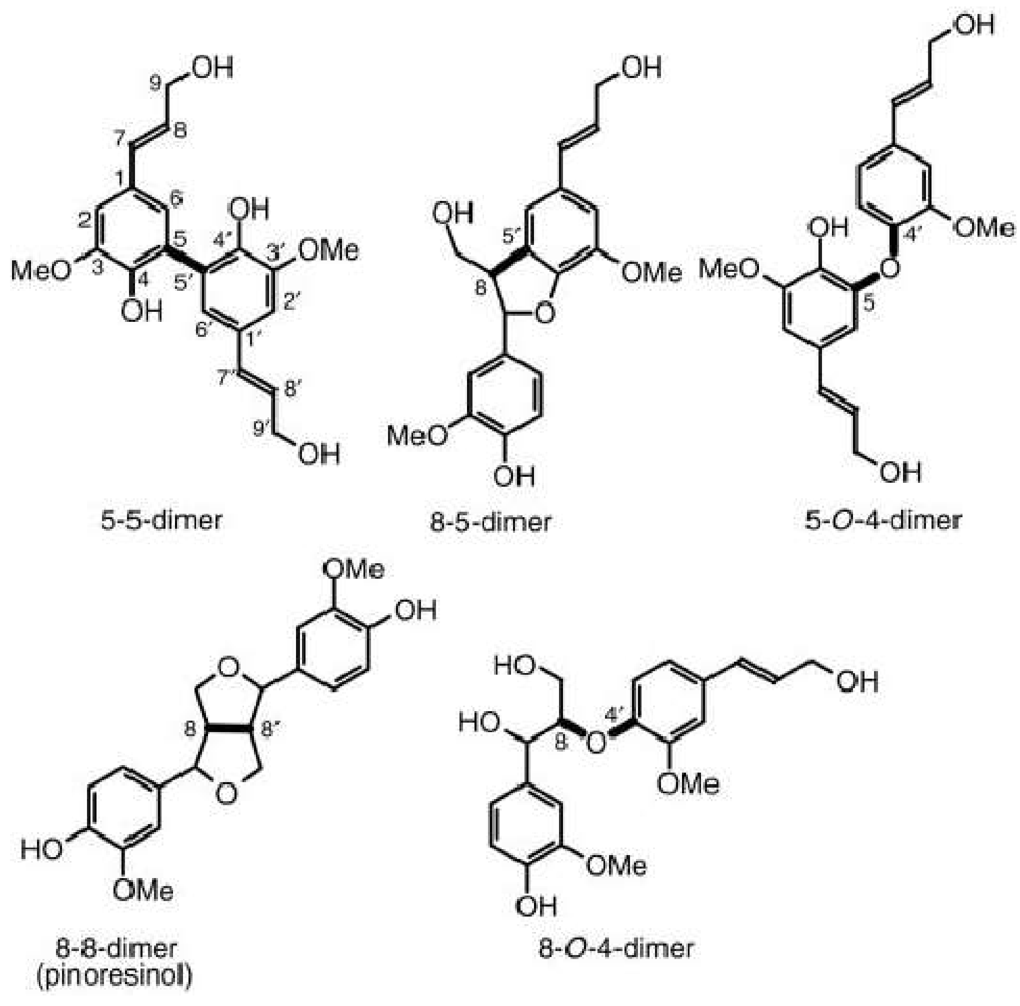


Figure 2.3b: Scheme representation of possible bonds of lignin polymer (adapted from Hatfield and Vermerris, 2001)

2.7.4 Extractives

Extractives are a heterogeneous low molecular weight group of materials which can be removed from wood by means of polar and non-polar diluents. According to Telmo and Lousada(2011), extractives are made up of a variety of organic compounds such as waxes, alkaloids, proteins, phenols, tannins simple sugars, pectins, mucilages, gums, resins, terpenes, starches, glycosides, saponins and tan oil. Tree metabolism, defense mechanism and energy reserve are some of the functions of extractives in wood.

2.8 Fourier transform infrared reflectance (FTIR) in wood

Standard wet chemical analysis procedures have been used to analyse elemental composition of wood and herbaceous materials and this has proved to be successful over the years. It however looks inappropriate for large scale analysis because it is labourious and time-consuming. Current advances in the wet chemical procedure have been made to reduce the time spent in analysis and increasing the amount of samples analysed (Demartini *et al*., 2011). However, these methods still need to be developed further because some components of biomass such as acid-soluble lignin and ash cannot be determined (Xu *et al*., 2013). Researchers such as Hames *et al*. (2004); Sills and Gossett (2012) reported other disadvantages of this method to include inability to differentiate among types of hemicellulose, such as xyloglucan and arabinoxylan, the need for pre-conditioning to remove extractives while it can only give accurate results from samples within a certain range of particle size

The disadvantages of wet chemical method has led to the development of Infrared spectroscopy (IRS) which is a low cost and time saving method of biomass analysis. It has been widely used for qualitative and quantitative analysis in various areas such as the food and pharmaceutical industries and for biomass application (Tuker *et al*., 2001; Xu *et al*., 2013 and Hames *et al.,* 2013). Simple sample preparation, fast and precise analysis, and analyzing many samples/components at the same time are some of the major advantages of using infrared spectroscopy. In using IRS, sample could be reused for other analysis after IRS measurement which makes it a non-destructive method of analysis and also uses no hazardous chemicals (Xu *et al*., 2013). The IRS techniques could be used for composition and structural analysis, such as detection of functional groups (Liu *et al*., 2011).

Fourier transform infrared reflectance (FTIR) spectroscopy is a powerful analytical tool that can be used for the rapid characterization of lignocellulosic biomass. FTIR spectroscopy could help to determine chemical compound or class of compounds that are present in a particular biomass through fundamental molecular vibrations (Acquah *et al*., 2016). For some studies on the use of FTIR on raw biomass, Naik *et al*. (2010) used FTIR spectroscopy to characterise several agricultural residues and their extractives content while (Rana *et al*., 2010; Zhou *et al*., 2015) used it in the qualitatively analyse wood and lignin from five timber species, and to predict the chemical composition of hardwoods respectively. Qualitative and quantitative analysis of biomass with FTIR spectroscopy can be quite precise. This can be achieved when materials vary considerably in chemical structure as Brink *et al*. (2010) described woody tissue to be differentiating wood tissues from bark tissues aspen and birch and also to differentiate beech from pine due to considerable differences in moieties (Pandey and Pitman, 2003). Fourier transform infrared (FTIR) spectroscopy has been applied in various aspect i.e. determination of wood density by Meder *et al*. (1999), chemical composition (Ferraz *et al*., 2000 and Rodrigues *et al*., 2001), lignin distribution (Luo and Polle, 2009), discrimination of wood from various tree species (Rana *et al*., 2009; 2010), changes in wood properties during wood composites manufacture (Muller and Polle, 2008 and Muller *et al*., 2009) and to determine the syringyl guaiacyl ratio of poplar wood (Robinson and Mansfield, 2009).

2.9 Physical Properties of Wood

Wood behaviour is influenced by its physical properties. The physical properties of wood can be expressed in relation to the amount of cell wall materials present in a given volume of wood (relating to density/specific gravity), the amount of moisture available in the cell wall and the proportional composition of the primary constituents of the cell wall (Panshin and Dezeeuw, 1980). It also includes the quality and nature of extraneous substances present in the wood, the arrangement and orientation of cell wall materials, the kind, size, proportion and the arrangement of the cells making up the woody (xylem) tissue. Density, specific gravity, wood-water relations, shrinkage, swelling and colour are the most studied physical properties (Bowyer *et al.,* 2003; Ojo, 2016).

2.9.1 Moisture Content of Wood

Moisture content is the water available in a given wood either in a standing tree or wood in service. Moisture is a natural component of all parts of a living tree and contributes about half of the total mass (Hossain*et al*., 1991). Desch and Dinwoodie (1996), reported that wood of living tree and freshly harvested log contain a large volume of water which has a profound effect on the wood properties such as weight and strength. Wood is susceptible to pathological attack by some insects and fungi when moisture content is high (Ojo, 2016).

The amount of water in wood and its fluctuations with regards to its environment and usage affects wood properties most especially the physical properties, dimensional stability mechanical properties and resistance to biodeterioration (Haygreen and Bowyer, 1989). The actual amount of water in wood varies considerably among and within trees (axially and radially) and species (Desch and Dinwoodie, 1996). For effective physical and mechanical properties evaluation of any wood species, the moisture content has to be examined. Heartwood has much lower moisture content than sapwood and a butt log has lower moisture content than upper logs due to a high proportion of sapwood in the top part of the tree (Haygreen and Bowyer, 1989;Desch and Dinwoodie, 1996). Shupe *et al*. (1995), reported that moisture content decreased along the radial plane from core wood (inner portion) to outer wood. Oluwayemisi, (2002), pointed out that the amount of moisture needed is dependent on the use of lumber or wood products and the climate. Higher moisture content is normallylinked with lower strength hence the bottompart should have lower moisture content than the other parts as the specificgravity is higher at the bottom and lowers towards the upper part of the tree (Norul Izani and Sahri, 2008).

Strength properties of wood vary only when the moisture level is below Fibre Saturation Point (FSP). Most strength properties of wood vary inversely with the moisture content (Ojo, 2016). Below the fibre saturation point, strength of wood increases as it dries, thus, as water is lost from the cell walls, wood shrinks and becomes stiffer and harder (Desch, 1988). Shupe, *et al*. (1997), observed that modulus of rupture was highly significant responsive to moisture changes while modulus of elasticity was not significant at the same moisture changes. A 1% drop in moisture, 5% change in the bending property was observed with a moisture range of 6 – 12% and a 3% increase within a 12 – 20% range of moisture content. According to Findlay (1978), at 12% MC air-dried wood may support almost double the load a green lumber of similar dimension is able to support. All strength properties values are not affected in the same way when the moisture content changes. Toughness for instance may decrease with a decrease in MC, therefore it is necessary to control and measure the moisture content of test samples during the laboratory investigations on strength properties.

Determination of moisture content is carried out by 5 distinct methods among which is oven-dry method, distillation method, titration method, use of hygroscopic elements, and measurement of certain electrical properties, out of the methods listed, the most common is the use of basic gravimetric method. Dinwoodie opined in 1981 that the use of distillation process is preferred in order to prevent error as a result of loss of some volatile components of wood as a result of heating. Kollman and dan Cote (1968), expressed moisture content as the weight of water of the oven-dry wood and is computed as follow:

$$MC(\%) = \frac{Ww - Wo}{Wo} X100$$

Where:

MC = Moisture content

Ww = original weight of sampled wood before drying

Wo = the oven-dry weight of the sampled wood.

2.9.2 Shrinkage and swelling in Wood

When a wood looses moisture below fibre saturation point (FSP), it shrinks. The wood consequently swells when it absorbs water. The percentage change in wood dimension as a result of loss of moisture is termed shrinkage (Dinwoodie, 1989) while the percentage change in wood dimension when it absorbs moisture is termed swelling. Fibre saturation point (FSP) is a theoretical state where the cell walls are saturated with water however the surrounding wood cavities are empty (Desch, 1988 and Dinwoodie, 1989). The effect of shrinkage on the dimensions of wood are unequal along the three structural directions and this has been widely documented by various authors (Panshin and Dezeeuw, 1980; Dinwoodie, 1981 and Ogunsanwo, 2000) with Panshin and Dezeeuw (1980), noting that the geometric disposition of cells along the principal directions is mainly responsible for this observation.

The tangential plane has the greatest dimensional shrinkage closely followed by the radial shrinkage while the shrinkage along the longitudinal direction has been widely reported to be the least. The longitudinal shrinkage ranges from 0.1 to 0.3% and its mostly ignored (Desch, 1988; Dinwoodie, 1989; Wengert, 2006 and Bauer 2003). Suitability of wood for end uses has been linked with Tangential/Radial shrinkage ratio (T/R). Panshin and Dezeeuw (1980), noted that low value of T/R is synonymous with high suitability of wood for end uses. Rijsdijk and Laming(1994) reported that the ratios of tangential-radial shrinkage considered to be high are those over 2.2%

2.9.3Density

Density of wood is defined basically as mass of wood per unit volume otherwise as the amount of wood substance per unit volume of wood. The density of wood is dependent on the fibre wall thickness and also on the level of development of the cell wall (Ogunsanwo, 2000; Ojo, 2016). Wood density is also positively correlated with cellulose content as high cellulose content in wood indicates a high density.

Density varies in wood which may be as a result of the anatomical makeup of the wood as well as the wood moisture content.

Desch and Dinwoodie (1996) also reported that some strength properties such as compression strength parallel to the grain, bending strength and hardness show a strong correlation with density. They added that the density of a piece of wood is also determined by the presence of extractives as well as moisture content of the wood.

2.9.4Specific Gravity

This is a measure of the relative amount of the solid cell wall materials and extractives in the cell lumen of a piece of wood (Panshin and Dezeeuw, 1980). It is also known as the relative density or density index. It has been found alongside density to be the best index of the quality and strength of wood (Kellog, 1981). This is due to the fact that it is directly related to many wood properties. Specific gravity also has a direct effect on wood strength, machinability, acoustic properties, wearability and paper yield.

Specific gravity is the most effective indicator to predict suitability of wood for many end product uses (Pashin and de Zeeuw, 1980; Korkut, 2011; Naji *et al*., 2014). It reflect the presence of gums, resins, and extractives, which contribute little to mechanical properties (Forest Product Laboratory, 2010). Haygreen and Bowyer (1996) added that specific gravity is the ratio of the density of wood to the density of water. It is calculated using oven-dry weight or mass. Specific gravity is computed using the relation:

$$Specific\ Gravity = \frac{Density\ of\ oven\ dried\ wood}{Density\ of\ water}$$

Several reports have shown the variation patterns in the woods of hardwoods and some conifers. For instance, Haygreen and Bowyer (1982); Osadare (2001) and Ajala (2005), observed an increase in specific gravity from the inner wood (pith) towards the outer wood (bark) especially in most softwoods while it decreases with increasing height of the tree (from base to top) (Onilude, 1987). In softwood, specific gravity increase from pith to bark (Panshin and Dezeeuw, 1980), while in hardwood there is consistent variation of specific gravity along the stem.

2.10 Mechanical Properties of Wood

The mechanical properties of wood tend to describe how wood behaves in the presence of an external force applied on it which tends to deform its mass (Panshin and Dezeeuw, 1980 Tsoumis 1991; Desch and Dinwoodie, 1996). The strength of wood referred to its ability to resist external forces or load that can change its size and its shape or ability of the wood to carry applied load (Haygreen and Bowyer, 1996; Ojo, 2016). The resistance involves a number of specific mechanical properties and it is these that determine the suitability of different species of timbers for the various use for which the wood is put into (Illston *et al.,* 1987). Haygreen and Bowyer (1996) indicated that strength properties are the most important characteristics of wood products used in determining their structural applications.

2.10.1 Modulus of Elasticity (MOE)

Modulus of Elasticity of wood is the ability of a wood to retain its original figure (shape and size) after being stressed (Panshin and Dezeeuw, 1980). Desch (1988), stated that the ability of wood to bend freely and regain normal shape is called flexibility, and the ability to resist bending is called stiffness.

Forest Products Laboratory (2010) reported that elasticity implies that wood is able to completely recover its shape when a low stress loads are removed. However, it gives way or fails when loaded with higher levels of applied stress. Modulus of elasticity relates the stress applied along one axis to the strain occurring on the same axis. It is usually considered in conjunction with bending strength. The strength of a long timber column or strut is a critical property determined by the stiffness (MOE) of the material. Shrivastava (1997) also added that MOE is the measure of stiffness; the higher the MOE, the less is the deflection or the greater the stiffness. He observed that the MOE measures the relation between stress and strain within the limit of proportionality.

2.10.2 Compression Strength

This is referred to as the maximum crushing strength. Compression strength is considered in directions parallel and perpendicular to grain direction. Compression parallel to the grain may cause buckling of wood during application of load thereby subjecting it to a bending rather than a compressive stress (Desch, 1988). However, crushing strength across the grain does not exist because wood will only be densified under the influence of compressive force acting perpendicular to the grain.

When the applied forces tend to decrease the length of a body, it is under compression, and the stress is called the compressive stress. Compressive stress may be parallel to or perpendicular to the grain (Shrivastava, 1997). Compressive strength parallel to the grain or maximum crushing strength is the property that measures the ability of timber to withstand loads when applied on the end grain (Timings 1991). Compressive strength perpendicular to the grain which is the resistance to crushing is an important property in a few selected end uses such as in building constructions, railway sleepers, rollers, wedges, bearing blocks and bolted timbers. Timbers with high density have high compression strength across the grain (Kollman and dan Cote, 1968; Desch, 1988; Desch and Dinwoodie, 1996).

2.10.3 Modulus of Rupture (MOR)

Modulus of Rupture (MOR) is a parameter for measuring bending strength of wood. It measures the equivalent of stress (compressive or tensile stress) in the extreme fibres of the specimen at the point which the wood fails (Shrivastava, 1997; Ojo, 2016). Panshin and Dezeeuw (1980), described MOR as the magnitude of load required to cause failure in bending stresses. According to the report, the shape of the wood for the bending load deformation relationship in wood beyond the maximum load will be abruptly terminated in brittle woods and will decrease stepwise in tough woods.

Wilcox *et al*. (1991) stated that modulus of rupture (MOR) is an index of the maximum load a bending member can be expected to support before failing, weighted for the effects of span, width and depth. This is obtained from the static bending property of a material in which the maximum bending strength or equivalent fibre stress at maximum load is measured. The modulus of rupture is important in members subjected to transverse loading as in the loading of roof trusses (Timings, 1991).

2.11 Factors Affecting Strength Properties

Density is the most important single factor that affects the strength properties of wood. Others include, some anatomical features such as knots, slope of grain and microfibrillar angle, and some environmental factors such as moisture content and temperature (Desch and Dinwoodie, 1983).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Study location

Wood samples used for this study were harvested from Agbarha Rubber plantations. It is intensively managed for latex production. It is located in Ughelli North Local Government Area of Delta State. It lies within latitude 05º 30ˈN – 5º 48ˈN and longitude 05º 58ˈE – 6º 70ˈE of the Equator as represented in Figure 3.1.

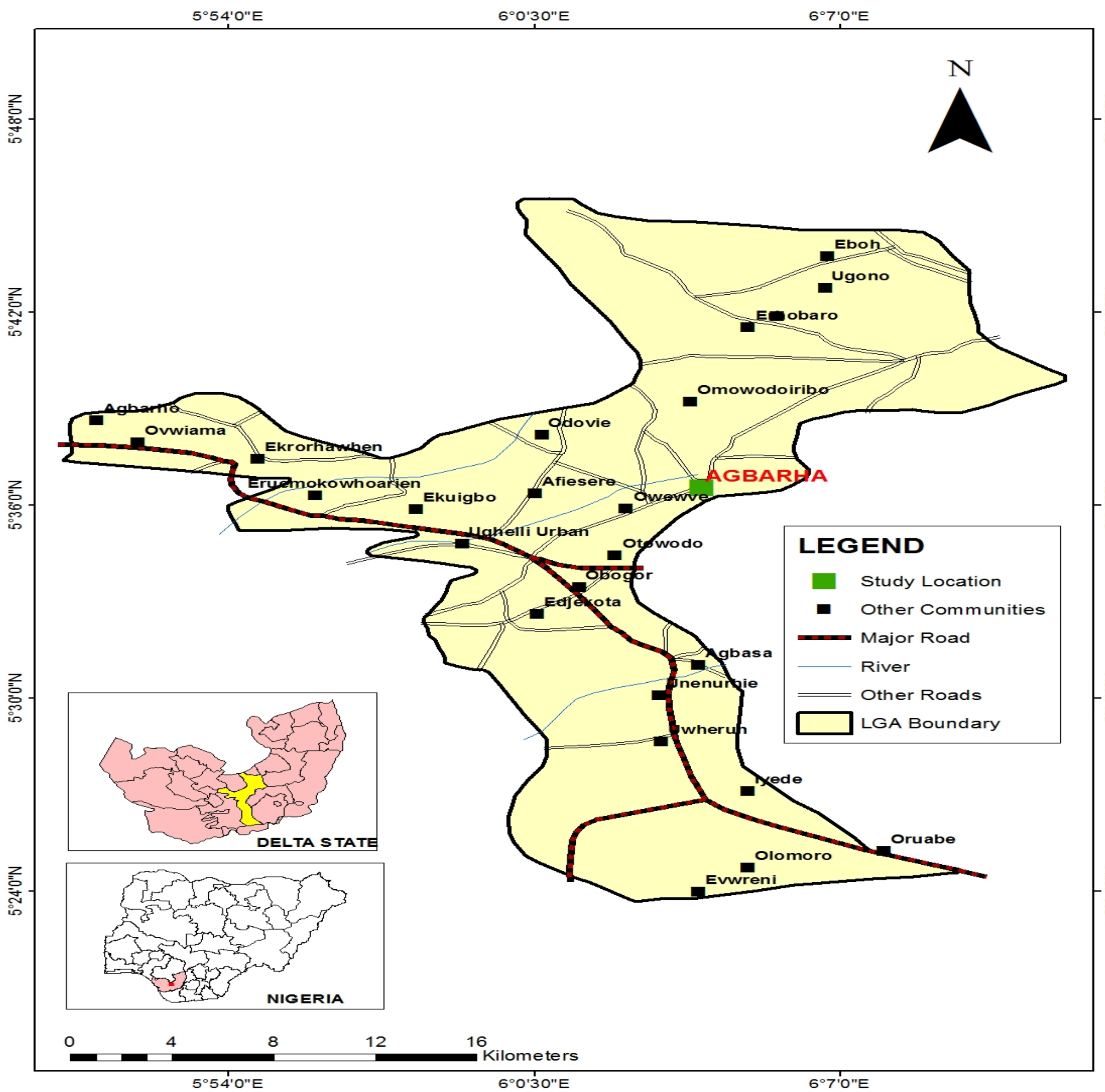


Figure 3.1: Map of Sample Site

3.1.1 Relief and soil

The site is located within a low-lying plain with land elevation generally less than 50 m above mean sea level. The soils are deeply weathered and nutrient-deficient derived mainly from unconsolidated sediments of sandstone which makes it suitable for rubber cultivation. They are largely sandy in nature with about 90% of sand making up the top 10 cm of the soil composite. This makes them loosed and poorly aggregated (Aweto, 2002). The soil pH in the sample site is usually below 5.0 and seldomly reaches 4.0 in the top 20 cm of the soil profile. Rubber used to be the most widely cultivated crop with about 80% of the agricultural land being used for cultivation of rubber. Rubber is produced in large scale in Ughelli because they are tolerant of the acidic sandy soils in the area.

3.1.2 Climate

The climate of sample site is moist subequatorial with a long wet season and dry season that starts between March till October (wet season) and November till February (dry season). Mean annual rainfall is about 2800 mm. The beginning and end of the wet season are usually distinct by strong thunderstorms of short duration and frequently go along with strong winds. The rainfall pattern is double-peak, with the first coming in June/July while the second occurs in September. These peak periods are separated by a relatively dry period in August often termed august break. Annual average temperature in Ughelli is about 27°C with a slight deviation rarely exceeding 3°C. The mean annual relative humidity is about 80.1% throughout the year.

3.2 Sample collection

3.2.1 Reconnaisance survey

A preliminary trip to the extraction site was embarked upon in order to get acquainted with the terrain and nature of the site. This was necessary to device a successful and efficient way of wood extraction.

3.2.2 Sampling strategy

Sampled trees were harvested from a private rubber plantation in Agbarha in 2016. The rubber trees were grouped into age series based on the years of tapping. The four age series were 5, 10, 15, 20 years of tapping. Five trees per tapping age series were purposively selected based on the absence of reaction tendencies, fairly straight and free from natural defects as well as excessive knot and harvested. Felled trees were cut into bolts of 60cm long which were collected at two different positions (butt and top) along the length of the bole i.e 10% and 90% of merchantable height making a total of 40bolts. Where possible, recently wind uprooted trees were selected, because during these age series, rubber production is in full swing. Rubber wood is much biodegradable because of this it was sprayed with sodium pentachloride preservative immediately after harvesting and sawing as used by Majumdar *et al.*(2014).

3.3 Sample preparation:

Bolts of the rubber wood were sawn into sizes of 25mm x 25mm x 350mm before they were finally machined to their final dimensions of 20mm x 20mm x 60mm and 20mm x 20mm x 300mm (Figure 3.2). The blocks were prepared for testing by oven drying at 103±2ºC until constant weight. The initial weight and oven dry weight for each wood sample were recorded after which they were bagged in an air tight nylon bag to prevent them from reabsorbing moisture.

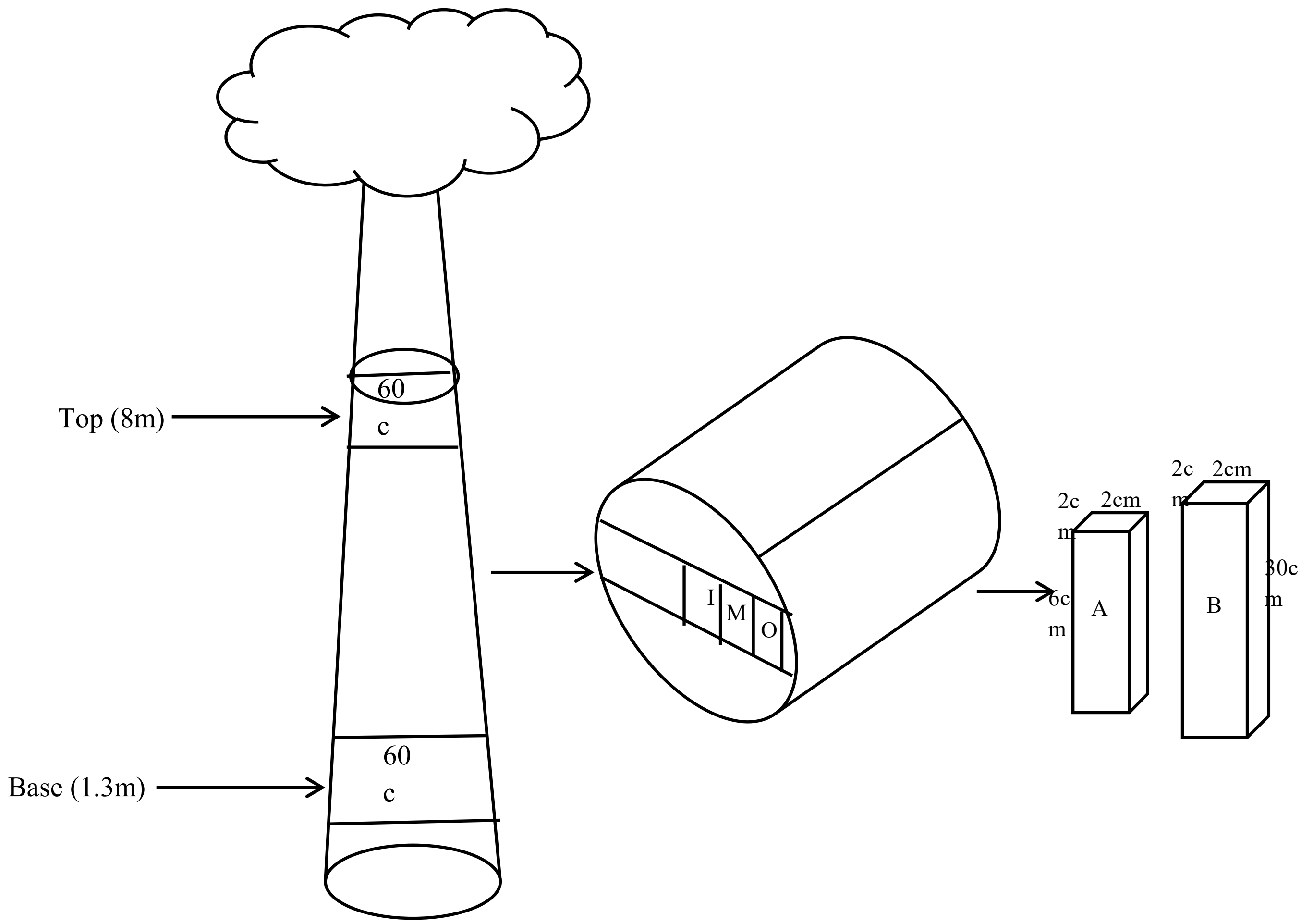


Figure 3.2: Schematics of sampling strategy

Where I=Innerwood, M= Middlewood, O= Outerwood

A= Samples for shrinkage, Specific gravity and Maximum compressive strength

B= Samples for Modulus of elasticity and rupture

3.4 Data collection

Wood samples were prepared in line with standard techniques to collect data for the determination the physical, anatomical, mechanical and chemical properties of tapped rubberwood.

3.4.1 Physical characteristics

The physical properties assessed were moisture content, specific gravity and shrinkage

3.4.1.1 Determination of moisture content:

Moisture content was determined by weighing samples of 20 mm x 20 mm x 60 mm and then oven drying. The original weight of the samples was noted before drying starts. The samples were then placed in an oven until a constant weight was obtained. The samples were allowed to cool off and then reweighed for their final measurements which were also noted. Moisture content was then calculated using the formula in equation 3.1.

Moisture content (%) = $\frac{W1-W2}{W2} \times 100$ -------------------------- Equation 3.1

Where

W1 = original weight of wood sample before drying

W2 = final weight of sample after drying

3.4.1.2 Determination of specific gravity

Dimension of 20 mm x 20 mm x 20 mmwas used for the determining specific gravity. The samples were subjected to a gravimetric method developed by Smith (1954). Wood samples were completely saturated by soaking in water. Each sample were removed from water and blotted to remove dripping water. It was weighed and then oven dried to a constant weight at 103ºC. Specific gravity was therefore analysedwith the formula in equation 3.2

Specific Gravity = $\frac{1}{\frac{Ws-Wo}{Wo} + \frac{1}{1.53}}$ -------------------------- Equation 3.2

Where Ws = saturated weight of wood

Wo = oven dry weight of wood

3.4.1.3 Determination of shrinkage

Wood samples were in the form of 20mm × 20mm × 40mm. Radial, tangential and longitudinal shrinkage were evaluated from wet condition to oven dry condition(drying in oven to a constant weight at a temperature of 103±2ºC). Wood samples were then immersed in water for 48hours to get their moisture to be above fibre saturation point. The samples were removed from water and their dimensions measured in the nearest mm. Dimensional shrinkage was measured after samples have been oven dried. Dimensions of wood samples both in wet and oven dry condition were measured using a slide calliper. The formula to calculate the shrinkage is presented in equation 3.3 and 3.4

$S = \frac{Ds - Do}{Ds} \times 100$ -------------------------- Equation 3.3

Where

S = percentage shrinkage

Ds = Dimension of saturated wood samples

Do = Dimension of oven dry wood samples

$Vs = S_R + S_T + S_L$ -------------------------- Equation 3.4

Where Vs = Volumetric shrinkage

S_R = Radial shrinkage

S_T = Tangential shrinkage

S_L = Longitudinal shrinkage

3.4.2 Anatomical characteristics

The anatomical properties assessed were fibre length, lumen width, fibre diameter, cell wall thickness, slenderness coefficient, runkel ratio, coefficient of rigidity, luce shape factor, vessel length, vessel width, vessel diameter, ray width and height

3.4.2.1 Measurement of Fibre dimensions

Wood slivers were obtained from different sampling positions and macerated in equal volumes (1:1) of 10% glacial acetic acid and 30% hydrogen peroxide after the method of Franklin (1945). The macerated fibres were washed thoroughly in water and shaken vigorously in distilled water to free the individual fibres. The suspension was mounted on a slide with the aid of a rubber teat. The slides were mounted one after the other on the light microscope from which the fibres were viewed and measured with the objective lens of x40. The fibre morphology of 20 randomly selected fibres was measured according to tapping age, sampling height and radial position for statistical analysis. The fibre dimensions were measured with the aid of a Olympus Light microscope in the wood science laboratory of the Department of Forest Production and Products, University of Ibadan. Parameters to be measured include Fibre length (L in mm), Lumen width (d in µm) and Fibre diameter (D in µm)

From these measured dimensions, other derived parameters were also calculated. These include the following and their equations shown in equation 3.5-3.10

- Cell wall Thickness = $\frac{Fibre\ diameter - lu\qquad wid}{2}$ …..…………… Equation 3.5
- Flexibility Ratio = $\frac{lumen\ width}{fibre\ diameter} \times \frac{100}{1}$ ………………………… Equation 3.6
- Slenderness Coefficient = $\frac{Fibre\ length}{Fibre\ diameter}$ ………………………… Equation 3.7
- Runkel Ratio = $\frac{2 \times cell\ wall\ thicknes}{lumen\ widt}$ ……………………………… Equation 3.8
- Coefficient of rigidity = $\frac{cell\ wall\ thickness}{fibre\ diameter} \times \frac{100}{1}$ ………………… Equation 3.9
- Luce Shape Factor = $\frac{FD^2 - LW^2}{FD^2 + LW^2}$ ………………………………….. Equation 3.10

3.4.2.2 Stereological analysis

3.4.2.2.1 Sectioning

Sectioning of test samples was performed with a microtome sliding machine at Forestry Research Institute of Nigeria (FRIN), Ibadan. Softening of test samples was carried out by placing them in water inside a beaker and boiled until the samples sunk under their own weight. This is necessary to expel air in the cells before slide preparation. The samples were clamped in such a way that the samples were parallel to the direction of the knife travel while the knife forms an angle of about 15^o with the surface of the sample in the vertical plane and similar angle with the line of motion. Each sliced samplewas transferred into a dish containing methylated spirit using a soft brush. Each thin section was about 20µm thick.

3.4.2.2.2 Mounting

Sections were rinsed in distilled water and safranin was used to cover it fortwo minutes after which the section was rewashed with distilled water until the water became colourless. Dehydration was done by passing test samples through ethanol which replaced the water. The specimen was later covered with clove oil in order to drive off the ethanol. The sections were then placed on a clean slide and filter paper was used to drain off excess clove oil. A slight amount of Canada balsam was added while the slides were covered with a cover glass and the slides were gently heated so as to remove air bubbles within it.

3.4.2.2.3 Cell characterisation

Cell quantification was carried out in the laboratory of the Department of Forest Production and Products, University of Ibadan using an Olympus light microscope X10 magnification for cell counts and X40 magnification for cell dimensions. The number of vessel was counted by projecting the wood sections and viewing slides cross sectionally using 10 x 10 mm squares eyepiece fitted on the microscope. Vessels and ray dimensions (height and width) was measured using a calibrated ocular eyepiece. Vessel width was measured on the cross sectional direction while vessel length was measured in the tangential direction. Ray height and width was measured in the radial direction.

3.4.3 Strength characteristics

Strength properties assessed were modulus of rupture, modulus of elasticity and maximum compressive strength parallel to grain.

3.4.3.1 Determination of Modulus of Rupture (MOR)

The Modulus of Rupture was carried out in accordance with British Standard Method BS 373 and it involves the use of specimens of dimension 20mm x 20mm x 300 mm prepared and tested. This was performed on computerised OKH-600 Digital Universal Testing Machine (UTM). The samples were placed horizontally in between two plates of the universal testing machine. The load was applied at the rate of 0.1 KN/sec. The MOR was determined from the machine as the load at failure was recorded and the corresponding PC monitored values taken directly from the machine. MOR was then calculated using the formula in equation 3.11

$MOR = \frac{3PL}{2bd^2}$ …………………………… Equation 3.11

MOR = Modulus of Rupture (N/mm^2)

P = Load in Newton (N)

L = Span in mm

b = Width of samples in mm

d = Depth of samples in mm

3.4.3.2 Determination of Modulus of Elasticity (MOE)

The Modulus of Elasticity (MOE) was carried out using results from the MOR test. In addition to the previously obtained values, the corresponding MOE was calculated from the deflection value (Δ) obtained from the UTM. The MOE was calculated using the formula in equation 3.12.

$MOE = \frac{PL^2}{4\Delta bd^3}$ …………………………… Equation 3.12

MOE = Modulus of Elasticity (N/mm^2)

P = Load in Newton (N)

L = Span in mm

b = Width of samples in mm

d = Depth of samples in mm

Δ = deflection of the beam

3.4.3.3 Determination of Maximum Compressive Strength Parallel to grain (MCS//)

The maximum compressive strength parallel to grain was determined according to BS 373. Test specimens of 20mm x 20mm x 60 mm was prepared and tested on computerised OKH-600 Digital Universal Testing Machine (UTM). Load was prepared perpendicularly and load was applied at 0.01mm/sec. Load at failure was recorded and the corresponding PC monitored values taken directly from the machine. The Maximum Compressive Strength Parallel to Grain was then calculated using equation 3.13

$MCS// = \frac{P}{A}$................................ Equation 3.13

Where

MCS// = Maximum Compressive Strength Parallel to Grain (N/mm^2)

P = Load (N)

A = Area of wood samples (mm^2)

3.4.4 Chemical characteristics

Air dried rubberwood was reduced to sawdust and sieved by passing it through a 40mm mesh sieve and retained on the 60mm mesh sieve. The chemical analysis was then conducted on the sawdust. Fourier transform infrared reflectance(FTIR) was conducted as well as conventional chemical analysis. The conventional analysis carried out includes the following; Ash content, Lignin content, Holocellulose content and Alpha cellulose content.

3.4.4.1 Determination of ash content

Ash content was conducted according to the TAPPI standard T 211 om-02 (2002). An empty crucible was burnt in a muffle furnace at 600ºC and then cooled in a desiccator. The weight of the crucible and specimen were determined and then placed in the oven at 103 ± 2ºC. It was cooled in a desiccator and reweighed. This continued until a constant weight was obtained. The crucible and its content was then placed in the muffle furnace and burnt until the carbon was eliminated. The content was heated slowly at the start of this process to avoid flaming and mechanical loss of test specimen. The temperature at final ignition was between 580 – 600ºC. The crucible with its content was removed from the furnace and placed in a desiccator to cool and weighed accurately. The ash content was calculated with equation 3.14

Ash content (%) = $\frac{W2}{W1} \times 100$-------------------------- Equation 3.14

Where W1 = weight of crucible and ash

W2 = weight of crucible and oven dried sample

3.4.4.2 Determination of lignin content

Lignin content was determined according to the TAPPI standard T 222 om-02 (2002). 1g of oven dried weight of extractive free sawdust was digested with 15cm^3 of 72% cold H_2SO_4 acid which was added slowly. The reaction was allowed to continue for 2 hours with frequent stirring in a water bath at room temperature. Thereafter, 475cm^3 of distilled water was added and the solution heated. The content was allowed to boil for 4 hours with constant volume by addition of hot distilled water. The insoluble lignin formed was allowed to settle down overnight, filtered and washed with hot distilled water until it became neutral. The sample was then oven dried at 85ºC until constant weight is obtained. The percentage insoluble lignin was calculated using equation 3.15

% Lignin = $\frac{weight\ of\ lignin}{oven\ dried\ weigh\ \ of\ extractive\ free\ sawdust} \times 100$------ Equation 3.15

3.4.4.3 Determination of holocellulose content

Holocelluloses consists of cellulose and hemicellulose. The method developed by Wise *et al.* (1946) was used in the determination of the holocellulose content of rubberwood. 2g of extractive free sawdust of known moisture content was moistened with cold water and the excess moisture removed by suction. The sample was chlorinated for 5minutes followed by extraction with 50ml of 95% ethanol and hot ethanol-monoethanolamine solution. At the end of each extraction, the residue was washed thoroughly with distilled water followed by another round of extraction until the residue becomes white. The washing exercise was also repeated until the residue becomes neutral to litmus. The residue obtained was then oven dried to constant weight. The percentage holocellulose based on moisture free extractive free milled sample was calculated the equation given in equation 3.16

% Holocellulose = $\frac{W2}{W1} \times 100$-------------------------- Equation 3.16

Where

W1 = weight of moisture free and extractive free milled sample

W2 = weight of dried holocellulose residue

3.4.4.4 Determination of alpha cellulose content

Alpha-cellulose content was determined according to the TAPPI standard T 203 cm-99 (2002). 2g of cream coloured residue determined from the holocellulose solution was transferred into a 250cm^3 glass beaker followed by addition of 250cm^3 of 17.5% NaOH solution. After two minutes, 10cm^3 of 17.5% NaOH was then added and the holocellulose macerated lightly with a glass rod to get a well dispersed material. After five minutes, another 5cm^3 of NaOH was added, stirred and left to stand for 30minutes. After this 33cm^3 of cold distilled water was then added to bring the solution to 8.3%. The whole content was allowed to stand for one hour. The final caustic extraction was done after one hour using 100cm^3 of 8.3% NaOH. Thereafter, the residue was washed with distilled water and dispersed with a glass rod. The above step was repeated twice while the residue steeped in 15 cm^3 glacial acetic acid for 3 minutes. The residue was then washed with cold distilled water repeatedly until it became neutral to blue litmus paper. The washed residue was then transferred back into a crucible of known weight and dried in an oven at 103±2ºC until constant weight was obtained. The percentage alpha cellulose content was calculated with the equation in 3.17

% Alpha cellulose content = $\frac{W2}{W1} \times 100$-------------------------- Equation 3.17

Where

W1 = weight of moisture free and extractive free milled sample

W2 = weight of dried alpha cellulose

3.4.4.5 Fourier Transform Infrared Relectance (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy was used to determine the chemical structure (compositional analysis) of rubber wood. This was carried out using FTIR Spectrum BX by Perkin Elmer at the Multidisciplinary Research Laboratory, University of Ibadan.

3.5 Data analysis

Data wasanalysed through inferential and descriptive statistics. A three factor factorial experiment in a completely randomized design was used for this study. The main factors considered were; tapping duration, sampling height or axial position and radial position. The tapping age series were at 4 levels, the axial position at 2 levels while the radial position at 3 levels. Duncan multiple range test was used to test means with significant differences and to choose the best combination treatment. The mathematical model used is given below.

$Yijkl = \mu + Ai + Bj + Ck + (AB)ij + (AC)ik + (BC)jk + (ABC)ijk + Eijkl$ ----- Equation 3.18

Where;

$Yijkl$ = Individual observation

μ = General mean

Ai = Effect of variation of age (Factor A)

Bj = Effect of variation of axial position (Factor B)

Ck = Effect of variation of radial position (Factor C)

(AB)ij = Effect of interaction between tapping age and sampling height

(AC)ik = Effect of interaction between tapping age and radial variation

(BC)jk = Effect of interaction between sampling height and radial variation

(ABC)ijk = Effect of interaction between tapping age, sampling height and radial variation

Eijkl = Error associated with factor A, B and C

CHAPTER FOUR

4.0 RESULTS

4.1 Physical Properties

4.1.1 Specific gravity of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.1 shows the mean value for specific gravity for rubber wood of all the ages is 0.56. The mean values range from 0.55 to 0.59 for the various age series with 20years of tapping having the highest specific gravity. The specific gravity increased progressively from 5years of tapping up to 20years of tapping with mean values of 0.58, 0.59, 0.61, 0.62 for the top and 0.51, 0.54, 0.56, 0.56 for the base.

The specific gravity values along the bole was higher in the base than samples collected from the top of the wood with a mean value of 0.60 for the top as compared to 0.54 for the base (Table 4.2). The specific gravity value decreased slightly across the bole from innerwood to middle wood and then increased at the outer wood at 5, 10 and 15 years of tapping. However the specific gravity increased progressively from innerwood to outerwood at 20 years of tapping. General mean values are 0.58, 0.57 and 0.57 for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for specific gravity show that the values obtained with respect to the sampling age and height were highlysignificantlydifferent at 0.01 level of probability. However, there was no significant difference in the values obtained for the different across the bole (radial) as shown in Table 4.3.

Table 4.1: Specific gravity of tapped *Hevea brasiliensis* woodcollected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner	Middle	Outer	Mean
5	Top	0.57±0.02	0.57±0.02	0.59±0.01	**0.58**±0.01
	Base	0.54±0.01	0.50±0.01	0.51±0.02	**0.51**±0.01
	Mean	**0.55**±0.01	**0.54**±0.02	**0.55**±0.02	**0.55**±0.01
10	Top	0.60±0.02	0.60±0.02	0.57±0.01	**0.59**±0.01
	Base	0.56±0.01	0.52±0.01	0.54±0.02	**0.54**±0.01
	Mean	**0.58**±0.01	**0.56**±0.02	**0.56**±0.01	**0.57**±0.01
15	Top	0.61±0.01	0.60±0.03	0.61±0.02	**0.61**±0.01
	Base	0.58±0.02	0.54±0.04	0.56±0.02	**0.56**±0.02
	Mean	**0.59**±0.01	**0.57**±0.02	**0.59**±0.01	**0.58**±0.01
20	Top	0.61±0.03	0.61±0.01	0.64±0.01	**0.62**±0.01
	Base	0.56±0.03	0.57±0.03	0.56±0.02	**0.56**±0.01
	Mean	**0.53**±0.02	**0.54**±0.02	**0.55**±0.02	**0.59**±0.01

Table 4.2: Effects of Age, Axial and Radial variation on specific gravity of tapped*Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria

Sources	Mean Values
Tapping age (Years)	
5	0.55
10	0.57
15	0.58
20	0.59
Axial	
Base	0.54a
Top	0.60b
Radial	
Inner	0.58
Middle	0.57
Outer	0.57

Table 4.3: Analysis of variance (ANOVA) of specific gravity of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p- value
Age (A)	3	0.03640	0.01213	6.28	0.000629**
Axial (Ax)	1	0.08911	0.08911	46.12	0.000000**
Radial (Rad)	2	0.00274	0.00137	0.71	0.494735^{ns}
A*Ax	3	0.00107	0.00036	0.19	0.906196^{ns}
A*Rad	6	0.00636	0.00106	0.55	0.769754^{ns}
Ax*Rad	2	0.00462	0.00231	1.19	0.307529^{ns}
A*Ax*Rad	6	0.00513	0.00085	0.44	0.848562^{ns}
Error	93	0.17969	0.00193		
Total	116	0.33037			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.1.2 Moisture content of tapped *Hevea brasiliensis* woodcollected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean values of moisture content of tapped rubberwood is presented in Table 4.4. It shows the mean value for moisture content for rubber wood of all the ages is 9.17 %. The moisture content vary from 9.01% to 9.36% for the various age series with 15years of tapping having the lowest mean value of 9.01%. The moisture content increased from 5years of tapping to 10 years, decreased to 15years and increased at 20years of tapping with mean values of 9.13%, 9.52%, 8.80%, 8.92% for the top and 9.38%, 9.20%, 9.22 %, 9.18% for the base of 5, 10, 15 and 20 years of tapping respectively.

The samples collected from the top of the bole had a higher moisture content (9.09%) than samples collected from the base of the stem (9.28 %) as shown in table 4.5. The moisture content value decreased across the bole from innerwood to middle wood and then increased at the outer wood at 5 and 10years of tapping while it decreased progressively at 15years of tapping from innerwood to outerwood. At 20years of tapping, it increased from innerwood to middlewood and decreased at the outerwood.The mean values across the stem were 9.15%, 9.03% and 9.33% for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for moisture content show that the tapping age did not significantly affect moisture content of rubberwood at 0.05 level of probability. Similarly, no significant diffenece was observed along and across the stem bole (Table 4.6)

Table 4.4: Moisture content of tapped *Hevea brasiliensis* woodcollected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(%)	Middle(%)	Outer(%)	Mean(%)
5	Top	9.09±0.06	9.13±0.06	9.17±0.07	**9.13**±0.03
	Base	9.74±0.18	8.87±0.59	9.54±0.21	**9.38**±0.26
	Mean	**9.41**±0.15	**9.00**±0.32	**9.36**±0.13	**9.26**±0.13
10	Top	9.40±0.21	9.58±0.06	9.59±0.08	**9.52**±0.08
	Base	9.66±0.06	8.31±1.10	9.63±0.10	**9.20**±0.38
	Mean	**9.53**±0.11	**8.95**±0.56	**9.61**±0.06	**9.36**±0.19
15	Top	7.95±1.10	9.21±0.12	9.25±0.11	**8.80**±0.38
	Base	9.98±0.20	8.09±1.80	9.60±0.17	**9.22**±0.60
	Mean	**8.96**±0.62	**8.65**±0.87	**9.42**±0.11	**9.01**±0.35
20	Top	9.14±0.11	9.32±0.11	8.30±1.08	**8.92**±0.36
	Base	8.22±1.03	9.74±0.20	9.60±0.19	**9.18**±0.38
	Mean	**8.68**±0.51	**9.53**±0.13	**8.95**±0.56	**9.05**±0.26

Table 4.5: Effects of Age, Axial and Radial variation on moisture content of tapped*Hevea brasiliensis*

Sources	Mean Values (%)
Tapping Age (Years)	
5	9.26
10	9.36
15	9.01
20	9.05
Axial	
Base	9.28
Top	9.09
Radial	
Inner	9.15
Middle	9.03
Outer	9.34

Table 4.6: Analysis of variance (ANOVA) of moisture content of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p value
Age (A)	3	2.468	0.823	0.447	0.719953^{ns}
Axial (Ax)	1	0.705	0.705	0.383	0.537291^{ns}
Radial (Rad)	2	1.813	0.907	0.493	0.612521^{ns}
A*Ax	3	2.378	0.793	0.431	0.731412^{ns}
A*Rad	6	8.488	1.415	0.769	0.596235^{ns}
Ax*Rad	2	7.427	3.713	2.018	0.138667^{ns}
A*Ax*Rad	6	15.450	2.575	1.400	0.223119^{ns}
Error	93	171.105	1.840		
Total	116	210.256			

ns: Not significant (P>0.05)

4.1.3 Longitudinal shrinkage of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean value for longitudinal shrinkage for rubber wood of all the ages is 1.42% (table 4.7). Longitudinal shrinkage range from 1.10% to 1.69% for the various age series with 10years of tapping having the highest mean value of 1.69%. The longitudinal shrinkage increased from 5years of tapping to 10years and then decreased to 15years before increasing again at 20years of tapping with values of 1.42%, 1.26%, 0.82%, 1.13% for the top and 1.62%, 2.12%, 1.39%, 1.60 % for the base.

Wood samples obtained from the top of the bole had a mean longitudinal shrinkage of 1.15 % while those from the base had 1.68 % (table 4.8). The longitudinal shrinkage showed an inconsistent variation across the bole as it increased from innerwood to middlewood and then decreased at the outerwood with mean values ranging from 0.73-2.87%, 0.57-2.37% and 0.82-1.70% for the innerwood, middlewood and outerwood.

Table 4.9 shows the result of analysis of variance for longitudinal shrinkage where tapping age did not significantly affect the longitudinal shrinkage of rubberwood at 0.05 level of probability. Sampling height as well as radial variation did not also affect the longitudinal shrinkage.

Table 4.7: Longitudinal shrinkage of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	**Sampling height**	**Inner(%)**	**Middle(%)**	**Outer(%)**	**Mean(%)**
5	Top	0.92±024	1.49±0.24	1.85±0.94	**1.42**±0.32
	Base	1.51±0.50	1.88±0.26	1.49±0.30	**1.62**±0.20
	Mean	**1.21**±0.30	**1.68**±0.18	**1.67**±0.42	**1.52**±0.18
10	Top	0.94±0.27	1.83±0.42	1.00±0.29	**1.26**±0.21
	Base	2.87±1.58	1.82±0.27	1.66±0.31	**2.12**±0.52
	Mean	**1.91**±0.82	**1.83**±0.24	**1.33**±0.23	**1.69**±0.29
15	Top	0.97±0.23	0.57±0.17	0.92±0.36	**0.82**±0.15
	Base	1.62±0.74	1.10±0.31	1.43±0.46	**1.39**±0.29
	Mean	**1.29**±0.38	**0.83**±0.19	**1.18**±0.29	**1.10**±0.17
20	Top	1.41±0.73	1.14±0.31	0.82±0.07	**1.13**±0.26
	Base	0.73±0.14	2.37±0.99	1.70±0.39	**1.60**±0.38
	Mean	**1.07**±0.37	**1.76**±0.53	**1.26**±0.24	**1.36**±0.23

Table 4.8: Effects of Age, Axial and Radial variation on longitudinal shrinkage of tapped*Hevea brasiliensis*

Sources	Mean Values (%)
Tapping age (Years)	
5	1.52
10	1.69
15	1.10
20	1.36
Axial	
Base	1.68a
Top	1.14b
Radial	
Inner	1.38
Middle	1.53
Outer	1.35

Table 4.9: Analysis of variance (ANOVA) of longitudinal shrinkage of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p-value
Age (A)	3	5.5855	1.8618	1.2676	0.290113^{ns}
Axial (Ax)	1	8.0930	8.0930	5.5100	0.021029*
Radial (Rad)	2	0.6571	0.3285	0.2237	0.800001^{ns}
A*Ax	3	1.5304	0.5101	0.3473	0.791156^{ns}
A*Rad	6	6.2059	1.0343	0.7042	0.646939^{ns}
Ax*Rad	2	0.1913	0.0956	0.0651	0.937003^{ns}
A*Ax*Rad	6	11.0653	1.8442	1.2556	0.28562^{ns}
Error	93	136.5966	1.4688		
Total	116	170.1109			

*: significant (P<0.05)

ns: Not significant (P>0.05)

4.1.4 Tangential shrinkage of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.10 shows the mean value for tangential shrinkage for rubber wood of all the ages is 5.37%. The mean values ranges from 5.08% to 5.84% for the various age series with 15years of tapping having the lowest mean value of 5.08%. The mean values at the top were 4.35%, 5.52%, 4.89%, 5.29 % while the base had 6.14%, 6.16%, 5.26%, 5.38 % for 5, 10, 15 and 20 years of tapping respectively.The tangential shrinkage increased from 5years of tapping to 10 years, decreased to 15years before increasing at 20years of tapping.

The tangential shrinkage values along the bole was higher in the base than the top of the wood with a mean value of 5.01% for the top and 5.73% for the base (table 4.11). The tangential shrinkage value increased across the bole from innerwood to outer wood with mean values of 5.30%, 5.34% and 5.48% for the innerwood, middlewood and outerwood respectively and it follows the general trend where tangential shrinkage increases from pith to bark.

Result of analysis of variance for tangential shrinkage presented in table 4.12 shows that the tangential shrinkage was not significantly affected by tapping age at 0.05 level of probability. Tangential shrinkage was not also significantly affected by the sampling height and radial variation.

Table 4.10: Tangential shrinkage of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(%)	Middle(%)	Outer(%)	Mean(%)
5	Top	4.55±0.72	4.33±0.20	4.17±0.65	**4.35**±0.30
	Base	6.54±1.42	5.89±1.59	5.99±1.13	**6.14**±0.75
	Mean	**5.54**±0.88	**5.11**±0.89	**5.08**±0.73	**5.24**±0.46
10	Top	5.12±0.46	5.10±0.68	6.34±0.34	**5.52**±0.32
	Base	6.09±1.29	6.21±0.87	6.19±0.11	**6.16**±0.48
	Mean	**5.61**±0.66	**5.66**±0.55	**6.26**±0.17	**5.84**±0.30
15	Top	4.20±0.54	5.60±1.46	4.87±0.18	**4.89**±0.51
	Base	5.81±0.28	4.91±0.91	5.06±0.29	**5.26**±0.33
	Mean	**5.01**±0.39	**5.26**±0.82	**4.97**±0.16	**5.08**±0.30
20	Top	5.11±0.62	5.11±0.50	5.65±0.53	**5.29**±0.30
	Base	4.98±0.61	5.59±0.42	5.56±0.25	**5.38**±0.25
	Mean	**5.05**±0.41	**5.35**±0.32	**5.61**±0.28	**5.33**±0.19

Table 4.11: Effects of Age, Axial and Radial variation on tangential shrinkage of tapped*Hevea brasiliensis*

Sources	**Mean Values (%)**
Tapping age (Years)	
5	5.24
10	5.84
15	5.08
20	5.33
Axial	
Base	5.73a
Top	5.05b
Radial	
Inner	5.32
Middle	5.37
Outer	5.51

Table 4.12: Analysis of variance (ANOVA) of tangential shrinkage of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	9.749	3.250	1.037	0.380044^{ns}
Axial (Ax)	1	15.124	15.124	4.826	0.030524*
Radial (Rad)	2	0.678	0.339	0.108	0.897619^{ns}
A*Ax	3	11.576	3.859	1.231	0.302872^{ns}
A*Rad	6	5.138	0.856	0.273	0.948176^{ns}
Ax*Rad	2	2.360	1.180	0.376	0.687337^{ns}
A*Ax*Rad	6	7.573	1.262	0.403	0.875548^{ns}
Error	93	291.476	3.134		
Total	116	342.271			

*: significant (P<0.05)

ns: Not significant (P>0.05)

4.1.5 Radial shrinkage of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean value for radial shrinkage for rubber woodranges from 2.87% to 3.84% for the various tapping ages as shown in Table 4.13. The mean values radial shrinkage was highest at 10 years of tapping(3.84%) and lowest at 5 years of tapping (2.87 %). The radial shrinkage showed no consistent variation as the years of tapping increased. Increasing from 5years of tapping to 10years and then decreased to 15years before increasing again at 20years of tapping with mean values of 2.72%, 3.55%, 3.39%, 3.62% for the top and 3.01%, 4.12%, 3.27%, 3.68 % for the base.

Table 4.14 shows the radial shrinkage values along the bole was observed to be higher in the base (3.52%) than the top (3.32%)of the wood. The radial shrinkage value decreased across the bole from innerwood to outer wood with mean values of 3.58%, 3.36% and 3.32% for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for radial shrinkage in Table 4.15 show that the radial shrinkage was significantly affected by the age of tapping at 0.05 level of probability. However there was no significant difference in the values obtained across the bole and in the sampling height.

Table 4.13: Radial shrinkage of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(%)	Middle(%)	Outer(%)	Mean(%)
5	Top	2.65±0.32	2.99±0.42	2.52±0.63	**2.72**±0.25
	Base	3.62±0.46	2.50±0.53	2.93±0.20	**3.01**±0.26
	Mean	**3.13**±0.32	**2.74**±0.34	**2.72**±0.29	**2.87**±0.18a
10	Top	3.94±0.51	3.19±0.22	3.53±0.73	**3.55**±0.30
	Base	5.14±0.91	3.46±0.38	3.75±0.40	**4.12**±0.38
	Mean	**4.54**±0.53	**3.33**±0.21	**3.64**±0.40	**3.84**±0.24b
15	Top	2.88±0.28	3.97±0.53	3.31±0.26	**3.39**±0.24
	Base	3.56±0.21	2.94±0.44	3.32±0.56	**3.27**±0.24
	Mean	**3.22**±0.20	**3.46**±0.37	**3.32**±0.30	**3.33**±0.17ab
20	Top	3.29±0.40	3.82±0.15	3.78±0.38	**3.63**±0.19
	Base	3.58±0.69	4.02±0.29	3.46±0.47	**3.68**±0.28
	Mean	**3.44**±0.38	**3.92**±0.15	**3.62**±0.29	**3.66**±0.17b

Table 4.14: Effects of Age, Axial and Radial variation on radial shrinkage of tapped*Hevea brasiliensis*

Sources	Mean Values (%)
Tapping age (Years)	
5	2.87a
10	3.84b
15	3.33ab
20	3.66b
Axial	
Base	3.52a
Top	3.36b
Radial	
Inner	3.61
Middle	3.37
Outer	3.35

Table 4.15: Analysis of variance (ANOVA) of radial shrinkage of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	15.304	5.101	4.727	0.004089**
Axial (Ax)	1	1.162	1.162	1.077	0.302171^{ns}
Radial (Rad)	2	1.545	0.772	0.716	0.491515^{ns}
A*Ax	3	1.973	0.658	0.609	0.610568^{ns}
A*Rad	6	8.912	1.485	1.376	0.232294^{ns}
Ax*Rad	2	5.536	2.768	2.565	0.082341^{ns}
A*Ax*Rad	6	2.738	0.456	0.423	0.862100^{ns}
Error	93	100.360	1.079		
Total	116	137.277			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.1.6 Volumetric shrinkage of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.16 shows the mean value for volumetric shrinkage for rubber wood of all the ages is 10.22%. 15years of tapping having the lowest mean volumetric shrinkage of 9.51% with mean values ranging from 8.48% to 11.37% for the across the tapping age. The volumetric shrinkage across the tapping ages also varied inconsistently as it increased from 5years of tapping (9.63) to 10years of tapping (11.37) and then decreased to 15years (9.51) before increasing again at 20years of tapping (10.35) with mean values of 8.48%, 10.34%, 9.10%, 10.05% for the top and 10.78%, 12.40%, 9.92%, 10.66% for the base respectively.

The volumetric shrinkage values decreased from the bole (10.94%) to the top (9.49%) of the wood as shown in Table 4.17. The volumetric shrinkage value across the bole varied inconsistently as it decreased from innerwood (10.26%) to middlewood (10.23%) and then increased at the outerwood (10.17%).

Result of analysis of variance for volumetric shrinkage show that tapping age did not significantly affect volumetric shrinkage at 0.05 level of probability. It also shows that the sampling height as well as radial variation did not significantly affect the volumetric shrinkage (Table 4.18).

Table 4.16: Volumetric shrinkage of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of tapping	Sampling height	Inner (%)	Middle (%)	Outer (%)	Mean (%)
5	**Top**	8.11±0.59	8.80±0.60	8.53±1.38	8.48±0.49
	Base	11.66±1.32	10.26±1.74	10.41±1.11	10.78±0.77
	Mean	**9.89±0.81**	**9.53±0.97**	**9.47±0.91**	**9.63±0.52a**
10	**Top**	10.01±1.01	10.12±0.88	10.88±0.74	10.34±0.48
	Base	14.11±3.75	11.50±1.42	11.60±0.55	12.40±1.29
	Mean	**12.06±1.18**	**10.81±0.73**	**11.24±0.43**	**11.37±0.70a**
15	**Top**	8.05±0.83	10.14±2.06	9.11±0.35	9.10±0.73
	Base	11.00±0.67	8.95±1.24	9.81±0.90	9.92±0.56
	Mean	**9.53±0.56**	**9.55±1.13**	**9.46±0.42**	**9.51±0.46a**
20	**Top**	9.81±0.57	10.07±0.46	10.26±0.77	10.05±0.33
	Base	9.29±1.23	11.97±1.30	10.72±0.72	10.66±0.66
	Mean	**9.55±0.67**	**11.02±0.33**	**10.49±0.44**	**10.35±0.37a**

Table 4.17: Effects of Age, Axial and Radial variation on volumetric shrinkage of tapped *Hevea brasiliensis*

Sources	Mean Values (%)
Tapping age (Years)	
5	9.63
10	11.37
15	9.51
20	10.35
Axial	
Base	10.94a
Top	9.54b
Radial	
Inner	10.31
Middle	10.26
Outer	10.21

Table 4.18: Analysis of variance (ANOVA) of volumetric shrinkage of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	64.56	21.52	2.565	0.059350^{ns}
Axial (Ax)	1	61.02	61.02	7.272	0.008314**
Radial (Rad)	2	0.17	0.08	0.010	0.990058^{ns}
A*Ax	3	15.81	5.27	0.628	0.598585^{ns}
A*Rad	6	19.94	3.32	0.396	0.879809^{ns}
Ax*Rad	2	16.65	8.33	0.992	0.374645^{ns}
A*Ax*Rad	6	33.88	5.65	0.673	0.671663^{ns}
Error	93	780.38	8.39		
Total	116	987.28			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.2 Anatomical Properties

4.2.1 Fibre characterisation

4.2.1.1 Fibre length of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean fibre length of tapped rubber wood of all the ages was 1.47mm (Table 4.19). The mean fibre lengthvaried from 1.40mm to 1.52mm for the various age series with 5years of tapping having the lowest fibre length while 20years of tapping had the highest. The fibre length increased from 5years of tapping to 10years and then decreased slightly at 15years before increasing again at 20years of tapping with mean values of 1.41mm, 1.55mm, 1.47mm, 1.57mm for the top and 1.39mm, 1.44mm, 1.42mm, 1.47mm for the base respectively.

Table 4.20 also shows that the fibre length values along the bole was higher in the top than with a mean fibre length of 1.50mm than the base with mean fibre length of 1.43mm. The fibre length decreased from innerwood to middlewood and increased at the outerwood region at 5 and 10 years of tapping while it increased from innerwood to outerwood at 15 and 20 years of tapping. The mean fibre length across the bole was 1.46mm, 1.46mm and 1.48mm for the innerwood, middlewood and outerwood respectively (Table 4.20).

Result of analysis of variance for fibre length show the fibre length of tapped rubberwood was significantly affected by tapping age at 0.05 level of probability. Significant difference was also observed for the sampling height. However there was no significant difference in the values obtained across the bole as shown in Table 4.21.

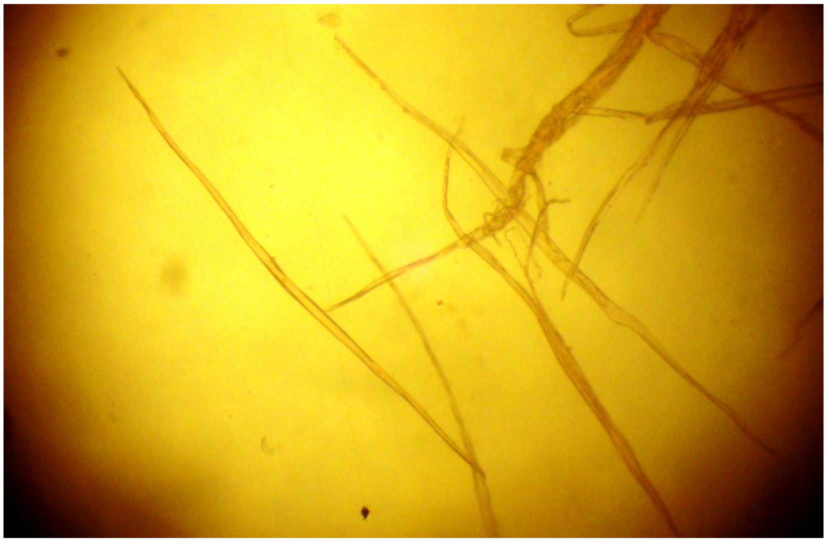


Plate 4.1: Fibres of macerated tapped *Heveabrasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria

Table 4.19: Fibre length of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner (mm)	Middle (mm)	Outer (mm)	Mean (mm)
5	Top	1.41±0.03	1.37±0.03	1.45±0.06	**1.41**±0.02
	Base	1.40±0.04	1.39±0.05	1.39±0.07	**1.39**±0.03
	Mean	**1.40**±0.02	**1.38**±0.03	**1.42**±0.04	**1.40**±0.02a
10	Top	1.51±0.03	1.53±0.03	1.61±0.05	**1.55**±0.02
	Base	1.50±0.06	1.40±0.06	1.41±0.03	**1.44**±0.03
	Mean	**1.50**±0.03	**1.47**±0.04	**1.51**±0.04	**1.49**±0.02bc
15	Top	1.45±0.06	1.50±0.06	1.48±0.05	**1.47**±0.03
	Base	1.41±0.06	1.39±0.04	1.45±0.07	**1.42**±0.03
	Mean	**1.43**±0.04	**1.45**±0.04	**1.46**±0.04	**1.45**±0.02ab
20	Top	1.51±0.06	1.58±0.05	1.61±0.07	**1.57**±0.03
	Base	1.46±0.04	1.48±0.03	1.46±0.05	**1.47**±0.02
	Mean	**1.49**±0.03	**1.53**±0.03	**1.54**±0.05	**1.52**±0.02c

Table 4.20: Effects of Age, Axial and Radial variation on fibre length of tapped *Hevea brasiliensis*

Sources	Mean Values (mm)
Tapping age (Years)	
5	1.40a
10	1.49bc
15	1.45ab
20	1.52c
Axial	
Base	1.43a
Top	1.51b
Radial	
Inner	1.46
Middle	1.46
Outer	1.48

Table 4.21: Analysis of variance (ANOVA) of fibre length of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	233638	77879	6.27	0.000635**
Axial (Ax)	1	151084	151084	12.17	0.000745**
Radial (Rad)	2	20565	10283	0.83	0.440059^{ns}
A*Ax	3	40185	13395	1.08	0.362046^{ns}
A*Rad	6	19610	3268	0.26	0.952618^{ns}
Ax*Rad	2	31746	15873	1.28	0.283340^{ns}
A*Ax*Rad	6	39833	6639	0.53	0.780622^{ns}
Error	93	1154737	12417		
Total	116	1703194			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.2.1.2 Lumen width of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The average lumen width as shown in Table 4.22 is 16.87µm for tapped rubber wood of all the age series. The mean lumen width is within a rangeof 16.02µm and 17.78µm for the various age series. The highest value of lumen width was observed at 20years of tapping(17.78µm) while 10 years of tapping had the least lumen width (16.02). Lumen width varied inconsistently across the age series as it decreased from 5years of tapping to 10years and it then increased to 20 years of tapping.

The lumen width values along the bole increased from base to top with a mean value of 17.46 µm for the topand 16.27µm for the base as shown in Table 4.23. The lumen width decreased from inner to middlewood and increasing towards the outer region at 5 and 15 years of tapping while it increased from innerwood to outerwood at 10 years of tapping. However, the lumen width decreased from innerwood to outer wood at 20 years of tapping. The lumen width decreased from innerwood to outerwood with general mean values of 16.96µm, 16.95µm and 16.69µm for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for lumen width show that tapping age and sampling height significantly affected the lumen width at 0.05 level of probability. However there was no significant difference in the lumen width across the bole as shown in Table 4.24.

Table 4.22: Lumen width of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(µm)	Middle(µm)	Outer(µm)	Mean(µm)
5	Top	19.02±0.47	18.50±0.57	16.89±0.41	**18.14**±0.37
	Base	16.66±1.24	16.05±0.57	15.82±0.31	**16.18**±0.44
	Mean	**17.84**±0.80	**17.28**±0.57	**16.36**±0.30	**17.16**±0.35a
10	Top	15.69±0.91	16.53±0.72	16.80±0.99	**16.34**±0.49
	Base	14.89±0.56	15.74±0.58	16.48±0.40	**15.70**±0.33
	Mean	**15.29**±0.52	**16.13**±0.45	**16.64**±0.51	**16.02**±0.30b
15	Top	17.74±1.22	17.13±1.01	16.91±0.43	**17.26**±0.51
	Base	15.30±0.79	15.78±0.79	16.25±0.59	**15.78**±0.40
	Mean	**16.52**±0.80	**16.45**±0.64	**16.58**±0.36	**16.52**±0.35ab
20	Top	18.36±0.73	18.31±0.73	17.69±1.09	**18.12**±0.47
	Base	18.04±0.86	17.60±0.80	16.68±0.93	**17.44**±0.49
	Mean	**18.20**±0.53	**17.96**±0.52	**17.18**±0.70	**17.78**±0.34ac

Table 4.23: Effects of Age, Axial and Radial variation on lumen width of tapped *Hevea brasiliensis*

Sources	Mean Values (µm)
Tapping age (Years)	
5	17.16a
10	16.02b
15	16.52ab
20	17.78ac
Axial	
Base	16.27a
Top	17.43b
Radial	
Inner	16.91
Middle	16.91
Outer	16.68

Table 4.24: Analysis of variance (ANOVA) of lumen width of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	52.47	17.49	5.69	0.001270**
Axial (Ax)	1	41.20	41.20	13.41	0.000416**
Radial (Rad)	2	1.86	0.93	0.30	0.740124^{ns}
A*Ax	3	8.76	2.92	0.95	0.419702^{ns}
A*Rad	6	23.48	3.91	1.27	0.277239^{ns}
Ax*Rad	2	2.73	1.36	0.44	0.643087^{ns}
A*Ax*Rad	6	5.04	0.84	0.27	0.948174^{ns}
Error	93	285.77	3.07		
Total	116	417.06			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.2.1.3 Fibre diameter of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Fibre diameter across the tapping age seriesranges from 25.02µm to 27.23µm as shown in Table 4.25. The fibre diameter was highest at 20years of tapping and least at 10 years of tapping with a mean value of 27.23µm 27.02µm respectively. The fibre diameter decreased from 5years of tapping to 10years and then increased to 20years of tapping with mean values of 27.05µm, 26.33µm, 26.39µm, 28.30µm for the top and 24.38µm, 23.70µm, 24.68µm, 26.17µm for the base respectively.

The fibre diameter values along the bole was higher in the top (27.02µm) than the base (24.73µm) of the wood (Table 4.26). The fibre diameter decreased from innerwood to outerwood at 5 years of tapping while it increased from inner to outer wood at 10 and 15 years of tapping. However, it increased from innerwood to middle wood and decreased at the outer wood at 20 years of tapping.The general mean values across the bole are 25.86µm, 25.94µm and 25.83µm for the innerwood, middlewood and outerwood respectively for all the ages.

Result of analysis of variance for fibre diameter show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. There was also significant difference along the bole but no significant difference was observed for fibre diameter across the bole as shown in Table 4.27.

Table 4.25: Fibre diameter of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	**Sampling height**	**Inner(µm)**	**Middle(µm)**	**Outer(µm)**	**Mean(µm)**
5	Top	27.72±0.67	27.49±0.58	25.97±0.80	**27.05**±0.43
	Base	25.13±1.19	24.04±0.62	23.98±0.26	**24.38**±0.44
	Mean	**26.42**±0.82	**25.75**±0.73	**24.97**±0.50	**25.72**±0.40a
10	Top	25.53±0.75	26.44±0.97	27.04±1.10	**26.33**±0.53
	Base	23.26±0.62	23.64±0.79	24.20±0.53	**23.70**±0.37
	Mean	**24.39**±0.59	**25.04**±0.75	**25.62**±0.74	**25.02**±0.40a
15	Top	26.40±1.14	26.49±1.11	26.28±0.48	**26.39**±0.51
	Base	24.18±0.66	24.30±0.83	25.58±0.55	**24.68**±0.41
	Mean	**25.29**±0.72	**25.39**±0.75	**25.93**±0.36	**25.54**±0.36a
20	Top	28.11±0.83	28.60±0.77	28.19±1.07	**28.30**±0.48
	Base	26.53±0.98	26.56±1.04	25.41±0.92	**26.17**±0.54
	Mean	**27.32**±0.66	**27.58**±0.70	**26.80**±0.81	**27.23**±0.41b

Table 4.26: Effects of Age, Axial and Radial variation on fibre diameter of tapped *Hevea brasiliensis*

Sources	Mean Values (µm)
Tapping age (Years)	
5	25.72a
10	25.02a
15	25.54a
20	27.23b
Axial	
Base	24.73a
Top	27.02b
Radial	
Inner	25.81
Middle	25.90
Outer	25.83

Table 4.27: Analysis of variance (ANOVA) of fibre diameter of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	81.59	27.20	7.81	0.000105**
Axial (Ax)	1	152.01	152.01	43.64	0.000000**
Radial (Rad)	2	0.27	0.13	0.04	0.962246^{ns}
A*Ax	3	4.61	1.54	0.44	0.723943^{ns}
A*Rad	6	22.10	3.68	1.06	0.393877^{ns}
Ax*Rad	2	1.61	0.80	0.23	0.794598^{ns}
A*Ax*Rad	6	6.93	1.16	0.33	0.918704^{ns}
Error	93	323.98	3.48		
Total	116	593.35			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.2.1.4 Cell wall thickness of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.28 shows the mean value for cell wall thickness for rubber wood of all the ages is 4.50µm. The mean values ranges from 4.28µm to 4.73µm for the various age series with 5years of tapping having the lowest mean value of 4.28 µm. The cell wall thickness increased progressively from 5years of tapping to 20years of tapping with mean values of 4.46µm, 5.00µm, 4.56µm, 5.09µm for the top and 4.10µm, 4.00µm, 4.45µm, 4.36µm for the base for 5, 10, 15 and twenty years of tapping respectively.

The cell wall thickness values along the bole was higher in the top than samples collected from the base of the wood with a mean value of 4.78µm for the top as compared to 4.23µm for the base. The cell wall thickness decreased from inner to middle wood and then increased at the outerwood at 5 and 10 years of tapping. However, it increased across the bole from innerwood to outer wood at 15 and 20 years of tapping. The cell wall thickness increased from innerwood to outerwood with general mean values of 4.45µm, 4.49µm and 4.57µm for the innerwood, middlewood and outerwood respectively as shown in Table 4.29.

Table 4.30 shows the result of analysis of variance for cell wall thickness. It shows that cell wall thickness was notsignificantly affected by tapping age and sampling height at 0.05 level of probability. However there was no significant difference in the values obtained across the bole.

Table 4.28: Cell wall thickness of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(μm)	Middle(μm)	Outer(μm)	Mean(μm)
5	Top	4.35±0.26	4.48±0.20	4.54±0.24	**4.46**±0.13
	Base	4.23±0.25	3.99±0.08	4.08±0.04	**4.10**±0.09
	Mean	**4.29**±0.17	**4.24**±0.12	**4.31**±0.13	**4.28**±0.08a
10	Top	4.92±0.13	4.96±0.19	5.12±0.11	**5.00**±0.08
	Base	4.19±0.23	3.95±0.13	3.86±0.16	**4.00**±0.10
	Mean	**4.55**±0.17	**4.45**±0.20	**4.49**±0.23	**4.50**±0.11b
15	Top	4.33±0.15	4.68±0.15	4.68±0.09	**4.56**±0.08
	Base	4.44±0.27	4.26±0.15	4.66±0.33	**4.45**±0.15
	Mean	**4.38**±0.15	**4.47**±0.12	**4.67**±0.16	**4.51**±0.08b
20	Top	4.88±0.07	5.14±0.10	5.25±0.40	**5.09**±0.14
	Base	4.24±0.27	4.48±0.20	4.37±0.21	**4.36**±0.12
	Mean	**4.56**±0.17	**4.81**±0.15	**4.81**±0.26	**4.73**±0.11b

Table 4.29: Effects of Age, Axial and Radial variation on cell wall thickness oftapped*Hevea brasiliensis*

Sources	**Mean Values (µm)**
Tapping age (Years)	
5	4.28a
10	4.50b
15	4.51b
20	4.73b
Axial	
Base	4.23a
Top	4.79b
Radial	
Inner	4.45
Middle	4.49
Outer	4.57

Table 4.30: Analysis of variance (ANOVA) of cell wall thickness of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	2.838	0.946	4.81	0.003688**
Axial (Ax)	1	8.733	8.733	44.42	0.000000**
Radial (Rad)	2	0.297	0.149	0.76	0.472703^{ns}
A*Ax	3	3.428	1.143	5.81	0.001100**
A*Rad	6	0.618	0.103	0.52	0.788736^{ns}
Ax*Rad	2	0.605	0.302	1.54	0.220362^{ns}
A*Ax*Rad	6	0.403	0.067	0.34	0.913178^{ns}
Error	93	18.285	0.197		
Total	116	35.697			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

Table 4.31: Anatomical properties of some timber species in Nigeria in comparison with the present study

Species	FL(mm)	LW(µm)	FD(µm)	CWT	Ref
Glirisidia sepium	1.14	12.18	21.78	4.91	Riki (2018)
Delonix regia	1.34	26.83	39.42	6.49	Riki (2018)
Senna siamea	1.29	11.46	20.71	4.95	Riki (2018)
R*hizophora racemosa*	1.76	18.92	36.09	8.58	Emerhi (2012)
R. harrisonii	1.54	17.55	34.25	9.45	Emerhi (2012)
Tectona grandis	1.73	15.6	29.47	7.89	Izekor and Fuwape (2011)
Rhicinodendron heudelotti	1.36	32.3	41.5	4.6	Ogunleye *et al.* (2016)
Triplochiton scleroxylon	1.35	12.5	20.3		Ogunsanwo (2000)
Gmelina arborea	1.28	20.06	26.46	3.83	Ogunkunle (2010)
Leucaena leucocephala	0.65	9.87	15.67	2.9	Oluwadare & Sotannde (2007)
Ficus spp	0.99-1.28	14.85-20.99	18.69-28.93	1.94-4.99	Ogunkunle (2010)
Pinus spp	2.34-4.23	40.78-47.62	54.22-62.08	6.01-9.5	Oluwadare (2007)
*Hevea brasiliensis**	1.4-1.52	16.02-17.78	25.02-27.23	4.28-4.73	

* present study

4.2.1.5 Slenderness ratio of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The slenderness ratio for rubber wood of all the ages is presented in Table 4.32. It shows that the average slenderness ratio of rubberwood is 56.86. The mean values ranges from 54.77 to 59.98 for the various age series with 10years of tapping having the highest mean value of 59.98.The slenderness ratio increased progressively from 5years of tapping to 10years of tapping and steadily declined till 20years of tapping with mean values of 52.34, 59.12, 55.97, 55.46 for the top and 57.21, 60.84, 57.56, 56.37 for the base at 5, 10, 15 and 20 years of tapping respectively.

The slenderness ratio values along the bole was higher in the base than samples collected from the top of the wood with a mean value of 55.72 and 57.99 for the top and base respectively. The slenderness ratio increased from innerwood to outerwood at 5 and 20 years of tapping. It decreased across the bole from innerwood to middlewood and increased in the outerwood at 10 years of tapping while the reverse was the case at 15 years of tapping. The slenderness ratio was least in the middlewood (56.34) and highest at the outerwood (57.54) as shown in Table 4.33.

Result of analysis of variance for slenderness ratio show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. It also showed that the sampling heights are not significantly difference. The same goes for the radial position showing there was no significant difference in the values obtained across the bole as shown in Table 4.34.

Table 4.32: Slenderness ratio of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	**Sampling height**	**Inner**	**Middle**	**Outer**	**Mean**
5	Top	50.79±1.17	50.10±2.07	56.12±3.86	**52.34**±1.59
	Base	55.89±1.82	57.64±2.11	58.10±2.90	**57.21**±1.27
	Mean	**53.34**±1.40	**53.87**±1.92	**57.11**±2.22	**54.77**±1.09a
10	top	59.35±2.27	58.11±1.89	59.89±1.59	**59.12**±1.05
	Base	64.55±3.25	59.42±1.31	58.53±1.80	**60.84**±1.41
	Mean	**61.95**±2.06	**58.77**±1.10	**59.21**±1.15	**59.98**±0.88b
15	Top	55.22±2.55	56.56±0.96	56.13±1.57	**55.97**±0.98
	Base	58.36±2.75	57.49±1.10	56.82±2.39	**57.56**±1.19
	Mean	**56.79**±1.84	**57.03**±0.71	**56.47**±1.35	**56.76**±0.77a
20	Top	53.74±0.70	55.32±1.15	57.30±1.89	**55.46**±0.82
	Base	55.54±2.78	56.11±2.69	57.47±1.51	**56.37**±1.30
	Mean	**54.64**±1.39	**55.72**±1.39	**57.38**±1.14	**55.91**±0.76a

Table 4.33: Effects of Age, Axial and Radial variation on slenderness ratio of tapped *Hevea brasiliensis*

Sources	Mean Values
Tapping age (Years)	
5	54.77a
10	59.98b
15	56.76a
20	55.91a
Axial	
Base	57.99a
Top	55.90b
Radial	
Inner	56.83
Middle	56.50
Outer	57.58

Table 4.34: Analysis of variance (ANOVA) of slenderness ratio of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	434.2	144.7	6.58	0.000441**
Axial (Ax)	1	150.4	150.4	6.84	0.010423*
Radial (Rad)	2	29.8	14.9	0.68	0.510811^{ns}
A*Ax	3	64.5	21.5	0.98	0.406640^{ns}
A*Rad	6	146.8	24.5	1.11	0.361117^{ns}
Ax*Rad	2	59.2	29.6	1.35	0.265253^{ns}
A*Ax*Rad	6	42.1	7.0	0.32	0.925468^{ns}
Error	93	2045.9	22.0		
Total	116	2923.9			

**: Highly significant (P<0.01)

*: Significant (P<0.05)

ns: Not significant (P>0.05)

4.2.1.6 Flexibility ratio of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.35 shows the mean value for flexibility ratio for rubber wood of all the ages is 65.13. The mean values ranges from 64.06 to 66.65 for the various age series with 5years of tapping having the highest mean value. The flexibility decreased from 5years of tapping to 10years of tapping and then increased till 20years of tapping. Mean values at 5, 10, 15 and 20 years of tapping were 67.03, 61.90, 65.25 and 63.95 for the top and 66.26, 66.21, 63.88 and 66.56 for the base respectively.

The cell flexibility ratio values along the bole was higher in the base than samples collected from the top of the wood with a mean value of 64.53 for the top as compared to 65.73 for the base as shown in Table 4.36. The flexibility ratio decreased across the bole from innerwood to outer wood at 5, 15 and 20 years of tapping while it increased from innerwood towards the outerwood at 10years of tapping. The flexibility ratio decreased as it progresses from innerwood to outerwood with mean values of 65.42, 65.32 and 64.65 for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for flexibility ratio show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. Significant difference was also observed for the sampling height. However there was no significant difference in the values obtained across the bole as shown in Table 4.37.

Table 4.35: Flexibility ratio of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	**Sampling height**	**Inner**	**Middle**	**Outer**	**Mean**
5	Top	68.65±1.42	67.34±1.31	65.11±1.04	**67.03**±0.80
	Base	66.09±2.31	66.71±0.84	65.98±0.64	**66.26**±0.79
	Mean	**67.37**±1.42	**67.03**±0.70	**65.54**±0.56	**66.65**±0.56a
10	Top	61.27±1.85	62.46±0.96	61.97±1.23	**61.90**±0.76
	Base	63.99±1.72	66.56±0.57	68.09±1.00	**66.21**±0.78
	Mean	**62.63**±1.27	**64.51**±0.86	**65.03**±1.26	**64.06**±0.67b
15	Top	66.91±2.00	64.50±1.37	64.34±0.71	**65.25**±0.84
	Base	63.23±2.31	64.81±1.37	63.59±2.18	**63.88**±1.08
	Mean	**65.07**±1.56	**64.66**±0.91	**63.97**±1.09	**64.56**±0.68b
20	Top	65.24±0.71	63.95±0.99	62.66±2.77	**63.95**±0.98
	Base	67.96±1.82	66.22±1.05	65.49±1.85	**66.56**±0.91
	Mean	**66.60**±1.02	**65.09**±0.78	**64.08**±1.64	**65.26**±0.70ab

Table 4.36: Effects of Age, Axial and Radial variation on flexibility ratio of tapped *Hevea brasiliensis*

Sources	Mean Values
Tapping age (Years)	
5	66.65a
10	64.06b
15	64.56b
20	65.26ab
Axial	
Base	65.73
Top	64.40
Radial	
Inner	65.33
Middle	65.27
Outer	64.64

Table 4.37: Analysis of variance (ANOVA) of flexibility ratio of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	105.8	35.3	2.99	0.034999*
Axial (Ax)	1	41.4	41.4	3.51	0.064110^{ns}
Radial (Rad)	2	13.4	6.7	0.57	0.569227^{ns}
A*Ax	3	163.1	54.4	4.61	0.004716**
A*Rad	6	74.6	12.4	1.05	0.395411^{ns}
Ax*Rad	2	31.0	15.5	1.31	0.274077^{ns}
A*Ax*Rad	6	19.1	3.2	0.27	0.949513^{ns}
Error	93	1096.8	11.8		
Total	116	1542.5			

**: Highly significant (P<0.01)

*: Significant (P<0.05)

ns: Not significant (P>0.05)

4.2.1.7 Runkel ratio of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Runkel ratio of tapped*Hevea brasiliensis* varies from 0.50 to 0.57 for the various age series with an average mean of 0.54 as shown in Table 4.38. The runkel ratio increased from 5years of tapping to 10years of tapping and then decreased till 20years of tapping.Themean values of 0.49, 0.62, 0.54 and 0.57 were obtained for the top and 0.51, 0.51, 0.57 and 0.51 for the base at 5, 10, 15 and 20 years of tapping respectively.

The runkel ratio values along the bole increased from base to top mean values of 0.55 for the top and 0.53 for the base as shown in Table 4.39. The runkel ratio across the bole increased from innerwood to outer wood at 5, 15 and 20 years of tapping while it decreased from innerwood towards the outerwood at 10years. The runkel ratio was highest at the outerwood and least at the innerwood with mean values of 0.54, 0.53 and 0.55 for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for runkel ratio show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. Significant difference was also observed for the sampling height. However there was no significant difference in the values obtained across the bole as shown in Table 4.40.

Table 4.38: Runkel ratio of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner	Middle	Outer	Mean
5	Top	0.46±0.03	0.49±0.03	0.54±0.02	**0.49**±0.02
	Base	0.52±0.06	0.50±0.02	0.52±0.02	**0.51**±0.02
	Mean	**0.49**±0.03	**0.49**±0.02	**0.53**±0.01	**0.50**±0.01a
10	Top	0.64±0.05	0.60±0.02	0.62±0.03	**0.62**±0.02
	Base	0.57±0.04	0.50±0.01	0.47±0.02	**0.51**±0.02
	Mean	**0.60**±0.03	**0.55**±0.02	**0.54**±0.03	**0.57**±0.02b
15	Top	0.50±0.05	0.55±0.03	0.55±0.02	**0.54**±0.02
	Base	0.59±0.06	0.55±0.03	0.58±0.06	**0.57**±0.03
	Mean	**0.55**±0.04	**0.55**±0.02	**0.57**±0.03	**0.55**±0.02b
20	Top	0.53±0.02	0.57±0.02	0.61±0.08	**0.57**±0.03
	Base	0.48±0.04	0.51±0.02	0.53±0.05	**0.51**±0.02
	Mean	**0.50**±0.02	**0.54**±0.02	**0.57**±0.04	**0.54**±0.02ab

Table 4.39: Effects of Age, Axial and Radial variation on runkel ratio of tapped *Hevea brasiliensis*

Sources	Mean Values
Tapping age (Years)	
5	0.50a
10	0.57b
15	0.55b
20	0.54ab
Axial	
Base	0.53
Top	0.56
Radial	
Inner	0.54
Middle	0.53
Outer	0.55

Table 4.40: Analysis of variance (ANOVA) of runkel ratio of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	0.06252	0.02084	2.827	0.042833*
Axial (Ax)	1	0.02359	0.02359	3.200	0.076914^{ns}
Radial (Rad)	2	0.00801	0.00401	0.543	0.582698^{ns}
A*Ax	3	0.09953	0.03318	4.500	0.005402**
A*Rad	6	0.04485	0.00748	1.014	0.421151^{ns}
Ax*Rad	2	0.01888	0.00944	1.280	0.282771^{ns}
A*Ax*Rad	6	0.00971	0.00162	0.219	0.969675^{ns}
Error	93	0.68565	0.00737		
Total	116	0.95151			

**: Highly significant (P<0.01)

*: Significant (P<0.05)

ns: Not significant (P>0.05)

4.2.1.8 Coefficient of rigidity of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.41 shows the mean value for coefficient of rigidity for rubber wood of all the ages is 17.43. The mean values ranges from 16.68 to 17.97 for the various age series with 10years of tapping having the highest mean value of 17.97. The coefficient of rigidity increased from 5years of tapping to 10years of tapping and decreased progressively till 20years of tapping. The mean values for the different tapping ages were 16.48, 19.05, 17.37 and 18.02 for the top and 16.87, 16.89, 18.06 and 16.72 for the base.

Table 4.42 also shows that the coefficient of rigidity values along the bole was higher in the top than samples collected from the base of the wood with a mean value of 17.73 for the top as compared to 17.14 for the base. The coefficient of rigidity across the bole increased from innerwood to outer wood at 5, 15 and 20 years of tapping while it decreased from innerwood towards the outerwood at 10years with general mean values of 17.29, 17.34 and 17.67 for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for coefficient of rigidity show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. Significant difference was also observed for the sampling height. However there was no significant difference in the values obtained across the bole as shown in Table 4.43.

Table 4.41: Coefficient of rigidity of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner	Middle	Outer	Mean
5	Top	15.68±0.71	16.33±0.66	17.45±0.52	**16.48**±0.40
	Base	16.95±1.16	16.64±0.42	17.01±0.32	**16.87**±0.39
	Mean	**16.32**±0.71	**16.49**±0.35	**17.23**±0.28	**16.68**±0.28a
10	Top	19.37±0.93	18.77±0.48	19.02±0.61	**19.05**±0.38
	Base	18.00±0.86	16.72±0.29	15.95±0.50	**16.89**±0.39
	Mean	**18.68**±0.64	**17.75**±0.43	**17.49**±0.63	**17.97**±0.33b
15	Top	16.54±0.10	17.75±0.68	17.83±0.35	**17.37**±0.42
	Base	18.39±1.15	17.59±0.68	18.20±1.09	**18.06**±0.54
	Mean	**17.47**±0.78	**17.67**±0.46	**18.02**±0.54	**17.72**±0.34b
20	Top	17.38±0.36	18.02±0.49	18.67±1.39	**18.02**±0.49
	Base	16.02±0.91	16.89±0.52	17.26±0.92	**16.72**±0.45
	Mean	**16.70**±0.51	**17.46**±0.39	**17.96**±0.82	**17.37**±0.35ab

Table 4.42: Effects of Age, Axial and Radial variation on coefficient of rigidity of tapped *Hevea brasiliensis*

Sources	Mean Values
Tapping age (Years)	
5	16.68a
10	17.97b
15	17.72b
20	17.37ab
Axial	
Base	17.14
Top	17.80
Radial	
Inner	17.33
Middle	17.37
Outer	17.68

Table 4.43: Analysis of variance (ANOVA) of coefficient of rigidity of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	26.44	8.81	2.99	0.034999*
Axial (Ax)	1	10.35	10.35	3.51	0.064110^{ns}
Radial (Rad)	2	3.34	1.67	0.57	0.569227^{ns}
A*Ax	3	40.79	13.60	4.61	0.004716**
A*Rad	6	18.66	3.11	1.05	0.395411^{ns}
Ax*Rad	2	7.74	3.87	1.31	0.274077^{ns}
A*Ax*Rad	6	4.78	0.80	0.27	0.949513^{ns}
Error	93	274.21	2.95		
Total	116	385.62			

**: Highly significant (P<0.01)

*: Significant (P<0.05)

ns: Not significant (P>0.05)

4.2.1.9 Luce’s shape factor of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean value for luce’s shape factor which is mostly related to paper density for rubber wood of all the ages is 0.40 is shown in Table 4.44. The mean values ranges from 0.39 to 0.42 for the various age series with 5years of tapping having the lowest mean luce’s shape factor. The luce’s shape factor across tapping ages increased from 5years of tapping to 10years of tapping and decreased till 20years of tapping.

The luce’s shape factor values along the bole was higher in the top than samples collected from the base of the wood with a mean value of 0.41 and 0.40 for the top and base respectively (Table 4.45). The luce’s shape factor across the bole increased from innerwood to outer wood at 5, 15 and 20 years of tapping while it decreased from innerwood towards the outerwood at 10years. The luce’s shape factor increased from innerwood to outerwood with mean values of 0.40, 0.40 and 0.41 for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for luce’s shape factor show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. Significant difference was also observed for the sampling height. However there was no significant difference in the values obtained across the bole as shown in Table 4.46.

Table 4.44: Luce's shape factor of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner	Middle	Outer	Mean
5	Top	0.36±0.02	0.38±0.02	0.40±0.01	**0.38**±0.01
	Base	0.39±0.030	0.38±0.01	0.39±0.01	**0.39**±0.01
	Mean	**0.38**±0.02	**0.38**±0.01	**0.40**±0.01	**0.39**±0.01a
10	Top	0.45±0.02	0.44±0.01	0.45±0.02	**0.45**±0.01
	Base	0.42±0.02	0.39±0.01	0.37±0.01	**0.39**±0.01
	Mean	**0.44**±0.02	**0.41**±0.01	**0.41**±0.02	**0.42**±0.01b
15	Top	0.38±0.03	0.41±0.02	0.41±0.01	**0.40**±0.01
	Base	0.43±0.03	0.41±0.02	0.42±0.03	**0.42**±0.01
	Mean	**0.41**±0.02	**0.41**±0.01	**0.42**±0.01	**0.41**±0.01b
20	Top	0.40±0.01	0.42±0.01	0.44±0.04	**0.42**±0.01
	Base	0.37±0.02	0.39±0.01	0.40±0.02	**0.39**±0.01
	Mean	**0.39**±0.01	**0.40**±0.01	**0.42**±0.02	**0.40**±0.01ab

Table 4.45: Effects of Age, Axial and Radial variation on luce shape factor of tapped *Hevea brasiliensis*

Sources	Mean Values
Tapping age (Years)	
5	0.39a
10	0.42b
15	0.41b
20	0.40ab
Axial	
Base	0.40
Top	0.41
Radial	
Inner	0.40
Middle	0.40
Outer	0.41

Table 4.46: Analysis of variance (ANOVA) of luce shape factor of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

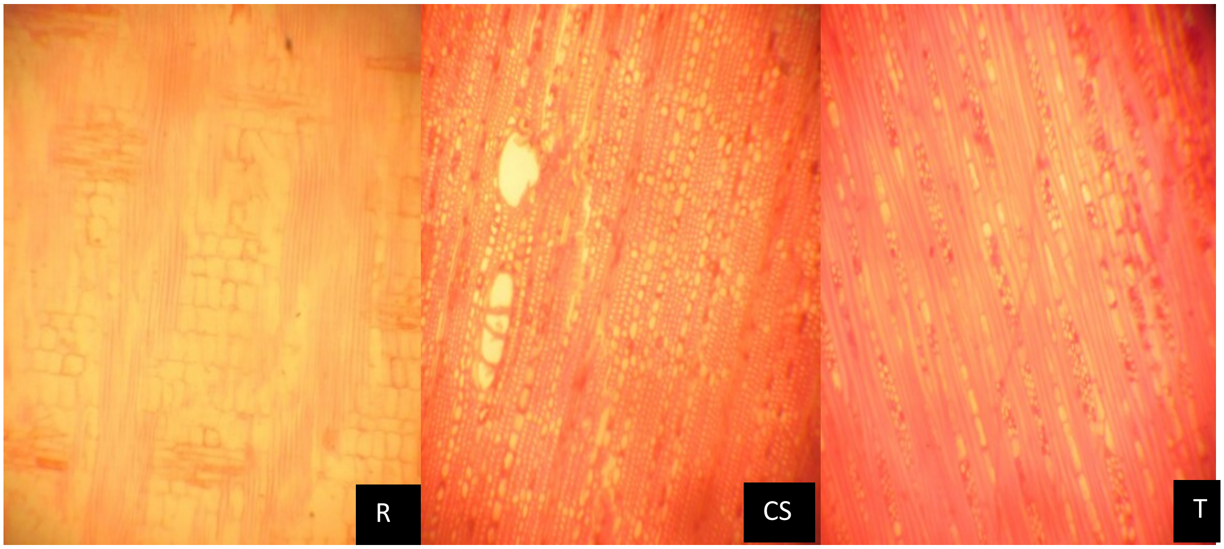
Sources of Variation	DF	SS	MS	F	p
Age (A)	3	0.01745	0.00582	2.985	0.035209*
Axial (Ax)	1	0.00683	0.00683	3.502	0.064424^{ns}
Radial (Rad)	2	0.00218	0.00109	0.560	0.573287^{ns}
A*Ax	3	0.02693	0.00898	4.605	0.004749**
A*Rad	6	0.01229	0.00205	1.050	0.398145^{ns}
Ax*Rad	2	0.00512	0.00256	1.314	0.273621^{ns}
A*Ax*Rad	6	0.00309	0.00052	0.264	0.952129^{ns}
Error	93	0.18128	0.00195		
Total	116	0.25472			

**: Highly significant (P<0.01)

*: Significant (P<0.05)

ns: Not significant (P>0.05)

4.2.2 Cell Quantification



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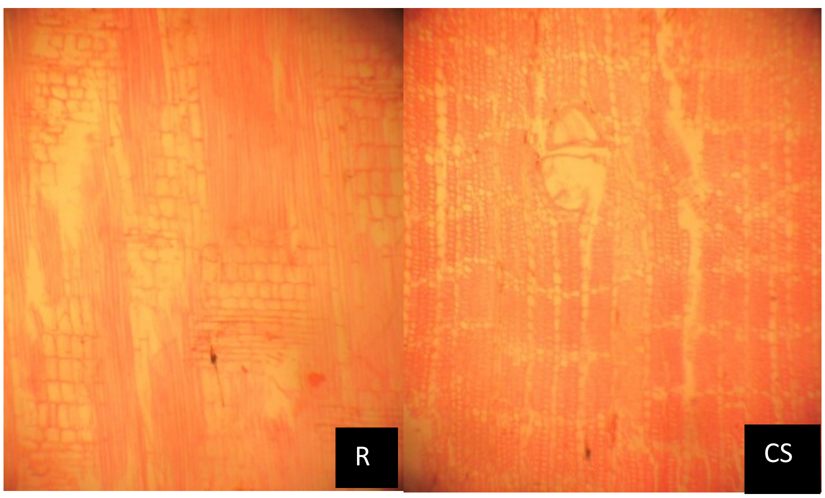
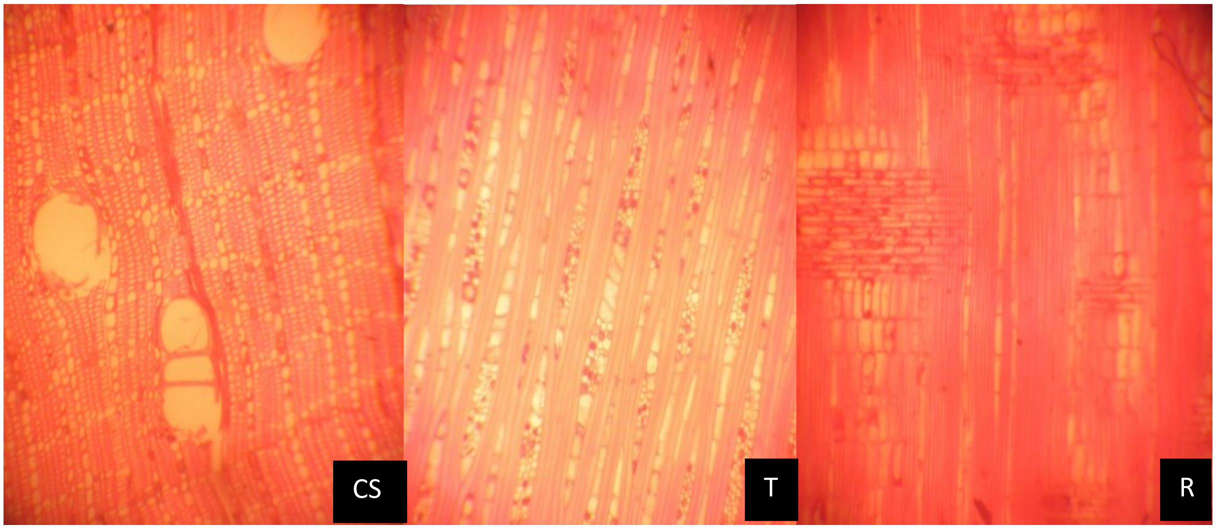


Top

Plate 4.2: photomicrographs of 5 years tapped rubber tree woodcollected from Agbarha rubber plantation, Delta State, Nigeria



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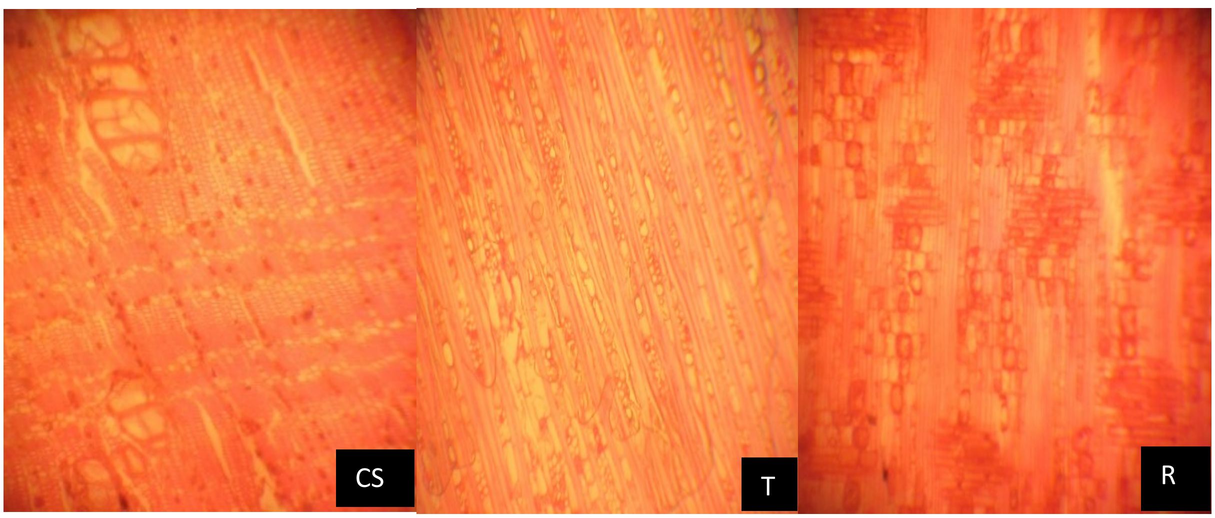
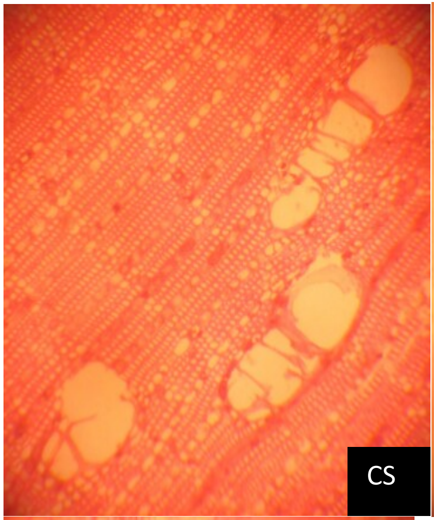


Top

Plate 4.3: photomicrographs of 10 years tapped rubber tree woodcollected from Agbarha rubber plantation, Delta State, Nigeria



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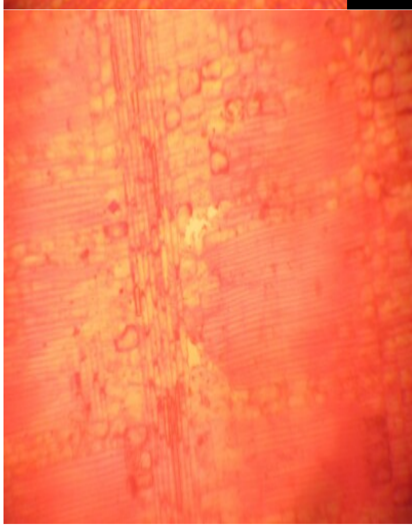

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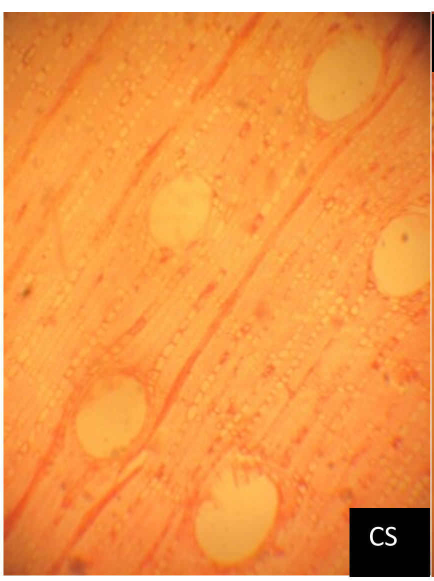

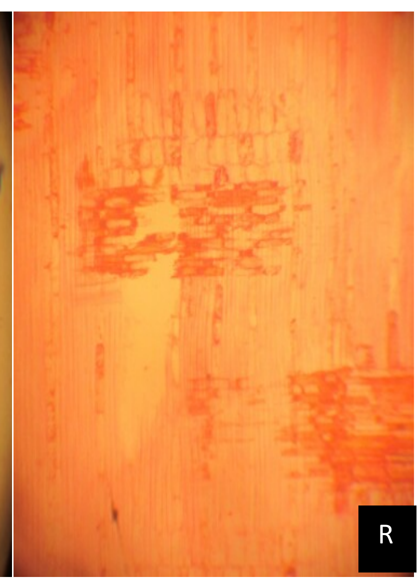

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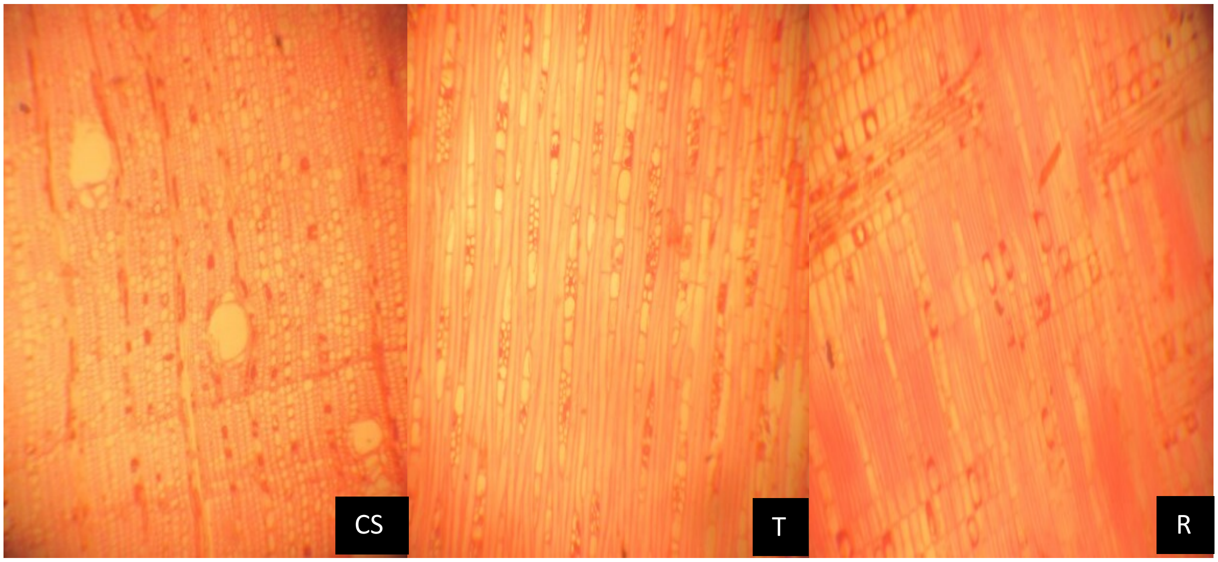
Plate 4.4: photomicrographs of 15 years tapped rubber tree woodcollected from Agbarha rubber plantation, Delta State, Nigeria



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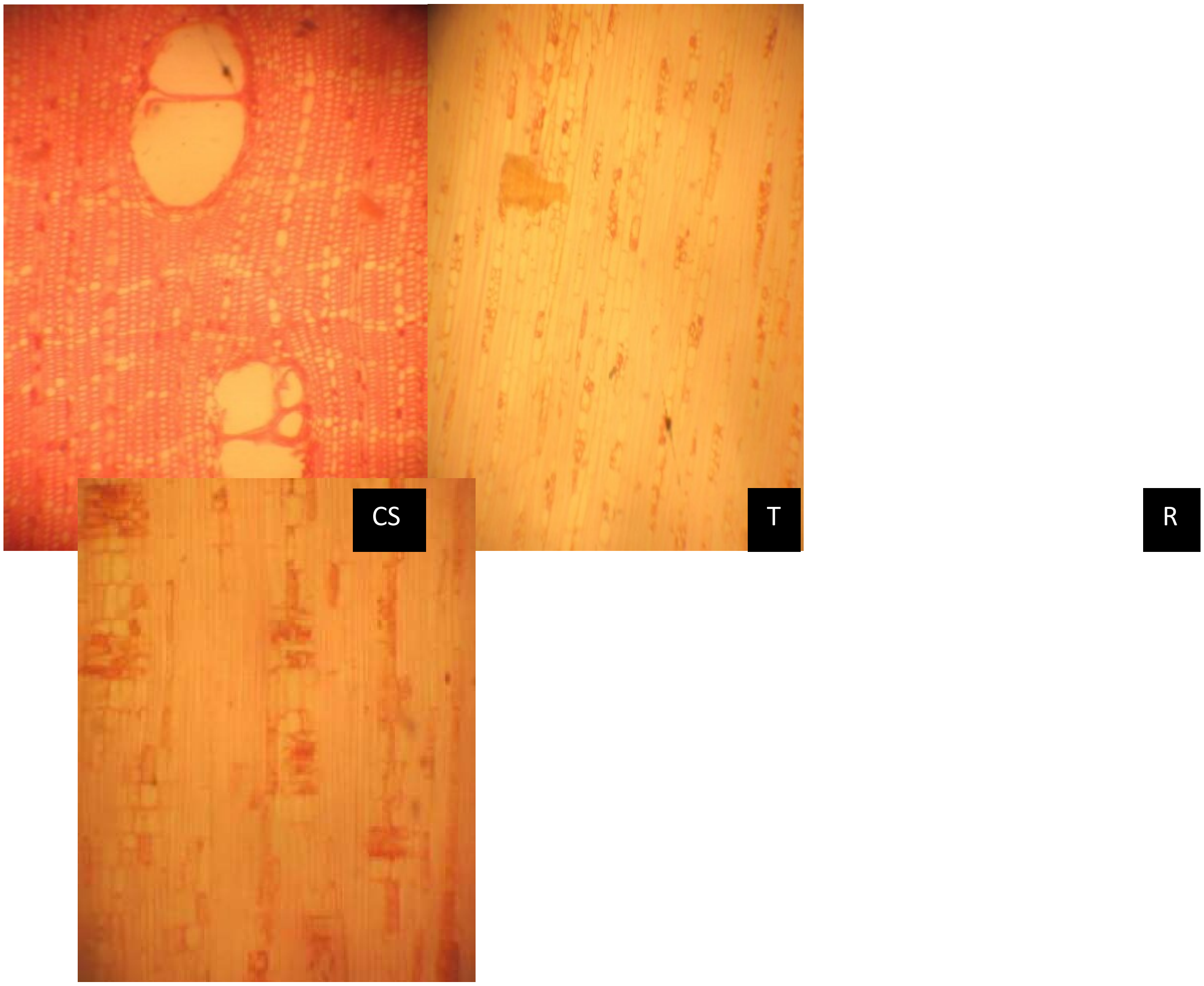

Top

Plate 4.5: photomicrographs of 20 years tapped rubber tree woodcollected from Agbarha rubber plantation, Delta State, Nigeria

4.2.2.1 Vessel counts of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean value for vessel count for rubber wood of all the ages is presented in Table 4.47. The mean values ranges from 2.28vessels/mm^2 to 3.25vessels/mm^2 for the various age series. The highest vessel count was observed at 10years of tapping. The vessel count increased from 5years of tapping to 10years of tapping and decreased progressively till 20years of tapping. The mean values for vessel count at 5, 10, 15 and 20years of tapping are 2.66vessels/mm^2, 2.98vessels/mm^2, 2.68vessels/mm^2 and 2.61vessels/mm^2 respectively.

The vessel count along the bole was higher in the top than samples collected from the base of the wood with a mean count of 2.82vessels/mm^2 for the top and 2.66vessels/mm^2 for the base (Table 4.48). The vessel count decreased across the bole from innerwood to outer wood for all the tapping age series with mean values of 2.89vessels/mm^2, 2.73vessels/mm^2 and 2.58vessels/mm^2 for innerwood, middlewood and outerwood respectively.

The result of analysis of variance shows that vessel count of rubberwood was significantly influenced by the tapping age at 0.05 level of probability. However, there was also no significant difference in the sampling height as well as across the radial position (Table 4.49)

Table 4.47: Vessel counts (vessels/mm^2) of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner	Middle	Outer	Mean

5	Top	3.25±0.23	2.93±0.17	2.28±0.27	**2.82**±0.17
	Base	2.48±0.31	2.59±0.09	2.55±0.37	**2.54**±0.15
	Mean	**2.87**±0.23	**2.76**±0.10	**2.42**±0.23	**2.66**±0.11a
10	Top	3.25±0.38	3.09±0.39	3.02±0.36	**3.11**±0.20
	Base	2.92±0.35	2.83±0.08	2.78±0.37	**2.84**±0.16
	Mean	**3.09**±0.25	**2.96**±0.19	**2.90**±0.25	**2.98**±0.13a
15	Top	2.87±0.18	2.72±0.24	2.38±0.21	**2.66**±0.13
	Base	3.05±0.38	2.38±0.23	2.67±0.30	**2.70**±0.18
	Mean	**2.96**±0.20	**2.55**±0.17	**2.53**±0.18	**2.68**±0.11a
20	Top	2.86±0.50	2.68±0.34	2.47±0.18	**2.67**±0.20
	Base	2.47±0.26	2.65±0.20	2.50±0.24	**2.54**±0.13
	Mean	**2.67**±0.27	**2.67**±0.18	**2.49**±0.14	**2.61**±0.12a

Table 4.48: Effects of Age, Axial and Radial variation on vessel count of tapped *Hevea brasiliensis*

Sources (vessels/mm^2)	**Mean**	**Values**

Tapping age (Years)	
5	2.66
10	2.98
15	2.68
20	2.61
Axial	
Base	2.66
Top	2.81
Radial	
Inner	2.88
Middle	2.73
Outer	2.59

Table 4.49: Analysis of variance (ANOVA) of vessel count of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of	DF	SS	MS	F	p

Variation					
Age (A)	3	2.5067	0.8356	1.941	0.128305^{ns}
Axial (Ax)	1	0.7401	0.7401	1.720	0.192983^{ns}
Radial (Rad)	2	1.9079	0.9539	2.216	0.114728^{ns}
A*Ax	3	0.5073	0.1691	0.393	0.758372^{ns}
A*Rad	6	0.7115	0.1186	0.276	0.947146^{ns}
Ax*Rad	2	0.9332	0.4666	1.084	0.342420^{ns}
A*Ax*Rad	6	1.1934	0.1989	0.462	0.834659^{ns}
Error	93	40.0271	0.4304		
Total	116	48.2280			

ns: Not significant (P>0.05)

4.2.2.2 Vessel diameter of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean values for vessel diameter for rubber wood of all the ages are presented in Table 4.50. The mean values ranges from 241.80µm to 318.50µm for the various age series with 10years of tapping having the highest mean value. The vessel diameter increased from 5years of tapping to 10years of tapping and decreased progressively till 20years of tapping. The mean values for vessel diameter at 5, 10, 15 and 20years of tapping are 260.60µm, 292.12µm, 262.66µm and 258.76µm respectively.

The vessel diameter values obtained from the top of the bole was higher than samples collected from the base of the wood with a mean value of 277.06µm for the top as compared to 260.75µm for the base as shown in Table 4.51. The vessel diameter value decreased across the bole from innerwood to outer wood at 5 and 10 years of tapping. It decreased from innerwood to middlewood and increased at the outerwood region at 15 years of tapping. The reverse was the case at 20 years of tapping. General mean values are 285.55µm, 268.34µm and 252.86µm for the innerwood, middlewood and outerwood respectively.

The result of analysis of variance shows that vessel count of rubberwood was significantly influenced by the tapping age at 0.05 level of probability. However, there was also no significant difference in the sampling height as well as across the radial position (Table 4.52)

Table 4.50: Vessel diameter of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(µm)	Middle(µm)	Outer(µm)	Mean(µm)
5	Top	318.50±22.19	286.65±16.68	220.73±25.51	**275.29**±16.73
	Base	242.80±30.50	253.82±8.54	249.90±36.47	**248.84**±14.96
	Mean	**280.65**±22.74	**270.24**±9.94	**235.32**±22.45	**260.60**±11.23a
10	Top	318.50±36.83	302.82±38.41	295.47±34.90	**305.60**±19.81
	Base	286.16±33.86	277.34±7.84	272.44±36.59	**278.65**±15.65
	Mean	**302.33**±24.19	**290.08**±18.96	**283.96**±24.14	**292.12**±12.65a
15	Top	284.72±15.84	256.01±18.17	241.80±19.05	**260.84**±10.61
	Base	298.90±36.86	233.24±22.65	261.67±29.78	**264.47**±17.73
	Mean	**291.81**±19.06	**244.63**±14.20	**251.74**±16.98	**262.66**±10.16a
20	Top	280.28±48.94	277.13±30.96	242.06±17.64	**266.49**±19.25
	Base	254.57±26.00	259.70±19.60	238.80±23.21	**251.03**±12.57
	Mean	**267.43**±26.45	**268.42**±17.51	**240.43**±13.75	**258.76**±11.38a

Table 4.51: Effects of Age, Axial and Radial variation on vessel diameter of tapped *Hevea brasiliensis*

Sources (µm)	Mean Values
Tapping age (Years)	
5	260.60
10	292.12
15	262.66
20	258.76
Axial	
Base	260.75
Top	277.15
Radial	
Inner	284.71
Middle	267.87
Outer	253.63

Table 4.52: Analysis of variance (ANOVA) of vessel diameter of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	21674	7225	1.792	0.154138^{ns}
Axial (Ax)	1	7738	7738	1.919	0.169263^{ns}
Radial (Rad)	2	20814	10407	2.581	0.081107^{ns}
A*Ax	3	4519	1506	0.374	0.772251^{ns}
A*Rad	6	9373	1562	0.387	0.885398^{ns}
Ax*Rad	2	7109	3554	0.882	0.417587^{ns}
A*Ax*Rad	6	9287	1548	0.384	0.887638^{ns}
Error	93	374979	4032		
Total	116	452668			

ns: Not significant (P>0.05)

4.2.2.3 Vessel length of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.53 shows the mean value for vessel length for rubber wood of all the ages. The mean values ranges from 414.43µm to 626.66µm for the various age series with 10years of tapping having the highest mean value. The vessel length of rubberwood for this study increased from 5years of tapping to 10years of tapping and decreased progressively till 20years of tapping. The mean values for vessel length at 5, 10, 15 and 20years of tapping are 538.44µm, 556.66µm, 534.17µm and 508.84µm

Table 4.54 shows that the vessel length values along the bole was higher in the top than samples collected from the base of the wood with a mean value of 572.04µm for the top as compared to 499.57µm for the base. The vessel length value increased across the bole from innerwood to outerwood with mean values of 538.22µm, 523.81µm and 545.38µm for the innerwood, middlewood and outerwood respectively.

Sampling height was observed to significantly influence the vessel length. However, the tapping age and radial position had no significant influence in the vessel length of *Hevea brasiliensis* at 0.05 level of probability (Table 4.55).

Table 4.53: Vessel length of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(µm)	Middle(µm)	Outer(µm)	Mean(µm)
5	Top	587.59±15.49	570.76±26.89	610.05±13.36	**589.47**±11.28
	Base	508.82±21.06	481.61±13.96	502.41±13.71	**497.61**±9.40
	Mean	**548.21**±18.83	**526.19**±20.49	**556.23**±20.96	**538.44**±11.42a
10	Top	568.84±32.96	603.68±45.42	626.66±52.80	**599.73**±24.61
	Base	504.46±53.89	496.92±50.39	539.39±40.81	**513.59**±26.48
	Mean	**536.65**±31.65	**550.30**±36.60	**583.03**±34.66	**556.66**±19.48a
15	Top	516.50±49.65	569.23±28.78	566.14±19.70	**550.62**±19.81
	Base	555.00±56.01	518.03±18.97	480.13±59.18	**517.72**±27.08
	Mean	**535.75**±35.86	**543.63**±18.35	**523.14**±32.71	**534.17**±16.76a
20	Top	580.25±59.25	535.78±22.82	528.95±18.86	**548.32**±21.33
	Base	484.31±25.72	414.43±66.11	509.34±36.51	**469.35**±26.86
	Mean	**532.28**±34.39	**475.11**±38.68	**519.15**±19.65	**508.84**±18.38a

Table 4.54: Effects of Age, Axial and Radial variation on vessel length of tapped *Hevea brasiliensis*

Sources	**Mean Values (µm)**
Tapping age (Years)	
5	538.44
10	556.66
15	534.17
20	508.84
Axial	
Base	499.57a
Top	571.12b
Radial	
Inner	536.95
Middle	522.60
Outer	543.73

Table 4.55: Analysis of variance (ANOVA) of vessel length of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	36527	12176	1.573	0.201146^{ns}
Axial (Ax)	1	152760	152760	19.737	0.000024**
Radial (Rad)	2	9371	4686	0.605	0.547992^{ns}
A*Ax	3	15957	5319	0.687	0.562086^{ns}
A*Rad	6	26559	4427	0.572	0.751740^{ns}
Ax*Rad	2	8641	4321	0.558	0.574129^{ns}
A*Ax*Rad	6	28841	4807	0.621	0.712970^{ns}
Error	93	719797	7740		
Total	116	994944			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.2.2.4 Ray width of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.56 shows the mean value for ray width for rubber wood of all the ages. The mean values ranges from 28.65µm to 49.29µm for the various age series with 5years of tapping having the highest mean value. The ray width of rubberwood decreased progressively as the years of tapping increased from 5years of tapping to 20years of tapping. The mean values for ray width at 5, 10, 15 and 20years of tapping are 43.88µm, 40.35µm, 39.77µm and 39.46µm respectively

The ray width values along the bole was higher in the top than samples collected from the base of the wood with a mean value of 36.19µm for the top as compared to 44.16µm for the base as shown in Table 4.57. The ray width across the bolewas highest (36.59µm) at the outerwood and least (43.34µm) at the middlewood

Sampling height was observed to significantly influence the ray width. However, the tapping age and radial position had no significant influence in the ray width of *Hevea brasiliensis* at 0.05 level of probability (Table 4.58).

Table 4.56: Ray width of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(µm)	Middle(µm)	Outer(µm)	Mean(µm)
5	Top	36.14±3.36	32.46±2.07	40.36±1.59	**38.32**±1.61
	Base	41.67±2.57	42.63±2.23	47.33±4.08	**43.88**±1.77
	Mean	**38.91**±2.16	**37.55**±2.30	**43.85**±2.56	**43.88**±1.40a
10	Top	34.26±3.52	31.95±1.66	38.22±4.51	**34.81**±1.96
	Base	44.29±3.61	44.10±2.38	49.29±1.94	**45.90**±1.60
	Mean	**39.28**±2.91	**38.03**±2.44	**43.76**±2.96	**40.35**±1.61a
15	Top	36.94±3.14	36.36±2.94	40.85±2.68	**38.05**±1.65
	Base	41.45±5.59	38.51±2.52	44.49±1.76	**41.49**±2.07
	Mean	**39.20**±3.12	**37.44**±1.86	**42.67**±1.63	**39.77**±1.34a
20	Top	35.57±2.96	28.65±1.71	36.46±2.74	**33.56**±1.64
	Base	48.34±6.30	38.02±3.12	49.73±5.26	**45.37**±3.05
	Mean	**41.96**±3.91	**33.34**±2.29	**43.10**±3.57	**39.46**±2.02a

Table 4.57: Effects of Age, Axial and Radial variation on ray width of tapped *Hevea brasiliensis*

Sources	Mean Values (µm)
Tapping age (Years)	
5	43.88
10	40.35
15	39.77
20	39.46
Axial	
Base	44.16a
Top	35.65b
Radial	
Inner	39.93a
Middle	36.69a
Outer	43.42b

Table 4.58: Analysis of variance (ANOVA) of ray width of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	13.4	4.5	0.080	0.970849^{ns}
Axial (Ax)	1	2087.9	2087.9	37.363	0.000000**
Radial (Rad)	2	885.6	442.8	7.924	0.000664**
A*Ax	3	330.6	110.2	1.972	0.123575^{ns}
A*Rad	6	197.3	32.9	0.588	0.738755^{ns}
Ax*Rad	2	1.3	0.7	0.012	0.988014^{ns}
A*Ax*Rad	6	59.0	9.8	0.176	0.982750^{ns}
Error	93	5197.0	55.9		
Total	116	8800.0			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.2.2.5 Ray height of tapped *Hevea brasiliensis* woodcollected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.59 shows the mean value for ray height for rubber wood of all the ages. The mean values ranges from 413.85µm to 581.14µm for the various age series with 10years of tapping having the highest mean value. The ray height increased from 5years of tapping to 10years of tapping and decreased as tapping continues till 20years of tapping. The mean values for ray height across tapping age are 529.72µm, 532.44µm, 524.47µm and 466.19µm for 5, 10, 15 and 20 years of tapping respectively.

The ray height along the bole was higher in the top than samples collected from the base of the wood with a mean value of 518.1µm for the top as compared to 507.67 µm for the base as shown in Table 4.60. The ray height value increased across the bole from innerwood to outerwood with mean values of 508.86µm, 518.37µm and 512.30µm for the innerwood, middlewood and outerwood respectively.

Tapping age was observed to significantly influence the ray height. However, the sampling height and radial position had no significant influence in the ray height of *Hevea brasiliensis* at 0.05 level of probability (Table 4.61).

Table 4.59: Ray height of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner(µm)	Middle(µm)	Outer(µm)	Mean(µm)
5	Top	534.66±35.66	519.65±24.93	487.33±24.98	**516.88**±16.63
	Base	551.70±30.02	552.33±10.81	515.97±23.83	**540.00**±13.10
	Mean	**543.18**±21.52	**535.99**±13.00	**501.65**±16.94	**529.72**±10.41a
10	Top	501.87±26.35	531.94±45.43	581.14±19.36	**538.32**±19.35
	Base	503.23±30.07	580.75±21.75	495.68±48.10	**526.55**±21.38
	Mean	**502.55**±18.84	**556.35**±25.10	**538.41**±28.29	**532.44**±14.21a
15	Top	512.38±114.03	507.93±24.26	536.64±17.37	**518.99**±10.72
	Base	538.21±20.76	544.00±14.85	507.64±44.28	**529.95**±16.34
	Mean	**525.30**±12.57	**525.97**±14.70	**522.14**±22.94	**524.47**±9.65a
20	Top	468.64±36.46	496.52±19.94	529.49±20.12	**498.22**±15.72
	Base	444.18±21.72	413.85±57.92	444.48±50.80	**434.17**±25.00
	Mean	**456.41**±20.41	**455.19**±32.00	**486.99**±29.40	**466.19**±15.68b

Table 4.60: Effects of Age, Axial and Radial variation on ray height of tapped *Hevea brasiliensis*

Sources	Mean Values (µm)
Tapping age (Years)	
5	529.72a
10	532.44a
15	524.47a
20	466.19b
Axial	
Base	507.67
Top	518.16
Radial	
Inner	507.07
Middle	518.34
Outer	512.94

Table 4.61: Analysis of variance (ANOVA) of ray height oftapped*Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	87321	29107	6.109	0.000771**
Axial (Ax)	1	3165	3165	0.664	0.417136^{ns}
Radial (Rad)	2	2112	1056	0.222	0.801634^{ns}
A*Ax	3	32483	10828	2.273	0.085242^{ns}
A*Rad	6	29396	4899	1.028	0.411976^{ns}
Ax*Rad	2	15331	7665	1.609	0.205621^{ns}
A*Ax*Rad	6	19585	3264	0.685	0.662034^{ns}
Error	93	443074	4764		
Total	116	635375			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.3 Mechanical Properties

4.3.1 Modulus of elasticity of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.62presents the mean value for Modulus of elasticity for rubber wood of 5, 10, 15 and 20 years of tapping. It shows that the averageModulus of elasticity is 13218.53Nmm^{-2} with ranges of 12459.67Nmm^{-2} to 14155.34Nmm^{-2} for the various age series. The highest mean was obtained at 20years of tapping (14155.34Nmm^{-2}) while 10 years of tapping have a mean value of 12459.67Nmm^{-2}.The Modulus of Elasticity for the different tapping age series decreased from 5years of tapping to 10years and then increased progressively to 20years of tapping. Starting from 5years of tapping the mean values are 15508.03Nmm^{-2}, 15773.00Nmm^{-2}, 15225.84Nmm^{-2}, 15653.35Nmm^{-2} for the top and 10162.59Nmm^{-2}, 9146.35Nmm^{-2}, 11621.74 Nmm^{-2},12657.32Nmm^{-2} for the base respectively.

The MOE values along the bole was generally higher in the top than samples collected from the base of the wood with a mean value of 15540.06Nmm^{-2} for the top as compared to 10897Nmm^{-2} for the base as shown in Table 4.63. The Modulus of Elasticity decreased across the bole from inner wood to outer wood at 5 and 15 years of tapping while it decreased from innerwood to middlewood and increased to innerwood at 10 and 20years of tapping with general mean values of 13801.11Nmm^{-2}, 12983.97Nmm^{-2} and 12879.50Nmm^{-2} for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for modulus of elasticity show that the values obtained with respect to the sampling heights are significantly different at 0.05 level of probability. However there was no significant difference in the values obtained across the bole and the various tapping age series as shown in Table 4.64.

Table 4.62: Modulus of elasticity (Nmm^{-2}) of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner	Middle	Outer	Mean
5	Top	16263.67±2202.43	16261.66±598.53	13998.76±1989.14	**15508.03**±967.87
	Base	10733.51±970.50	10620.76±537.46	9133.49±874.77	**10162.59**±477.56
	Mean	**13498.59**±1419.15	**13441.21**±1059.26	**11566.13**±1265.94	**12835.31**±718.82a
10	Top	16043.00±1952.05	15268.49±1112.59	16007.52±1020.05	**15773.00**±767.43
	Base	9515.45±1537.72	7942.576±752.02	9981.009±991.71	**9146.35**±653.50
	Mean	**12779.22**±1598.70	**11605.53**±1375.34	**12994.26**±1207.74	**12459.67**±789.82a
15	Top	16821.14±1202.30	15849.27±1533.31	13007.12±876.60	**15225.84**±788.55
	Base	12142.84±467.91	10577.3±786.02	12145.08±2516.12	**11621.74**±489.12
	Mean	**14481.99**±988.86	**13213.28**±1196.58	**12576.1**±687.59	**13423.79**±565.53a
20	Top	15047.38±2405.96	15900.64±1593.70	16012.03±800.20	**15653.35**±931.36
	Base	13841.94±1911.92	11451.07±1042.32	12678.95±948.38	**12657.32**±778.03
	Mean	**14444.66**±1462.55	**13675.86**±1164.39	**14345.49**±806.70	**14155.34**±657.93a

Table 4.63: Effects of Age, Axial and Radial variation on modulus of elasticity of tapped *Hevea brasiliensis*

Sources	Mean Values (Nmm^{-2})
Tapping age (Years)	
5	12835.21
10	12459.67
15	13423.79
20	14155.34
Axial	
Base	10897.00a
Top	15541.74b
Radial	
Inner	13737.97
Middle	12899.93
Outer	12841.57

Table 4.64: Analysis of variance (ANOVA) of modulus of elasticity of tapped *Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	4.88E+07	1.63E+07	1.95	0.127033^{ns}
Axial (Ax)	1	6.27E+08	6.27E+08	75.207	0.000000**
Radial (Rad)	2	2.00E+07	1.00E+07	1.199	0.306104^{ns}
A*Ax	3	6.12E+07	2.04E+07	2.447	0.068637^{ns}
A*Rad	6	3.53E+07	5.88E+06	0.705	0.646343^{ns}
Ax*Rad	2	1.79E+07	8.94E+06	1.072	0.346661^{ns}
A*Ax*Rad	6	2.66E+07	4.43E+06	0.531	0.783187^{ns}
Error	93	7.76E+08	8.34E+06		
Total	116	1.62E+09			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.3.2 Modulus of rupture of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The Modulus of rupture for rubber wood of all the ages is 429.94Nmm^{-2} as shown in Table 4.65. It ranges from 422.19Nmm^{-2} to 438.78Nmm^{-2} for the various age series with 10years of tapping having the highest value of 438.78Nmm^{-2} while 20years of tapping age series have a mean value of 425.70Nmm^{-2}. The Modulus of rupture for the different tapping age series increased from 5years of tapping to 10years and then decreased progressively to 20years of tapping. The mean values were 428.36Nmm^{-2}, 448.83Nmm^{-2}, 439.95Nmm^{-2}, 437.43Nmm^{-2} for the top and 416.01Nmm^{-2}, 428.73Nmm^{-2}, 426.24Nmm^{-2},413.97Nmm^{-2} for the base at 5, 10, 15 and 20 years of tapping respectively.

The MOR values along the bole was generally higher in the top than samples collected from the base of the wood with a mean value of 438.64Nmm^{-2} for the top as compared to 421.24Nmm^{-2} for the base (Table 4.66). The Modulus of rupture increased across the bole from inner wood to outer wood with mean values of 428.81Nmm^{-2}, 430.45Nmm^{-2} and 430.56Nmm^{-2} for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for modulus of rupture show that the values obtained with respect to the sampling heights are significantly different at 0.05 level of probability. Significant differences were also observed in the age series. However there was no significant difference in the values obtained across the bole as shown in Table 4.67

Table 4.65: Modulus of rupture (Nmm^{-2}) of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner	Middle	Outer	Mean
5	Top	426.04±3.76	430.20±3.82	428.85±9.51	**428.36**±3.33
	Base	414.45±7.45	410.67±7.63	422.91±3.23	**416.01**±3.70
	Mean	**420.24**±4.68	**420.44**±5.51	**425.88**±4.37	**422.19**±2.92a
10	Top	448.74±7.32	444.69±6.47	453.06±3.46	**448.83**±3.32
	Base	429.39±5.45	432.99±4.65	423.81±6.40	**428.73**±3.13
	Mean	**439.07**±5.38	**438.84**±4.23	**438.44**±5.96	**438.78**±2.92b
15	Top	440.01±7.81	437.13±8.95	442.71±7.10	**439.95**±4.31
	Base	427.68±2.19	426.87±2.89	424.17±7.22	**426.24**±2.52
	Mean	**433.85**±4.34	**432.00**±4.75	**433.44**±5.69	**433.10**±2.77b
20	Top	432.90±8.46	444.33±5.29	435.06±6.03	**437.43**±3.83
	Base	411.30±9.65	416.70±1.98	413.91±7.26	**413.97**±3.82
	Mean	**422.10**±7.04	**430.52**±5.31	**424.49**±5.68	**425.70**±3.44a

Table 4.66: Effects of Age, Axial and Radial variation on modulus of ruptureof tapped *Hevea brasiliensis*

Sources	Mean Values (Nmm^{-2})
Tapping age (Years)	
5	422.19a
10	438.78b
15	433.10b
20	425.70a
Axial	
Base	421.24a
Top	439.18b
Radial	
Inner	428.88
Middle	430.45
Outer	430.60

Table 4.67: Analysis of variance (ANOVA) of modulus of rupture oftapped*Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	4780	1593	7.9	0.000094**
Axial (Ax)	1	8813	8813	43.7	0.000000**
Radial (Rad)	2	74	37	0.2	0.832397^{ns}
A*Ax	3	601	200	1.0	0.399178^{ns}
A*Rad	6	508	85	0.4	0.864077^{ns}
Ax*Rad	2	31	15	0.1	0.926969^{ns}
A*Ax*Rad	6	715	119	0.6	0.737061^{ns}
Error	93	18753	202		
Total	116	34814			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.3.3 Maximum Compression Strength Parallel to grain oftapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.68 shows the mean value for Maximum Compression Strength Parallel to grain for rubber wood of all the ages is 74.91Nmm^{-2}. It ranges from 69.43Nmm^{-2} to 77.89Nmm^{-2} for the various age series with 15years of tapping having the highest mean value of 77.89Nmm^{-2}. The Maximum Compression Strength Parallel to grain increased from 5years of tapping until 15years of tapping and then slightly decreased at 20years of tapping with values of 76.88Nmm^{-2}, 83.55Nmm^{-2}, 84.46Nmm^{-2}, 84.86Nmm^{-2} for the top and 61.97Nmm^{-2}, 67.10Nmm^{-2}, 71.33Nmm^{-2}, 69.13Nmm^{-2} for the base at 5, 10, 15 and 20 years of tapping respectively.

Table 4.69 shows that the Maximum Compression Strength Parallel to grain values along the bole was higher in the top than the base of the wood with a mean value of 82.44Nmm^{-2} for the top and 67.38Nmm^{-2} for the base. The Maximum Compression Strength Parallel to grain increased across the bole from innerwood to middlewood and decreased towards the outer wood at 5, 15 and 20 years of tapping while the reverse was obtained at 10 years of tapping. Generally, it decreased across the bole with mean values are 75.30Nmm^{-2}, 75.12Nmm^{-2} and 74.31Nmm^{-2} for the innerwood, middlewood and outerwood respectively.

Result of analysis of variance for maximum compressive strength parallel to grain show that the values obtained with respect to the sampling heights are significantly different at 0.05 level of probability. Significant differences were also found in the age series. However there was no significant difference in the values obtained across the bole as shown in Table 4.70

Table 4.68: Maximum Compression Strength Parallel to grain (Nmm^{-2}) oftapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner	Middle	Outer	Mean
5	Top	74.91±1.81	75.81±2.63	79.93±1.72	**76.88**±1.26
	Base	62.37±4.10	64.16±2.59	59.35±0.92	**61.97**±1.61
	Mean	**68.64**±3.17	**70.00**±2.68	**69.64**±3.71	**69.43**±1.79a
10	Top	87.38±2.78	80.10±5.39	83.18±2.55	**83.55**±2.18
	Base	70.19±3.23	65.32±3.27	65.78±2.45	**67.10**±1.71
	Mean	**78.78**±3.50	**72.71**±3.86	**74.48**±3.34	**75.32**±2.05b
15	Top	85.50±2.92	85.52±3.71	82.36±0.53	**84.46**±1.52
	Base	71.45±1.15	72.75±4.08	69.79±4.36	**71.33**±1.90
	Mean	**78.47**±2.77	**79.13**±3.36	**76.06**±2.94	**77.89**±1.71b
20	Top	81.80±3.05	88.49±1.15	84.30±0.51	**84.86**±1.26
	Base	68.80±4.51	68.78±3.33	69.80±3.74	**69.13**±2.08
	Mean	**75.30**±3.36	**78.64**±3.68	**77.05**±3.00	**76.99**±1.89b

Table 4.69: Effects of Age, Axial and Radial variation on maximum compressive strength parallel to grain (Nmm^{-2}) of tapped *Hevea brasiliensis*

Sources	**Mean Values**
Tapping age (Years)	
5	69.43a
10	75.32b
15	77.89b
20	76.99b
Axial	
Base	67.38a
Top	82.73b
Radial	
Inner	75.31
Middle	75.10
Outer	74.16

Table 4.70: Analysis of variance (ANOVA) of maximum compressive strength parallel to grain of tapped*Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	1201.8	400.6	8.53	0.000046**
Axial (Ax)	1	6597.9	6597.9	140.47	0.000000**
Radial (Rad)	2	21.6	10.8	0.23	0.795226^{ns}
A*Ax	3	46.0	15.3	0.33	0.806383^{ns}
A*Rad	6	287.8	48.0	1.02	0.416605^{ns}
Ax*Rad	2	22.4	11.2	0.24	0.788539^{ns}
A*Ax*Rad	6	165.3	27.5	0.59	0.740288^{ns}
Error	93	4368.4	47.0		
Total	116	13006.8			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.4 Chemical Properties

4.4.1 Ash content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.71 shows the mean value for ash content for rubber wood. The average ash content was 0.32 with mean values ranging from 0.28 to 0.36.Across the tapping age, 5years of tapping had the lowest mean value of 0.28. The ash content varied inconsistently as it increased from 5years of tapping to 10years of tapping and decreased at 15years of tapping before increasing at 20years of tapping. The mean values across the ages were 0.25, 0.38, 0.30, 0.32 for the top and 0.31, 0.34, 0.31, 0.38 for the base respectively.

The ash content values increased along the bole from base to top with a mean value of 0.33 for the base and 0.31 for the top as shown in Table 4.72. The ash content value increased across the bole from innerwood to middlewood and decreased towards the outer wood at 5, 15 and 20 years of tapping while it increased steadily from innerwood to outerwood at 10 years of tapping. Generally mean values for the innerwood, middlewood and outerwood are 0.31, 0.35 and 0.31 respectively.

Result of analysis of variance for ash content show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. Significant difference was also observed for the sampling height and also radially (across the bole) as shown in Table 4.73.

Table 4.71: Ash content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner (%)	Middle (%)	Outer (%)	Mean (%)
5	Top	0.24±0.00	0.29±0.00	0.23±0.00	**0.25±0.01**
	Base	0.29±0.00	0.33±0.01	0.3±0.01	**0.31±0.00**
	Mean	**0.27**±0.01	**0.31**±0.01	**0.27**±0.01	**0.28±0.01**
10	Top	0.38±0.01	0.34±0.01	0.41±0.01	**0.38±0.01**
	Base	0.31±0.00	0.37±0.01	0.34±0.01	**0.34±0.01**
	Mean	**0.35**±0.01	**0.36**±0.01	**0.38**±0.02	**0.36±0.01**
15	Top	0.33±0.00	0.26±0.01	0.32±0.00	**0.30±0.01**
	Base	0.29±0.00	0.37±0.00	0.26±0.01	**0.31±0.01**
	Mean	**0.31**±0.01	**0.32**±0.02	**0.29**±0.02	**0.31±0.01**
20	Top	0.28±0.01	0.31±0.01	0.38±0.00	**0.32±0.01**
	Base	0.35±0.01	0.53±0.00	0.27±0.00	**0.38±0.03**
	Mean	**0.32**±0.01	**0.42**±0.04	**0.33**±0.02	**0.35±0.01**

Table 4.72: Effects of Age, Axial and Radial variation on ash content of tapped*Hevea brasiliensis*

Sources	Mean Values (%)
Tapping age (Years)	
5	0.28a
10	0.36b
15	0.31c
20	0.35b
Axial	
Base	0.33
Top	0.31
Radial	
Inner	0.31a
Middle	0.35b
Outer	0.31a

Table 4.73: Analysis of variance (ANOVA) of ash content of tapped*Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	0.09116	0.03039	35.85	0.000000**
Axial (Ax)	1	0.01647	0.01647	19.43	0.000028**
Radial (Rad)	2	0.04248	0.02124	25.05	0.000000**
A*Ax	3	0.03370	0.01123	13.25	0.000000**
A*Rad	6	0.03439	0.00573	6.76	0.000006**
Ax*Rad	2	0.09753	0.04877	57.53	0.000000**
A*Ax*Rad	6	0.08887	0.01481	17.47	0.000000**
Error	93	0.07883	0.00085		
Total	116	0.48301			

**: Highly significant (P<0.01)

4.4.2 Lignin content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean value for lignin content for rubber wood of all the ages is 22.52 % (Table 4.74). The mean values ranges from 21.36% to 23.78% for the various age series with 10years of tapping having the lowest mean value of 21.36%. The lignin content also varied inconsistently across the tapping ages as it decreased from 5years of tapping to 10years of tapping. It later increased at 15years of tapping and decreased at 20years of tapping with mean values of 24.76%, 22.33%, 21.30%, 22.75% for the top and 20.62%, 20.39%, 26.26%, 22.24% for the base at 5, 10, 15 and 20 years of tapping respectively.

The lignin content values along the bole was higher in the top than the base of the wood with a mean value of 22.78 % (top) and 22.25 % (base) as shown in Table 4.75. The lignin content increased progressively across the bole from innerwood to outer wood at 5, 10 and 20 years of tapping while it decreased from innerwood to outerwood and increased towards the outerwood at 15 years of tapping. Generallymean values across the bole are 20.45% (innerwood), 22.19% (middlewood) and 24.92 % (outerwood).

Result of analysis of variance for lignin content show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. Significant difference was also observed for the sampling height and also radially (across the bole) as shown in Table 4.76

Table 4.74: Lignin content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner (%)	Middle (%)	Outer (%)	Mean (%)
5	Top	20.37±0.41	26.30±0.54	27.60±0.92	**24.76±0.91**
	Base	19.85±0.46	18.74±0.12	23.27±0.98	**20.62±0.62**
	Mean	**20.11**±0.34	**22.52**±1.37	**25.44**±1.04	**22.69±0.66**
10	Top	18.91±0.57	24.33±0.72	23.75±0.85	**22.33±0.75**
	Base	19.74±0.53	19.20±0.45	22 .24±0.67	**20.39±0.46**
	Mean	**19.33**±0.40	**21.77**±1.00	**23.00**±0.68	**21.36±0.47**
15	Top	18.80±0.67	20.34±0.48	24.75±1.09	**21.30±0.80**
	Base	26.10±0.67	23.39±0.61	29.30±0.87	**26.26±0.75**
	Mean	**22.45**±1.20	**21.87**±0.66	**27.03**±0.93	**23.78±0.71**
20	Top	21.51±1.06	19.60±1.08	27.15±1.34	**22.75±1.06**
	Base	18.30±1.67	25.60±0.59	21.30±1.35	**21.73±0.99**
	Mean	**19.91**±0.85	**22.60**±1.06	**24.23**±1.22	**22.24±0.72**

Table 4.75: Effects of Age, Axial and Radial variation on lignin content of tapped*Hevea brasiliensis*

Sources	Mean Values(%)
Tapping age (Years)	
5	22.69a
10	21.36a
15	23.78b
20	22.24a
Axial	
Base	22.25
Top	22.75
Radial	
Inner	20.36a
Middle	22.30b
Outer	24.82c

Table 4.76: Analysis of variance (ANOVA) of lignin content of tapped*Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	118.85	39.62	10.45	0.000005**
Axial (Ax)	1	10.26	10.26	2.70	0.103436^{ns}
Radial (Rad)	2	397.94	198.97	52.46	0.000000**
A*Ax	3	284.46	94.82	25.00	0.000000**
A*Rad	6	66.13	11.02	2.91	0.012140*
Ax*Rad	2	51.30	25.65	6.76	0.001810**
A*Ax*Rad	6	219.56	36.59	9.65	0.000000**
Error	93	352.70	3.79		
Total	116	1485.27			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.4.3 Holocellulose content of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Table 4.77 shows the mean value for holocellulose content for rubber wood of all the ages is 60.94%. The mean values ranges from 59.30% to 63.86% for the various age series with 15years of tapping having the lowest mean value of 59.30 %. There was also an inconsistent variation across the years of tapping as holocellulose content increased from 5years of tapping to 10years of tapping and decreased at 15years of tapping before it increased slightly at 20years of tapping. Mean values of 5, 10, 15 and 20 years of tapping are 61.08%, 64.95%, 58.96%, 57.23% for the top and 61.26%, 62.77%, 59.64%, 61.66% for the base respectively.

The holocellulose content along the bole was lower in the top than the base of the wood with a mean value of 60.56 % for the top and 61.33 % for the base as shown in Table 4.78. The holocellulose content varied inconsistently across the bole as it decreased from innerwood to middlewood and later increased at the outer wood portion at 5, 15 and 20 years of tapping while the reverse was noticed at 10years of tapping.The holocellulose contentwas 60.99%, 59.15% and 62.94% for innerwood, middlewood and outerwood respectively.

Result of analysis of variance for holocellulose content show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. Significant difference was also observed for the sampling height and also radially (across the bole) as shown in Table 4.79.

Table 4.77: Holocellulose content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Tapping	Sampling height	Inner (%)	Middle (%)	Outer (%)	Mean (%)
5	Top	60.96±1.86	60.75±2.00	61.53±1.26	**61.08±0.93**
	Base	58.56±1.23	64.51±0.91	60.70±1.76	**61.26±0.98**
	Mean	**59.76**±1.12	**62.63**±1.31	**61.12**±1.15	**61.17±0.66**
10	Top	65.80±1.31	61.55±1.19	67.50±1.88	**64.95±1.04**
	Base	63.20±1.71	62.37±1.71	62.73±1.38	**62.77±0.87**
	Mean	**64.50**±1.45	**61.96**±1.05	**65.12**±1.37	**63.86±0.69**
15	Top	54.73±0.81	59.34±1.56	62.80±1.46	**58.96±1.13**
	Base	61.27±1.08	51.37±1.22	66.27±1.70	**59.64±1.81**
	Mean	**58.00**±1.34	**55.36**±1.74	**64.54**±1,21	**59.30±1.05**
20	Top	61.57±2.18	50.83±1.92	59.30±1.69	**57.23±1.61**
	Base	61.80±1.72	62.50±1.25	60.68±2.20	**61.66±0.96**
	Mean	**61.69**±1.52	**56.67**±1.87	**59.99**±1.33	**59.45±1.01**

Table 4.78: Effects of Age, Axial and Radial variation on holocellulose content of tapped *Hevea brasiliensis*

Sources	Mean Values (%)
Tapping age (Years)	
5	61.17a
10	63.86b
15	59.30a
20	59.45a
Axial	
Base	61.32
Top	60.81
Radial	
Inner	60.99a
Middle	59.49a
Outer	62.74b

Table 4.79: Analysis of variance (ANOVA) of holocellulose content of tapped*Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	DF	SS	MS	F	p
Age (A)	3	261.1	87.0	5.80	0.001111**
Axial (Ax)	1	7.1	7.1	0.47	0.494251^{ns}
Radial (Rad)	2	201.6	100.8	6.72	0.001877**
A*Ax	3	137.5	45.8	3.06	0.032252*
A*Rad	6	320.6	53.4	3.56	0.003207**
Ax*Rad	2	12.7	6.3	0.42	0.656394^{ns}
A*Ax*Rad	6	465.0	77.5	5.17	0.000127**
Error	93	1395.0	15.0		
Total	116	2822.3			

**: Highly significant (P<0.01)

*: Significant (P<0.05)

ns: Not significant (P>0.05)

4.4.4 Alpha cellulose content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The Alpha cellulose content of tapped rubberwood which is the purest form of celluloseis 40.84 % as shown in Table 4.80. The mean values ranges from 37.33% to 45% for the various age series with 20years of tapping having the lowest alpha cellulose content. The alpha cellulose content decreased progressively from 5years of tapping to 20years of tapping with mean values of 44.94%, 43.86%, 38.17%, 36.56 % for the top and 45%, 38.8%, 41.23%, 38.1% for the base of 5, 10, 15 and 20 years of tapped rubberwood respectively.

The mean value of the alpha cellulose content along the bole decreased from base to top with a mean value of 40.47 for the top and 40.78 for the base (Table 4.81). The alpha cellulose content across the bole decreased slightly from innerwood to middlewood and increased at the outer wood portion at 5 and 15 years of tapping however the opposite was observed at 10 and 20 years of tapping.The alpha cellulose content was 39.80%, 39.40% and 43.31% for innerwood, middlewood and outerwood respectively.

Result of analysis of variance for alpha cellulose content show that the values obtained with respect to the age series of tapping are significantly different at 0.05 level of probability. Significant difference was also observed for the sampling height and also radially (across the bole) as shown in Table 4.82

Table 4.80: Alpha cellulose content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Years of Taping	**Sampling height**	**Inner (%)**	**Middle (%)**	**Outer (%)**	**Mean (%)**
5	Top	47.23±1.68	45.71±1.72	41.98±1.60	**44.97±1.07**
	Base	40.51±1.42	49.21±2.15	45.27±1.40	**45.00±1.31**
	Mean	**43.87**±1.32	**47.46**±1.58	**43.63**±1.03	**45.00±0.83**
10	Top	43.44±1.45	39.75±1.36	48.39±2.26	**43.86±1.33**
	Base	38.94±1.61	36.62±1.39	40.83±1.45	**38.80±0.92**
	Mean	**41.19**±1.71	**38.19**±1.48	**44.61**±1.92	**41.33±0.92**
15	Top	32.63±1.88	40.38±1.44	41.50±1.23	**38.17±1.34**
	Base	41.07±1.35	30.57±0.67	52.04±1.55	**41.23±2.44**
	Mean	**34.35**±1.53	**35.48**±1.90	**46.77**±1.90	**39.56±1.39**
20	Top	38.89±1.31	31.73±1.26	39.07±1.40	**36.56±1.16**
	Base	35.69±0.95	41.20±2.26	37.41±1.41	**38.10±1.07**
	Mean	**37.29**±1.32	**36.47**±1.84	**38.24**±0.98	**37.33±0.79**

Table 4.81: Effects of Age, Axial and Radial variation on alpha cellulose content of tapped *Hevea brasiliensis*

Sources	Mean Values (%)
Tapping age (Years)	
5	45.00a
10	41.33b
15	39.56b
20	37.33c
Axial	
Base	40.78
Top	41.15
Radial	
Inner	39.83a
Middle	39.65a
Outer	43.40b

Table 4.82: Analysis of variance (ANOVA) of alpha cellulose content of tapped*Hevea brasiliensis*collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Sources of Variation	**DF**	**SS**	**MS**	**F**	**p**
Age (A)	3	851.3	283.8	18.90	0.000000**
Axial (Ax)	1	8.6	8.6	0.57	0.450505^{ns}
Radial (Rad)	2	318.6	159.3	10.61	0.000071**
A*Ax	3	288.0	96.0	6.39	0.000549**
Age*Rad	6	556.3	92.7	6.18	0.000018**
Ax*Rad	2	40.3	20.1	1.34	0.266309^{ns}
A*Ax*Rad	6	851.3	141.9	9.45	0.000000**
Error	93	1396.0	15.0		
Total	116	4362.9			

**: Highly significant (P<0.01)

ns: Not significant (P>0.05)

4.4.5 FTIR spectroscopy of tapped*Hevea brasiliensis* woodcollected from Agbarha rubber plantation, Delta State, Nigeria

The infrared spectra of various ages of tapping of *Hevea brasiliensis* wood with axial and radial variation using Fourier transform infrared (FTIR) spectroscopy is shown in figure 4.1 – 4.9. While the summary of infrared bands observed in *H. brasiliensis* wood with their peak assignments and structural polymers is presented in Table 4.83. For clarity, the spectra at 4000-600 cm^{-1} were considered. The fingerprints show the position of most bands and their intensities thus indicating different bonds such as 3410 cm^{-1} O-H stretch in lignin, 2848 cm^{-1} C-H stretching in lignin, 1724 cm^{-1} and 1632 cm^{-1} C=O in hemicellulose and lignin respectively, 1430 cm^{-1} C-H aromatic ring stretch in lignin, 1375 cm^{-1} C-H bending in cellulose, hemicellulose and lignin, 1230 cm^{-1} C-C + C-O stretch in lignin, 1030 cm^{-1} C-O, C=C and C-C-O in cellulose, hemicellulose and lignin obtained from the wood. The positions of most bands and their intensities in the fingerprint region are similar both along the longitudinal and across the radial direction of *H. brasiliensis* as well as the various tapping ages under consideration with few exceptions. The peak intensity depicts the level of concentration of each of the functional groups representing a macromolecule, for example lignin at 1230, 1430 and 1632, 2848, 2910, 3410, 3750 cm^{-1}.

Table 4.83:Summary of infrared spectra bands observed in tapped*Hevea brasiliensis* woodcollected from Agbarha rubber plantation, Delta State, Nigeria

Frequency (cm^{-1})	Functional group	Polymer
3750	O - H stretching	Lignin
3410	O - H stretching	Lignin
2910	C -H stretching	Lignin
2848	C - H stretching	Lignin
2340	P – H	
1724	ketone/aldehyde C = O	Hemicellulose
1632	C = O stretching	Lignin
1430	C - H with aromatic ring stretch	Lignin
1375	C - H bending	Cellulose, Hemicellulose and Lignin
1230	C - C + C - O stretch	Lignin
1030	C - O, C = C and C - C - O stretch	Cellulose, Hemicellulose and Lignin
605.87	C - H bending	Cellulose, Hemicellulose and Lignin

Polymer and functional groups adapted from Xu *et al.* (2013)

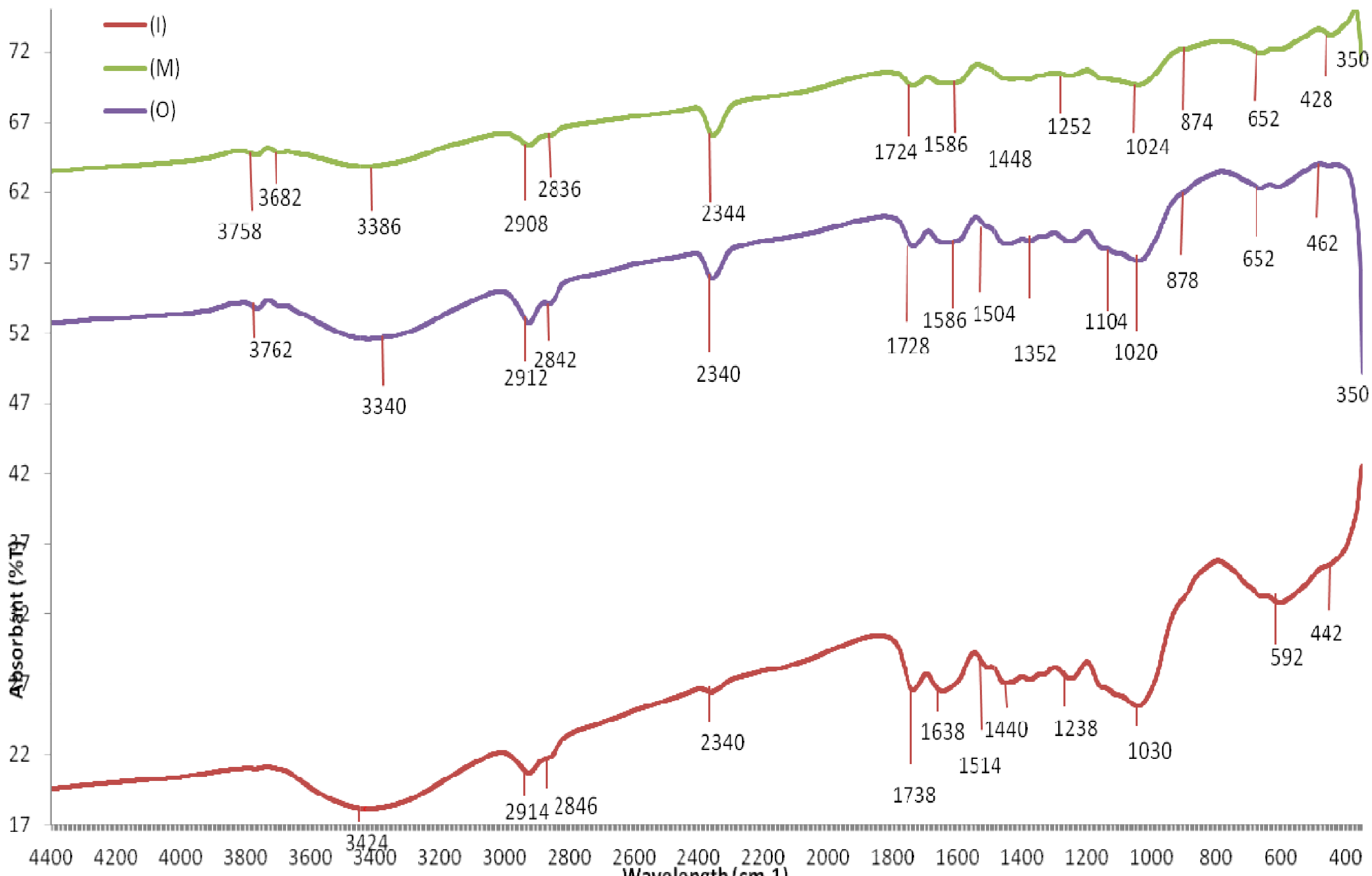

Figure 4.1: FTIR spectra of 5years base wood of tapped *Hevea brasilensis*collected from Agbarha rubber plantation, Delta State, Nigeria

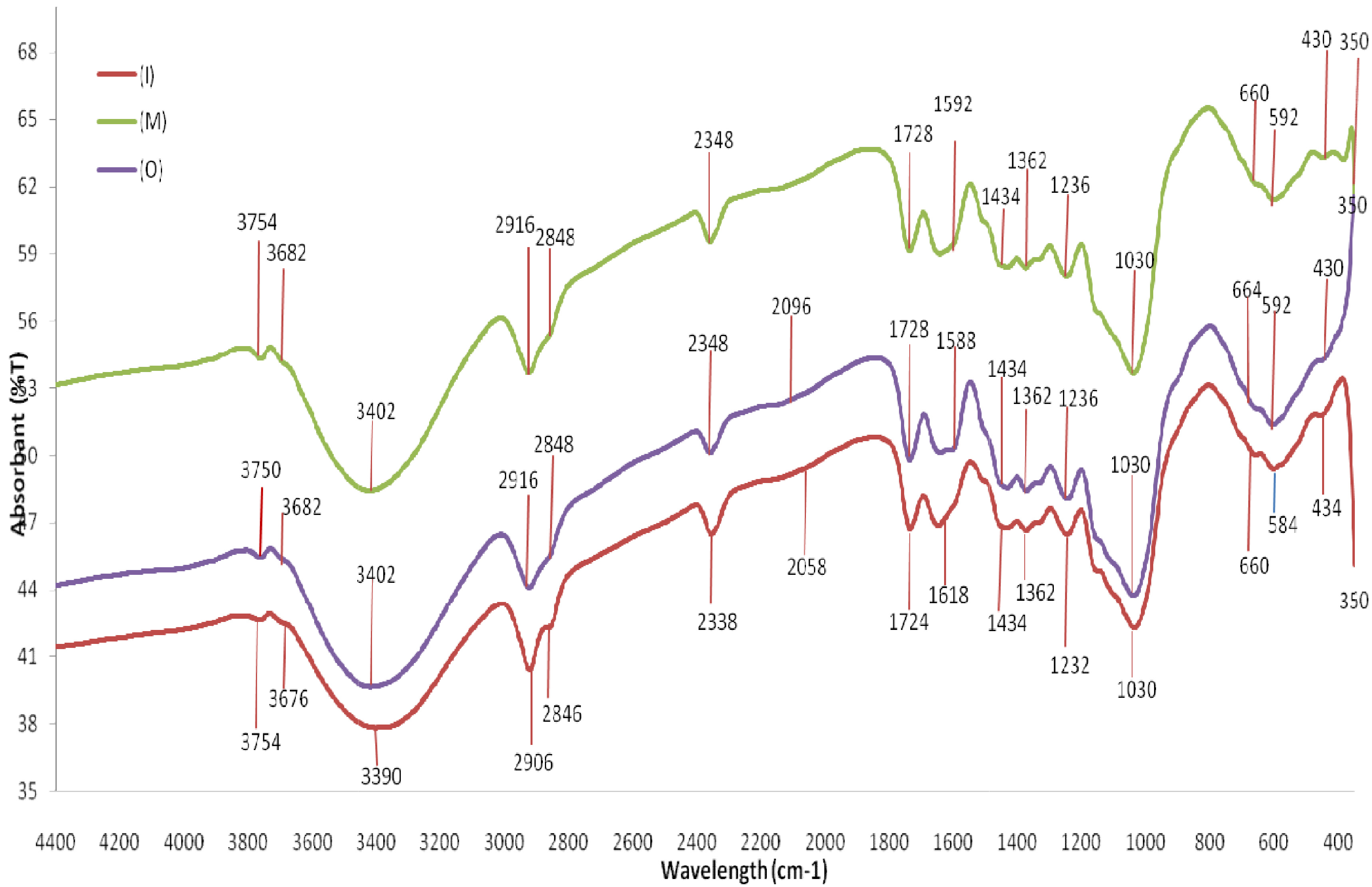

Figure 4.2: FTIR spectra of 5years top wood of tapped *Hevea brasilensis*collected from Agbarha rubber plantation, Delta State, Nigeria

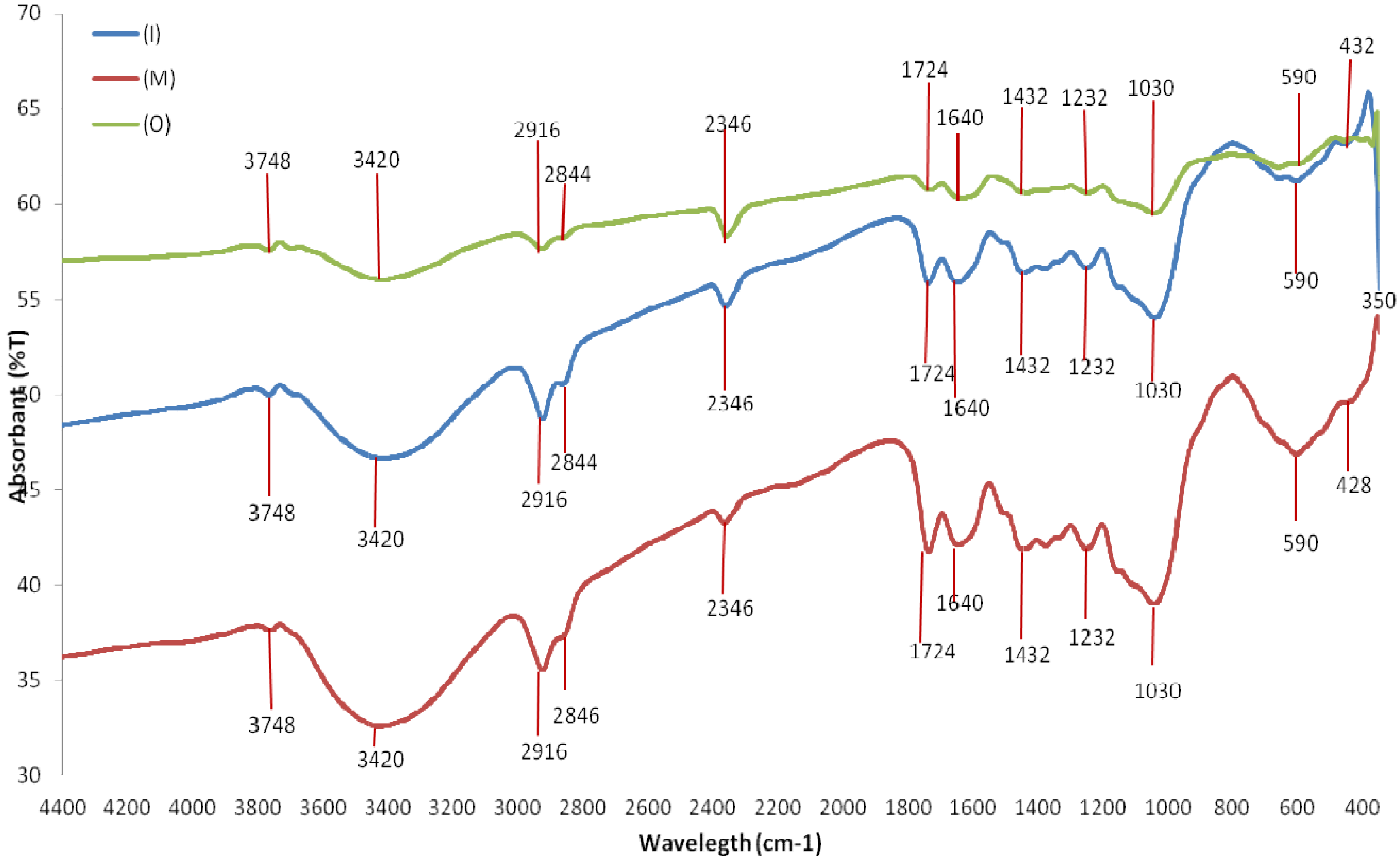

Figure 4.3: FTIR spectra of 10years base wood of tapped *Hevea brasilensis*collected from Agbarha rubber plantation, Delta State, Nigeria

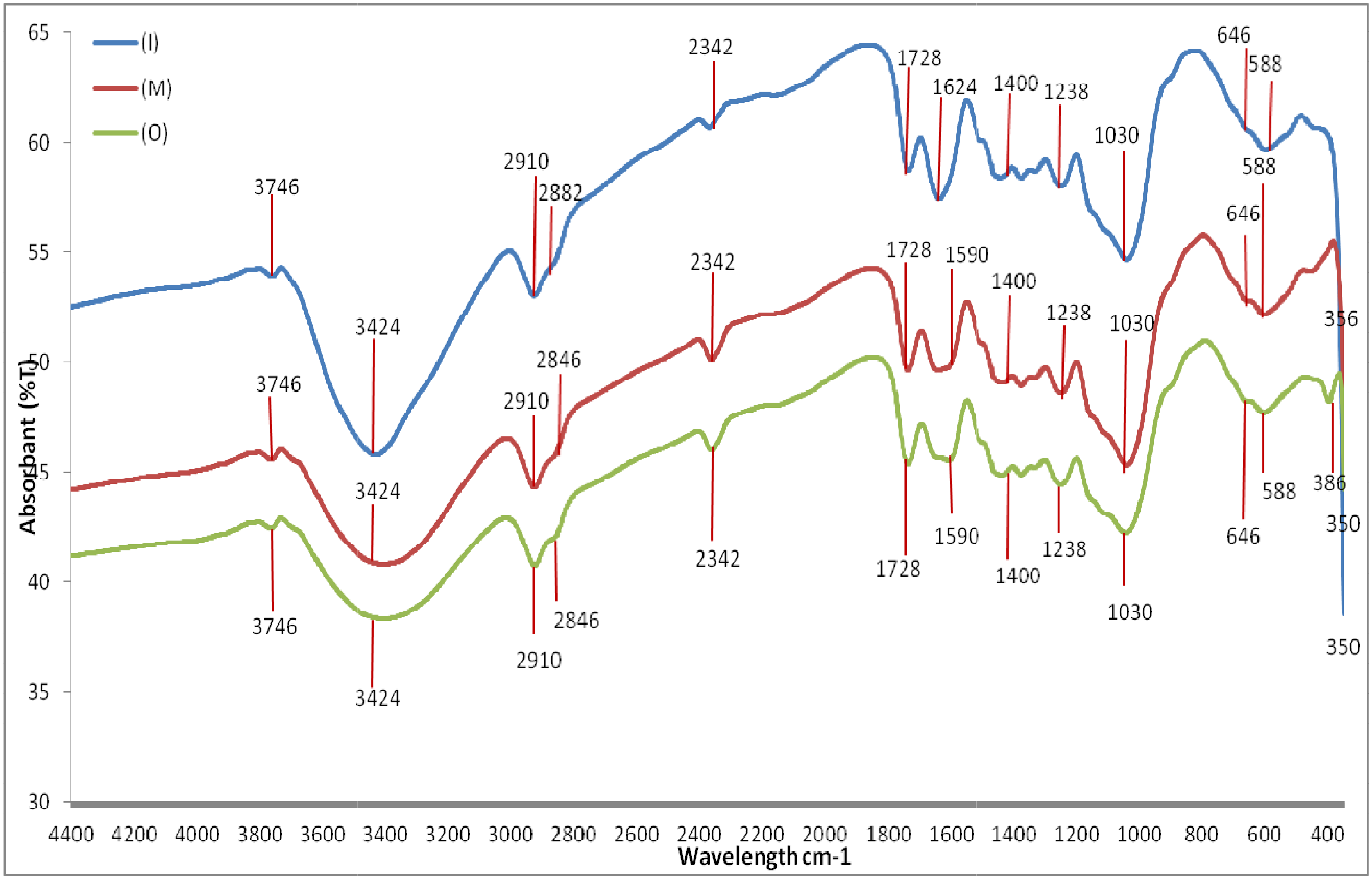

Figure 4.4: FTIR spectra of 10years top wood of tapped *Hevea brasilensis*collected from Agbarha rubber plantation, Delta State, Nigeria

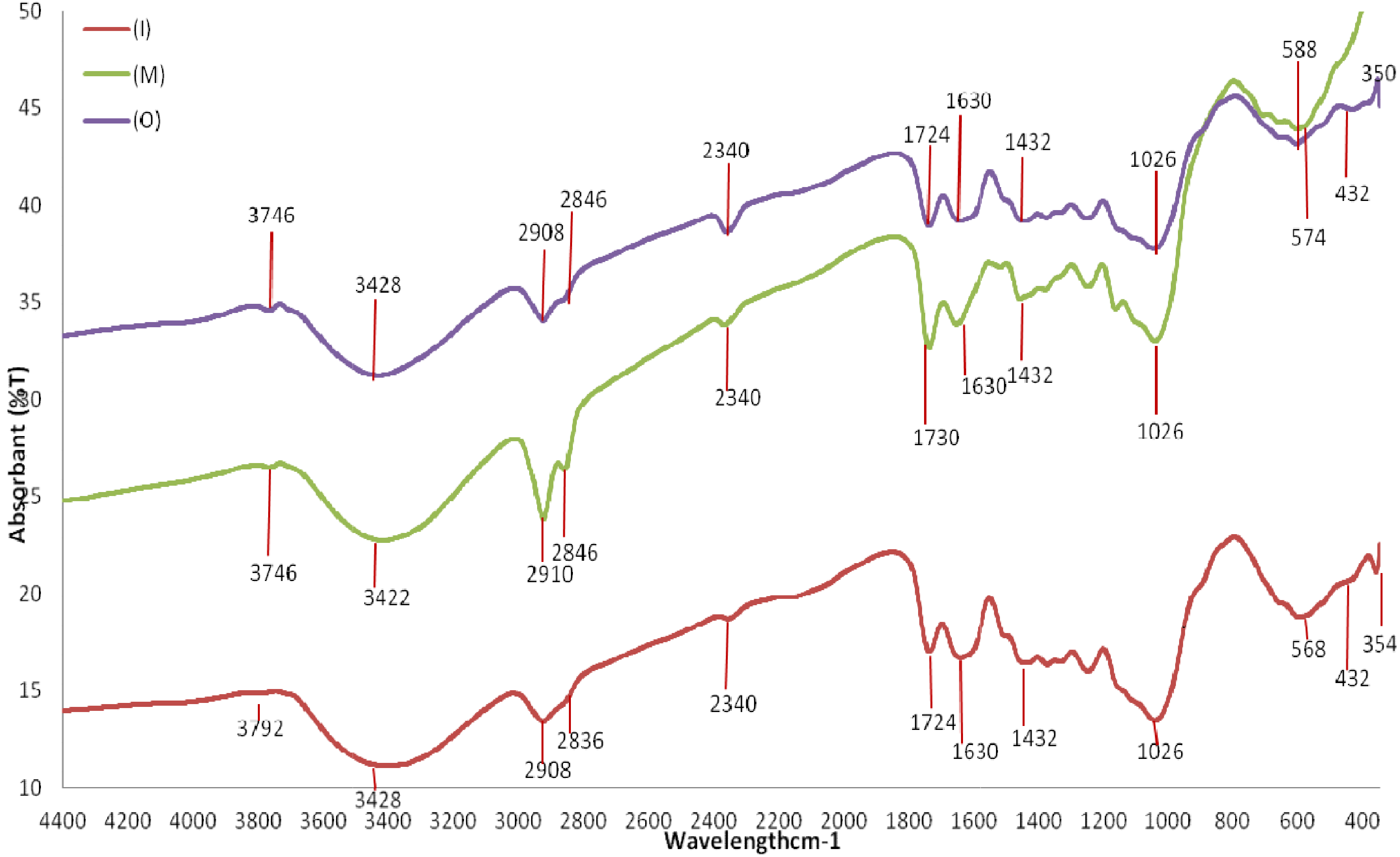

Figure 4.5: FTIR spectra of 15years base wood of tapped *Hevea brasilensis*collected from Agbarha rubber plantation, Delta State, Nigeria

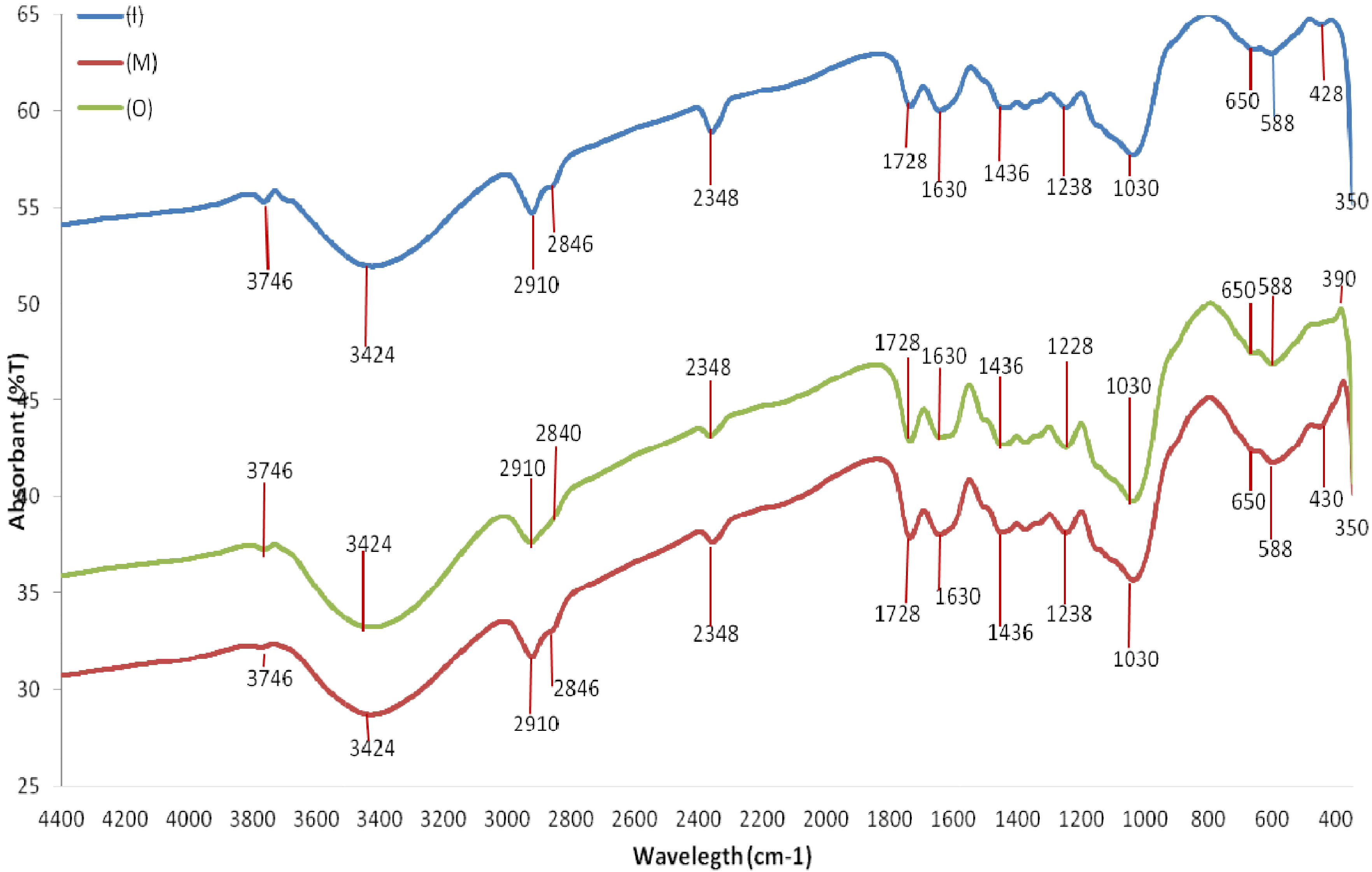

Figure 4.6: FTIR spectra of 15years top wood of tapped *Hevea brasilensis*collected from Agbarha rubber plantation, Delta State, Nigeria

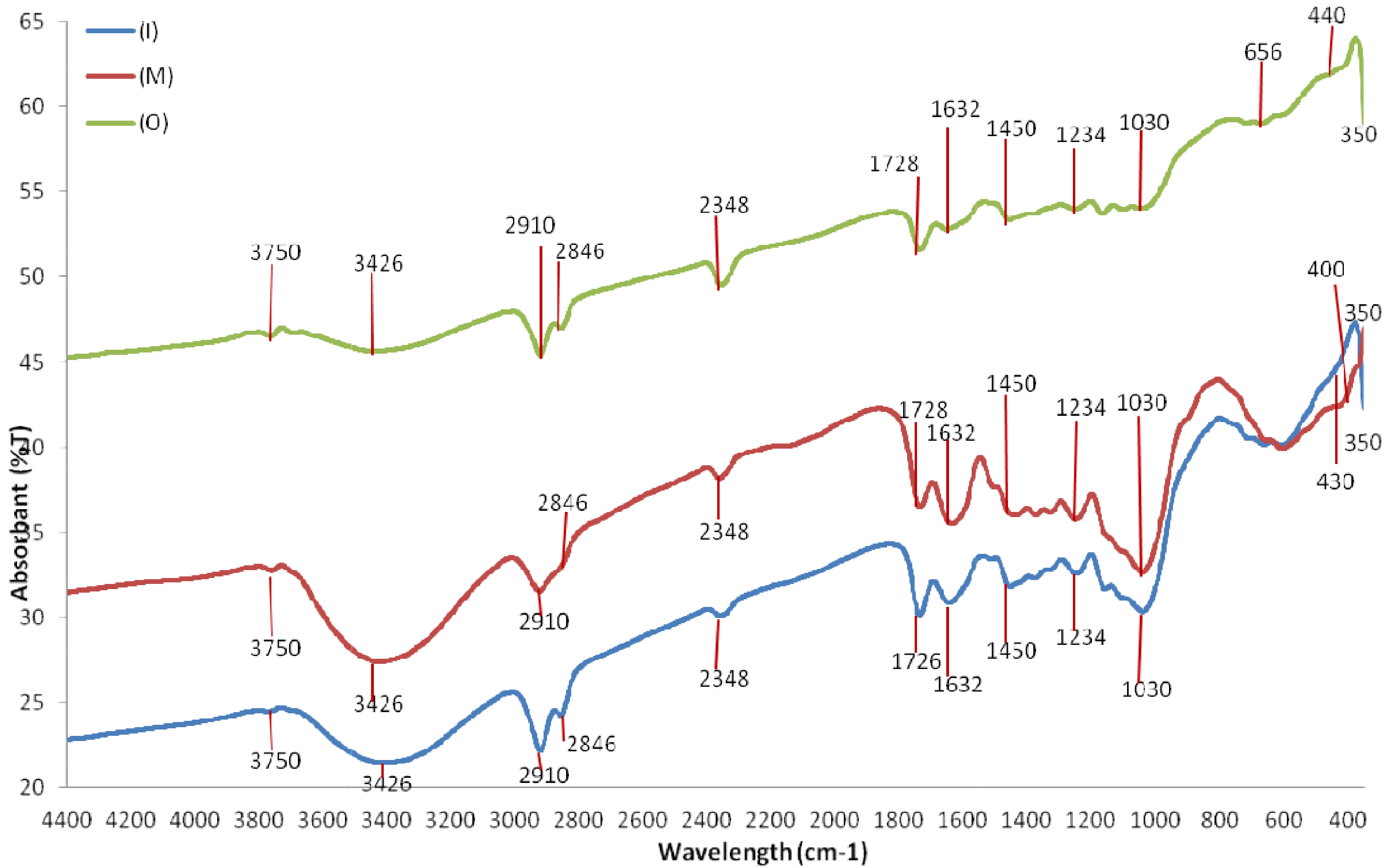

Figure 4.7: FTIR spectra of 20years base wood of tapped *Hevea brasilensis*collected from Agbarha rubber plantation, Delta State, Nigeria

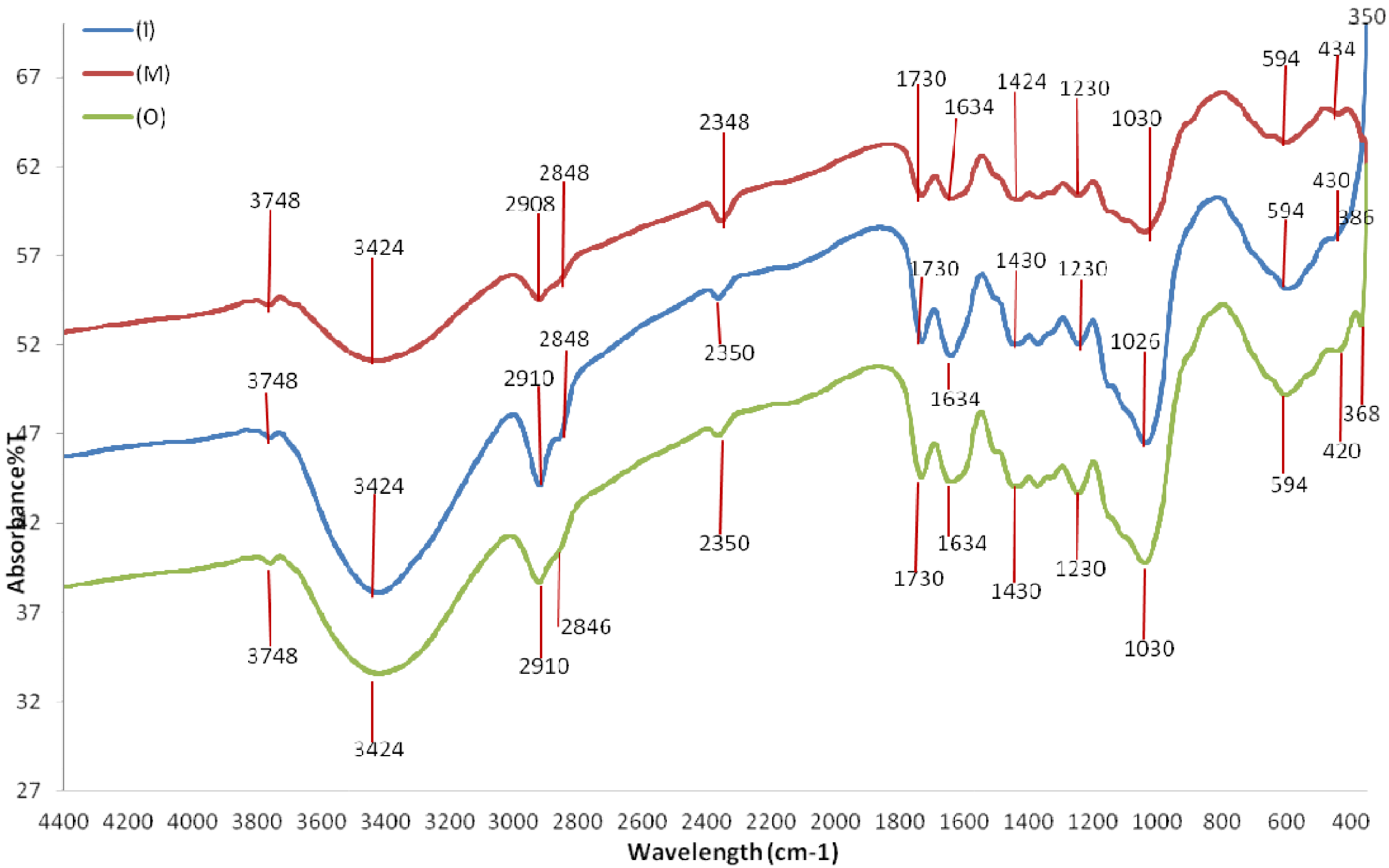

Figure 4.8: FTIR spectra of 20years top wood of tapped *Hevea brasilensis*collected from Agbarha rubber plantation, Delta State, Nigeria

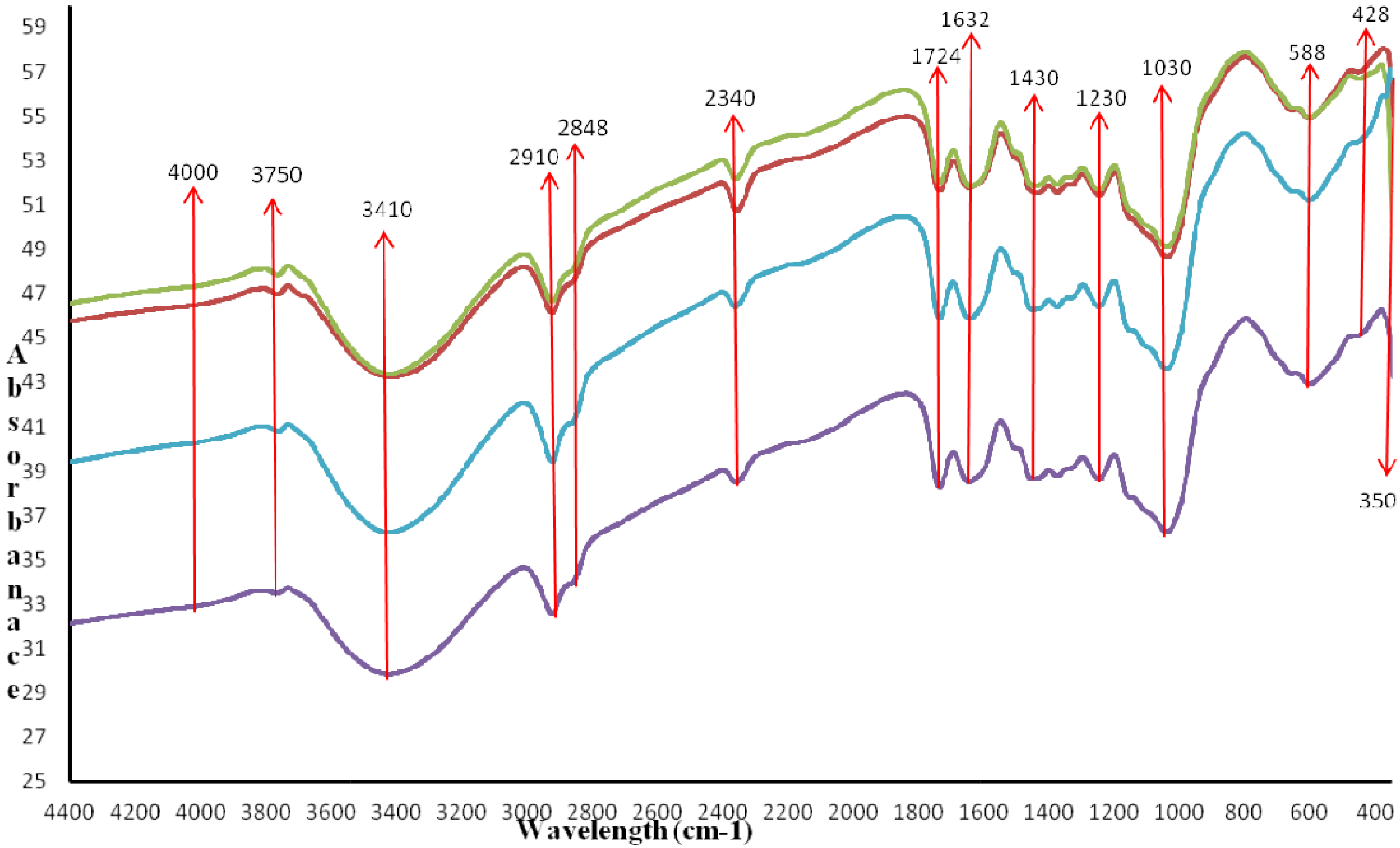

Figure 4.9: FTIR spectra of tapped*Hevea brasilensis* woodcollected from Agbarha rubber plantation, Delta State, Nigeria showing tapping age variation

CHAPTER FIVE

5.0 DISCUSSION

5.1 Physical Properties of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

5.1.1 Specific gravity of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The specific gravity increased steadily from 5years of tapping to at 20years of tapping. The trend of variations obtained in this study support the fact that younger part of trees have lower density and that density increases with increasing age (Zobel and Van Buijtenen, 1989; Bao *et al.*, 2001; Githiomi and Kariuki, 2010; Naji *et al.*, 2012). The mean values obtained in this study compares favourably with that of Lee (1982), Roslan (1998) and Mohd Shukari (1999) with a value of 0.56-0.65, 0.61 and 0.56-0.58 respectively. Teoh *et al.* (2011) reported the approximated value of specific gravity of *Hevea brasiliensis* as 0.56 while earlier studies of Roghu *et al.* (2006) and Norul Izani and Sahri (2008) reported values ranging from 0.51 - 0.57 and 0.58 - 0.60 respectively. These variations in the reported specific gravity of rubber wood may be as a result of species diversity, clones of hevea studied as well as environmental conditions where the tree is grown. Poku *et al.* (2001) reported the specific gravity of *Petersianthus Macrotrarpus*a lesser known species to be 0.69.

5.1.2 Moisture content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The age and radial variation of the moisture content of rubber wood observed in this study showed no particular pattern as also observed by Mohd Shukari (1999) and Poku *et al.* (2001) for rubberwood and other lesser known species. The range of values obtained from this study for moisture content of *Hevea brasiliensis* is lower than that of Mohd Shukari (1999) but higher than that of Poku *et al*. (2001) who reported a value of 13.63 – 15.3% for air dried *Hevea brasiliensis* of different ages and 7.86% for *Petersianthus macrotrarpus* respectively. However, it is lesser than that of Olajide (2017) who reported a mean value of 10.48% for untreated bamboo wood.

Higher moisture content is normallylinked with lower strength hence the bottompart of the stem should have lower moisture content than the other parts (increasing as it move up the stem) as the specificgravity is higher at the bottom and lowers towards the upper part of the tree (Norul Izani and Sahri, 2008).

5.1.3 Longitudinal shrinkage of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The variation of the longitudinal shrinkage of rubber wood as observed in this study showed no consistent pattern. The range of value obtained for longitudinal shrinkage of rubberwood in this study is higher than that reported by Roslan (1998) and Majumdar *et al*. (2014). Both reports recorded values of 0.34% and 0.16% respectively for rubberwood. Sotannde *et al*. (2010) reported longitudinal shrinkage of *Azadirachta indica* to be 0.65%. According to Wengert (2006) and Bauer (2003), wood shrinks longitudinally to amaximum of 0.3% and is ignored normally because it is small and negligible. Rubberwood from this study exhibited excessive longitudinal shrinkage greater than 0.3 % and as a result, attention should be paid to the woodwhen using it in designs where longitudinal stability is important. This excessive shrinkage observed may be related to the response of the tree to the tapping which causes injury to the tree. Continuous tapping leads to the formation of wound wood which could also be called reaction wood. Previous studies have shown reaction wood to have high longitudinal shrinkage.

5.1.4 Tangential shrinkage of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Poku *et al.* (2001) observed the tangential shrinkage to be higher at the top than at the middle and base which is as a result of the top being compose mainly of young wood cells. The range of values obtained in this study for tangential shrinkage of rubberwood is higher than that reported by Roslan (1998) who reported a value of 1.49 % and Majumdar *et al.* (2014) reported a mean value of 4.85 % for *Hevea brasileinsis* while Ojo (2016) also reported a lower value of 3.71 % for *Borassus aethiopum*. Poku *et al.* (2001) and Sotannde *et al*. (2010) however recorded values of 6.9 % and 7.93 % for *Petersianthus macrotrarpus* and *Azadirachta indica* which is higher than the mean value obtained in this study.

The ratio between the tangential shrinkage and radial shrinkage is 1.57 and this supports the report of Bodig and Jayne (1973) and Panshin and de Zeeuw (1980) that the tangential shrinkage is greater than the radial shrinkage by a factor between 1.5 and 3.0. Rijsdijk and Laming, (1994)considered to be high the ratios of tangential-radial shrinkage that are above 2.2 %. The 1:1.57% tangential-radial shrinkage recorded in this study is low which indicates the wood is less likely to be deformed during seasoning.

5.1.5 Radial shrinkage of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The variation in age of tapping series of the radial shrinkage of rubber wood as observed in this study showed no particular pattern as also observed by Poku *et al.* (2001). The range of values obtained for radial shrinkage from this study is higher than that reported by Roslan (1998) and Majumdar *et al.* (2014). Roslan in his study reported a value of 0.64 % and 0.99% for mature wood and juvenile wood of *Hevea brasiliensis* respectively while Majumdar *et al.* (2014) reported 2.40%. Poku *et al.* (2001) obtained a value of 4.0 % for *Petersianthus macrotrarpus* which is closely comparable but higher than the mean value of 3.42% obtained for this study while Sotannde *et al*. (2010) recorded a much higher value of 4.64% for *Azadirachta indica*. This value also compares favourably with that of Ojo (2016) for who reported a value of 3.24% for the radial shrinkage of *Borassus aethiopum*.

5.1.6 Volumetric shrinkage of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The variation of the volumetric shrinkage of rubber wood as observed in this study also showed no particular pattern as observed by Poku *et al.* (2001). Sotannde *et* *al*.(2010) recorded the volumetric shrinkage of *Azadirachta indica* to be 12.78% which is higher than that of this study. The difference in the longitudinal, radial and tangential shrinkage is due to the alignment of wood cells (Josue, 2004; Sotannde *et al*., 2010). As water is removed from the cell walls, the cells move closer together thus leading to shrinkage of the wood. This is supported by the findings of Kollman and dan Cote (1968), who noted that the shrinkage was not the same in different directions as a result of the straining influence of the wood rays in the radial direction due to the different helical arrangement of fibrils in the radial and tangential cell walls.

5.2 Anatomical Properties of tapped *Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

5.2.1 Fibre characterisation of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

5.2.1.1 Fibre length of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The range of values of observed in this study for fibre length is lower than that reported by Tembe *et al.* (2010) and Boerhendy *et al*. (2010) who reported a mean value of 1.59 mm and 1.68 mm for a mature wood of *Hevea brasiliensis* respectively. Teoh *et al.* (2011) and Naji *et al,* (2012) reported fibre length varying from 1.1mm to 1.78mm and 1.0mm to 1.46mm respectively while Norul Izani and Sahri (2008) reported values ranging from 1.15 to 1.21 and Suhaimi and Sahri (2003) reported 1.17 to 1.35mm for fibre length of Rubberwood.

The axial and radial variation observed in this study is in line with the report of Haifah (2002) who reported that wood from the top portion had the longest fibre length when compared to those from the middle and bottom. The longest fibre as stated by Haifah (2002) was also located in the sapwood region (outerwood). Previous researches such as Shupe *et al*., 1996; Jorge *et al.*, 2000; Ogunsanwo 2000; Bao *et al.,* 2001; Honjo *et al.,* 2005; Walker 2006; Izekor, 2010 and Naji *et al.*, 2012 show shorter fibres were found towards the centre of the wood and increasing slightly outwardly towards the bark of the wood. The increase in fibre length from innerwood to outerwood could be as a result of increase in length of cambial initials with increasing cambial age and crown formation (Jorge *et al.,* 2000).

Salehi (2001) classified fibres into three categories; short fibres having lengths that are less than 0.9mm, average fibres having lengths that range from 0.9-1.9mm and long fibres having lengths that are greater than 1.9mm. From this classification, *Hevea brasiliensis* belongs to the group of average fibres.

Dinwoodie, (1981); Kaila and Aittamaa, (2006); and Ogunleye *et al.*(2016) noted that fibre length as an important aspect in determining the quality of wood because it related to mechanical strength and shrinkage as well as influencing the paper strength properties. The importanceof fibre length in determining pulp and paper properties cannot be over-emphasized as Ogunleye *et al*. (2016) reported fibre length have influence on most of the pulp strength and paper qualities. Positive correlations was observed by between fibre length and tear index, burst strength, tear strength and folding endurance (Ademiluyi and Okeke 1979; Haygreen and Bowyer 1996; Ona *et al.*, 2001). Paper quality and strength are negatively impacted upon with decrease in fibre length. Oluwadare and Sotande (2007) reported that longer fibre lengths could result in greater resistance of the paper to tearing Therefore the longer the fibre length, the higher the quality of paper produced. Ogunleye *et al*. (2016) reported that longer fibres tended to give a more open and less uniform sheet structure.

5.2.1.2 Lumen width of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean value of 16.87 μm observed in this study is higher than that reported by Boerhendy *et al*. (2010) who reported a mean value of 15.81 μm. Norul Izani and Sahri (2008) reported values for lumen width of rubberwood to range between 10 and 12 μm while Naji *et al.* (2012) reported values 16.43 and 26.56 μm.

Haifah (2002) reported the widest lumen to be found in the innerwood region which is in line with this study. Lumen width is also very important in the pulping processas larger lumen width gives better pulp beating because of ease ofliquid penetration into the empty spaces of the fibres (Sharma *et al*., 2011 and Emerhi, 2012). When the lumen diameter is large, the percentage of shrinkage is lower due to the lumen content affecting shrinkage. The specific gravity is also lower if the lumen diameter is large (Norul Izani and Sahri, 2008).

5.2.1.3 Fibre diameter of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Mohd Izham, 2001 reported that a large fibre diameter will increase the strength properties of the wood. Teoh *et al.* (2011) and Naji *et al.* (2012) reported that fibre diameter of Hevea ranges from 26 to 30 µm and 26.33 to 32.84 µm respectively while Norul Izani and Sahri (2008) obtained values ranging from 23.5 and 24.9 µm.

5.2.1.4 Cell wall thickness of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Teoh *et al.* (2011) reported cell wall thickness of fibres of rubberwood to range between 5.1 and 7.0 µm. Naji *et al.* (2012) reported values ranging from 4.08 to 5.69 µm while Norul Izani and Sahri (2008) recorded values between 6.08 and 6.51 µm.

Specific gravity, shrinkage and the strength of the tree are all related to the cell wall thickness (Norul Izani and Sahri, 2008). The cell wall thickness of fibres increases with increasing age which may be as a result of the combined effects ofincrease in fibre diameter with a commesurate decrease in lumen size. This relates to the report of Akachuku (1982) who attributed the increase in cell wall thickness of *Gmelina arborea* to changes in the size of the cell (fibre diameter and lumen width) associated with annual and periodic growth cycles as well as the increasing age of the cambium. The values and pattern of variation in this study is in conformity with that obtained by Izekor and Fuwupe, (2011) and Harmean *et al.* (2014) who observed that fibres with the thickest walls are found in the outerwood region while those with the thinnest walls were located in the innerwood region of the bottom of the stem.

Wood with thick cell walls produces paper with a poor printing surface, bulky with lower tensile, poor burst strength, high tearing strength and a low folding endurance (Haygreen and Bowyer 1996; Sharma *et al*., 2011). Thick-walled cells do not bend easily and do not collapse easily upon pulping and this inhibits chemical bonding while the opposite is achieved for thin-walled cells (Zobel and van Buijtenen 1989). Cell wall thickness also governs fibre flexibility (Sharma *et al*., 2011)

5.2.1.5 Slenderness ratio of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Theslenderness ratio reported by Ogunleye *et al.* (2016) for *R.heudelotii* (35.85) is less than the 56.86 obtained for this study. However, Ogunkunle (2010) and Sharma *et al.* (2013) reported that *G. arborea* has a slenderness ratio of 50.06 and 39.1 respectively while 42.38 to 71.99 was reported for different Ficus species by Ogunkunle (2010).

Slenderness ratio measures the tearing property of pulp in paper making. The fibres with a high slenderness ratio are long, thin hencea high tearing resistance, whereas short and thick fibres have less slenderness ratio hence a low tearing resistance (Ogunleye *et al*., 2016). It has been reported that slenderness ratio that is above 33 for fibrous materials is considered good for pulp and paper production (Xu *et al.,* 2006). Low slenderness ratio will therefore produce of weak paper. The strength properties of papers positively correlates with the slenderness ratio as Ona *et al.*(2001) reported a positive correlation between the slenderness ratio and folding endurance.

5.2.1.6 Flexibility ratio of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The observed coefficient of flexibility (0.65) is closely similar to that reported by Boerhendy *et al*. (2010) who obtained a value of 0.67 for Indonesian rubberwood. Ogunleye *et al.* (2016) reported a value of 0.77 for the flexibility ratio of *R. heudelotti* and 0.73 was obtained by Ogunkunle (2010) for *G. arborea,* and 0.63 to 0.79 reported for Ficus species. The flexibility ratio of *Gmelina arborea* and *Pinus kesiya* as reported by Sharma *et al.* (2013)was 0.76 and 0.82.

Flexibility coefficient whichdetermines the degree of fibre bonding in paper sheet is influenced by lumen width and fibre diameter (Ogunleye *et al*., 2016).The degree of fibre bonding depends largely on the flexibility of individual fibres (Kiaei *et al*., 2014). Smook (1997) reported the values for hardwood and softwoods to be 0.55-0.70 and 0.75 respectively. Thus fibres with a flexibility coefficient of more than 0.75 considered as highly elastic while those between 0.50-0.75 are elastic fibres (Bektas *et al*., 1999). This therefore shows that the fibres in *Hevea brasiliensis* wood as observed from this study are flexible (elastic) and satisfies the requirement for their suitability as a material for pulp and paper production.

5.2.1.7 Runkel ratio of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean Runkel ratio of 0.54 is lesser than that reported by Boerhendy *et al*. (2010) who obtained a mean value of 0.61 for Indonesian rubberwood. Ogunleye *et al.* (2016) reported runkel ratio of *R. heudelotti* to be 0.31 while Ogunkunle (2010) reported 0.39 for *G. arborea* and a range of 0.26 to 0.68 for Ficus species.

Runkel ratio also measures the suitability of fibre for pulp and paper production. The fibres with runkel's ratio less than 1 have been reported as good for paper making because the fibres are more flexible, they will collapse easily and form a paper with large bonded area with good mechanical strength properties (Ververis *et al.,* 2004; Istek 2006; Dutt *et al.*, 2009; Sharma *et al*., 2011; Ogunleye *et al.*, 2016). Ona *et al*. (2001) reported runkel ratio to be correlated to paper conformability and pulp yield.

5.2.1.8 Coefficient of rigidity of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The observed mean coefficient of rigidity 17.43% is a bit higher than that reported by Boerhendy *et al*. (2010) who obtained 16% for Indonesian rubberwood.

5.2.1.9 Luce's shape factor of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Ona *et al*.(2001) found Luce's shape factor to be related to paper density and also correlated to breaking length of paper while Luce (1970) and Takeuchi *et al*. (2016) found it to be related to resistance to beating so that a low value for Luce's shape factor indicates a decreased resistance to beating in paper making. Ogunleye *et al.* (2016) reported luce's shape factor of *R. heudelotii* to be 0.26 while Ogunkunle (2010) reported the luce's shape factor of *Gmelina arborea* to be 0.29, *Ficus mucuso* to be 0.25 and *F. exasperate* to be 0.16. Ojo (2013) reported Luce's shape factor of 0.20 for *Gmelina arborea,* 0.47 for *Afzelia Africana and* 0.73 for *Detarium senegalense* while Oluwadare and Sotannde (2007) reported 0.41 on *Leucaena leucocephala*. Ohshima *et al*. (2005) also reported mean values of Luce's shape factor of 0.37 for *Eucalyptus camaldulensis* and 0.42 for *Eucalyptus globulus*. These values compare favourably with the values obtained from this study.

5.2.2.1 Vessel counts of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The range of values obtained for vessel count from this study is similar with that obtained by Norul Izani and Sahri (2008) various Hevea species. They reported the vessel counts of *H. pauciflora, H. guianensis, H. benthamiana* and *H. spruceana* to be 2.60, 2.48, 2.47 and 2.46 vessels/mm^2 respectively. Sekhar (1989) reported that the mean vessel count for rubberwood is 3 to 4 vessels/mm^2 while Naji *et al.* (2011) reported values of 3.62, 4.1, 6.58 and 7.83 vessels/mm^2 for two different clones of rubber in two different planting densities. These later reported values are way higher than the values obtained from this study. The results showed that the vessel count decreased from pith to bark which correlate with the report of Norul Izani and Sahri (2008).

5.2.2.2 Vessel diameter of yapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The range of values obtained for vessel diameter of tapped *Hevea brasiliensis* from this study is higher than that reported by Norul Izani and Sahri (2008) various

Hevea species. They reported the vessel diameter of *H. pauciflora, H. guianensis, H. benthamiana* and *H. spruceana* to be 138.4µm, 122.6µm, 139.5µm and 154.7µm respectively. It is also higher than that reported by Naji *et al.* (2011) who reported the vessel diameter for two different clones of rubber in two different planting densities to be 177 and 144 µm; 186 and 156 µm.

5.2.2.3 Vessel length of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean vessel length obtained from this study is higher than 0.24mm reported for *Acacia auriculiformis* (Chowdhury *et al*., 2009), 0.31 mm for *Eucalyptus tereticornis* (Sharma *et al*., 2005), 0.22 mm for *Eucalyptus camaldulensis*, and 0.19 mm for *Eucalyptus maculate* (Pirralho *et al*., 2014). It is however lower than *Macaranga bancana* and *pearsonii* with 1.11mm and 0.93mm respectively for the vessel length (Takeuchi *et al*., 2016). These vessel morphology results indicate the possibility of a relatively lesser occurrence of vessel picking in paper made from the two Macaranga species and higher occurrence than Acacia and Eucalyptus species.

5.2.2.4 Ray width of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean ray width obtained from this study is higher than 34.5 µm reported for *Paulownia tomentosa* (Qi *et al*., 2014) It is however lower than 57 µm reported by Rahman *et al*. (2005) for average ray width of *Tectona grandis* from two different locations.

5.2.2.5 Ray height of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The mean ray height obtained from this study is higher than 227.7 µm reported for *Paulownia tomentosa* (Qi *et al*., 2014) It is however lower than 525 µm reported by Rahman *et al.* (2005) for average ray width of *Tectona grandis* from two different locations.

5.3 Mechanical Properties of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

5.3.1 Modulus of elasticity of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The range of values obtained in this study is higher than those obtained by Roslan (1998), Ogunsanwo *et al.* (2001), Majumdar *et al.* (2014), and Naji *et al.* (2014) but far higher than what they reported. These researchers reported mean values of 10422.48N/mm^2, 8029.26N/mm^2, 8770N/mm^2 and 9015N/mm^2 respectively for MOE of the same species. However the range of values compares with the report of Ojo (2016) who recorded 13223N/mm2 for MOE of *Borassus aethiopum* which is also a lesser known species. This variability may be as a result of a combination of several other factors, including the inherent variability within trees, growth and environmental conditions, presence of high extractive contents and the heterogeneous composition (Poku *et al.*, 2001). The difference may also arise as a result of the different clones of *Hevea brasiliensis* used for the studies.

Unlike the general trend where MOE varies consistently along the axial and radial direction, this study show an inconsistent trend of variation in all parameters measured which are age, sampling height and sampling position. However, the pattern of variation in the axial direction is similar to that of Ogunsanwo *et al.* (2001) and Poku *et al.* (2001) who observed in their study that the MOE at the top and middle is greater than the MOE at the base. This inconsistent pattern of variation may be as a result of the stress the wood is being exposed to due to the continuous tapping carried out causing injury to the cambium of the tree leading to development of wood with high density around the area of injury.

Modulus of rupture measures the stiffness of a wood. High values of Modulus of elasticity means the wood indicates increased stiffness (Desch and Dinwoodie, 1981).Ojo (2016) classified strength of species based on the modulus of rupture at 12% moisture content as follows: 'Very High'(19,000N/mm^2 and more), 'High' (14,000-19,000N/mm^2), 'Medium' (11000-14,000N/mm^2), 'Low/ Medium' (9,000-11,000N/mm^2), and 'Low'(below 9,000N/mm^2). From the above classification, rubberwood used for this study with modulus of elasticity of 13218N/mm^2 is medium in its strength which makes it suitable for furniture making.

5.3.2 Modulus of rupture of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The variation of the modulus of rupture of rubber wood as observed in the radial direction as well as the various age series in this study showed no particular pattern as also observed by Poku *et al.* (2001) which is dissimilar to the general trend where modulus of rupture is reported to vary consistently across the bole (decreasing from base to top) and age wise (increasing as the tree ages). However, the pattern of variation in the axial direction is similar to that of Ogunsanwo *et al.* (2001) and Poku *et al.* (2001) who also observed in their study that the modulus of rupture at the top and middle is greater than the modulus of rupture at the base. This pattern may be as a result of the stress the wood is being exposed to due to the continuous tapping carried out which causes injury to the cambium of the tree leading to development of wood with high density around the injured location which is normally at the middle of the tree. Wood tissues produce thereafter will then be physiologically prepared to absorb the stress the wood is exposed to.

The range of values obtained in this study is greater than those reported by by Roslan (1998), Ogunsanwo *et al.* (2001), Majumdar *et al.* (2014), and Naji *et al.* (2014). High values of modulus of rupture will indicate increase strength in the wood (Desch and Dinwoodie, 1981)

5.3.3 Maximum Compression Strength Parallel to grain of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

The variation of the maximum compressive strength parallel to grain of rubber wood as observed in this study in terms of age showed no particular pattern as also observed by Poku *et al.* (2001). The axial variation in this study is similar to Ogunsanwo *et al.* (2001) and Poku *et al.* (2001) who observed in their study that the maximum compressive strength parallel to grain at the top and middle is greater than the maximum compressive strength parallel to grain at the base. This pattern may also be as a result of the stress the wood is being exposed to due to the continuous tapping carried out which causes injury to the cambium of the tree leading to development of wood with high density.

The Compression strength parallel to grain have been classified according to Ojo (2016), as very low, low, medium, high, and very high when the strength values are under 20N/mm^2, ranging from 20-35N/mm^2, 35-55N/mm^2, 55-85N/mm^2 and over 85N/mm^2 respectively. This classification consequently rates the wood from rubber at the various tapping age as wood with high compressive strength parallel to grain.

5.4 Chemical Properties of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

5.4.1 Ash content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Harmean *et al.* 2014 reported the ash content of young rubberwood to range from 0.35% to 0.58% while Harmean *et al.*(2005) recorded a value of 0.6%. Zaki *et al.* (2012) obtained mean values for two clones of rubberwood ranging from 0.69 and 0.80%. The observed trend axially is similar to that of Zaki *et al.* (2012); Harmean *et al.* (2014) and Riyaphan *et al*. (2015) as they all observed the highest ash content to be available in the bottom part of the tree while the lowest value was found in the upper part of the tree which is in line with this study. This may be related to the development of more mature wood at the bottom portion of the wood and thus containing more heartwood proportion.

Generally, the ash content of wood should be below 1%. A higher level of ash in the wood is considered unsuitable for paper manufacture (Riyaphan *et al*., 2015) High percentage of ash content is also reported to be detrimental to cutting tool (Zaki *et al*., 2012). Result from this study therefore shows *Hevea brasiliensis* would be a suitable raw material for paper and pulp industries as well as other wood industries due to its low ash content. The ash content in wood is normally correlated to the amount of mineral such as silica that is present in the wood (Balsiger *et al*., 2000). These mineral salts are located in the cell wall and cell lumen (Zaki *et al*., 2012; Riyaphan *et al*., 2015).

5.4.2 Lignin content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Harmean *et al.* (2014) reported values of lignin content to be between 11.56 and 13.55% while Harmean *et al.* (2005) and Boerhendy *et al*. (2010) recorded 23% and 20.78% lignin content respectively. Zaki *et al.* (2012) reported lignin content in two clones of rubberwood to be 16.59% and 17.30%. Lignin content in this study was found to be more at the top than at the base which agrees with the trend reported by Zaki *et al.* (2012) and Riyaphan *et al*. (2015) however Harmean *et al.* (2014) reported lignin content to be higher at the base than at the top. Reghu (2011) reported that the percentage of lignin in wild *Hevea* germplasm ranged from 19–25%, while that in Wickham trees ranged from 21–23%. Sjostrom (1981) reported hardwood to contain 20 to 28% lignin by mass while softwood to contain 26 to 30% lignin.

Lignin functions as a binding agent which holds the individual fibers together and contributes to the mechanical strength (Via *et al*., 2007; Zaki *et al*., 2012). Normally, the percentage of lignin content in hardwoods is between 19 – 25% as reported by Zaki *et al.* (2012). Lignin content as observed from this study were at satisfactory levels (<30%) for all age series. Woody biomass with lower percentages of lignin content is more favoured as raw material for pulp and paper manufacturing. This, in practice means that *Hevea brasileinsis* will need milder pulping conditions (lower temperatures and chemical charges) in order to reach a satisfactory kappa number (Ververis *et al.,* 2004). It also indicates that *H. brasiliensis* fibres will easily undergo bleaching using few chemicals (Ververis *et al.,* 2004). According to Saka and Goring (1985), the thicker the cell wall the lower the lignin content in wood.

5.4.3 Holocellulose content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Harmean *et al.* (2014) recorded values of 73.20% and 76.47% for hololelullulose content of rubberwood. Zaki *et al.* (2012) reported 58.58% and 57.67% for the two clones of rubberwood they studied. However, Hong (1994) reported values of 65% and 78% for rubberwood. Boerhendy *et al*. (2010) reported 67.38% for holocellulose content of Indonesian rubberwood while Khoo and Peh (1982) reported values of between 59.4 and 85.4% for holocellulose content of Malaysian tropical hardwood. The holocellulose content was higher in the base than the top which is in line with the findings of Zaki *et al.* (2012), Harmean *et al.* (2014) and Riyaphan *et al*. (2015) who also reported higher holocellulose content in the base than the top of the tree. This variation may be as a result of the top portion of the wood being active in the production of new cells (Zaki *et al*., 2012).

High holocellulose content is considered desirable for pulp and paper production because of its correlation with higher pulp yield and swelling behaviour of the pulp produced by it (Shakes *et al*., 2011; Singh *et al.,* 2011 and Anguruwa, 2018). High hemicellulose content which makes up the holocellulose content has been linked to increase in mechanical strength properties of pulp and paper produced (tensile and burst strength) as well as double folds and decrease in beating energy (Tyagi *et al*., 2004)

5.4.4 Alpha cellulose content of tapped*Hevea brasiliensis* wood collected from Agbarha rubber plantation, Delta State, Nigeria at various tapping age

Hong (1995) reported alpha cellulose content in rubberwood to be between 45 and 50% while Khoo and Peh (1982) recorded that most Malaysian hardwood had alpha cellulose content ranging between 35.1% and 54.2%. Harmean *et al.* (2014) recorded values ranging between 51.13% and 54.41% for alpha cellulose content in rubberwood. Zaki *et al.* (2012) obtained 41.41% and 38.13% of alpha-cellulose. In general, the alpha cellulose value indicates an undegraded, higher-molecular-weight cellulose content in pulp (Riyaphan *et al*., 2015). Alpha cellulose content of *Hevea brasiliensis* observed in this study is satisfactory as it is close or above 40% for all age series.Ververis *et al.* (2004),classified plant materials having alpha cellulose content of 34% and above as favourable materials manufacture of pulp and paper from a chemical composition point of view. This makes *Hevea brasiliensis* of the sampled ages suitable for the production of pulp and paper.

Higher alpha cellulose content results in stronger wood as alpha cellulose contributes to wood strength, and increases resistance to crushing (Rowell, 2005 and Sixta, 2006). Higher alpha cellulose content also results in greater resistance to static bending (MOR and MOE) as reported by Rowell (2005) and Windeisen *et al*. (2009). When wood contained high percentages of alpha cellulose, the amount of force necessary to achieve maximum load increased (Riyaphan *et al.*, 2015). The high alpha cellulose content in the base than the top observed in this study is similar to reports of Harmean *et al.* (2014) and Riyaphan *et al.* (2015) who also recorded higher alpha cellulose content in the base than the top of the tree. This decreasing value of alpha cellulose with increasing tree height is explained by Kollmann and dan Cote (1968) who reported the bottom portion of tree to consist mainly matured cells and cellulose and hemicellulose are the major constituents that form the thick secondary walls found in mature cells at the base of the tree.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This study assessed selected properties of tapped rubberwood from a private plantation in Agbarha, Ughelli North Area of delta State Nigeria. It therefore revealed useful information towards maximising the use of rubberwood in the Nigerian wood industry. Based on the findings from this research, the following conclusions were drawn:

- Tapping causes injury to the tree. However, tapping duration had no negative impact on physical, anatomical, mechanical and chemical properties of the wood.
- Continuous tapping leads to the formation of wound wood which could also be called reaction wood. Previous studies have shown reaction wood to have high longitudinal shrinkage which may be responsible for the high longitudinal shrinkage observed in this study.
- The results of physical properties showed that rubberwood has a moisture content of 7.95-9.98% and a specific gravity of 0.5-0.61. The shrinkage ranged from 0.57-1.88%, 4.17-6.21%, 2.52-5.14% and 6.69-11.24% for longitudinal, tangential, radial and volumetric shrinkage respectively. The ratio of tangential-radial shrinkage recorded in this study is low and indicates the wood is less likely to be deformed during seasoning. Also, the wood from this study exhibited excessive longitudinal shrinkage greater than 0.3. Hence, attention should be paid towhen using it in designs where longitudinal stability is important. With the exception of specific gravity and radial shrinkage, tapping age was not found to be significant.This observed significant difference in specific gravity may be as a result of the production of thickened cell walls as the wood reacts to the tapping activities.

- From the result of the mechanical properties, the Modulus of Elasticity, Modulus of Rupture and Maximum compressive strength parallel to grain of rubberwood were between 7942-16821N/mm^2, 410-453N/mm^2 and 59-88N/mm^2 respectively. The tapping age had a significant effect on the modulus of rupture and maximum compressive strength parallel to grain.
- The analysis of the fibre properties of rubberwood revealed that the fibre length, lumen width and fibre diameter ranged between 1.37-1.61mm, 14.89-19.02µm and 23.26-28.60µm respectively. Also the derived parameters i.e. cell wall thickness, runkel ratio, flexibility and slenderness coefficient ranges between 3.93-5.25µm, 0.46-0.64, 61.29-68.65 and 50.10-64.55 respectively. Tapping age was observed to significantly affect the fibre length, lumen with and fibre diameter. *Hevea brasiliensis* belongs to the group of average fibres. The wood possesses properties that fall within the desirable range which makes it suitable for pulp and paper production
- The anatomical cell characterization showed that the vessel count, diameter and length was between 2.38-3.25 vessels/mm^2, 220.73-318.50µm and 414.43-626.66µm while the ray height and width ranged between 28.65-49.73µm and 413.85-581.14µm. With the exception of ray height, tapping age was observed not to influence the cell characterization significantly.
- The result also showed that the chemical composition of rubberwood has a lignin content ranging between 18.30-29.30% while the ash content was between 0.24-0.53%. However, the holocellulose and alpha cellulose content were between 51.37-67.50% and 30.57-52.04% respectively. The high alpha cellulose content (greater than 35%), low lignin content (less than 30%) as well as the low ash content (between 0.2 and 1%) favours its use as a raw material for pulp and paper production. Tapping age also observed to have significantly influenced the chemical composition of rubberwood,
- From the result of the FT-IR, functional groups present in rubber wood were O-H, C-H, C=O, C-C, C-O, C=C, C-C-O
- Physical, anatomical, mechanical and chemical properties of tapped rubberwood are within standard specifications and could therefore be used as timber.

6.2 RECOMMENDATION

Based on the findings of this study, the following recommendations were drawn

- Research should be conducted on the wood properties of *Hevea brasiliensis* at the actual cut or tapped area
- Futher studies should also be carried out on the wood properties of opposite wood in *Hevea brasiliensis* as compared to reaction wood (tapped area)
- Research on the preservation of rubberwood using thermal treatment or acetylation and other preservative methods with a view towards increasing its service life as well as improving other properties e.g. dimensional stability.
- Investigation of the economies of production of sawn rubberwood in Nigeria should be carried out towards promoting its use in the timber market majorly for construction purposes which is an important and readily available market in Nigeria and other parts of West Africa.
- Developing strategies towards adequate acceptability and marketability of *Hevea brasiliensis* in Nigeria
- More research should be carried out on lesser known/used species especially from agriculture e.g. *Eleasis guiniensis, Terminalia catappa, Mangifera indica, Cocus nucifera* etc. to explore their utilisation potentials. This will create more diversification of the timber market in the country and might equally contribute to reduce pressure on the well-known species.
- More research should also be conducted on the response of trees to bark and cambial injuries and how it affects wood quality.
- Also reseach on the measurement of physiognomic properties of wood should be carried out.

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