UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION KUMASI

INVESTIGATING SOME CHEMICAL, PHYSICAL AND MECHANICAL PROPERTIES OF *LAGUNCULARIA RACEMOSA* (WHITE MANGROVES) FROM CENTRAL AND WESTERN REGIONS OF GHANA FOR ITS EFFICIENT UTILIZATION

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A thesis in the DEPARTMENT OF CONSTRUCTION AND WOOD TECHNOLOGY EDUCATION, FACULTY OF TECHNICAL EDUCATION, submitted to the School of Graduate Studies, University of Education, Winneba in partial fulfilment of the requirements for the award of Master of Philosophy (Wood Science and Technology) degree.

MAY, 2019

DECLARATION

STUDENT'S DECLARATION

I, Wilberforce Eshun Benjamin, declare that this thesis with the exception of quotations and references contained in published works, which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE: …………………………………… DATE: ………………………….

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for the supervision of thesis as laid down by the University of Education, Winneba.

SIGNATURE: …………………………… DATE: ……………………

SUPERVISOR: DR. FRANCIS KOFI BIH

ACKNOWLEDGMENT

I wish to acknowledge with sincere gratitude the immense assistance, guidance and pieces of advice given me by all lecturers of UEW-Kumasi.

Many special thanks to Dr. Francis Kofi Bih my supervisor, for this direction and correction in preparation of this project.

To Mr. Douglas Amoah (Department of Wood Science and Technology, KNUST), Mr. Haruna Iddrisu (FORIG, Kumasi), Mad. Bridget Brentuo (FORIG, Kumasi), Mr. Kennedy (Anlo Beach), Mr. Sampson Dadzie (Cape Coast Technical Institute),Mr Gary Asamoh and finally, Mrs. Benedicta Mensah-Eshun.

To all of you I say God richly bless you.

DEDICATION

This work is affectionately dedicated to my dear wife Mrs. Benedicta Mensah Eshun and my son, Bernard Wilberforce Eshun.

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ACRONYMS AND ABBREVIATIONS

The following abbreviations and symbols were used in the document:

ASTM	American Society of Testing and Materials
ANOVA	Analysis of Variance
BS	British Standard of Testing Small Clear Samples
CCMA	Cape Coast Metropolitan Assembly
CPG	Compression Parallel to Grain
EBT	Eriochrome Black T
P – Value	Probability Value
MC	Moisture Content
MOE	Modulus of Elasticity
MOR	Modular of Rupture
Fig.	Figure

ABSTRACT

This study aimed at investigating the physico-mechanical properties of *Laguncularia racemosa* (white mangroves) in two coastal regions of Ghana, Western and Central Region, for their efficient utilization. Moisture content and basic density along the stem recorded mean values of 30.81 - 37.19% and 31.49 - 35.30% as well as 612.69 – 625.62 Kg/m^3 and 595.69 – 635.43 Kg/m^3 for Central and Western regions respectively. The mean mechanical property values of trees from the two regions (Central and Western) respectively were: 52.82 – 63.21 Nmm^{-2} and 51.23 – 56.84 Nmm^{-2} (MOR), 6827.24-7711.07 Nmm^{-2} and 5852.73 – 7157.55 Nmm^{-2} (MOE) and 27.05 – 30.73 N/mm^2 and 24.57 – 28.33 N/mm^2 (CPG). The trees from the two regions can be classified as moderately dense wood. The chemical properties commonly showed a fairly low composition in all the parameters analysed, with Western Region generally having higher values. The average values for Central and Western Regions respectively were: 10.59 – 11.27% and 12.65 – 15.62% (lignin), 23.09 – 28.09% and 25.78 – 29.38% (cellulose), 30.72 – 31.52% and 30.52 – 31.56% (organic carbon), 2.39 – 3.26% and 2.62 – 2.94% (ash), 223.41 – 300.32 mg/Kg and 199.55 – 242.66 mg/Kg (nitrogen), 796.64 – 1099.21 mg/Kg and 588.81 – 1035.02 mg/Kg (potassium), 0.01 – 0.02 mg/Kg and 0.02 – 0.04 mg/Kg (phosphorus), 122.29 – 438.57 mg/Kg and 181.98- 475.97 (calcium) and 774.63 - 882.59 mg/Kg and 1024.29 – 1096.83 mg/Kg (sodium). *L. racemosa* generally showed a comparatively higher values in physical and mechanical properties, and low values in chemical properties. It could be exploited for structural applications and fuel energy source for environmentally safe emissions. The organic carbon, ash and inorganic mineral elements composition of *L. racemosa* makes it suitable as a biofuel energy source for industrial purposes.

CHAPTER ONE

INTRODUCTION

1.1 Backgrounds to the Study

Mangroves are trees which have specific characteristics such as tough root system, special bark, leaf structures, and other unique adaptation to enable them to survive in their habitat's harsh conditions. Lewis *et al*. (1995) were of the view that it is possible to restore some functions of the mangrove forests although certain parameters such as the condition and types of soil and the flora and fauna may have changed.

Mangroves are highly valuable ecosystems, providing an array of essential goods and services to human communities living in coastal areas. The array of benefits derived from mangroves includes wood and non-wood products, fisheries, recreation, ecotourism, bio-filtration, coastal protection and carbon sequestration (Spalding *et al*., 2010).

Mangrove forests grow in intertidal coastal habitats in the tropical and subtropics regions of the world. Globally, they are under pressure from the expansion of human activities. Forests are cut down to create new band for aquaculture and urban settlements (Alongi, 2002). Different mangroves species have different wood and bark properties, making some more suitable than others for specific uses (FAO, 1994).

Mangroves ecosystems and their ecological functions potentially provide an array of important indirect services for people such as prevention of storm damage, flood and water control, support of fisheries waste absorption, recreation, and transport (Barbier, 1994). Furthermore, mangroves wetlands may be significant sources of benefits that are independent of human use such as biodiversity services (Aylward and Barbier 1992), Barbier, 1994; Barbier *et al*, 1997). While many of these services and their supporting ecological functions are apparent to scientists, it is unclear if and how local beneficiaries perceive of such services.

The red mangrove is the most distinctive and commonly encountered mangrove in African. With its arching prop roots, it often forms large nearly impenetrable colonies that provide an excellent nesting area and refuge for birds and marine animals. Red mangrove leaves are, blunt at the tip, and have no conspicuous glands. The prominent, long and sharp point's terminal bud is distinctive, as is the horizontal scar seen on the stem between the leaves. Red mangrove flowers have whitish petal that are separate from each other and yellowish sepals. The seeds germinate while still on the plant and grow into elongated torpeds-like structure before falling off. The bark of the red mangrove, which is used for dying and tanning, is the smoothness of the mangroves. Flowering is year-round, though heavier in spring and summer (Giesen *et al.,* 2007).

Historically, mangrove spatial extent and forest type were quantified using aerial photographs taken by systematic flights from a fixed-wing aircraft (Eglar, 1952). Estimates of cover were then made using transparent grid paper and the percent of habitat estimated (Eglar, 1952). Fuelled by scientific evidence supporting their importance, a turnaround in the view of mangroves has been brought about in the last decade. Mangroves act as nursing areas for young fish and other marine life, which are observe to later migrate to coral reefs and other offshore ecosystems (Nagelkerken *et al*, 2000).

Despite the fact that up to 84 species of plants have been recognized as mangroves (Saenger, 2002), an inspection of the literature will reveal that debate and disagreement still occurs when scientists attempt to assign true status to many mangroves. Some follow Tomlinson (1986) and appear comfortable with a two-way categorization of mangroves as either true or associate (Primavera et al., 2004, Kitamura et al., 1997, Hong & San, 1993). Others in contrast prefer to talk of exclusive vs non-exclusives mangroves. This latter group has also been tended back mangroves-references to their typical occurrence toward the landward end of an intertidal mangrove forest. Here the ecotone species would be more appropriate and has been used at various Ecotone Conferences (Maxwell, 1995).

Mangroves have little capacity for vegetative propagation and are thus dependent on seedlings for forest maintenance and spread (Tomlinson, 1995). Although some species (*agerminants and C racemosa*) can respond from stumps (coppicing), this process is not equivalent to propagation. Mangroves exhibit two relatively unique reproductive strategies: Hydrochorg and vivipary (Tomlison 1995, Rabinowitz 1978).

A comprehensive knowledge of the characteristics of any material is essential for its utilization. Ishengoma *et al*. (2004) underlines the importance of knowledge of wood properties of timber species prior to their market promotion. The unique materials of wood are interrelated to each other (Essien, 2011). Analytical studies on these properties by Winandy (1994); Simpson and Tenwolde (1999) and Chowdhury *et al.* (2007), show that they are good examples to each other in terms of unity and interrelations of their properties.

Mechanical properties are the characteristics of a material in response to externally applied forces. Wood density and moisture determine to a great extent the mechanical properties of wood including elastic properties which affect resistance to deformation and strength properties that characterize resistance to applied loads (Tsoumis, 1991). According to Green *et al*. (1999), the most commonly determined mechanical properties are modulus of rupture (MOR) in static bending, maximum stress in compression parallel to grain, shear strength parallel to grain and compressive stress perpendicular to grain. Chemical composition of wood has proven to influence several wood properties and therefore, the suitability of wood to specific purposes (Pereira et al. 2003).

Resource Managers and Foresters, in order to maximise forest values, need to understand not only the principles of tree growth, but also some of the macroscopic and microscopic features that determine wood (Jozsa and Middleton, 1994).

1.2 Statement of the Problem

Depletion of tropical forest remains a major concern to policy makers and environmentalists on account of the critical role that tropical forest play in protecting the global ecosystem. Ghana's rainforest is rapidly disappearing. In 2008, the country saw an alarming 60% decrease in primary rainforest leading to loss of major economic species. This was the highest percentage of rainforest loss of any tropical country. Mangrove forests are another important tropical environment rich in biodiversity, which can be an alternative to the supply of wood to the timber industry. ITTO promotes the use of mangrove forest resources in the tropics. Despite the fact that mangrove ecosystems have tremendous values for coastal communities and associated species, wood from mangroves have received much less publicity and are largely neglected in national and regional policies in West- Central Africa (CEC, 1992; Diop, 1993; FAO,2007). The impact of mangrove utilization are unclear and a recent assessment of the degree of use of forest products rated mangrove use and impacts as not significant for all products (Lawes *et al*., 2004).

1.3 The Purposes of the Study

The purpose of this study is to investigate some physical, mechanical and chemical properties of *Laguncularia racemosa* (white mangrove) from Western and Central regions of Ghana to determine the most appropriate application for it in the wood industry.

1.4. Objective of the Study

The objectives of the study were to:

1. Determine the chemical composition of *Laguncularia racemosa* (white mangrove) wood from Western and Central regions of Ghana.
2. Compare axial variation of mechanical properties of *Laguncularia racemosa* (white mangrove) wood from Western and Central regions of Ghana.
3. Examine axial variation of physical properties of *Laguncularia racemosa* (white mangrove) wood from Western and Central region of Ghana.

1.5 Research Questions

1. What is the chemical composition of *Laguncularia racemosa* (white Mangrove) wood from Western and Central regions Ghana?
2. How does the axial variation of mechanical property of *Laguncularia racemosa* (white Mangrove) wood from Western region compare with those from Central region of Ghana?

3. How does physical property of *Laguncularia racemosa* wood (white Mangrove) from Western and Central regions Ghana vary axially?

1.6 Significance of the Study

The values and uses of mangrove resources are many and of great importance to the socio-economy of human communities that live in the mangrove areas. Mangrove products and the mangrove environment have traditionally been used by the local people who live in the mangrove areas for a long time. The findings of the study are expected to provide data on mangrove species in Western and Central Region of Ghana to ensure effective utilization of Mangroves by all stakeholders and also to stimulate intensive research into other management areas, as well as other mangrove ecosystems of the country. Also, availability of reliable data on species composition and properties is crucial to the development/review of policies governing mangrove utilization.

1.9 General Layout of the Study

This study comprised of six chapters. The chapter one deals with the background to the study, statement of the problem, the purpose of the study. Research questions, significant of the study, limitation of the study, delimitation of the study and general layout of the study.

Literature review is the subject of chapter two. This chapter deals with mangroves and its ecosysytems, importance and uses of mangroves, wood biomass properties, physical and mechanical properties of wood. Chapter three focus on the materials and methods, which includes the research design, the collection of tree samples and procedures for preparing specimens for various tests conducted. Chapter four outline the result of the study form the data gathered from the experiment. Chapter five discussed the result of the study. The final chapter deals with summary of the findings, conclusion, recommendation and suggestion for future studies.

CHAPTER TWO

LITERATURE REVIEW

This chapter focused on reviews literature on mangroves and other related literature to the topic as expressed by the various authors.

2.1 Mangrove

Mangrove forest grows in intertidal coastal habitats in the tropics and subtropics. Globally, they are under pressure from the expansion of human activities. Forest are cut down to create new land for agriculture, aquaculture and urban settlement (Giri *et al.,* 2008). Mangrove act as nursing areas for young fish and other marine life, which are observed to later migrate to coral reefs and other offshore ecosystems (Nagalkerken *et al.,* 2008).

The term "mangrove" refers to an assemblage of tropical shrubs that grow in the intertidal zone. Mangrove includes approximately 16 families and 40 to 50 species (depending on classification) (Ellison, 2000; Christensen, 1983). Mangrove is a non-taxonomic term used to describe a diverse group of plants that are all adapted to a wet saline habitat. Mangrove may typically refer to an individual species. Terms such as mangrove community, mangrove ecosystem, mangrove forest, mangrove swamp, and mangle are used interchangeably to describe the entire mangrove community (McKee, 1996).

There is a general latitudinal trend in mangrove productivity such that it is highest in forest near the equator and decreases with latitude (Saenger and Snedaker, 1993). At finger spatial scales mangrove productivity is influenced by a variety of factors such as, climatic condition, species composition, forest age and structure, hydrology, salinity, and soil characteristics (Twilley *et al*., 1990).

In general mangrove vegetation is more luxuriant in lower salinities (Kathiresan et al, 1996). Experimental evidences indicate that at high salinity, mangroves spend more energy to maintain water balance and ion concentration rather than for primary production and growth (Clough, 1984).

2.2 Types of Mangroves

2.2.1 Red mangrove

The red mangrove has stout, curve drop roots, which arch down into the water from their trunks, and long, slender aerial roots, which are like thin fingers reaching into the water, cannot be mistaken for any other tree like other roots, theirs have two main functions – support and breathing. Extraordinary conditions require special adaptations (changes in the structure and function that make a plant or animal more suited to its environments and the prop roots are very different from normal roots (FAO, 2007).

Arching around the main trunk like tangled legs; they support and spread the weight of the trunk branches, and leaves and thus enable the tree to stay upright in muddy, tidal, and windy conditions. Like the aerial roots, the parts above the water are covered with tiny pores or l or lenticels (which look like small knobs, through which the tree can breathe. This is necessary because the mud on which Red Mangroves grow is so low in oxygen that no ordinary roots could breathe there. If the lenticels are covered with water for too long, the mangroves will die. This often happens as a result of a cyclone (FAO, 2007).

2.2.2 Black mangrove (*Aricennianitida*)

Black mangrove is an evergreen shrub or small tree 3 – 12 meters in height. Pneumatophores, pencil-like projects that often rise 5 – 10cm, can be found along the horizontal roots. The bark is dark grey or brown and smooth on small trunks. Leaves are opposite, lance-shaped are thick and leathery. They are 5 – 11cm long and 2 – 4cm wide. Fine hares on the underside of the foliage give it a grayish hue (Duke, 1983).

The seed is flat, fuzzy and tear-drop shaped, 2 – 3cm in length and 1 – 2cm in width. As seed ripen, they turn from bright green to a greenish-yellow. If seeds drop from the shrub into water, the seed coat will loosen and fall off. The cotyledons will swell and open, with the primary root emerging from the widest end (Little, 1983).

2.2.3 White mangrove

The white mangrove is one of the three true species of mangroves found within the West African. This mangrove is found further inland than the red mangroves. It is usually best identified by the coloration of its flowers which are white. White mangrove flowers are easy identification markers. Also note the round shape of the leaf. White mangrove propagates (seed) after flowers are pollinated; they develop into these seeds which can become a new white mangrove tree. Since white mangroves are found closer inland than the red mangroves, they act as a catchment system for some environmental pollutants, capturing the marine environment and affect other marine life (FAO, 2007).

2.2.4 Mangrove ecosystem

Mangrove ecosystems, like other complex environmental and natural resources are potential sources of wood services (Aylward and Barbier, 1992; Barbier, 1994, Barbier *et al* 1997). Nonuse services are those benefit to people that do not flow from direct use of the ecosystems (Freeman, 1993). Example of nonuse services include; the value of knowing that a resource simply exists, These vital coastal ecosystems protect the shore against erosion, filter and assimilate pollutants, stabilize bottom sediments, and provide breeding habitat and protection for maturing offspring of birds, mammals, crustacean, and fish populations (Mitsch and Gosselink 2000).

Research on large-scale model ecosystems, or mesocosms began in the 1960s and has been applied extensively to waste water treatment, aquaculture, and environmental impact and ecological a risk assessment (Giesy 1980, Odum 1984, Graney *et al.,* 1994). Mangrove ecosystems are found in intertidal areas of sheltered coastlines called lagoons and estuaries. Mangrove wetlands maintain high levels of biological producing, export nutrients to outside water, and provide habitat for valuable plants and animal species (Clark 1996). Researchers have identified mangrove ecosystems as important to the subsistence livelihoods of tropical coastal communities (Hamilton and Snedaker, 1984). Mangrove ecosystems may be directly exploited by extracting food such as fish, agricultural product, wildlife and wood (Kunstadter et al., 1985; Hirsch and Mauser, 1992; Ruitenbeek 1992; Bennet and Raynold, 1993; Bann, 1997; Farnsworth and Ellison, 1997; Kovacs, 1999).

2.3 Importance and Uses of Mangrove

Fuelled by scientific evidence supporting their importance, turnaround in the view of mangroves has been brought about in the last decade. Mangroves act as nursing areas for young fish and other marine life, which are observed to later migrate to coral reefs and other offshore ecosystems (Nagelkerken *et al* 2000). They are also known to capture pollutants, and to prevent coastal erosion by consolidating sediments (Alongi, 2008). These functions support adjacent coastal and offshore environments, as well as the people dependant on these resources (Walters et al., 2008).

Mangroves are important ecosystem that provides a wide range of goods and services to human communities living in coastal areas. The array of benefit derived from mangroves includes wood and non-wood forest products, fisheries, recreation, ecotourism, bio-filtration, coastal protection, and carbon storage and sequestration (Spalding *et al*., 2010). The impact of mangrove resources use by local villages can be sustained as if forms an integral part of the ecology and functioning of the ecosystem (Spalding *et al.,* 2010). Mangrove resources use by local villages can be sustainable as it forms an integral part of the ecology and functioning of the ecosystem (Spalding *et al,* 2010. One of the most common use of mangrove is as a source of wood (e.g. Ewel *et al.,* 1998; Spalding, 2004; Walters *et al.,* 2008; Spalding *et al*., 2010).

Mangroves are also an important resource for a wide range of non-wood forest product such as are tannin, dye, medicine, thatch and single, nypa sap for vinegar, wine making and food, and honey. (Spalding, 2004; Walter et al., 2008; Spalding *et al*., 2010).

The importance of mangrove generally cannot be over emphasized. Mangrove trees remained the most efficient photo synthesizers than almost any other plant; mangrove forms a life support system for much of the tropical world's coastal marine life (Russell 1996). Equally Quarto (2001) in a quarterly report of mangrove Action project showed statistically that three-fourth of the tropical world's fisheries depend upon mangrove forest.

In a related development, Mantra (1986) in the study of socio-economic problems of the Kampung Laut community in central Java also showed that mangrove serves in the protection of shorelines from erosion and flooding regulation, violent storms an and hurricanes.

2.4 Wood Biomass Properties

Telmo, Lousada, and Moriera, (2010) made known that the largest constituents in wood is carbon, which comprises 45 to 50 percent of its mass, followed by hydrogen, at roughly 6 percent. Other major elements in order of decreasing amount are nitrogen (N), calcium (Ca), Potassium (k), sodum (Na), Magnesium (Mg), Manganese (Mn), Iron (Fe) and aluminum (Al).

Minor element includes: cadmium (cd), Chromium (Cr), Copper (Cu), nickel (Ni) Zinc (Zn), arsenic (As), mercury (Hg) and lead (Pd). Mckendry (2002) also revealed the moisture properties of wood biomass, during processing as an energy source related to: moisture content (intrinsic and extrinsic), Calorific value, properties of fixed carbon and volatiles, ash/residue content, alkali metal content, cellulose/lignin ratio. Potassium is needed for the photosynthetic process, stomatal activity, protein synthesis, and enzyme activation (Reef *et al*., 2010). Though in saline environment, such as mangrove ecosystems, K is also important on mangrove nutrition, most focus has been on nitrogen and phosphorus. Usually, they are limited by low availability of either N, or P, and sometimes both (Kravss *et al*., 2008; Lovelock *et al*., 2004). While mangrove are less limited by the availability of potassium, calcium and magnesium due to their ampleness in sea water (Along, 2011).

2.5 Biomass

Biomass is a renewable fuel that supplies 2% to 3% of U.S energy needs and an even larger percentage in some other countries (OTA 1980; DOE 1982). The potential of biomass for world use is equally great (Bioenergy 1985). Care must be taken to ensure that biomass use as fuel is on a renewable basis (Lowdermilk 1975; Reed 1978). Backman *et al.* (1990) derived a correlation for biomass derived oils. The predictions of the correlations were found to be within 5%. Grabosky and Bain (1981) has derived the correlation of biomass based on pertinent reactions of C, H, S and N to CO_2, H_2O, SO_2 and NO_2. The predictions of the correlations were found to be within 1.5%. Gravalos (2010) has tested the biomass lignocelluloses crop samples in the laboratory and found out the root and main stem of the plant have the same calorific value and lowest calorific value can be obtained at the leaves. Also seeds flowers of a plant can be the highest calorific value.

2.5.1 Hydrogen content

Consideration of hydrogen from carbonaceous materials has a long history in the hydrogen literature. At the first world energy conference, Tsaros *et al.* (1976) reported on three routes to hydrogen using sub-bituminous coal. Hydrogen yield of 93-96% of the theoretical were predicted Gallin-ast (1999) has a patent entitled "method and apparatus for production of hydrogen, particularly high-purity hydrogen, during gasification of biomass. Midilli *et al*. (2001) was studying the use of an air-blown, downdraft gasifier for hydrogen from hazelnut shells. Higher hydrogen content leads to a higher heating value (Clarke & Preto, 2011).

2.5.2 Oxygen content

The oxygen however solely sustains the progression of the oxidation process. It constitutes 44.3% with the rest of inorganic ash. Softwood has lower oxygen content than the hardwood (Clark & Preto, 2011).

2.5.3 Nitrogen (N) content

The allocation of biomass, nitrogen and sapwood within a tree all have profound impact on the physiology, growth, and distribution of species. Stem cross-section sapwood area and total sapwood volume greatly influence foliage area, transpiration and stem respiration. Following the pipe model theory (Shinozaki *et al.,* 1964), leaf area is correlated with cross-sectional sapwood area (Waring et al., 1977, 1980, 1982; Rogers & Hinckley 1979; Kaufman &Troendle, 1981).

The nitrogen content of biomass varies from 0.2% more than 1% (Jenkins et al 1998). Telmo, Lousada and Moriera, (2010) are of the view that nitrogen content in wood is lower than in cereals.

2.5.4 Carbon (C) content

According to Francescasto and Bergomi (2008) in their wood fuel handbook carbon is the solid biofuel component through whose oxidation the fuel energy content is released. Carbon is the name applied to a chemical element that occurs in dozens of physical forms, both pure (such as diamond and graphite) and impure (such as coke, charcoal, and soot).

Furthermore, Sean, Martin, Thomas and Adam (2012) indicated that 50% carbon content assumptions is not accurate also maintained that there is substantial variation in carbon content among species as well as among tissues types. They asserted that wood carbon content varied widely across species ranging from 41.9-51.6% in tropical species, 45.7-60.7% in subtropical/Mediterranean species, and 43.4 – 55.6% in temperate/boreal species. Stem wood carbon content varied significantly as a function of biome and species type (Conifer, angiosperm). Conifer species exhibited greater wood carbon content than angiosperm species (50.8 + 0.7%) and 47.7 + 0.3% respectively.

Also, Ragland *et al.* (1991) asserted that the carbon content of softwood species is 50-53% and that of hardwood species 47 - 50% due to the varying lignin and extractives content. Higher carbon content leads to a higher heating value.

2.5.5 Ash content

It is the inorganic matter left out after complete combustion of the biomass. The inorganic component can be expressed as some as the moisture content on a wet, dry and ash free basis. In general, it is expressed on dry basis.

The chemical composition of ash has an immediate effect upon its thermal characteristics. The thermal characteristics of ash from biofuel depend significantly upon the content of calcium, magnesium, and potassium in the ash of biofuel (Malatak and Vaculik 2008; Jandacka*et al* 2011; Dzurenda and Jandavcka 2015).

2.5.6 Volatile matter content

Volatile matter refers to the biomass that released when the biomass is heated (up to 400 to 500ºC). During this heating process the biomass decomposes into volatile gases and solid char. Biomass typically has a high volatile matter content (up to 80 percent), whereas coal has a low volatile matter content (less than 20 percent) or, in the case of anthracite coal, a negligible one.

2.5.7 Calorific value

The calorific value is one of the most important characteristics of a fuel, and it is useful. For planning and control of the content that develops the mass (weight) in its complete combustion with oxygen in a calorimeter standardize. It is defined as the amount of heat energy released during the complete combustion of unit mass of biomass (Francescato, Antonini & Bergoni, 2008).

Tillman (1978) observed that the calorific value has a very strong influence of its carbon content and accordingly he derived the correlation for colorific value of biomass and its elementary components. Khan and Abu Garah (1991) found a new approach for finding calorific value of municipal solid waste based on combustible components such as waste paper, plastic waste, leather, rubber and food.

2.5.8 Charcoal

Charcoal manufacture dates to prehistoric times and is a well-established industry today with standard for its various uses. Charcoal is simpler to gasify, and it is easier to clean up the gas for engine use than biomass gas because of charcoal's low volatile content. Charcoal is produced by heating wood at conditions that restrict the amount of oxygen.

2.6 Lignin

Lignin is a complex hydrophobic network of phenylopropanoid units that is thought to result from the oxidative polymerization of one or more. Lignin, the third cell wall component, is an aromatic polymer synthesized from phenylpropanoid precursors (Adler 1997).

Koch et al., (2004) made known that lignin provides the hydrophobic surface that allows plants to transport water to heights greater than 100m and contributes to the mechanical strength that can support trees weighing more than 20,000 metric tons. Lignin has higher energy content than cellulose or hemicelluloses. One gram of lignin has an average 2.27KJ, 30% more than the energy of cellulosic carbohydrate (White, 1987). The energy content of lignin is similar to that of coal (Malaughlin et al., 1996). Mcknedry (2002) revealed that lignin influences calorific value.

2.7 Cellulose

Cellulose is a simple polysaccharide. It is polymer of the six-carbon reducing sugar, D-glucose. A single unbraced cellulose molecule, about 3 to 5um in length, is comprised of about 7000 to 12,000 glucose units. The basic structural component of plant cell walls, cellulose comprise about 33 percent of all vegetable matter, 90 percent of cotton, 40-55 percent of hardwood are cellulose and 40-50 percent of softwood are cellulose and is the most abundant of all naturally occurring organic compound. Non-digestible by man, cellulose is a food for herbivorous animals (e.g. cows, horses) because they retain it long enough for digestion by micro-organisms present in the alimentary tract, protozoans in the gut of insects such as termites also digests cellulose.

Cellulose is abundantly found in wood and other lignocellulose plants. It has been mainly derived from wood since Burgess and Watt in England employed caustic soda to pulp wood chips in 1851. Cellulose also undergoes changes in crystalline structure, cellulose can be dissolved in certain specific complexes and concentrated and bases. Celluloses is a long-chain linear polymer exclusively constructed of β-1, 4- linked D-glucose units which can appear as a highly crystalline material (Fan et al,, 1982).

2.8 Extractives

There is evidence that the extractives in wood act as lubricants and effectively decrease the coefficient of friction during wood cutting (Mckenzie and Karpovich, 1968); however, studies indicate that the extractives in wood adversely affect wearing of cutting tools (Darmawan *et al*., 2012).

In the period after 1980, chemical wear due to extractives in the woods, such as gums, fat, resins, sugars, oils, starches, alkaloids, and tannins, has also been reported as an important factor in determining the overall wear of woodworking factor in determining the overall wear of woodworking cutting tools (Fukuda et al, 1992; Krilov 1986; Morita et al. 199; Murase 1984; and Darmawan and Tanaka 2006).

Heartwood extractives are formed in situ at the sapwood-heartwood extractives are formed translocated carbohydrates or lipid substrates that infiltrate the cell walls (Saranpaa and Piispanen 1994; Hillinger et al. 1996; Margel 2000; Beritognolo et al, 2002). Larch heart wood contains high amount for extractives (Dix and Rofferel 1997); the major part consists of arabinogalactan, a water-soluble and heavily branched polysaccharide comprising 5-30% of the total by weight (Cote et al 1966).

2.9 Wood Cells

The plant cell wall protects the protoplast from osmotic lysis and often provides mechanical support to the plant at large (Esau 1977, Raven and other 1999, Dickson 2000).

Cell wall substance plays an important role in material properties. Boyd (1974) found that variations in shape of cell cross-section and wall thickness have an influence on anisotropy of shrinkage. Wood anisotropic material properties and shrinkage has been demonstrated to be related to the cell wall amount and structure in wood (Shaar 1988 and Pentony1952). Quirk (1984) gave his testing results to show that wood basic density was highly correlated with cell-wall thickness.

2.10 Hemicelluloses

Hemicelluloses' consist of relatively short heteropolymer consisting of the pentose's D-xylose and L-arabinose and the hexoses, D-glucoses, D-mannose, D-galactose, D-rhamose and their corresponding ironic acids. It is composed of only 500-3000 sugar units, and thus has a shorter chain than cellulose (Saka 1991,).

2.11 Mechanical Properties of Wood

Wood may be described as an orthographic material that is it has unique and independent mechanical properties in the directions of three mutually perpendicular axes; longitudinal, radial and tangential. According to Green and Evans (1987) mechanical properties most commonly measured and represented as strength properties for design include modulus of rupture in bending, modulus of elasticity parallel to the grain, compressive stress parallel and perpendicular to the grain, and shear strength parallel to grain. Additional measurements are often made to evaluate work to maximum load in bending, impact bending strength, tensile strength perpendicular to grain, and hardness.

2.11.1 Modulus of elasticity (MOE)

Elasticity is the ability of a material to return to its pervious shape after stress is released. In many materials the relation between applied stress and the resulting strain is directly proportional (up to a certain limit), and a graph representing those two quantities is a straight line. The slope of this line is known as Young's Modulus or the Modulus of elasticity (Timoshenko, 1976). The En 408 specifies two methods or forms of determining modulus of elasticity: the local and global. The local modulus of elasticity is in principle based on pure bending deflection whilst the global modulus of elasticity is influenced by shear deflection (Solli, 1999). When measuring the global modulus of elasticity, the total deflection will be a combination of bending and shear deflection. The contributory effect of the shear deflection makes a fundamental difference between the global and local modulus of elasticity (Bostrom and Holmquist, Soli 1999).

The global modulus is not as sensitive to inaccurate measurements as the local modulus since the global deflection is about ten times the local. The local modulus is a principle based on pure bending deflection whilst global modulus is also influenced by shear deflection. A measurement of the global modulus contains a higher number of possible sources of error. Because of the size of the total deflection the consequences of an error will normally be relatively small. If the intended use of MOE is to estimate the corresponding bending strength of a piece of timber, the local modulus is the unveiled alternative of the two methods. This is of special importance concerning bending type of strength.

2.11.2 Modulus of rigidity

The modulus of rigidity, also called shear modulus, indicates the resistance to deflection of a member caused by shear stresses (Green *et al*., 1999). The three moduli of rigidity denoted by GLR, GLT, and GRT are the elastic constants in the LR, LT, and RT planes, respectively. As with moduli of elasticity, the moduli of rigidity vary within and between species and with moisture content and specific gravity (Forest Products Laboratory, 2010).

2.11.3 Compressive strength

Maximum stress sustained by a compression parallel-to-grain specimen having a ratio of length to least dimension of less than 11(Forest Products Laboratory, 2010). The compression strength of a wood sample can be measured either in the longitudinal direction or in the radial and tangential directions. The maximum compressive strength parallel to the grain is a measure of the wood strength when used as a stud or column. The strength of the relationship between density and compression strength increases with increasing distance from the pith. Generally, compressive strength perpendicular to the grain is calculated from either the applied load at the proportional limit or the load required to generate a fixed amount of deformation (Green *et al*., 1999)

2.11.4 Tensile strength

Tensile strength is the ability of a material to resist the force that pulls the material and tries to elongate or stretch it (Dinwoodie, 2000). Tensile strength perpendicular to the grain is vital in design of the connections between wood members in a building. In contrast, tensile strength parallel to the grain is essential for the bottom member in a wood trusses and in the design of connection between structural members (Haygreen and Bowyer, 1996). However, because of the extreme variability associated with ultimate stress in tension perpendicular to the grain, design situations that bring about this stress should be avoided (Bodig and Jayne, 1982).

2.11.5 Shear strength

According to Shrivastava (1997), shear strength measures the ability of wood to resist forces that tend to cause one part of the material to slide or slip on another part adjacent to it. Shearing stresses may be parallel to, or perpendicular to the grain, but it can be shown that a shearing stress sets up an equal stress at right angel to it, and since wood is much stronger in shear across the grain than it is along the grain, it is very challenging to acquire the true shear strength perpendicular to the grain, as failure always occurs by shear parallel to the grain. Shear strength parallel to the grain is the ability to resist internal slipping of one part upon another along the grain (Forest Products Laboratory, 2010). Horizontal shear, a shearing force that tends to move the fibers of a beam past each other in a longitudinal direction. This result from the slipping over one another of the fibers as several boards are placed longitudinal on each other, tend to bend. Tsuomis (1991) stressed that the wood strength in axial shear has the greatest practical importance; under the influence of shearing loads, wood usually fails in this manner.

2.11.6 Factors affecting strength properties of wood

Aside density, other factors also influences strength and stiffness of timber. Factors such as knots, slope of grain and microfibrillar angle, and moisture content and temperature, all play an important role in determining the strength and stiffness of wood (Desch and Dinwoodie, 1996). Natural defects such as pitch pockets may arise as a result of biological or climatic elements which in turn influences tree growth. These wood characteristics must be considered when assessing actual properties or estimating the actual performance of wood products (Forest Products Laboratory, 1999).

2.12 Physical Properties of Wood

2.12.1 The density of wood

The basic density of wood can be defined as mass of the wood per unit volume. Haygreen and Bowyer (1996) indicated that density is possibly one of the most important factors influencing the mechanical properties of timber and perhaps, it is for this reason that density was the first wood property to be scientifically investigated. Tsoumis (1991) pointed out that density is the best and simplest index of the strength of a clear wood, with increasing density, strength also increases. This is because density is a measure of the amount of cell wall materials contained in a given volume of wood. Therefore, higher density denotes larger amount of cell wall available to resist external forces. The density of wood is probably the most descriptive of all properties. The main structural compounds, such as the cellulose, hemicelluloses and lignin have similar densities, thus any combination of these compounds leads to an approximate density of 1.53g/cm^3 of the cell wall substance regardless the wood species (Kollmann and Côté, 1984).

Wood density is also an important timber property that influences the yield and quality of solid wood products and wood-based composites (Alteyrac*et al*., 2006; Gryc and Horácek, 2007). Thermal conductivity and diffusivity of wood are influenced by density and porosity (Suleiman *et al*., 1999). Wood density varies within the plant, during the life of the plant, and between individuals of the same species. The branches and the outer part of the trunk tend to have a lighter wood than the pith (Chave*et al*., 2006). The density of wood therefore, varies with cell size, cell wall thickness, and the volume proportion of cells of a given type and affects wood shrinkage and swelling, machinability (Haygreen and Bowyer, 1996). However, use of relative density as a single indicator of the strength and stiffness of wood can be misleading because wood of the same relative density can have a wide range of bending strengths due to other factors such as fibril angle and grain length (Skaar, 1998).

There is no universally accepted procedure for calculating the density of wood. Wood density is frequently expressed in terms of their green weight and green volume when calculating weights for transportation or construction. Therefore, it is very important to be sure of the basis of the calculation when working on wood density. It is good practice to calculate density (the mass per unit volume) by determining the mass and the volume at the same moisture content. The moisture content at which the density is determined should then be noted (Shmulsky, 2011).

The density of wood is not evenly distributed along the stem radius but it is distributed relatively to the growth ring structure. The growth ring consists of lighter earlywood and darker latewood. Latewood is made of cells which have thicker walls and smaller lumina as compared to earlywood. This results in a higher density of latewood (Fromm *et al*.,

2001) and explains why the density of wood increases with increasing proportion of latewood (Panshin and De Zeeuw, 1980, Tsoumis, 1991). Since denser wood shrinks more than less dense wood, it is expected that variations in basic density might lead to some variation in shrinkage (Ofori and Brentuo, 2010).

2.12.2 The moisture content of wood

Moisture Content of wood can be defined as the quantity of water contained in the woody material (Alexandre, 2011). The moisture content in wood is found as water vapour, free water in the cell lumens and cavities and as bound water within the cell walls (Siau, 1979; Choong and Achmadi, 1991). The amount of free water depends on porosity, while the amount of bound water is related to the free hydroxyl groups of the main structural compounds that can attract water molecules by electro-static forces (Suleiman *et al.*, 2006).

The equilibrium moisture content (EMC) is defined as the MC at which wood neither gains nor loses moisture (Choong and Achmadi, 1991). The equilibrium moisture content (EMC) of wood therefore constantly changes, sometimes when wood is exposed to rain. Wood exposed to high humidity conditions or to liquid water during use may be subjected to biological deterioration. Kirk and Cowling (1984), states that, “liquid water is needed in wood cells to provide a medium for diffusion of the enzymes or other metabolites by which wood-decomposing organisms can digest the wood substance. The MC of wood below the FSP is a function of temperature and relative humidity (RH) of the surrounding environment (Skaar, 1998).

Moisture affects the strength properties when it changes below the fiber saturation point. When moisture is reduced, strength increases and vice versa. This increase is due to changes in the cell walls, which become more compact (Tsoumis, 1991). However, Desch and Dinwoodie (1996) indicated that the change in strength with changing moisture content is non-linear and that the percentage increase in strength for a given reduction in moisture content is greater at low compared with high levels of moisture content.

In buildings, wood is subjected to shrinkage, swelling, mould growth and rot if exposed to unfavourable environmental conditions. These phenomena are all related to moisture content and moisture conditions in a building. Rot may occur in wood which is in contact with liquid water for some time, while shrinkage, swelling and mould growth are mainly related to hygroscopic moisture. Wood and wooden materials during construction are exposed to changes in climate continuously. Outdoor climate changes occur throughout the day and night, and throughout the year (Skaar, 1998).

According to Findlay (1978), at 12% MC air-dried wood may carry twice the load green timber is able to bear. All strength properties values are not affected in the same way by changes in MC. 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.

In Ghana, the monthly range of equilibrium moisture content of wood when exposed to normal conditions outdoors but under cover, is between 4.8 – 19.3%. This mean annual values ranges from 9.8% in the Northern part of Ghana to 18.3% in Central part of Ghana

(Ofori, 1999). Desch and Dinwoodie (1996) also reported that moisture content may vary with height in a tree.

2.12.3 Shrinkage

Wood is dimensionally stable when the moisture content is greater than the fiber saturation point. Wood changes dimension as it gains or loses moisture below that point. It shrinks when losing moisture from the cell walls and swells when gaining moisture in the cell walls (Forest Products Laboratory, 1999). This shrinking and swelling can result in warping, checking, splitting, and loosening of tool handles, gaps in strip flooring, or performance problems that detract from the usefulness of the wood product. Therefore, it is important that these phenomena be understood and considered when they can affect a product in which wood is used (Forest Products Laboratory, 1999).

With respect to shrinkage characteristics, wood is an anisotropic material. It shrinks most in the direction of the annual growth rings (tangentially), about half as much across the rings (radially), and only slightly along the grain (longitudinally). The combined effects of radial and tangential shrinkage can distort the shape of wood pieces because of the difference in shrinkage and the curvature of annual rings (Forest Products Laboratory, 1999).

CHAPTER THREE

MATERIALS AND METHODS

This chapter of the study includes a description of the research design, study area, collection of samples and sample procedure, data collection techniques and instrument and data analysis.

3.1 Research Design

Experimental research was used to investigate the chemical composition, physical and mechanical properties of *Laguncularia rasamosa* (white mangroves).

Purposive sampling was used for the selection of trees in both Regions. Trees of 14-16 m in height and 30 cm in diameter were selected. In Central Region three sample trees were cut from Abakam in Cape Coast metropolis and Western Region three sample tree from Anglo beach in the Shama District.

3.2 Study Area

Laguncularia rasamosa were obtained from Abakam in the Central Region and Anlo beach in the Shama District of Western Region of Ghana.

3.2.1 Abakam study area

Abakam is characterized by a dry-summer tropical savanna climate. It is a humid area with mean monthly relative humidity varying between 85% and 99%.It has a double

maximal rainfall, with annual rainfall total between 750 and 1000mm. Vegetation consists of mainly shrubs, grasses and trees.

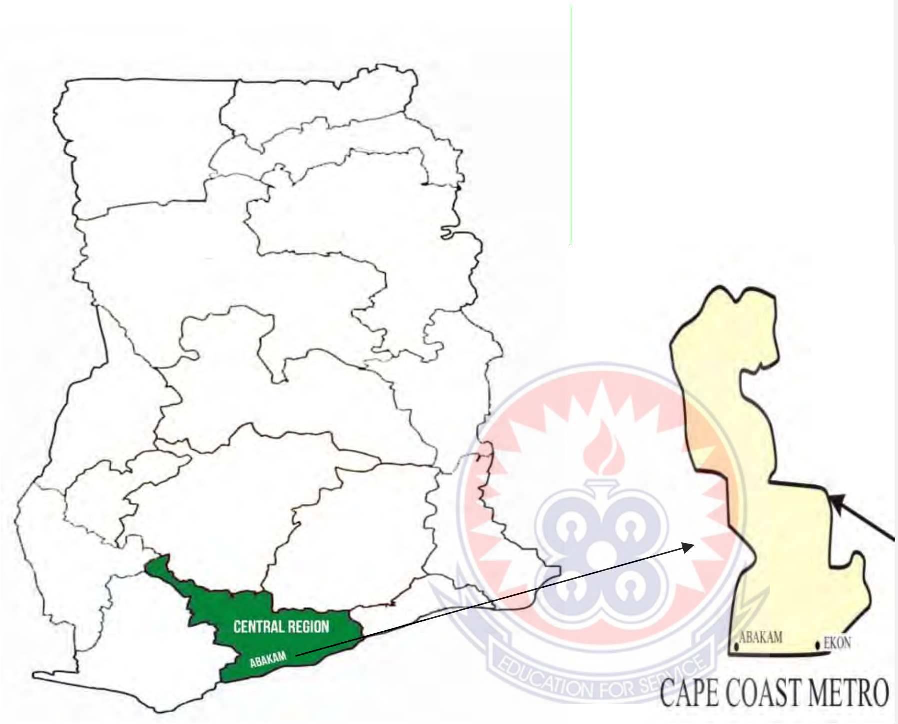

Plate 3.1: Map Showing the Sampled Community in the Central Region of Ghana

3.2.2 Anglo beach study area

Anglo beach area in the Shama District of Western Region lies within the tropical climate zone and experiences two raining seasons. Mild temperatures are experienced in the Anlo beach area ranging between 22ºC and 28ºC. Vegetation is comprised mainly coastal thicket, thin to dense shrubs. Coastal thicket is intermingled with tall grass species and mangroves swamps. The Northern part is made of thick bushes with other small trees.

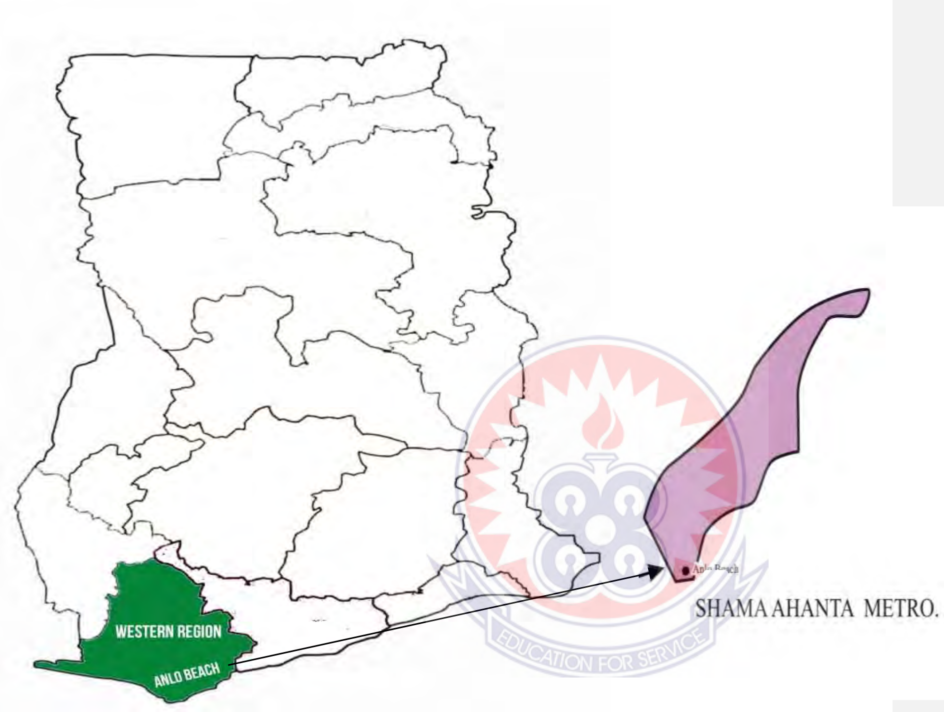

Plate 3.1: Map Showing the Sampled Community in the Western Region of Ghana

3.3 Collection of *Laguncularia racemosa*

Three matured *laguncularia racemosa* trees measuring 14-16 m in length and 30 cm in diameter were randomly selected from the Abakam in the Central Region and Anloga beach in Western Region of Ghana. The felled *Laguncularia racemosa* (white mangrove) bole was divided into three sections above the breast height of 1.3 m; the base, middle and top with each section measuring 3.3 m. They were labeled and transported to the Workshop for further processing.

3.4 Physical Properties of *Laguncularia racemosa*

The physical properties that were determined for this research were: moisture content (MC) and basic density according to BS 373 (1957).

3.4.1 Preparation of test samples

At the workshop, 2 x 2 x 2 cm discs were cut from air-dried, defect free billets prepared from each section of the trees from the two regions and labelled accordingly and again wrapped in a polythene bag to reduce the rate of moisture loss. In all, a total of sixty samples comprising twenty from each section were processed for each physical property and was sent to laboratory for testing.

3.4.2 Moisture content

MC was determined using the oven-dry method with the dimensions, 20 × 20 × 20 mm (Panshin*et al.,* 1980). The samples were weighed and oven-dried for 24 hours at 103±2°C and then re-weighed until constant mass was attained. The moisture content (MC) was calculated using the formula (Hartley and Merchant, 1995):

$$\%\ \mathrm{MC} = \frac{\text{Initial mass} - \text{oven dry mass}}{\text{oven dry mass}} \times 100$$

3.4.3 Basic density

The test samples were cut into the dimensions of 20 × 20 × 20 mm (Panshin*et al.,* 1980). Wood samples were soaked in water for 72 hours to ensure that their moisture content was above the Fiber Saturation Point (FSP). The dimensions for each sample was measured with a digital caliper to the nearest 0.001 mm. The samples were then oven-dried at 103 ± 2º C for 24 hours and re-weighed. They were re-dried at 2 hour intervals until no difference in weight was recorded. The basic density was calculated using the formula (Erwinsyah, 2008):

$$\rho = \frac{\text{oven dry mass}}{\text{saturated volume}}$$

Where, ρ is density (g/cm^3)

3.5 Mechanical Properties of *Laguncularia racemosa*

Determination of mechanical properties (MOR, MOE and CPG) of was carried out using BS 373 (1957).

3.5.1 Preparation of test samples

The sections of air-dried *Laguncularia racemosa* were sawn into billets using the quarter sawing method. Desired samples sizes (Table 3.1) for the various tests (compression parallel to the grain, and static bending) were then obtained from defect-free billets. Twenty samples each from the base, middle, and the crown of *Laguncularia racemose* were used for each of the mechanical properties test.

Table 3.1: Sample sizes and the number of replicates used for Mechanical Properties

Type of Test	Sample Size (mm)	Part of Stem Used			Total
		Base	Middle	Top	
Compression Parallel to Grain	20×20×60	20	20	20	60
MOE and MOR	20×20×300	20	20	20	60

3.5.1 MOR and MOE of L*aguncularia rasomosa*

The test procedure for MOR and MOE involved the determination of the maximum load required to cause rupture using small clear wood specimens (BS 373, 1957). A laboratory table with two metal supports solidly mounted by means of screws was used for the experiment. A rectangular-shaped metal was hanged at the midpoint of the specimen and a hook with a circular base was hanged on the metal. The test specimen was placed on the supports, maintaining a length of 10mm at both ends of the support. Weights were placed on the specimen until failure and the maximum load that caused failure of the test samples were recorded. The MOR in three-point bending was calculated using the formula (Haygreen and Bowyer, 1981):

$$\text{MOR} = \frac{3\text{PL}}{2\text{bd}^2}$$

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

P = maximum load (N),

L = span in mm,

b = the width of sample (mm), and

d = depth of sample (mm).

The ultimate strength [pW (12%)] was computed at an adjustment of strength at 12% moisture content, using the equation $pW(12\%) = pW\{1 + \alpha(\text{W} - 12)\}$(Haygreen and Bowyer, 1981), where: W is the mc of the test specimen and α is a constant, 0.04.

The Modulus of Elasticity (MOE) in three-point bending was calculated using the formula (Pashin, 1974; Bektas*et al*., 2002);

$$\text{MOE}=\frac{l^3}{4bd^3}\text{ x }\frac{\Delta W}{\Delta X}:$$

Where: MOE is Modulus of Elasticity (N/mm²),

W= load (N),

L= the length of span (mm),

b= width of specimen (mm),

d= depth or thickness of specimen (mm) and

Δx= deflection at mid-span.

The term $\frac{\Delta W}{\Delta X}$is the gradient of the elastic region of the load-deflection graph.

3.5.2 Compressive strength parallel to the grain

A crosshead load was applied at a rate of 0.01 mm/s through a ball contact plunger. The compressive strength parallel to the grain of each piece was calculated by dividing the maximum load (Pmax) recorded during test by the cross- sectional area (A) of the specimen using the formula (Haygreen and Bowyer, 1981):

$$\text{pW}=\frac{pmax}{b.l}$$

Where: Compressive strength parallel to the grain (N/mm²),

pmax = the maximum load (N) and

b = the thickness of the piece (mm) and l = the length.

3.6 Determination of Chemical Composition of *Laguncularia racemosa* (white mangroves)

The samples were sent to the General Chemistry Laboratory, Department of Wood Science and Technology, Kwame Nkrumah University of Science and Technology for determination of organic and inorganic components such as cellulose, lignin, carbon, sodium, calcium, potassium, phosphorus and ash content.

3.6.1 Sample preparation

Defect free, air-dried samples from each section were made into small chips and further milled with a high-speed laboratory blender and sieved with 250 µm sieve. The samples were kept in polythene bags until they were used for the various chemical properties test.

3.6.2 Preparation of extractive free material [ASTM D 1105 – 96 (2007)]

An amount of 10 g air-dried, milled wood sample was placed in an extraction thimble ensuring that it did not extend above the top level of the siphoning tube. The sample was extracted for 4 hours with 200 ml of alcohol-acetone mixture (1:2) in the Soxhlet extraction apparatus. The excess solvent was recovered with suction and the wood in the thimble washed with alcohol to remove the excess acetone. The sample in the thimble was returned to the extractor and extraction continued with 95% alcohol (200 ml) for 4 hours until the alcohol siphoned over colourless. The sample was removed from the thimble and spread out on a thin layer and allowed to dry in the air until it was free of alcohol. The dried alcohol-free sample was returned into the thimble and extracted with 200 ml of hot water for 4 hours. The material after hot water extraction was air-dried thoroughly and used as extractive-free material for the determination of lignin and cellulose.

3.6.3 Determination of lignin [ASTMD 1106 – 96 (2007)]

A 1g air-dried extractive-free wood samples were placed in a 50 ml beaker and 15 ml of cold sulphuric acid (72%) was added slowly while stirring. The reaction was continued for 2 hours with frequent stirring in a water bath maintained at 20 ºc. The specimens were transferred by washing with 560 ml of distilled water into 1 litre Erlenmeyer flasks, diluting the concentration of the sulphuric acid to 3%. The resulting sample-solution mixtures were boiled for 4 hours to a near constant volume. The insoluble material was allowed to cool and settled for overnight. The contents of the flasks were filtered through pre-weighed filter papers. The residue was washed free of acid with 500 ml of hot distilled water and oven dried at 103 ± 2 ºC. The crucibles with the oven-dried samples were cooled in a desiccator and weighed to constant weight. The lignin content in the samples was determined as:

$$\text{Lignin (\%)} = \frac{W1}{W2} \times 100$$

Where,

W_1 = Weight of oven – dried lignin (g).

W_2 = Weight of oven–dried un-extracted wood (g).

3.6.4 Determination of cellulose [ASTM D 1103 – 60 (2007)]

First holocellulose material was prepared according to ASTM D 1104 – 96 (2007) from the previously prepared extractive free wood as follows: a 2g samples of air-dried extractive-free sample from each section was placed into a 250 ml beaker and treated with a mixture of 180 ml of distilled water, 8.6 g of sodium acetate, 6.6 g of sodium chlorite and 5.7 ml of ethanoic acid. The sample - solution mixture was covered with a glass cover and placed in water bath at 60ºC for 4 hours. The content of the flask was filtered onto a filter paper, washed with distilled water and air dried.

The Air-dried holocellulose material from each part of the stem was transferred into 250 ml beakers with a watch glass cover. The samples were treated with a total of 25 ml of 17.5% NaOH in 45 minutes. A 10 ml portion of the 17.5% NaOH was first added to the sample, thoroughly mixed and placed in a water bath at 20°C and manipulated with a glass rod 2 minutes after the addition of the first 10ml portion. Five minutes after the addition of the first portion, additional 5 ml portion was added and thoroughly mixed. Five minutes later, the next 5 ml portion was also added followed by the addition of the last 5 ml portion and thorough mixing, 15 minutes after the addition of the first portion. The sample-solution mixtures were allowed to stand at 20 °C in the water bath for 30 minutes, making the NaOH treatment 45 minutes. Following the NaOH treatment, 33 ml of distilled water previously maintained at 20 °C was added to the mixture and the contents of the flasks thoroughly mixed and allowed to stand at 20 °C for 1hour. The contents of the flask were filtered through pre-weighed filter papers and the residue washed first with 100 ml of 8.3% NaOH, then with distilled water and treated with 15 ml of 10% acetic acid for 3 minutes. The residue was finally washed free of acid with distilled water, oven-dried at 103 ± 2ºC, cooled in a desiccator, and weighed until a constant weight was obtained. The cellulose content was determined as:

$$\text{Cellulose (\%)} = \frac{W1}{W2} \times 100$$

Where,

W_1 = Weight of/ oven – dried cellulose (g).

W_2= Weight of original oven - dried wood (g).

3.6.5 Determination of ash content [ASTM D 1102 – 84 (2007)]

Empty crucibles were first ignited in a muffle furnace at 600 ºC, cooled in a desiccator, and weighed to the nearest 0.1 mg. A 2 g sample of air-dried wood samples were weighed into the pre-weighed crucibles and placed in an oven at 103 ± 2 ºC, cooled in desiccator and weighed. The heating and cooling were repeated until the weights were constant. The crucibles and their contents were then placed in the muffle furnace at 600 ºC for 4 hours to burn off all the/ carbon. They were heated slowly at the start to avoid flaming, while protecting the crucible from strong drafts at all times to avoid mechanical loss of the test specimen. The temperature of final ignition was 580 - 600 ºC. The crucibles with their contents were then placed in a desiccator to cool and weighed. The heating was repeated until the weight after cooling was constant to within 0.2 g. The ash content was calculated as:

$$\text{Ash (\%)} = \frac{W1}{W2} \times 100$$

Where:

W_1= Weight of ash

W_2 = Weight of oven-dried sample

3.6.6 Determination of organic carbon (C)

The organic carbon content of the wood samples was determined by the Walkley – black wet oxidation method (Nelson and Sommers, 1982; Heanes, 1984).A 0.1 g of samples were weighed into 500 ml Erlenmeyer flasks followed by the addition of 10 ml of 1.0 N Potassium dichromate solution and 20 ml of conc. H_2SO_4. The mixture was swirled, ensuring that the solution was in contact with all the particles of the wood samples. The flasks and its content were allowed to cool on an asbestos sheet for 30 minutes after which 200 ml of distilled water and 10 ml of orthorphosphoric acid added. Finally, 2.0 ml (of 10 ml) of diphenylamine indicator was added and the resulting solution sample mixture titrated with 1.0 N ferrous sulphate solution until the colour changed to blue and then to a green end – point. A blank determination was made without a sample and the carbon content of the samples determined by the formula:

$$\% \text{ Organic C} = \frac{\text{Blank} - (T \times N) \times 0.3}{\text{Wt. of soil}}$$

Where Blank = Titre value for blank (≥ 10.5)

T = ml of Fe_2SO_4 used for titration (titre value)

N = Normality of $FeSO_4$

3.6.7 Determination of nitrogen (N)

The nitrogen content of the wood samples was determined by the Kjeldahl method (Bremner and Mulvaney, 1982). An amount of 2 g air dried samples was weighed into 500 ml long-necked kjeldahl flasks and 10 ml distilled water was added to moisten the sample. A spatula full of kjeldahl catalyst (mixture of 1-part selenium + 10 parts $CUSO_4$ + 100 parts Na_2SO_4) was added, followed by 20 ml conc. H_2SO_4. The sample-solution mixtures were placed in the macro Kjeldahl digestion unit to digest until the solution was clear and colorless. The flasks were allowed to cool and the fluid decanted into a 100 ml volumetric flasks and distilled water added to make up the mark. An aliquot of 10 ml was transferred from the digested samples by means of a pipette into kjeldahl distillation flasks and 90 ml of distilled water added to make up to 100 ml in the distillation flasks. An additional 20 ml of 40% NaOH was added to the content of the distillation flasks and distillates collected over 10 ml of 4% boric acid already containing 3 drops of mixed indicator in 200 ml conical flasks. The presence of nitrogen gives a light blue colour. The collected distillates (about 100 ml) were titrated with 0.1 N HCl until the blue colour changed to grey and then suddenly flashed to pink. A blank determination was carried out without a sample. The Nitrogen content in the samples were determined using the formula:

$$\% \text{ N} = \frac{14 \times (A-B) \times N \times 100}{1000 \times 0.2}$$

Where,

A = volume of standard HCL used in sample titration

B = volume of standard HCL used in blank titration

N = normality of standard HCL

$$\text{Weight of sample used} = \frac{2 \text{ g} \times 10 \text{ ml}}{100 \text{ ml}} = 0.2 \text{ g}$$

3.6.8 Determination of inorganic mineral elements: Na, K, Ca, P

To determine the amount of inorganic minerals in the samples, acid digestion was first carried out to release the various elements into solution. A 1.00 g sample was weighed into clean ceramic crucibles and ignited in a furnace for 4 hours at 500 °C and allowed to cool in a desiccator. The ashed samples were transferred into already labelled 50 ml centrifuge tubes and the crucibles rinsed with 10 ml of distilled water followed by an additional 10 ml of aqua regia (3:1 HCl, HNO_3) into the centrifuge tubes. The samples were shaken for 5 minutes for proper mixing and centrifuged for 10 minutes at 3000 rpm. The supernatant solutions were decanted and used for Na, K and P determination (Hunter *et al*., 1984; Jones and Case, 1990).

3.6.8.1 Sodium and potassium

Potassium (K^+) and Sodium (Na^+) in the wood samples were determined by flame photometer method using Jenway PFP7 model (ref). Five serial standards of 1, 2, 5, 10, 15 mg/l K^+ and 1, 2.5, 5, 10, and 15 mg/l Na^+ were prepared from stock K^+ and Na^+ solutions. Each serial standard and the sample solutions (digested samples) were aspirated in the Flame photometer starting from the least and their corresponding absorbance values recorded. A standard or calibration curve was plotted from the serial standards to generate an equation from which the concentrations of K^+ and Na^+ in the wood samples were determined.

3.6.8.2 Phosphorus

The Phosphorous content of the wood samples was determined using vanadium phosphomolybdate method by a colorimeter (Bernhart and Wreath 1955). A 5 ml of the previously digested sample solutions were transferred into a 50 ml volumetric flask, followed by an addition of 10 ml Vanadomolybdate reagent and distilled water to make up the 100 ml mark. The resulting mixture was shaken vigorously and kept for 30 minutes. A yellow colour developed and was read at 430 nm with a colorimeter. Serial standards were prepared (1.0, 2.0, 4.0, 6.0, 8.0, and 10.0 mg/l) and P content in the samples determined from the resulting standard curve plotted.

3.6.8.3 Calcium content

The Calcium (Ca^{2+}) content of the wood samples was determined by a titrimetric method (Moss, 1961). A 10 ml solution of KOH was added to 10 ml of digested samples in a 100 ml followed by the addition of 1 ml of 30% Triethanolamine. A 3 drops of 10% KCN solution and few crystals of Cal-red indicator were added and shaken vigorously for uniform mixture. The sample-solution mixture was titrated with 0.02 N EDTA solution from red to blue endpoint. The calcium content in the solution was determine as:

$$\text{Ca (mg/Kg)} = \text{Titre value} \times 0.4 \times 10000$$

CHAPTER FOUR

RESULTS

4.1 Physical Properties of *Laguncularia racemosa*

4.1.1 Moisture content

Figure 4.1a shows the percentage mean moisture content of the various sections of *Laguncularia racemosa* (*L. racemosa*) from the two regions (Central and Western). Along the sapwood, the top portion recorded the highest moisture content (MC) (36.76 and 35.40%, Central and Western regions respectively) and the lowest at the base (31.50 and 30.75%, Central and Western Regions respectively). Similarly, wood of trees from both regions recorded the highest MC at the top portion (37.62 and 35.20%, Central and Western Regions respectively), and the least at the base (30.11 and 32.24%, Central and Western Regions respectively) along the heartwood. Generally, the sapwood was slightly higher in MC than heartwood at the top (35.40 and 35.20%, sapwood and heartwood respectively) and middle (33.90 and 32.67, sapwood and heartwood respectively) portions for Western Region but highest at the middle (32.76 and 31.51, sapwood and heartwood respectively) and base (31.50 and 30.11, sapwood and heartwood respectively) portions for Central Region. Figure 4.1b also shows the overall mean moisture content along the stem of *L. racemosa*. Central Region recorded mean values of 37.19 - 30.81% while Western Region recorded 35.30 - 31.49%. Wood from top portions of trees recorded the highest MC (37.19 and 35.30%, Central and Western Regions respectively) and the least at the base (30.81 and 31.49%, Central and Western Regions respectively) for both regions. Generally, wood of trees from Central Region had an overall higher MC at the top while Western Region recorded the highest at the middle and base portions (Fig. 4.1b).

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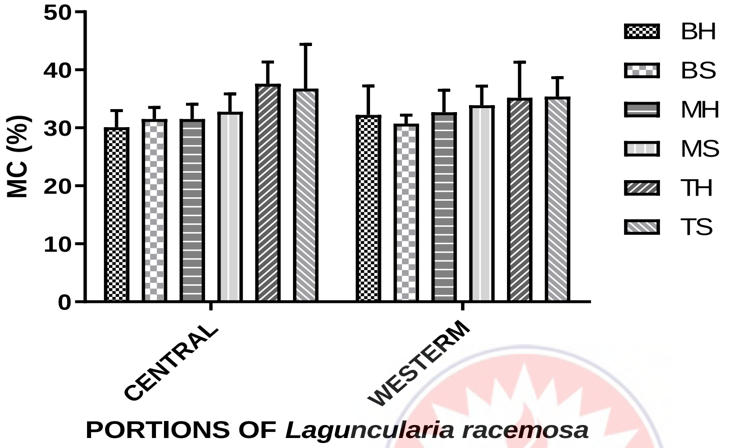

Fig. 4.1a: Mean Moisture Content of *Laguncularia racemosa* (axial and radial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

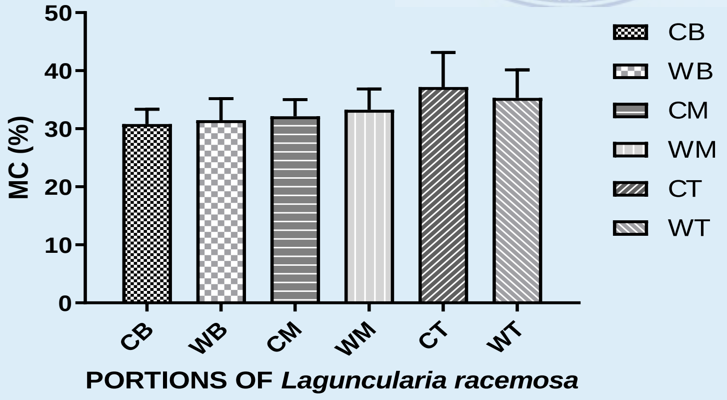

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Fig. 4.1b: Mean Moisture Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemosa*. CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

The analysis of variance for the mean moisture content of the various sections is shown in Table 4.1. There was a statistically significant difference in the mean moisture content ($p < 0.05$) of the various sections of the stem from both regions. However, the mean difference in MC for the sapwood and heartwood for each corresponding portion (such as top-heart and top-sap) as well as between the middle and the base of the trees from both regions was statistically insignificant ($p > 0.05$) (Appendix B1).

Table 4.1: ANOVA for Moisture Content of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	3.032	0.1049	Ns	No
Regions	0.0003084	0.9756	Ns	No
Stem location	22.06	<0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	154.3	5	30.86	F (5, 228) = 1.846	P=0.1049
Regions	0.01569	1	0.01569	F (1, 228) = 0.0009387	P=0.9756
Stem Location	1123	5	224.5	F (5, 228) = 13.43	P<0.0001
Residual	3812	228	16.72		

Alpha = 0.05

4.1.2 Basic density

Wood of trees from Central Region recorded the highest density at the base and the lowest at the top along both the heartwood (626.85 Kg/m^3 and 622.94 Kg/m^3, base and top respectively) and sapwood (624.39 Kg/m^3 and 602.44 Kg/m^3, base and top respectively). Similarly, Western Region recorded greatest value of 638.07 Kg/m^3 at its base and lowest at the top (605.47 Kg/m^3) along the heartwood while the sapwood also recorded greatest density at the base (632.80 Kg/m^3) and lowest at its top (585.90

Kg/m^3). The overall density along the stem (Fig. 4.2b) shows a decreasing trend from base to top for wood of trees from both regions. Generally, Central Region recorded a slightly higher density at the top (612.69 and 595.69 Kg/m^3, Central and Western respectively) and middle (616.09 and 611.31 Kg/m^3, Central and Western respectively) portions while Western Region had a comparatively higher density at the base (625.62 and 635.43 Kg/m^3, Central and Western respectively).

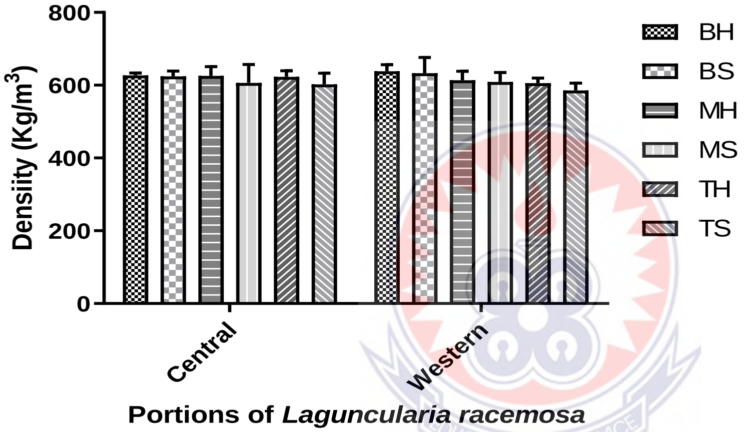


Fig. 4.2a: Mean Basic Density of *Laguncularia racemosa* (axial and radial sections) from Central and Western Regions of Ghana. BH = Beartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

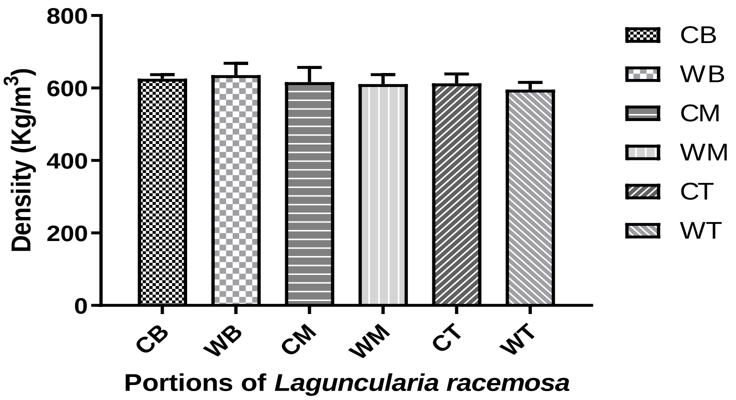


Fig. 4.2b: Mean Basic Density along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose*. CB = Central base, CM = Central middle, CT = Central, WB= Western Base, WM= Western Middle and **WT = Western Top**

There was a significant difference in mean basic density ($p < 0.05$) of the different portions of the stem for the two regions (Table 4.2). However, there was no difference in mean basic density for any of the portions of the trees from Central Region as well as for sapwood and heartwood of each equivalent portion (such as base-heart and base-sap) of the trees from Western (Appendix B2).

Table 4.2: ANOVA for Basic Density of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	3.833	0.0494	*	Yes
Regions	0.4415	0.2551	Ns	No
Stem location	18.40	<0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	8291	5	1658	F (5, 228) = 2.260	P=0.0494
Regions	955.0	1	955.0	F (1, 228) = 1.302	P=0.2551
Stem location	39798	5	7960	F (5, 228) = 10.85	P<0.0001
Residual	167291	228	733.7		

Alpha = 0.05

4.2 Mechanical Properties of *Laguncularia racemosa*

4.2.1 Modulus of rupture

Trees from Central Region recorded the highest modulus of rupture **(**MOR) at the base for heartwood (68.51 Nmm^{-2}) and sapwood (57.92 Nmm^{-2}) as well as lowest values at the top (54.65 Nmm^{-2} and 50.99 Nmm^{-2} heartwood and sapwood respectively) (Fig 4.3a). Similarly, trees from Western Region recorded highest values at the base (61.09 and 52.60 Nmm^{-2} heartwood and sapwood respectively) and lowest values at the top (56.80 and 45.66 Nmm^{-2} heartwood and sapwood respectively) (Fig 4.3a). Generally, the heartwood had a higher MOR than sapwood at all the portions for both regions. The overall mean MOR values (Fig 4.3b) indicate the base had a greater mean MOR (63.21 and 56.84 Nmm^{-2}, Central and Western Regions, respectively) and lowest at the top (52.82 and 51.23 Nmm^{-2}, Central and Western Regions, respectively). Central Region however, had a comparatively higher MOR values than Western Region (Fig. 4.3b).

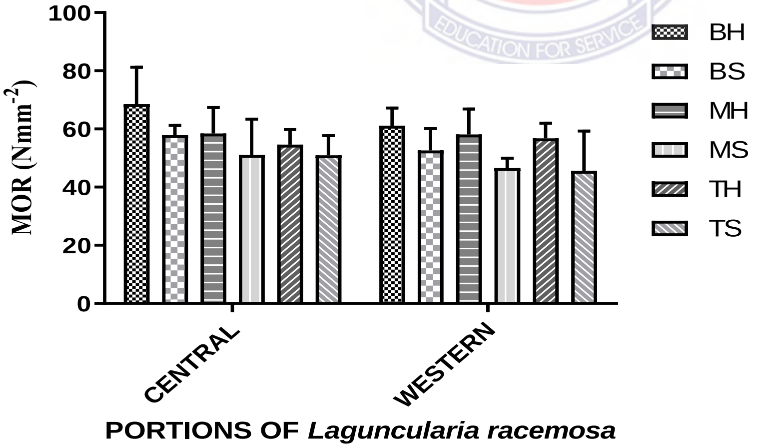


Fig. 4.3a: Mean MOR of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top,

TS = Sapwood of Top

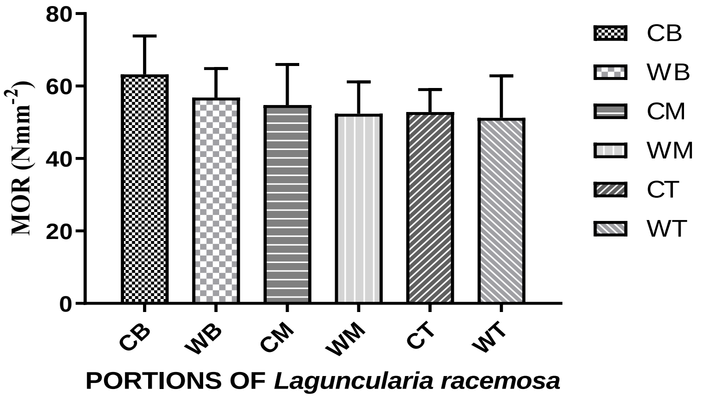


Fig. 4.3b: Mean MOR along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemosa.* CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

The difference in mean MOR for the various sections of the trees from both regions was statistically significant ($p < 0.05$) (Table 4.3). According to Tukey's multiple comparison test, there was no significant difference in MOR of the various sections along the sapwood of the stem for trees from Central region as well as along the heartwood for trees from Western Region (Appendix B3).

Table 4.3: ANOVA for MOR of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	2.550	0.1143	Ns	No
Regions	2.830	0.0018	**	Yes
Stem Location	29.92	<0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value

Interaction	648.5	5	129.7	F (5, 228) = 1.797 P=0.1143
Regions	719.6	1	719.6	F (1, 228) = 9.973 P=0.0018
Stem Location	7610	5	1522	F (5, 228) = 21.09 P<0.0001
Residual	16451	228	72.15	

Alpha = 0.05

4.2.2 Modulus of elasticity

The mean modulus of elasticity (MOE) for Central Region was greatest at the base portion (8407.78 and 7014.36 Nmm^{-2}, heartwood and sapwood respectively) and lowest at top (7138.24 and 6516.24 Nmm^{-2}, heartwood and sapwood respectively) (Fig 4.4a). Fig 4.4a also shows a highest MOE at the base-heart (7577.2 Nmm^{-2}) and base-sap (6737.9 Nmm^{-2}) as well as lowest at the top-heart (6212.85 Nmm^{-2}) and top-sap (5492.6 Nmm^{-2}) for Western region. The heartwood recorded a relatively higher MOE values along the stem for regions. The overall mean MOE along the stem (Fig 4.4b) indicate, base (7711.07 and 7157.55 Nmm^{-2}, Central and Western Regions respectively) > middle (7142.09 and 6100.25 Nmm^{-2}, Central and Western respectively) > top (6827.24 and 5852.73 Nmm^{-2}, Central and Western respectively) for both regions. Generally Central Region had the highest MOE along the stem than Western Region.

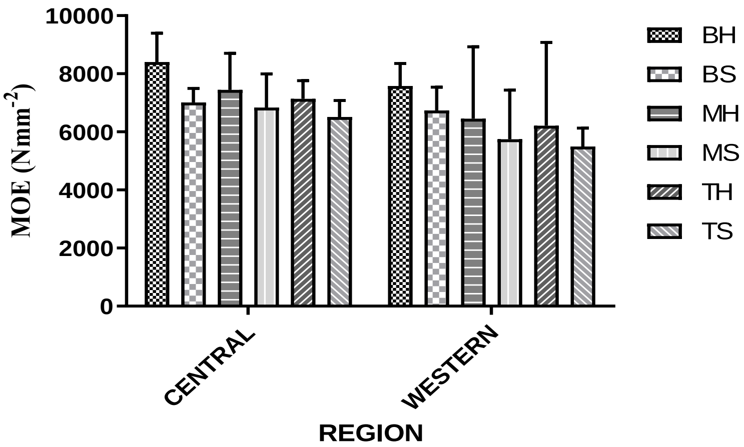


Fig. 4.4a: Mean MOE of *Laguncularia racemosa* (axial and redial sections) from Central and Western regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

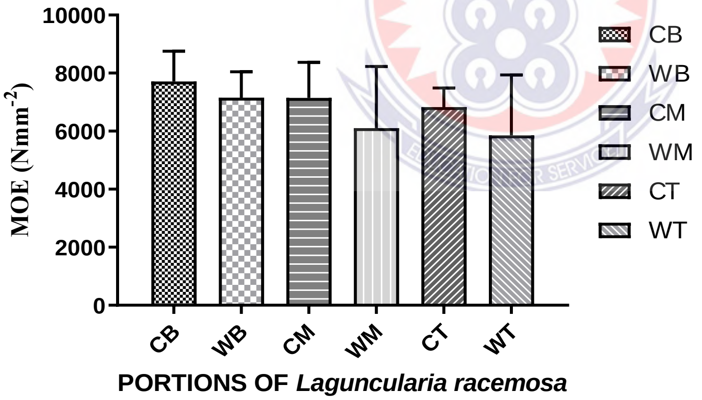


Fig. 4.4b: Mean MOE along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose*. CB = Central Base, CM = Central Middle and **CT = Central**

Top, **WB = Western Base, WM = Western Middle, WT = Western Top**

There was a statistically significant difference in the mean MOE ($p < 0.05$) for the various sections of the tree (Table 4.4). Tukey's multiple comparison test further indicated no significant difference in MOE between the middle and the top for both regions (Appendix B4).

Table 4.4: ANOVA for MOE of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	0.7497	0.8128	ns	No
Regions	7.431	<0.0001	****	Yes
Stem Location	15.91	<0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	4441988	5	888398	F (5, 228) = 0.4503	P=0.8128
Regions	44028097	1	44028097	F (1, 228) = 22.32	P<0.0001
Stem Location	94289626	5	18857925	F (5, 228) = 9.560	P<0.0001
Residual	449771819	228	1972683		

Alpha = 0.05

4.2.3 Compression strength parallel to grain

Figure 4.5a shows the mean compression strength parallel to grain (CPG) of the various sections along the stem of *L. racemosa.* For the sapwood, the base portion recorded the highest mean values of 30.58 and 26.34 Nmm^{-2} for Central and Western Regions respectively, while the top portion recorded the least values of 27.03 and 20.50 Nmm^{-2} for Central and Western Regions respectively. Similarly, the heartwood recorded highest CPG at the base (30.88 and 30.33 Nmm^{-2}, Central and Western Regions respectively) and lowest at the top (27.08 and 28.65 Nmm^{-2}, Central and Western Regions respectively). The mean CPG for the heartwood was generally higher than the sapwood. Figure 4.5b also shows the overall mean CPG along the stem of *L racemosa*. Western Region recorded highest mean value of 28.33 Nmm^{-2} at the base and least value of 24.57 Nmm^{-2} at the top, while Central Region recorded the highest and lowest mean values at the base

(30.73 Nmm^{-2}) and top (27.05 Nmm^{-2}) portions respectively. Generally, Central Region had an overall highest CPG compared to Western Region.

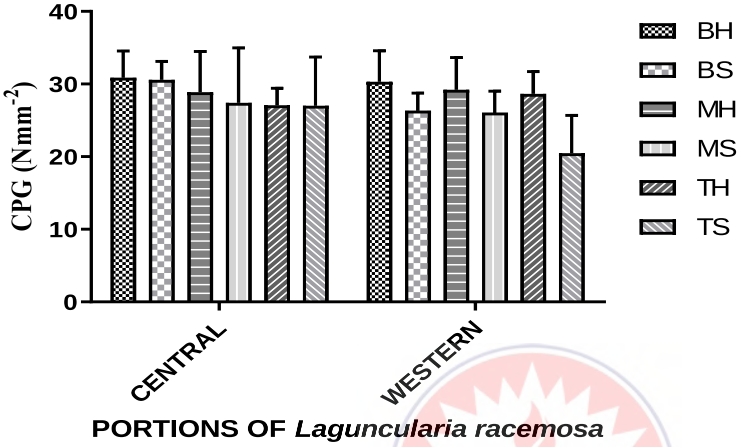


Fig. 4.5a: Mean CPG of *Laguncularia racemosa* (axial and redial sections) from Central and Western regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = sapwood of top

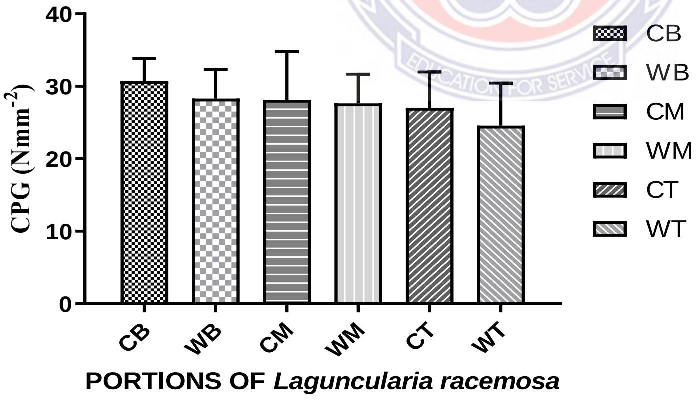


Fig. 4.5b: Mean CPG along the stem (combined heartwood and sapwood portions) of *Laguncularia racemosa.* CB = Central Base, CM = Central Middle, CT = Central Top,

WB = Western Base, WM = Western Middle, WT = Western Top

The difference in mean CPG along the stem also followed a similar pattern as MOR and was statistically significant ($p < 0.05$) (Table 4.5). A post hoc analysis (Tukey's multiple comparison test) further indicated no significant difference in mean CPG for any of the portions of the trees from Central Region.

Table 4.5: ANOVA for CPG of *Laguncularia racemosa* from Central and Western regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	7.136	0.0007	***	Yes
Regions	2.991	0.0025	**	Yes
Stem Location	16.88	<0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	460.2	5	92.05	F (5, 228) = 4.458	P=0.0007
Regions	192.9	1	192.9	F (1, 228) = 9.342	P=0.0025
Stem Location	1089	5	217.8	F (5, 228) = 10.55	P<0.0001
Residual	4707	228	20.65		

Alpha = 0.05

4.3 Chemical Properties of *Laguncularia racemosa*

4.3.1 Lignin

Along the heartwood, lignin content decreased from base (11.46 and 16.39%, Central and Western Regions respectively) to top (10.82 and 12.28% Central and Western Regions respectively) for both regions (Fig. 4.6a). However, while both regions recorded greatest lignin content at the sapwood of the base (11.08% and 14.85% Central and Western Regions respectively), the middle portion recorded the least value (10.82%) for Central Region and the top (12.28%) for Western Region (Fig. 4.6a). Generally Western Region recorded higher lignin content along the stem, 15.62 – 12.65% (base to top, heartwood and sapwood combined) compared to Central Region, 11.27 – 10.59% (base to top) (Fig. 4.6b).

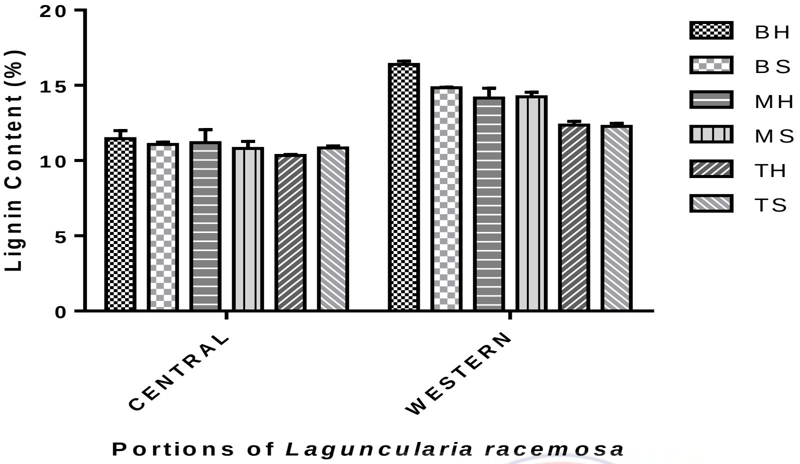


Fig. 4.6a: Mean lignin content of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

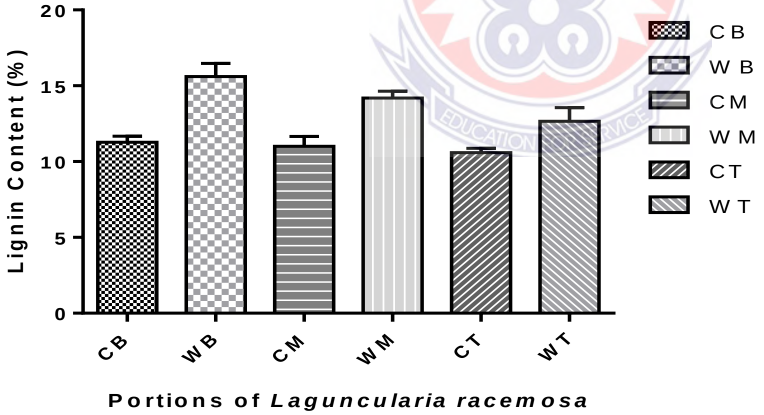


Fig. 4.6b: Mean lignin Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose.* CB = Central Base, CM = Central Middle, CT = Central Top,
WB = Western Base, WM = Western Middle, WT = Western Top

There was a significant difference in mean lignin content ($p < 0.05$) for the various portions along the stem (Table 4.6). However, a post hoc analysis (Tukey's multiple comparison test) showed that there was no difference in mean lignin content of the base and middle portions for trees from Central Region (Appendix B6).

Table 4.6: ANOVA for Lignin Content of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	9.129	< 0.0001	****	Yes
Regions	66.90	< 0.0001	****	Yes
Stem Location	20.89	< 0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	11.73	5	2.347	F (5, 24) = 14.27	P < 0.0001
Regions	85.99	1	85.99	F (1, 24) = 522.8	P < 0.0001
Stem Location	26.86	5	5.371	F (5, 24) = 32.65	P < 0.0001
Residual	3.948	24	0.1645		

Alpha = 0.05

4.3.2 Cellulose

Figure 4.7a shows that Central Region recorded the greatest alpha-cellulose content (29.85%) at the middle and lowest (22.82%) at its base along the sapwood while the heartwood recorded the highest at the top (26.79%) and lowest at the base (23.36%). Along the sapwood for Western Region, the middle also recorded the greatest value (30.63%) and lowest at its base (25.90%) while the heartwood recorded greatest (30.22%) at the top and least at its base (25.67%). The overall cellulose content along the stem (heartwood and sapwood combined) indicate the top recoded the highest value (28.09 and 29.38%, Central and Western Regions respectively) and lowest at the base (23.09 and 25.78% Central and Western Regions respectively) for both regions (Fig 4.7b). Generally Western Region recorded a comparatively higher cellulose content.

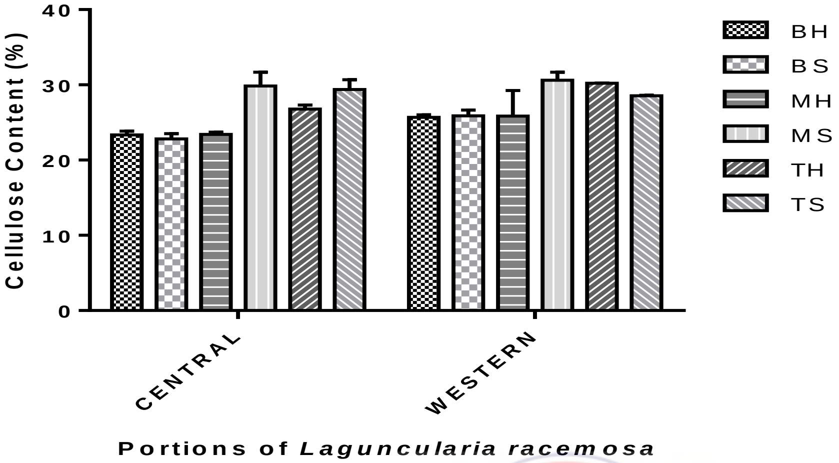


Fig. 4.7a: Mean Cellulose Content of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

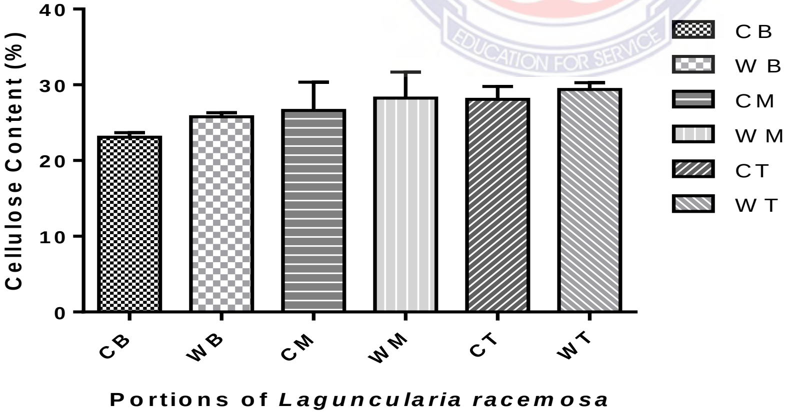


Fig. 4.7b: Mean Cellulose Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose.* CB = Central Base, CM = Central Middle and **CT = Central Top,** **WB = Western Base, WM = Western Middle, WT = Western Top**

As shown in Table 4.7, there was a statistically significant difference in the mean cellulose content ($p < 0.05$) for the various sections of the trees. The difference in mean cellulose content was however not significant for the heartwood and sapwood of both the top and base portions for the samples harvested from all the two regions (Appendix B7).

Table 4.7: ANOVA for Cellulose Content of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	6.435	0.0680	ns	No
Regions	10.42	0.0002	***	Yes
Stem Location	70.22	< 0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	19.39	5	3.879	F (5, 24) = 2.390	P = 0.0680
Regions	31.39	1	31.39	F (1, 24) = 19.34	P = 0.0002
Stem Location	211.6	5	42.33	F (5, 24) = 26.08	P < 0.0001
Residual	38.95	24	1.623		

Alpha = 0.05

4.3.3 Organic carbon

Figure 4.8a showed that Western Region recorded greatest organic carbon content at the middle (31.92%) and lowest at its top (30.72%) along the sapwood while the heartwood recorded highest at the base (31.59%) and least at both the middle (30.32%) and top (30.32%). Along the sapwood for Central Region, the base also recorded the greatest value (31.92%) and lowest at its middle (30.32%) while the heartwood recorded the greatest at the top (31.52%) and least at both the base (31.12%) and middle (31.12%) (Fig. 4.3.3a). The overall organic carbon content along the stem (Fig. 4.8b) indicate the base recoded the highest value (31.52 and 31.56%, Central and Western Regions respectively) and lowest at the middle (30.72%) and top (30.52%) for Central and Western Regions respectively.

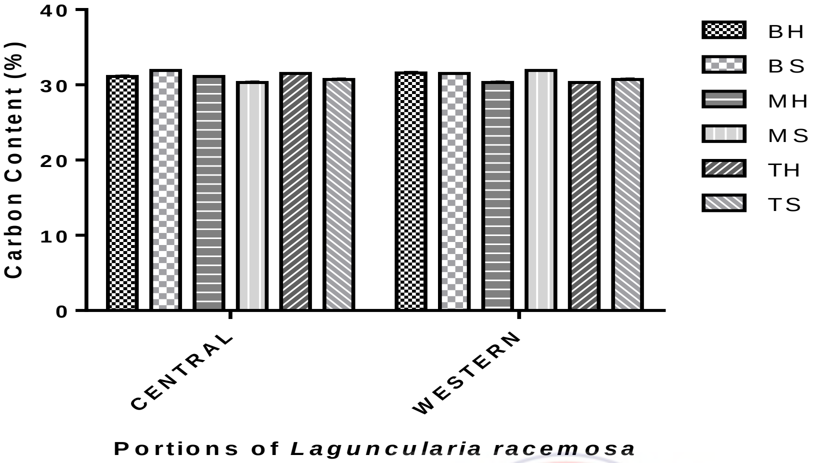


Fig. 4.8a: Mean Organic Carbon Content of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

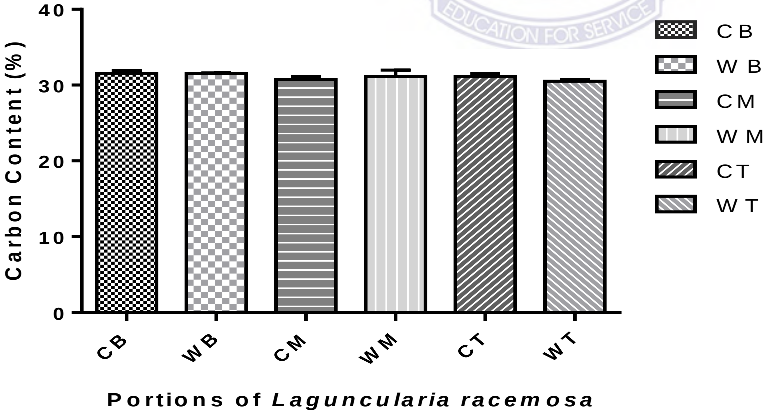


Fig. 4.8b: Mean Carbon Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose.* CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

There was a significant difference in mean carbon content ($p < 0.05$) for the various portions along the stem (Table 4.8). Tukey's multiple comparison test (post hoc analysis) further confirmed a significant difference ($p < 0.05$) in carbon content at all the portions from both regions except between base-heart and middle-heart for trees from Central Region as well as middle-heart and top-heart for samples from Western Region (Appendix B8).

Table 4.8: ANOVA for Organic Carbon content of *Laguncularia racemosa* from Central and Western regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?	
Interaction	61.65	< 0.0001	****	Yes	
Regions	0.2190	< 0.0001	****	Yes	
Stem Location	38.01	< 0.0001	****	Yes	
ANOVA table	**SS**	**DF**	**MS**	**F (DFn, DFd)**	**P value**
Interaction	7.509	5	1.502	F (5, 24) = 2527	P < 0.0001
Regions	0.02668	1	0.02668	F (1, 24) = 44.88	P < 0.0001
Stem Location	4.629	5	0.9259	F (5, 24) = 1558	P < 0.0001
Residual	0.01427	24	0.0005944		

Alpha = 0.05

4.3.4 Ash content

Figure 4.9a shows Central Region had a highest ash content at the base-sapwood (3.29%) followed by the top-sapwood (2.72%) and the middle-sapwood (2.42%). The heartwood was similarly higher in ash content at the base portion (3.22%), followed by the top (2.72%) and the middle (2.35%) for the same region. Western Region on the other hand had a highest mean value at the top for both sapwood and heartwood (2.98 and 2.89%, sapwood and heartwood respectively) and the least at the middle portion for sapwood (2.47%) but at the base for heartwood (2.70%). The sapwood was generally higher in ash content than heartwood except in the middle portion of samples from Western region where the heartwood was higher than the sapwood. The overall ash content (heartwood and sapwood combined) along the stem (Fig. 4.9b) indicate that ash content was highest at the base (3.26%), followed by the top (2.72%) and the middle (2.39%) for Central Region while it was high at the top (2.94%), followed by the base (2.72%) and middle (2.62%) for Western Region. Although Central Region recorded a generally higher ash content at the base, it was comparatively low at the middle and top portions than Western Region.

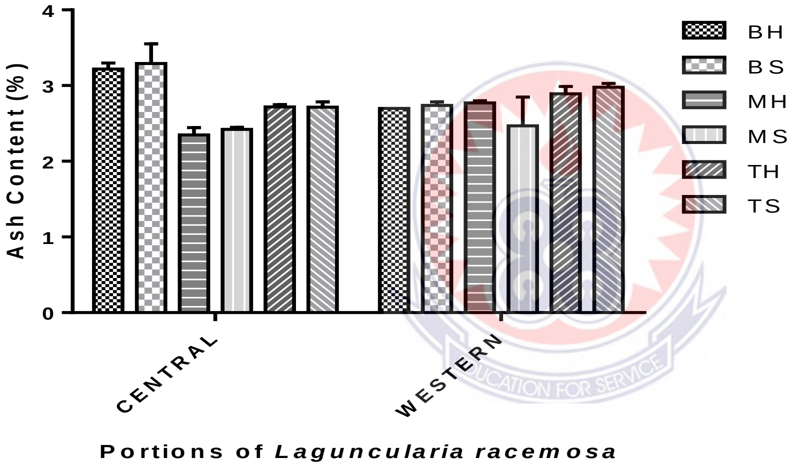


Fig. 4.9a: Mean Ash Content of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

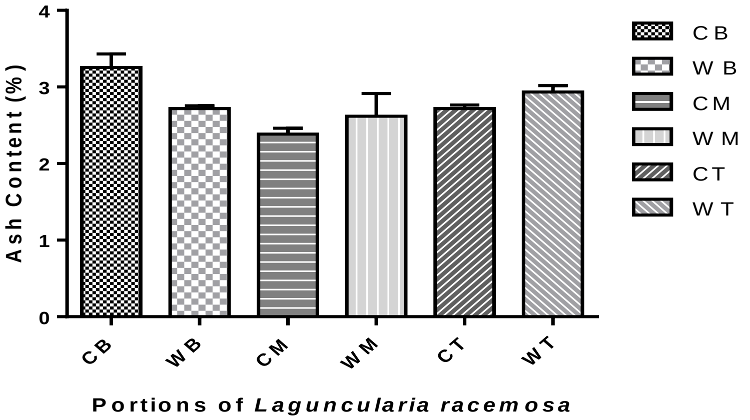


Fig. 4.9b: Mean Ash Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose*. CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

Table 4.9 indicates a significant difference in ash content ($p < 0.05$) for the different portions of the stem for the two regions. However, Tukey's multiple comparison test indicated the difference in ash content for the sapwood and heartwood of all the portions along the stem for Central Region as well as the base and middle portions for Western Region was statistically insignificant ($p > 0.05$). (Appendix B9).

Table 4.9: ANOVA for Ash Content of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	38.77	< 0.0001	****	Yes
Regions	0.2108	0.5677	ns	No
Stem Location	45.96	< 0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	1.283	5	0.2565	F (5, 24) = 12.36	P < 0.0001
Regions	0.006972	1	0.006972	F (1, 24) = 0.3358	P = 0.5677
Stem Location	1.520	5	0.3041	F (5, 24) = 14.64	P < 0.0001
Residual	0.4983	24	0.02076		

Alpha=0.05

4.3.5 Nitrogen (N)

Nitrogen content was high at the top for sapwood (343.81 and 257.16 mg/Kg, Central and Western Regions respectively) and heartwood (256.82 and 228.17 mg/Kg, Central and Western Regions respectively) for both regions (Fig. 4.10a). However, central Region recorded low values at the base for sapwood (237.82 mg/Kg) and middle for heartwood (234.31 mg/Kg) while Western Region recorded low values at the base (194.06 mg/Kg) for heartwood and middle for sapwood (204.90 mg/Kg) (Fig. 4.10a). From Fig 4.10b, nitrogen content was generally high for Central Region, increasing from base to top along the stem (223.41 – 300.32 mg/Kg) compared to Western Region (199.55 – 242.66 mg/Kg), also following the same trend.

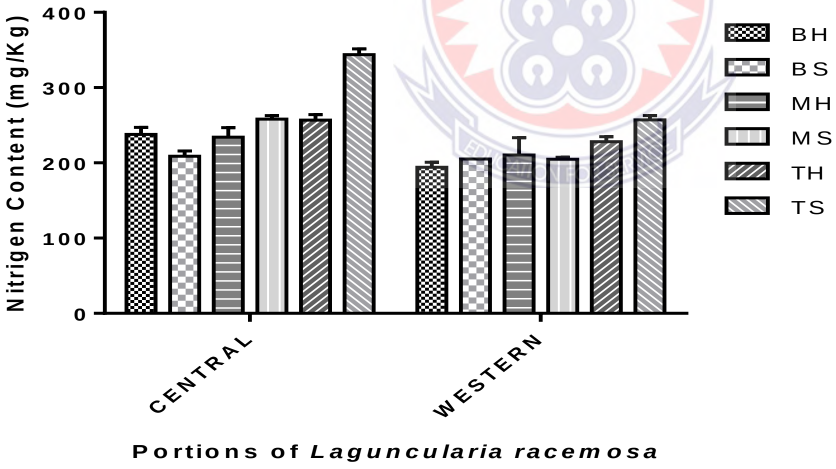


Fig. 4.10a: Mean Nitrogen Content of *laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

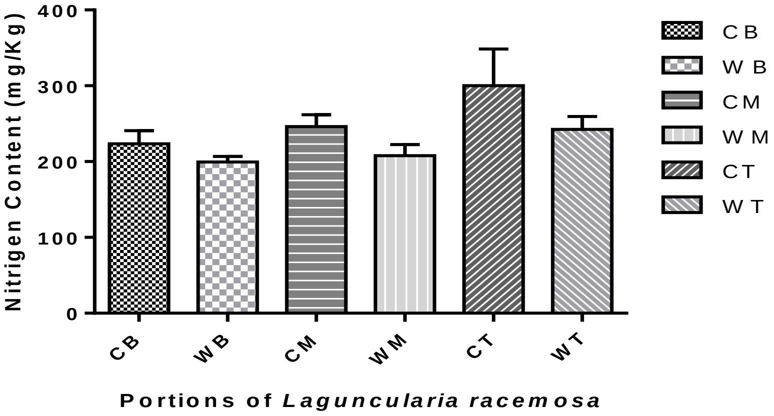


Fig. 4.10b: Mean Nitrogen Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose*. CB = Central Base, CM = Central Middle, CT = Central Top,

WB = Western Base, WM = Western Middle, WT = Western Top

Table 4.10 indicates a significant difference in mean nitrogen content ($p < 0.05$) for the various portions along the stem. No significant difference in nitrogen content was however observed for the base and middle portions of samples from Western Region (Appendix B10).

Table 4.10: ANOVA for Nitrogen Content of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	10.77	< 0.0001	****	Yes
Regions	25.50	< 0.0001	****	Yes
Stem Location	59.94	< 0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	0.006088	5	0.001218	F (5, 24) = 13.65	P < 0.0001
Regions	0.01441	1	0.01441	F (1, 24) = 161.5	P < 0.0001
Stem Location	0.03387	5	0.006774	F (5, 24) = 75.93	P < 0.0001
Residual	0.002141	24	8.921e-005		

Alpha =0.05

4.3.6 Potassium (K)

The sapwood along the stem of Central Region recorded the greatest potassium at its middle (1377.32 mg/Kg) and lowest at the base (885.27 mg/Kg). The heartwood also recorded greatest value of 1200.06 mg/Kg at the top but least at its base (708.00 mg/Kg) (Fig. 4.11a). Fig. 4.3.6a further shows that Western Region also recorded greatest amount of potassium along the sapwood at its base (1398.72 mg/Kg) and lowest at the middle (518.52 mg/Kg) but the heartwood recorded its greatest value of 695.78 mg/Kg at the top and lowest at the middle (659.11 mg/Kg). The overall potassium content (sapwood and heartwood combined) indicated an increase in values from base to top (796.64 – 1099.21 mg/Kg) for Central Region and base (1035.02 mg/Kg), followed by top (643.83 mg/Kg), followed by middle (588.81 mg/Kg) for Western Region (Fig. 4.11b). Generally, Central Region recorded a comparatively higher potassium content except at the base where Western Region recorded a highest value.

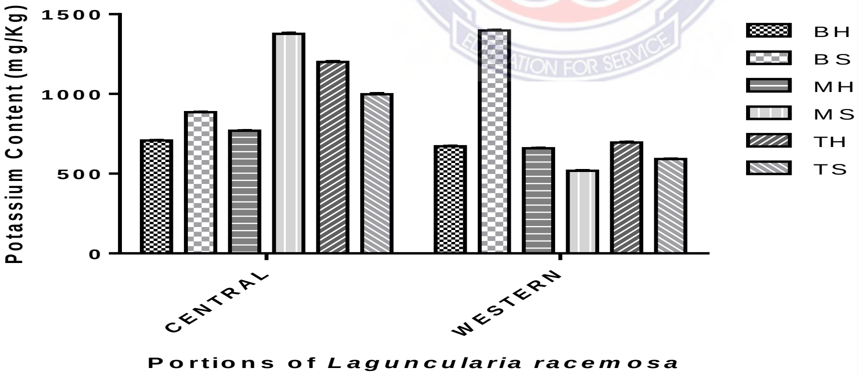


Fig. 4.11a: Mean Potassium Content of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

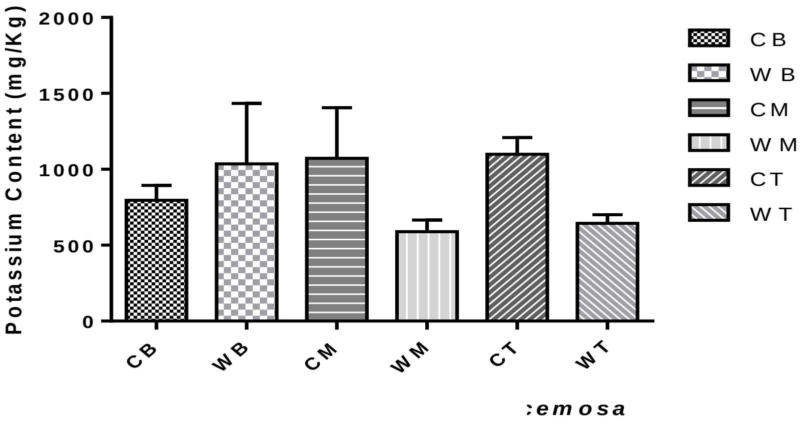


Fig. 4.11b: Mean Potassium Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose*. CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle and **WT = Western Top**

Samples from the two regions recorded a significant difference ($p < 0.05$) in potassium content within their stem positions (Table 4.11).

Table 4.11: ANOVA for Potassium Content of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	54.53	< 0.0001	****	Yes
Regions	16.17	< 0.0001	****	Yes
Stem Location	29.28	< 0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	1.659e+006	5	331849	F (5, 24) = 20301	P < 0.0001
Regions	491970	1	491970	F (1, 24) = 30097	P < 0.0001
Stem Location	891018	5	178204	F (5, 24) = 10902	P < 0.0001
Residual	392.3	24	16.35		

Alpha = 0.05

4.3.7 Phosphorus (P)

Central Region recorded the greatest phosphorus content of 20.39 mg/Kg at the top and lowest at its base (12.36 mg/Kg) along the sapwood, likewise the heartwood with 23.25 mg/Kg at the top and 13.81 mg/Kg at the base (Fig 4.12a). On the contrary, the sapwood of Western Region recorded greatest phosphorus content at its base (35.61 mg/Kg) and lowest at the top (23.14 mg/Kg) with the heartwood also recording 34.03 mg/Kg at the base and 12.96 mg/Kg at the top. Overall (heartwood and sapwood combined), Western Region recorded a decreasing phosphorus content from base to top (34.82 – 18.05 mg/Kg), while Central Region showed an increasing trend from base to top (13.09 – 21.82 mg/Kg) (Fig. 4.12b).

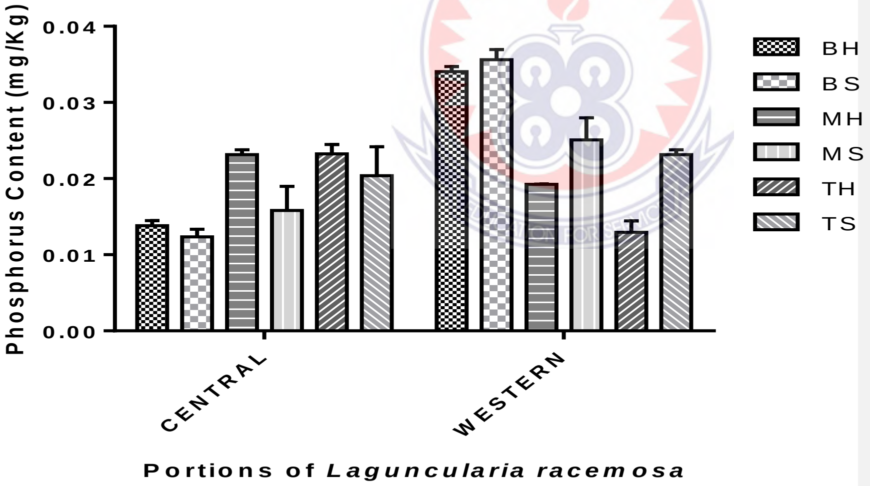


Fig. 4.12a: Mean Phosphorus Content of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

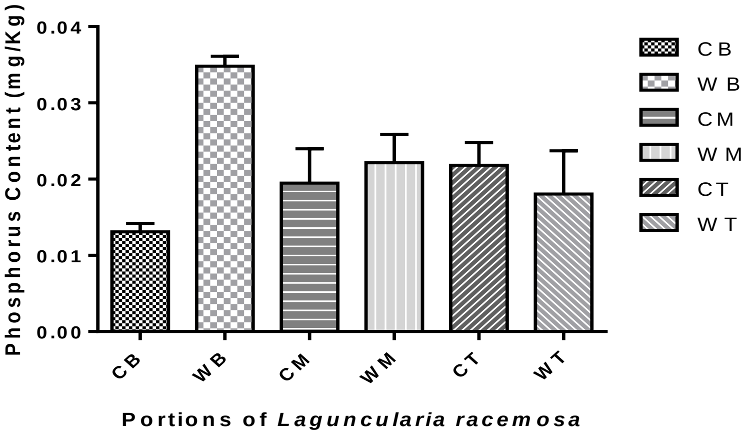


Fig. 4.12b: Mean Phosphorus along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemosa.* CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

Significant differences in mean phosphorus content ($p < 0.05$) was observed within the stem positions of the trees from the two regions (Table 4.12). A post hoc test (Tukey's multiple comparison test) showed no difference in mean phosphorus content for the heartwood and sapwood of the base and top portions of samples from Central Region (Appendix B12).

Table 4.12: ANOVA for Phosphorus Content of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	66.73	< 0.0001	****	Yes
Regions	21.56	< 0.0001	****	Yes
Stem Location	7.530	< 0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	0.001319	5	0.0002638	F (5, 24) = 76.80	P < 0.0001
Regions	0.0004262	1	0.0004262	F (1, 24) = 124.1	P < 0.0001
Stem Location	0.0001488	5	2.976e-005	F (5, 24) = 8.666	P < 0.0001
Residual	8.243e-005	24	3.434e-006		

Alpha = 0.05

4.3.8 Calcium (Ca)

Figure 4.13a shows that Western Region recorded the greatest calcium content at the base (598.84 mg/Kg) and lowest at its top (143.00 mg/Kg) along the sapwood while the heartwood recorded the highest at the middle (518.99 mg/Kg) and lowest at the top (220.54 mg/Kg). Along the sapwood for Central Region, the base also recorded the greatest value (537.21 mg/Kg) and lowest at its top (82.95 mg/Kg) while the heartwood also recorded the greatest at the base (339.92 mg/Kg) and lowest at its top (161.628 mg/Kg). The overall calcium content along the stem (Fig. 4.13b) also indicated the base (438.57 mg/Kg) and middle (475.97 mg/Kg) recoded the highest values for Central and Western Regions respectively and lowest at the top (122.29 and 181.98 mg/Kg, Central and Western Regions respectively). Generally Western Region recorded a comparatively higher calcium content.

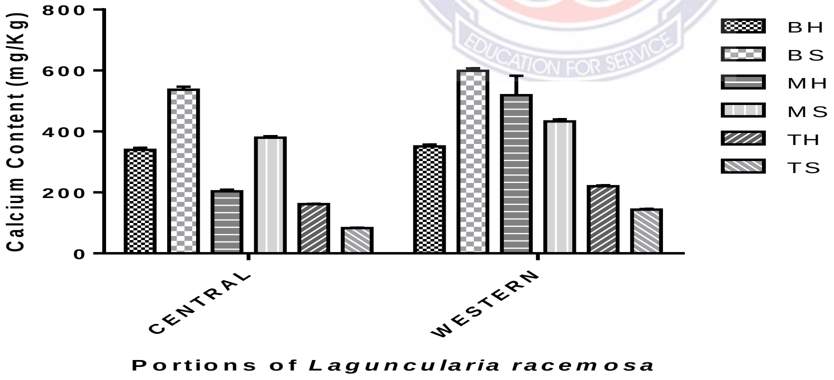


Fig. 4.13a: Mean Calcium Content of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

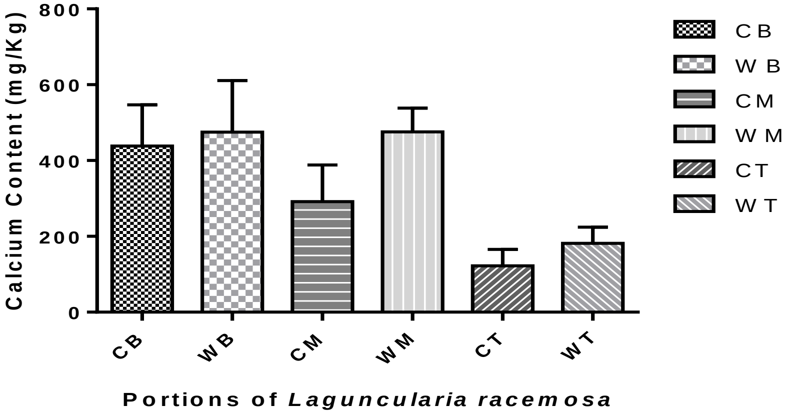


Fig. 4.13b: Mean Calcium Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose*.
CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

There was a significant difference in mean calcium content ($p < 0.05$) for the various portions along the stem (Table 4.13).

Table 4.13: ANOVA for calcium content of *Laguncularia racemosa* from Central and Western regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	9.524	< 0.0001	****	Yes
Regions	8.179	< 0.0001	****	Yes
Stem Location	81.36	< 0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	91319	5	18264	F (5, 24) = 49.03	P < 0.0001
Regions	78422	1	78422	F (1, 24) = 210.5	P < 0.0001
Stem Location	780114	5	156023	F (5, 24) = 418.8	P < 0.0001
Residual	8941	24	372.5		

Alpha =0.05

4.3.9 Sodium (Na)

Figure 4.14a shows Western Region had a highest sodium content at the base (1179.49 mg/Kg) followed by the middle (1081.65 mg/Kg) and the top (1051.28 mg/Kg) along the sapwood. The heartwood was similarly higher in sodium content at the middle portion (1112.01 mg/Kg), followed by the base (10004.05 mg/Kg) and the top (997.30 mg/Kg). Central Region on the other hand had a highest value at the top for heartwood (923.08 mg/Kg) and middle for sapwood (896.09 mg/Kg) with the least values at the middle (717.27 mg/Kg) and base (828.61 mg/Kg) portions for heartwood and sapwood respectively. The overall sodium content along the stem (heartwood and sapwood combined) indicate a highest value at the top (882.59 mg/Kg), followed by middle (806.68 mg/Kg) and base (774.63 mg/Kg) for Central Region while it was high at the middle (1096.83 mg/Kg), followed by the base (1091.77 mg/Kg) and the top (1024.29 mg/Kg) for Western Region (Fig. 4.14b). Western Region generally recorded a higher sodium content.

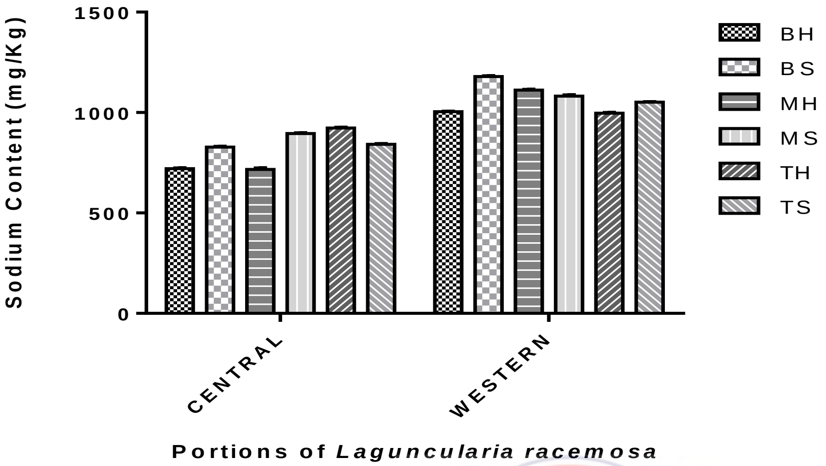


Fig. 4.14a: Mean Sodium Content of *Laguncularia racemosa* (axial and redial sections) from Central and Western Regions of Ghana. BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

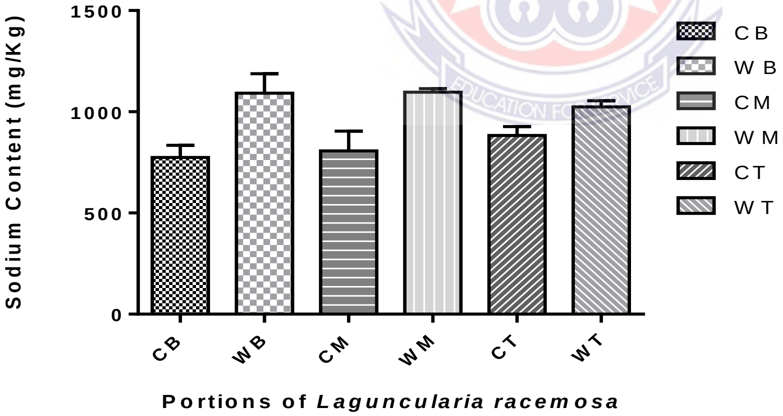


Fig. 4.14b: Mean Sodium Content along the Stem (combined heartwood and sapwood portions) of *Laguncularia racemose*. CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

As shown in Table 4.14, a significant difference in mean sodium content ($p < 0.05$) occurred along the stem positions of the trees from the two regions.

Table 4.14: ANOVA for Sodium Content of *Laguncularia racemosa* from Central and Western Regions of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant?
Interaction	13.88	< 0.0001	****	Yes
Regions	75.28	< 0.0001	****	Yes
Stem Location	10.78	< 0.0001	****	Yes

ANOVA table	SS	DF	MS	F (DFn, DFd)	P value
Interaction	103434	5	20687	F (5, 24) = 1212	P < 0.0001
Regions	560983	1	560983	F (1, 24) = 32856	P < 0.0001
Stem Location	80339	5	16068	F (5, 24) = 941.1	P < 0.0001
Residual	409.8	24	17.07		

Alpha =0.05

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter presents interpretations, explanations and deductions from results of the data collected from the study. The discussions have been presented on the physical properties (Moisture content, Basic density) mechanical properties (MOR, MOE, Compressive strength parallel to the grain (CPG)) and the chemical properties (ash, cellulose, lignin, nitrogen, organic carbon, sodium, potassium, phosphorus and calcium) of *Laguncularia racemosa (L. racemosa)* that were determined in the study.

5.2 Physical Properties of *L. racemosa*

5.2.1 Moisture content

Moisture content (MC) is an important parameter that influences wood performance and utilization (Desch & Dinwoodie, 1996). From this research, wood of trees from Central and Western Regions recorded an overall mean MC of 30.81 - 37.19% and 31.49 - 35.30% respectively (Fig. 4.1b). The sapwood recorded MC of 31.50 – 36.76% and 30.75 – 35.40% along the stem for Central and Western Regions respectively while the heartwood also recorded 30.11 – 37.62% and 32.24 – 35.20% for Central and Western Regions respectively (Fig. 4.1a). The moisture content of *L. racemosa* wood from this study shows variations at different sections of the stem. Variation in MC at different sections of the same piece of wood has been reported by Wood Floors Online (2009) and Reeb (1995). Thus, differences in MC at different sections of *L. racemosa* is expected.

Substantial moisture gradient can occur in the same log as well as in different logs of the same wood species of the same growing environments (Reeb, 1995).

Wood strength properties and utilization are linked to its MC (Nurfaizah et al., 2014; Desch, 1996; USDA, 1999). Low MC is associated with high strength properties (Barrett, 1975). From this research, the top portion was significantly higher in MC whereas there was no significant difference in MC between the base and the middle (Appendix B1) for both regions. The heartwood and sapwood of each corresponding portion was also not significantly different in MC (Appendix B1). According to Nurfaizah *et al*. (2014), high MC in woods recorded at the top of stem could be attributed to the presence of juvenile sclerenchyma fibres, and higher proportion of ground tissues as the tissues are very soft and spongy. Larson (2011) stated that mechanical properties of wooden materials depends on their moisture content and dimensional changes induced by moisture variation often leading to displacements which are greater than those caused by mechanical loading. Not only the moisture content level but also the variation of the moisture content is of great importance for the performance of timber structures and engineering, wood products. Variations in moisture content may cause stresses which may lead to cracks, reducing the load bearing capacity of the individual timber element and thus the whole structure.

5.2.2 Density

Wood quality and mechanical properties of wood are influenced by its density (Oyomoare & Zanne, 2013; Haygreen & Bowyer, 1996). From this study, mean densities of 602.44 - 624.39 kg/m^3 (top to base) for sapwood and 626.85 kg/m^3 (base), followed by 625.82 Kg/m^3 (middle), followed by 622.94 Kg/m^3 (top) for heartwood (Fig. 4.2a) was recorded for Central Region. Similarly, Western Region recorded mean densities of 638.065 - 605.47 Kg/m^3 (base to top) for sapwood and 632.80 Kg/m^3 (base), followed by 613.84 Kg/m^3 (middle), followed by 585.90 Kg/m^3 (top). The densities for the samples from the two regions indicated a decreasing trend from base to top for the heartwood and sapwood. The decreasing trend of density from the butt to the top for wood of tress from both regions and the overall mean densities along the stem for both regions agrees with the previous works of Ayarkwa (1998) and Agyeman (2014) in *Pterygota macrocarpa* (670 – 620 Kg/m^3, butt to top) and *Alstonia boonei* (450 – 410 Kg/m^3, butt to top) respectively. Timber is generally graded with very high, high, medium and low densities (Owoyemi and Olaniran, 2014; FAO, 1985). The limits between the grades are: Very high density: above 1000 Kg/m^3, High density: 800 – 1000 Kg/m^3, Medium density: 500 - 800 kg/m^3, low density: less than 500 Kg/m^3. From the results for basic density, *L. racemosa* can be classified as a medium density timber.

5.3 Mechanical Properties of *L. racemosa*

5.3.1 Static bending test (MOR)

The load required to cause failure of wood indicates its MOR (Hoyle, 1989); the higher the load required, the bigger the MOR. The results of the study indicated that MOR decreased from base to top along the sapwood and heartwood for both regions (Fig 4.3a). The overall mean MOR values (Fig 4.3b) indicate the base portion had a greater mean values for both regions (63.21 Nmm^{-2} and 56.84 Nmm^{-2}, Central and Western Regions respectively) and lowest at the top (52.82 Nmm^{-2} and 51.23 Nmm^{-2}, Central and Western Regions respectively). According to Tsoumis (1991) variability in MOR of wood may be attributed to the thin walls of the cells of the wood, the lower cellulose content and crystallinity of the wood. Strength properties of wood including MOR, may also be correlated with density (Rowell, 2005; Hoadley, 2000), the nature of wood and where it is situated (Stod *et al*., 2016; Zelalem *et al*., 2014). The observed trend in MOR from the two regions (Fig. 4.3a and b) is almost similar to its density variation (Fig 4.1.2a and b).

The bending strength, MOR, of small clear specimen at 12% MC according to Farmer (1972), is rated very low when it is under 50 Mpa, low if it ranges from 50 - 85 Mpa, medium if it ranges between 85-120 Mpa, high and very high if it ranges from 120-175 Mpa and over 175 Mpa respectively. *L. racemosa* from Central Region could be classified as having low MOR strength (51.03 - 63.50 N/mm^2). Sections from western Region may be considered low at the base (59.62 N/mm^2) and middle (54.70 N/mm^2) portions and very low at the top (46.11 N/mm^2). The mean MOR for *L. racemosa* from this study is however higher than *Alstonia boonei* (27.38 – 31.18 N/mm^2) (Agyemang, 2014) and almost similar to *Pinus patula* (43.14 - 63.61 N/mm^2) (Zelalem *et al.*, 2014). Nevertheless, it is relatively lower than some known Ghanaian species such as Wawabima (87.1 - 149.8 N/mm^2), Dahoma (73.1 - 139.0 N/mm^2) and *Celtis mildbraedii* (74.5 - 181.9 N/mm^2) (Ofori et al., 2009). This further suggest that although *L. racemosa* might perform relatively better under load than some species, it may not be a better option compared to many other species. Thus, for applications where MOR of *L. racemosa* is important, the entire heartwood for both regions might be considered.

5.3.2 Static bending test or Modulus of Elasticity (MOE)

MOE is an important property of wood that affects its use for structural applications (Kumar, 2004). The results of MOE from the study shows an overall trend of base > middle > top for both regions (Fig. 4.4b) with the heartwood recording relatively higher values for both region (Fig. 4.4a). Generally Central Region had the highest MOE along the stem (7711.07 – 6827.24 Nmm^{-2}) compared to Western Region (7157.55 – 5852.73 Nmm^{-2}) (Fig. 4.4b). Several researchers have reported of a decreasing trend in MOE from base to top (Zelalem *et al*., 2014; Schneider *et al.,* 1991). Regarding wood mechanical properties, the arrangement and proportions of ground tissues (axial and ray parenchyma, fibres and vessels) in hardwood species are considered to play a key role in variations of MOE in wood (Barnett and Jeronimidis 2003; Bowyer *et al*., 2003). Wood density is acknowledged to affect mechanical properties (Barnett and Jeronimidis, 2003; Bowyer *et al*., 2003). Earlier studies examined the predictability of some wood mechanical properties from density on various hardwood species such *Hevea brasiliensis* (Gnanaharan and Dhamodaran, 1992), *Eucalyptus globulus, E. nitens* and *E. regnans* (Yang and Evans, 2003), *Celtis mildbraedii* and *Maesopsis eminii* (Zziwa *et al*., 2006). Density was a good indicator of the mechanical properties in this study as sections with high densities recorded higher mechanical property values. The MOE of wood generally ranges from about 3,450 - 19,300 Mpa. Upton and Attah (2003) and TEDB (1994) classified strength of species based on the MOE at 12% moisture content as follows: 'Very High' [19,000 Mpa and more], 'High' [14,000-19,000 Mpa], 'Medium' [11000-14,000 Mpa], 'Low' [9,000-11,000 Mpa], and 'Low' [below 9,000 Mpa]. The various portions within the tree do not vary in terms of stiffness and the classification is Low.

Engineers and structural designers use knowledge of the MOE to determine required beam sizes (Shmulsky and Jones, 2011). MOE is also very important because it determines the amount the joist will bend or deflect under load and thus how solid the floor will seem. From the results, *L. racemosa* may not be recommended by structural engineers, for example, in floor joist constructions due to its low MOE strength values.

5.3.3 Compression strength parallel to the grain

Compressive Strength Parallel to the Grain (CPG) determines the performance of wood under crushing load (Gupta, 1985, Kollman and Côté, 1984). Along the sapwood, CPG decreased from base to top while the heartwood decreased in the order; base > middle > top for both regions (Figure 4.5a). With mean values of 28.93 – 28.20 N/mm^2 (Central Region) and 29.15 – 23.42 N/mm^2 (Western Region) (Fig. 4.5b). Overall order of decreasing Compression strength parallel to the grain of the sections was as follows: Butt Section > Middle Section > Top Section. The variation of CPG along the sapwood agrees with what was reported by Zelalem *et al.* (2014) and Ayarkwa (1998) in *Pinus patula* and *Pterygota Macrocarpa* respectively, where they observed a decreasing order from base to top. Compression Parallel to the Grain have been classified according to Farmer, (1972), as very low, low, medium, high and very high when the strength values are under 20 Mpa, ranging from 20-35 Mpa, 35-55 Mpa, 55-85 Mpa and over 85 Mpa respectively. This classification consequently rates the top, middle and butt sections as low. Moreover, the recorded values for *L. racemosa* were relatively lower than dry *Pinus patula,* 40.00 - 64.71 N/mm^2 (Zelalem *et al*., 2014) and *Pterygota Macrocarpa,* 51.60 - 66.12 N/mm^2 (Ayarkwa, 1998). Compression of wood and wood-based materials plays an important role in almost any construction projects. If the compression strength or bending strength of a 2-inch by 4-inch beam is not known, deflection due to bearing a load may cause significant deformation, which could even lead to its failure during service life.

5.4 Chemical Properties of *L. racemose*

5.4.1 Lignin content

The heartwood of the two regions recorded greater lignin content than their sapwoods with a decrease in value from the base to the top along the heartwood for both regions (Fig 4.6a). Central Region however recorded lignin content in the order: base > top > middle, along the sapwood (Fig 4.6a). According to Gonzalez (2007), the lignin content of wood generally decreases from the heartwood to the sapwood and from the base to the top. Thus, the observed variation of lignin content along the stem of *L. racemosa* is in agreement with the generally established trend.

Gellerstedt *et al.* (2009), indicated that lignin content of wood is generally estimated at 20-30%, for softwoods and 18-25%, for hardwoods. Other researchers have also reported 24-37% for softwoods and 17-30% for hardwoods (Fengel 1984; Dence 1992). Lignin content is noted as one of the factors that influence natural durability of many durable tropical species (Syafii *et al.*, 1988 a, b). Kim et al. (2006) also confirmed that lignin content contributed to the resistance of *Neobalonocarpus heimii* heartwood to soft rot decay. And according to Dickson (2000), wood strength (its resistance to applied forces) is also influenced by the quantity and proportion of lignin, cellulose and extractives. With percentage lignin content relatively lower in all sections than the minimum values recommended for hardwoods, the strength properties and resistance to bio-degraders of *L. racemosa* may not be significant. It may thus require preservation and other reinforcement before being used for structural applications and other uses requiring strength and long service. Moreover, since Western Region recorded a relatively higher lignin content, it may offer better resistance to bio-degraders as well as good strength properties and must be exploited ahead of that of Central Region for various applications. Carbon-rich building blocks in lignin helps convert wood into various forms for generating energy (Brookhaven National Laboratory, 2016).

5.4.2 Cellulose

Generally, cellulose content along the stem increased from base to top with Western Region recording slightly higher amount than Central Region (Fig 4.7b). According to Gonzalez (2007) and Reiniati (2009), cellulose constitutes 40 - 50% of wood dry weight. Cellulose values recorded from this studies, 23.09 - 28.09% (Central Region) and 25.78 - 29.38% (Western Region) (Fig 4.3.2b), indicate a relatively lower cellulose composition for *L. racemosa*. They were comparatively lower than what was reported for mongoy wood (43.13%), sipo wood (41.59%) and koto wood (43.03%) (Pawlicka and Waliszewsk, 2011). With cellulose being the principal food for termites, wood with high amount of alpha-cellulose and MC are readily eaten and destroyed by termites (Peralta et al; 2003). According to Syafii et al. (1988), wood species with lower amount of cellulose and higher lignin are insect resistant, while those with higher amounts of cellulose and lower amounts of lignin are susceptible to insect damage. Generally western Region recorded a comparatively higher cellulose content than Central Region. The butt portion of wood is known to possess more matured wood while the top is composed of juvenile wood while the sapwood is also known to change into heartwood as the tree grows with time (Stod *et al.*, 2016). The cellulose results from the study also indicated that the heartwood recorded lower values than the sapwood whereas an increasing trend from base to top was also observed (Fig 4.7a). This could thus be attributed to more matured cells at the heartwood and base portions of the stem than sapwood and towards the top portions of the tree which gives way to young and active cells. This phenomenon also suggests that the heartwood and towards the base portion of the wood may be more durable than the sapwood and top portions of *L. racemosa*.

5.4.3 Organic Carbon

According to Meier et al. (2013), carbon is the major constituent of wood making up 45 to 50% of its biomass. From this study, the overall organic carbon content (sapwood and heartwood combined) along the stem ranged from 30.72 – 31.52% for Central Region and 30.52 – 31.56% for Western Region (Fig 4.8b). Mitchual *et al.* (2014), indicated that carbon content contributes significantly to heating value of wood fuel with higher carbon content giving higher heating value.

According to Matthews (1993), differences in carbon content between different parts of trees are small in relation to the range of variations in overall carbon contents. Differences in carbon content between sapwood and heartwood reported for some species respectively are: Beech (48.92 and 49.06%), Oak (49.15 and 50.25%), Pine (50.18 and 54.38%) and Spruce (50.03 and 49.55%) (Daube, 1883). The results for organic carbon content for *L. racemosa* in this research followed the same trend with a relatively small differences between sapwood and heartwood for trees from each region (Fig. 4.8a).

5.4.4 Ash content

According to Imbeah (1998), ash content varies greatly within trees; being highest at the heartwood and decreasing towards the bark. From this study, the heartwood generally recorded a fairly higher ash content than the sapwood for both regions (Fig 4.9a). The trees from Central Region had their base portions also recording a significantly higher ash content whiles those from western Region recorded a relatively higher ash content at the top portions (Fig 4.9a). However, a post hoc analysis indicated nearly no significant difference in any of the portions for Western Region and between the corresponding portions along the heartwood and sapwood (Appendix B9). The observed trend in ash content variation is almost in agreement with density (Fig. 4.2b) and lignin (Fig. 4.3b) content variation observed in this study. This confirms the claim that ash content of wood is influenced by its density, lignin content and other chemical composition such as total extractives (Nurfaizah et al., 2014). According to Nurfaizah et al. (2014), wood portions with higher densities result in increase in percentage of ash content as a result of conversion of sapwood into heartwood from bottom to top portion of the tree, thus giving the bottom portion (with more heartwood and higher density) higher ash content than the top portion of the tree.

The overall mean ash content recorded were 3.26 - 2.39%, for Central Region, and 2.94 - 2.62%, for Western Region (Fig 4.9b). According to Ndlovu (2007), temperate-climate woods yield 0.1-1.0% ash, while tropical and sub-tropical woods yield up to 5%. Campbell (1990) also indicated that on the average, the burning of wood results in about 6 - 10% ash. The ash content of *L. racemosa* from this study is within the expected range for tropical woods. According to Kollmann (1959) and Campbell *et al.* (1990), other factors that influence the amount and composition of ash include the season, weather conditions, and soil minerals availability. Central Region with a generally high ash content suggest that the soil from which the samples were harvested might have more minerals compared to those from Western Region. Pintor-Ibarra et al. (2017) indicated that combustion equipment and their operators can be affected by high ash content notably due to excessive cleaning requirements. Acda and Devera (2014), also stated that thermal conversion processes do not require high amount of ash as a result of difficulties associated with as removal, slagging, corrosion of equipment and deposit formation. Thus *L. racemosa* wood with a relatively low ash content may be useful as biofuel for industrial applications.

5.4.5 Nitrogen, potassium, phosphorus, calcium and sodium

According to Zule and Dolenc (2012), Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Sulphur (S) are some of the major or macro-nutrients, since they are essential for plant growth, requiring about 1 to 150 g/Kg (1000 to 150, 000 mg/Kg). Deficiencies in the different macro and micro elements can have a serious impact on the general plant health deterioration as a result of interruption in key biochemical and physiological processes (Zule and Dolenc, 2012).

Research indicate that amount of each mineral element can vary within and between species and may be influenced by ecological factors (Antonović *et al*, 2007; Antonović *et al*, 2010). According to Zule and Dolenc (2012), while plants can absorb minerals through their leaves, greater proportion of the minerals are commonly transported to the tree from forest soil by means of its root system. Since *L. racemosa* from the two regions recorded different compositions of the various elements (Fig. 4.10b, 4.11b, 4.12b, 4.13b and 4.14b), it suggests that the soils from which the trees were harvested contained varying compositions of the various elements. Younger trees and hardwoods are also considered to have higher concentrations of nutrients than mature ones and softwoods (Zule and Dolenc, 2012). But because trees from both regions contained generally high compositions for some elements and lower composition in others, their degree of maturity may be fairly similar.

Zule and Dolenc, (2012) further indicated that distinctive difference exists between nutrient minerals largely due to the extent of their mobility. According to them, mobile elements including N, P, K, Cl, Mg and Mo are able to move from older plant parts to younger areas when there is the need for adequate supplies. The sapwood was largely high in the various mineral compositions for both regions (Fig. 4.10a, 4.11a, 4.12a, 4.13a and 4.14a) except phosphorus for Central Region where the heartwood recorded higher values along the stem. This confirms movement of the mineral elements from more matured, older heartwood to the growing, young sapwood.

The proportions of major elements in plants are generally in the decreasing order: nitrogen (N) > calcium (Ca) > potassium (K) > sodium (Na) > magnesium (Mg) > manganese (Mn) > iron (Fe) > aluminium (Al) (Meier et al., 2013). However, from this study, the most abundant elements were sodium and potassium with the order of decreasing values being: Na > K > Ca > N > P (Fig. 4.10b, 4.11b, 4.12b, 4.13b and 4.14b). With the order of mineral element proportions in *L. racemosa*, relatively different from what is proposed by Meier et al. (2013), it could be suggested that the relative proportions of mineral composition in plants may be species specific. It could also be influenced by the prevailing environmental factors such as availability of the elements in the surrounding soil.

For all the chemical elements considered in this study, Central Region recorded a generally high composition for Nitrogen (Fig. 4.10b) and Potassium (Fig. 4.11b) while Western Region had a comparatively higher values in Phosphorus (Fig. 4.12b), Calcium (Fig. 4.13b) and Sodium (Fig. 4.14b). The composition of the individual elements are discussed below.

5.4.5.1 Nitrogen

From this study, the combined nitrogen content (sapwood and heartwood) for *L. racemosa* ranged from 223.41 – 300.32 mg/Kg for Central Region and 199.55 – 242.66 mg/Kg for Western Region. According to Meier et al. (2013), when wood is burned for fuel, nitrogen oxide (NO_2) may be formed through oxidation of nitrogen in the wood. Mitchual *et al.* (2014), indicated that levels of NOx can have fertilizing effect and are beneficial since they can enrich forest soil. Thus *L. racemosa*, from western region with relatively low nitrogen content (Fig. 4.10b) may be recommended for use as wood fuel since the amount of nitrogen oxides emission from its combustion can be relatively low.

However, negative impact on health from emission of high levels of NOx including acidification of water and soils (Mitchual *et al*., 2014) and the risk of respiratory infections (Sillman, 2003) has been reported. Sillman (2003) also indicated that photochemical smog can be formed when NOx reacts with volatile organic compounds in the presence of sunlight and thus pollute the air. Since the sapwood generally recorded relatively high nitrogen content and the distribution along the stem largely increased from base to top (Fig 4.10a), the sapwood and towards the top portions of *L. racemosa* may have the potential to pollute the environment and can thus have negative health effect when used as fuel.

The values of nitrogen content recorded from this study are however, lower than what was reported by Mitchual *et al.* (2014) for *A. robusta* (481.3 mg/Kg), *C. pentandra* (481.7 mg/Kg) and *T. scleroxylon* (560.0 mg/Kg). The results from both regions were also below the recommended levels set by the Austria national standard for pellet and briquettes, Austria ÖNORM M7135 (i.e. Nitrogen content ≤ 0.6% or 600 mg/Kg), the German national standard for fuel pellet, except the sapwood of the top portion for Central Region, Germany DIN 51731 /DINplus (i.e. Nitrogen content ≤ 0.3%) (Mitchual *et al.,* 2014). This further confirms that *L. racemosa* especially those from Western Region may be ideal for use as wood fuel because of the relatively low nitrogen content.

5.4.5.2 Potassium

Potassium is among the major elements in plants (Meier et al., 2013). From this study, the ranges of mean values (heartwood and sapwood combined) recorded for potassium was 796.64 – 1099.21 mg/Kg (Central Region) and 588.81 – 1035.02 mg/Kg (Western Region) (Fig. 4.11b). Wood ash is considered a source of potash where the elemental composition in the ash enhance the soil nutrient to support plant growth (Misra et al., 1993) and potassium is one of the major components of wood ash elements required for plant growth (fertilization). From this research the potassium composition was quite high among the elements studied; it appeared only second to sodium (Fig. 4.14b). *L. racemosa* may thus have the potential to improve soil fertility especially those from Central Region, since it had a comparatively higher concentration of potassium. However, the amount of potassium in *L. racemosa* was relatively lower than *P. leiophylla* (13.16% or 131600 mg/Kg), *P. montezumae* (21.1% or 211000 mg/Kg) and *P. pseudostrobus* (12.23% or 122300 mg/Kg*)* (Pintor-Ibarra *et al.*, 2017). According to Campbell (1990), wood ash may have 3 – 4% (30000 – 40000 mg/Kg) potassium. This indicates that the potassium composition of *L. racemosa* may be lower than most wood species. High amounts of potassium is considered to increase the amount of aerosols in boilers resulting in emission of fine particles (Pintor-Ibarra et al., 2017). Thus *L. racemosa* with potassium composition perceived to be lower than most wood species may be an advantage when used as wood fuel in boilers and other operations.

5.4.5.3 Phosphorus

From this study, the ranges of mean values (heartwood and sapwood combined) recorded for phosphorus was 0.01 – 0.02 mg/Kg (Central Region) and 0.02 – 0.04 mg/Kg (Western

Region) (Fig. 4.12b). According to Campbell (1990), phosphorus composition of 0.3 – 1.4% (3000 – 14000 mg/Kg) is expected in wood ash and Mandre (2006**)** also reported of 15 500 mg/kg composition in wood ash. Phosphorus content of 5.37% (53700 mg/Kg), 4.06% (40600 mg/Kg) and 9.35 (93500 mg/Kg) for *P. leiophylla*, *P. montezumae* and *P. pseudostrobus* have also being reported (Pintor-Ibarra *et al.*, 2017). The amount of phosphorus in *L. racemosa* from the two regions were extremely low compared to any of the above species previously studied (Campbell, 1990; Mandre, 2006, Pintor-Ibarra *et al.*, 2017). The concentration of phosphorus in *L. racemosa* was too low to make any significant contribution to improve soil fertility when its ash is employed to enhance plant growth. However, according to Pintor-Ibarra *et al.* (2017), in boilers and other thermal processes that use wood fuel, the combustion process is affected by high concentration of phosphorous because of its volatile nature, forming phosphates which can melt the ash. Thus *L. racemosa* with low amount of phosphorous may be ideal as biofuel for thermal processes and similar applications.

5.4.5.4 Calcium

Calcium is the most dominant inorganic element in plants making up 50% of the total amount present (Zule and Dolenc, 2012)). However, this research reveals that calcium was the third abundant element after sodium and potassium. From this study, the ranges of mean values (heartwood and sapwood combined) recorded for calcium was 122.29 – 438.57 mg/Kg (Central Region) and 181.98 – 475.97 (Western Region) (Fig. 4.13b). The composition of mineral elements in trees have been identified to be influenced by factors such as ecological (Antonović *et al*, 2007; Antonović *et al*, 2010). It may therefore be reasoned that the amount of calcium in the available soil where wood samples from *L.*

racemosa trees used in the study were growing did not contain much calcium. Calcium contents of 7 – 33% (70 000 -330 000 mg/Kg) and 123 000 mg/Kg have been reported in wood ash (Campbell 1990; Mandre, 2006). Concentrations of 42.46% (424 600 mg/Kg), 42.44% (424 400 mg/Kg) and 25.48 (254 800 mg/Kg) for *P. leiophylla*, *P. montezumae* and *P. pseudostrobus* respectively have also been reported (Pintor-Ibarra *et al.*, 2017). High concentrations of Sodium reduces uptake of calcium by displacing the nutrients (Clatterbuck, 2003). This further confirms the limited amount of Calcium in *L. racemosa* trees from the two regions in comparison with the above species.

5.4.5.5 Sodium

According to Meier et al. (2013), sodium is one of the macro elements necessary for plant growth. From this study, the ranges of mean values (heartwood and sapwood combined) recorded for sodium was 774.63 – 882.59 mg/Kg (Central Region) and 1024.29 – 1096.83 mg/Kg (Western Region) (Fig. 4.14b). In all, sodium was the most abundant element in *L. racemosa* from the two regions. It may thus be established that sodium is the most abundant element in the geographical areas from which the samples were harvested according to the assertion by Antonović *et al.* (2007) and Antonović *et al.* (2010) that mineral elements in trees are influenced by the surrounding environment such as the soil. The amounts of Sodium in *L. racemosa* was however lower than what was reported for *P. leiophylla* (5.74% or 57400 mg/Kg), *P. montezumae* (2.33% or 23300 mg/Kg*)* and *P. pseudostrobus* (2.17% or 21700 mg/Kg*).* Moreover, high concentrations of sodium are known to lower the melting point of ash and produce slag in the combustion chambers of boilers when wood is used as fuel (Van Loo and Koppejan 2002, Biedermann and Obernberger 2005; Obernberger and Thek 2010). Higher amounts of sodium are also considered to be responsible for deposit formation as a result of vapour condensation inside the piping of combustion equipment (Werkelin et al. 2011). Therefore, the relatively low amount of Sodium in *L. racemosa,* in comparison with other species, is a good sign, making it a potentially desirable source of biofuel for industrial applications.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 Summary of Findings

- ✓ Moisture content in both regions were relatively higher at the top sections and lower in the butt section.
- ✓ Density increased from the base to the top in all the sections. Heartwood sections also recorded higher density values than sapwood sections in all regions.
- ✓ Mechanical properties decreased from the butt to top sections in both regions. The mechanical strength properties for *L. racemosa* was generally low with Central Region recording a fairly higher values and the heartwood also being relatively higher.
- ✓ The chemical properties commonly showed a fairly low amounts in all the parameters (Lignin, cellulose, organic carbon Na, K, Ca, P, N), with Western Region generally possessing higher values. Sodium and potassium were the most abundant inorganic elements with the order of decreasing values being: Na > K > Ca > N > P.

6.2 Conclusion

- The moisture content of *L. racemosa* wood from this study shows variations at different parts of the stem.
- L. racemosa can be classified as a medium density timber.The various portions within the tree do not vary in terms of stiffness and compression strength parallel to the grain and the classification is Low.

The chemical properties recorded were in low amounts in all the parameters in Central Region, whiles Western Region generally possessed higher values. 6.2

6.3 Recommendations

The following recommendations are made based on the study:

1.Due to the very low density and mechanical strength properties of *L. racemosa*, it should be used in non-load bearing applications such as fencing and carving.

2.The organic carbon, ash and inorganic mineral elements composition of *L. racemosa* makes it suitable as a biofuel energy source for industrial purposes.

3. Since trees from Central Region generally showed a comparatively higher values in physical and mechanical properties, and low values in chemical properties, it could be exploited for structural applications and fuel energy source for environmentally safe emissions.
4. Further studies on other properties must also be carried out to add to the database of this species along the coastal regions of Ghana.

REFERENCES

Acda MN & Devera, (2014). The Physico–Chemical Properties of Wood Pellets from Forest Residues Mn Acda & Ee Devera Forest Research Institute Malaysia 589 Journal Of Tropical Forest Science 26(4): 589–595.

Acreman, Mike, Albertengo, T, Amado, M., Amis, I. Bacchur, G. Basch, *et. al* (2012). Report of the Expert Group on Maintaining the Ability of Biodiversity to Continue to Support the Support of Water Cycle. Report to the Conference of the Parties to the Convention on Biological Diversity, Eleventh Meeting, Hyderabad, India, 8 – 19, October, 2012. UNEP/CBD/COP/H/INF/2 10 September, 2012.

Agyemang, **S.P. (2014)**. Determination of the Modulus of Rupture Variation (Static Bending Strength) And Density Variation in the wood of *Alstonia boonei*. KNUST. Unpublished.

Alongi, D.M. (1998). Coastal Ecosystems Processes. CRC Press, Boca Raton, FL, USA.

Alongi, D.M. (2002). Present State and Future of World's Mangrove Forest. Environmental Conservation; S0376892902000231 Volume 29

Antonović, A.; Jambreković, V.; Franjić, J.; Španić, N.; Pervan, S.; Ištvanić, J.; Bublić, A., (2010). Influence of sampling location on content and chemical composition of the beech native lignin (Fagus sylvatica L.), Periodicum Biologorum 112 (3):327-332.

Antonović. A.; Jambreković, V.; Pervan, S.; Ištvanić, J.; Moro, M.; Zule, J., (2007). Utjecaj lokaliteta uzorkovanja na grupni kemijski sastav bijeli bukovine (Fagus sylvatica L.), Drvna Industrija 58 (3):119-125.

ASTM D1102 – 84 (2007). Test method for ash in wood. 2008 Annual Book of ASTM Standards, 179 - 180

ASTM D1103 – 85 (2007). Test method for ash in wood. 2008 Annual Book of ASTM Standards, 156 - 157

ASTM D1104 – 86 (2007). Standard test method for holocellulose in wood.2008 Annual Book of ASTM Standards, 157 – 158

ASTM D1105 – 96 (2007). Standard test method for preparation of extractive-free wood.2008 Annual Book of ASTM Standards, 179 – 180

ASTM D1106 – 96 (2007). Standard test method for lignin in wood.2008 Annual Book of ASTM Standards, 183 – 184

Ayarkwa, J. (2009). Timber Technology for Researchers, Polytechnics and university students' p2-7. Kumasi, Classic Graphics Print.

Aylward, B and Barbier E. B. (1992). Vauing environmental functions in developing countries. London Environmental Economics Centre, UK; Biodiversity and Conservation 1, 34-50.

Bann, C. (1997). An Economic Analysis of Alternative Mangrove Management Strategies in Koh Kong Province, Cambodia. Research Report, Economic and environment program for SouthEast Asia, Singapore.

Barbier E., Acreman M. and Knowler D. (1997). Economic valuation of wetlands: a guide for policy makers and planners. Gland: Ramsar Convention Bureau.

Barbier E.B. (1994). Valuing environmental functions: tropical wetlands, Land Economics. 70:155 – 173

Barnett, J. R. and Jeronimidis, G. (Eds) (2003). Wood Quality and its Biological Basis. Blackwell Publishing Ltd. Oxford.

Barrett, J.D., Foschi, R.O. and Fox, S.P. (1975). Perpendicular-to Grain Strength of Douglas-fir. *Can.Jo.Civ.Eng*. 2(0:50-57).

Baver, J. E., W. J. Cai, P. A. Raymond, T. S. Bianchi, C.S. Hopkinson and P.A.G. Regnier (2013). The changing carbon cycle of the coastal ocean, *Nature*, 504, 61 – 70.

Benton, J. and Vernon W.C. (1990). Sampling, handling and analysing plant tissue samples. In R.L. Westerman (Ed.) Soil Testing and Plant Analysis (3rd ed.). SSSA Book Series No. 3.

Bernhart D. N and Wreath A. R. (1955). Colorimetric Determination of Phosphorus by Modified Phosphomolybdate Method *Anal. Chem.*, 27, 3, 440–441

Biedermann, F. and Obernberger, I., (2005): Ash-related problems duringbiomass combustion and possibilities for sustainable ashutilization. Disponible en línea: http://www.biosbioenergy.at/uploads/media

Bowyer, J., Shmulsky, R. and Haygreen, J.G. (2003).Forest Products and Wood Science: An Introduction. Ames, Iowa State Press.

Brookhaven National Laboratory (2016). Trees with altered lignin are better for biofuels. Science Daily, 28th June, 2016. www.sciencedaily.com/release/2016/06/160628072034

Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen – Total. In A. L.Page, R.H. Miller and D.R. Keeney (eds.). Methods of soil analysis. Part 2, *Agronomy* 9, 595-624.

Campbell, A. G. (1990). Recycling and disposing of wood ash. Department of Forestry, University of Idaho, Mosco, TAPPI journal, 73 (9):141 – 6 Chapman and Hall, N.Y., London, 494pp

Campbell, A. G., Kim, W. J. and Koch, P., (1990). Chemical variation in lodgepole pine with sapwood/heartwood, stem height and variety. Wood Fiber Sci 22: 22-30.

Christensen, B. (1983). Mangroves what are they worth? *An international journal of forestry and forest industries.* FAO.

Chowdhury, M. Q. (2007) .Effects of height on physical properties of wood of jhau (Casuarinaequisetifolia). Chowdhury, M. Q., Rashid, A. Z. M. M., Newaz and Alam, M. (2007). Effects of height on physical properties of wood of jhau (Casuarinaequisetifolia). Australian Forestry 70 (1), 33-36.

Clark, J.R. (1996). Coastal zone management handbook. New York: Lewis Publishers.

Clarke, S. and Preto, F. (2011). Biomass densification for energy production. Ontario Ministry Agriculture and Food factsheet. Pp. 11 – 033.

Clough, B.F. (1984). Growth and Salt Balance of the Mangroves Avicennia marina (Forsk). Vierh and Rhizopora stylosa Griff. In Relation to Salinity. Australian Journal of Plant Physiology, 11, 419-430.

Curkeet, R. P. (2011). Wood combustion. EPA Workshop. Retrieved from http://www.epa.gov/workshop2011/woodcombustion-curkeet

Darmawan, W, Rahayu, I., Nandika, D. and Marchal, R. (2012). The Importance of Extractives and Abrasives in Wood Materials on the Wearing Of Cutting Tools. Bioresources 7(4): 4715-4729.

Dence, C.W. (1992). The determination of lignin. In: (S.Y. Lin and C.W. Dence, Eds.). Methods in lignin chemistry.Springer-verlag: Heidelberg.33-61pp.

Desch, H.E. and Dinwoodie, J.M. (1996). Timber, Its Structure, Properties and Utilization Seventh Edition. 306pp. London. Mac Millan press limited..

Dickson, W. C. (2000). Integrative plant anatomy.Academic press. A Harcourt Science and Technology company. 525 B Street, Suite 1900, San Diego, California 92101-4495, USA. Pages 533.

Dinwoodie, J. M., (2000). Timber: its nature and behaviour. E & FN Spon. 29 West 35th Street, New York, NY 10001. Page 206.

Duke, J. A. (1983). Handbook of Energy Crops. NewCROPS web site,

Eglar, F.E. (1952). Southeast saline Everglades's vegetation, Florida, and its management. Vegetatio, 3: 213 – 265.

Ellison, A. M. (2000). Mangrove Restoration: Do we know enough? *Restoration Ecology* 8(3) pp: 219-229.

Essien, C. (2011). Physical, anatomical and treatment characteristics of the wood of *Cola gigantea* and *Ficus sur*. KNUST. Unpublished. Pg 44-46.

FAO, (1994). Mangrove forest management guidelines. FAO Forestry Paper No. 117. Rome

FAO, (2007). The World's Mangroves 1980-2005. FAO Forestry Paper 153. Rome

Farmer, R.H. (1972). Handbook of Hardwood. Second Edition. Pp 2, 49-50 .London, Her Majesty's Stationary Office.

Fengel, D. and G. Wegener. (1984). Wood: chemistry, ultrastructure, reactions. Berlin: Walter de Gruyter Publishers. 613 pp.

Food and Agriculture Organization of the United Nation, (FAO) 1985. Coconut Wood Processing and Use. Rome, Italy.

Forest Products Laboratory (1978). Wood handbook—Wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products. Chapter 4 page 27.

Francescato, V., Antonini, E. and Bergomi, L. Z. (2008). Wood fuel handbook. AIEL-Italy Agroforestry Energy Association. Legnaropd-Italy.

Freeman, A. M. (1993). The Measurement of Environmental and Resource Values. Resources for the Future, Washington DC, USA.

G. Matthews (1993). The Carbon Content of Trees, Forestry Commission Technical paper 4 Forestry Commission, Edinburgh, pp 1-21

Gellerstedt, G. Henriksson. and EK, M. (2009). Wood chemistry and biotechnology. Göttingen: Hubert & Co. ISBN 978-3-11-021339-3. Germany.http://www.qucosa.de/fileadmin/data/qucosa/documents/608/1211880694953

Giesen W, Wulffraat S., Zieren M and Scholten L. (2007). Mangrove Guidebook For SouthEast Asia. FAO and Wetlands International, 2007: Dharmasarn Co., Ltd. ISBN: 974-7946-85-8

Giri, C., Zhu Z., Tieszen L.L. Singh A., Gillette S. and Kelmelis J. A. (2008). Mangrove forest distributions and dynamics (1975-2005) of the Tsunami-affected region of Asia. *Journal of Biogeography (J. Biogeogr.)* 35, 519-528.

Gnanaharan, R. and Dhamodaran, T. K. (1992). Mechanical properties of rubberwood from a 35-year-old plantation in central Kerala, India. Journal of Tropical Forest Science 6 (2): 136-140.

Gonzalez, J. M. M (2007). Limiting Copper from Treated wood in or Near aquatic environment. 9-11pp.

Green, David W.; Winandy, Jerrold E.; Kretschmann, David E. (1999). Mechanical properties of wood. Wood handbook: wood as an engineering material.

Gupta, R.C. (1985). Mechanical Engineering, New Delhi-India. Khana Publisher. Pp11-12.

Hamilton, L.S. and Snedaker, S. C. (1984). Handbook for Mangrove Are Management. IUCN/UNESCO/UNEP,Honolulu: East-West Center.

Haygreen, J. G. and Bowyer, J. L. (1996). Forest Products and wood science. Third Edition. Iowa State University Press. Pp.243-247.

Heanes, D.L. (1984). Determination of total organic carbon in soils by an improved chromic acid digestion and spectrophotometric procedure. Communications in Soil Science and plant analysis 15: 1191-1213.

Hirsch, D. and Mauser, A. (1992). The Economic Value of Mangroves Two Case Studies: Mida Creek and Funzi Bay. (Unpublished). Amsterdam: University of Amsterdam.

Hoadley, **R. B**. **(2000).** *Understanding wood: A Craftsman's Guide to Wood Technology*. The Taunton Press, Newtown, Connecticute, USA.

Hong P. N and San H. T. (1993). Mangroves of Vietnem. IUCN, Bangkok, Thailand.

Hoyle, R. J. (1989). Wood Technology in the Design of Structures, Missoula Mantana. Mounting Press Publishing Company.

Hunter, R.C., Halverson, T.L. and Anderson, R.D. (1984). Quality assurance for plant tissue analysis by ICP-AES. Commun. In Soil Sci. Plant Anal., 15(11), 1285-1322.

Imbeah, M. (1998). Wood ash as mineral supplement for growing lambs under village conditions in the tropics. Department of Agriculture and Livestock, National

Veterinary Laboratory Boroko: Papua New Guinea Institute and State University, Blacksburg, p 227

Ishengoma, R. C., Gillah, P. R., Amartey, S. A. and Kitojo, D. H. (2004). Physical, mechanical and natural decay resistance properties of lesser known and lesser utilized Diospyrosmespiliformis, Tyrachylobiumverrucosum and Newtoniapaucijuga timber species from Tanzania. HolzRohWerkst 62: 387-389

Jenkins, B. M., Baxter, L.L., Miles Jr., R., Miles, J. R. (1998). Combustion properties of biomass. Fuel Processing Technology. 54(1) 17-46.

Jozsa, L. A. and Middleton G. R. (1994). A discussion of wood quality attributes and their practical implications. SP-34. Pacific Forestry Centre. Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II.

Kairo, J. G. (2001). Ecology and Restoration of Mangrove System in Kenya, PhD thesis at University of Brussels.

Kathiresan K., Rajendran N. and Thangadurai G. (1996). Growth of mangrove seedling in intertidal area of Vellar estuary southeast coast of India. Indian Journal of Marine Sciences 25: 240-243.

Kim, Y.S., Singh, A.P., Wong, A.H.H., Eom, T.J., and Lee, K.H. (2006). Micromorphological and chemical characteristics of cengal (Neobalanocarpus heimii) heartwood decayed by soft rot. Korean Journal of Wood Science and Technology 34(2), 68-77.

Kitamura S, Anwar C., Chaniago A. and Baba S. (1997). Handbook of mangroves in Indonesia – Bali and Lombok. International Society for Mangrove Ecosystems, Okinawa.

Kollmann, F., (1959): Wood technology and applications. (Tecnología de la Madera y sus Aplicaciones). Ministerio de Agricultura. Instituto Forestal de Investigaciones y experiencias, Madrid (in Spanish).

Kollmann, F.P., and Cote Jr., W.A. (1984). Principles of Wood Science and Technology I. Solid Wood. Springer-verlag, Berlin. Hielberg, New York.

Kolzlowski, T.T. (1971). Growth and development of trees, vol. II. Academic Press, New York. P. 86.

Kumar, S. (2004). Genetic parameter estimates for wood stiffness, strength, internal checking, and resin bleeding for radiata pine. Can. J. For. Res. 34(12): 2601-2610.

Kwarteng, F. K. (2014). Finger Jointing of some Tropical Hardwoods species in green and dry states for structural and non-structural applications. University of Winneba. College of Technology Education. Unpublished. Pp. 54-57.

Lawes, M.J., Obiri J.A.F and Eely H.A.C. (2004). The Uses and Value of Indigenous Forest Resources in South Africa. In: *Indigenous Forests and Woodlands in South Africa: Policy, People and Practice (*eds. Lawes M.J., Eely H.A.C., Shackleton C.M. , *et. al*.). pp. 227-273. University of KwaZulu-Natal Press, Pietermaritzburg, South Africa.

Lewis, R. R., Kusler, J. A. and Erwin, K. K (1995). Lessons learned from five Decades of Wetland Restoration and Creation in North America, in the Proceeding of Bases Ecologicas Para La Restauracion De Humedales En La Cuenca Mediterranea, Andulucia, p. 107.

Little E. L (1983). Common fuelwood crops: a handbook for their identification. McClain Printing Co., Parsons, WV

Luis Fernando Pintor-Ibarra, Artemio Carrillo-Parra, Rafael Herrera-Bucio, Pablo López-Albarrán, José G. Rutiaga-Quiñones (2017). Physical and chemical properties of timber by-products from *pinus leiophylla*, *p. montezumae* and *p. pseudostrobus* for a bioenergetics use Wood Research 62 (6): 2017 pp**.** 849-862

Mandre, M. (2006). Influence of wood ash on soil chemical composition and biochemical parameters of young Scots pine Proc. Estonian Acad. Sci. Biol. Ecol., 2006, 55, 2, 91–107. Influence of wood ash on soil chemical composition and biochemical parameters of young Scots pine. Estonian Acad. Sci. Biol. Ecol., 55, 2, 91 -107

Maxwell, G. S. (1995). Mangrove mitigation in Hong Kong. Proceedings of Ecotone IV, Surat Thani, Thailand, pp. 307 -315

McKee, K. L (1996). Mangrove Ecosystems: Definitions, Distribution, Zonation, Forest Structure, Trophic Structure, and Ecological Significance. In: Feller IC, Sitnk M (eds) Mangrove Ecology: a manual for a field course. Smithsonian Institution, Washington Dc, pp 15-22.

Misra, M. K. Ragland, K. W. And Baker, A. J. (1993). Wood Ash Composition As A Function Of Furnace Temperature Biomass and Bioenergy Vol. 4, No. 2, pp. 103-116, Chemical composition and properties of ashes from combustion plants using Miscanthus as fuel 2016 Christof Lanzerstorfer School of Engineering/Environmental Sciences, University of Applied Sciences Upper

Austria, A-4600 Wels, Austria Journal Of Environmental Sciences 5 4 (2 0 1 7) 1 7 8 – 1 8 3. Available Online at www.Sciencedirect.Com

Mitchual, S. J., Frimpong-Mensah, K. and Darkwa, N. A. (2014). Evaluation of Fuel Properties of Six Tropical Hardwood Timber Species for Briquettes. World Academy of Science, Engineering and Technology. International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol: 8, No: 7, 2014[International Scholarly and Scientific Research & Innovation 8(7) 2014]

Mitsch, W.J. and Gosselinks, J. G. (2000). Wetlands, 3rd ed. John Wiley, New York.

Moss, P. (1961). Limits of interference by iron, magnesium, aluminium and phosphate in the EDTA determination of calcium in the presence of magnesium using cal-red as indicator. *J. Sci, Fd Agriculture*, 12:30 -34

Nagelkerken I, van der Velde G, Gorissen M. W, Meijer GJ, van't Hof T, den Hartog C (2000). Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. Estuarine Coastal and Shelf Science 51:31-44

Ndlovu, H. (2007). Ash from homestead fireplaces and wood as possible sources of mineral for livestock. Nematology, Florida Cooperative Extension Service, Institute of Food and Agricultural.

Nelson, D.W. and Sommers, L.W. (1982). Total carbon and organic matter. In: Page, A.L., Miller, R.H. and Keeney, D.R. (eds.): Methods of soil analysis Part 2, 2nd ed. No.9. *American Society of Agronomy*. Soil Science of America. Madison, Wisconsin, USA.

Nurfaizah A. L., Nur S. M. T. and Jamaludin K. (2014). Physical and Chemical properties of kelempayan *(neolamarckia cadamba sp.),* wood International

Journal of Latest Research in Science and Technology Volume 3, Issue 6: Page No.215-219, November-December 2014 ISSN (Online):2278-5299

Nurfaizah, A. L., Nur, S. M., and Tamat, J. K. (2014). Physical and chemical properties of Kelempayan *(Neolamarckia cadamba sp.)* wood. *International Journal of Latest Research in Science and Technology, Volume 3, Issue 6: Page No.215-219,* Retrieved from http://www.mnkjournals.com/ijlrst.htm. (Accessed: 02/04/15).

Obernberger, I., Thek, G., 2010: The pellet handbook (1st ed.). London-Washington DC: Earthscan.

Ofori, J., and Appiah, J. K. (1998). Some drying characteristics of five Ghanaian lesser-known wood species. Ghana Journal of Forestry 6:19-27.

Owoyemi J. M., and Olaniran O. S. (2014). Natural Resistance of Ten Selected Nigerian Wood Species to Subterranean Termites' Attack. *International Journal of Biological Sciences and Applications.* Vol. 1, No. 2, pp. 35-39.

Owoyemi, J. M., and Olaniran, O. S. (2014). Natural Resistance of Ten Selected Nigerian Wood Species to Subterranean Termites' Attack. *International Journal of Biological Sciences and Applications.* Vol. 1, No. 2, 2014, pp. 35-39.

Pawlicka A., B. Waliszewska (2011). Chemical Composition Of Selected Species Of Exotic Wood Derived From The Region Of Africa Acta Sci. Pol. Silv. Colendar. Rat. Ind. Lignar. 10(1) 2011, 37-41

Pereira, H. Graca. J. and Rodrigues JC (2003). Wood chemistry in relation to quality. In: "Wood quality and its biological basis" (Barnett J, Jeronimidis G eds). John Wiley and Sons. Blackwell, Oxford, UK, pp. 53-86.

Peralta, R.C. G. Menezes, E. B. Carvalho A. G. Menezes E. L. A (2003). Feeding Preferences of Subterranean Termites for Forest Species associated or not to Wood Decaying Fungi.Floresta e Ambiente; Vol. 10, No 2, 58-63pp.

Peralta, R.C. G. Menezes, E. B. Carvalho A. G. Menezes E. L. A (2004). Wood consumption rates of Forest species by Subterrenean Termites (isopteran) under Field condition. Revista Arvore Vol. 28, No 2, 283 – 289pp

Plomion, C., Leprovost, & Stokes, A. (2001). Wood formation in trees. Plant Physiol 127: 1513-1523.

Primavera J. H., Sadaba R. B, Labata, M. J. H. and Altamirano J. P. (2004). Handbook of Mangroves in the Philippines – Panay. SEAFDEC Aquaculture Department, loilo PurdueUniversity.

Quarto, A. (2001). Analysis of mangrove resources; Mangrove Action Project, Mangrove Quarterly Report, UAS.

Rabinowitz D. (1978). Early growth of mangrove seedlings in Panama, and a hypothesis concerning the relationship of dispersal and zonation. J Biogeogr 5:113 – 133.

Racero Echenique C. S., Nieto Banda B. I. and Ávila Hernández J. R. (2015). "Physical and Mechanical Properties of the Wood Used in Indigenous Housing of the Tuchín Township, Department of Cordoba, Colombia" INGE CUC, vol. 11, no. 1, pp. 99-108.

Reeb, J.E. (1995). Wood and Moisture Relationships. Oregon State University Extension Service. U.S. Department of Agriculture. pp 1-5.

Reiniati, I. (2009). Chemical, physical, and viscoelastic properties of hot pressed hybrid poplar. Rhinotermitidae). Sociobiology 31: 25-39pp.

Rowell, **M. R**. **(2005).** *Handbook of Wood Chemistry and Wood Composite*. CRC Press. Retrieved from www.crcpress.com. (Accessed: 17/02/14).

Ruitenbeek, H. J. (1992). Mangrove Management:An Economic Analysis of Management options with a focus on Bintuni Bay, Irian Jaya. Environmental Management Development in Indonesia Project (EMDI) Environmental Reports, 8.(ISSN 1181-6457; 8) Jakarta and Halifax. *Forest Management options, ranging from clear cutting of a cutting ban, evaluated in a CBA incorporating environmental and economic leakages.

S. Meier, L. R.Rector, G. Allen, P K. Hopke, S. R. Chandrasekaran, L. Lin (2013). Elemental Analysis of Wood Fuels, New York State Energy Research and Development Authority (*NYSERDA*) Albany, New York, PP 1 - 46

Saenger P. (2002). Mangrove Ecology, Silviculture and Conservation. Kluwer Academic Publishers, Dordrecth, 11 -18.

Schneider, M.H., Sebestian, L.P., and Seepersad, J. (1991). Bending strength and stiffness of Caribbean pine from Trinad and Tobago. Wood and Fiber Science. 23(4): 468 – 471.

Shackleton, C. M., Grundy.l & Williams, A. (2004). Use of South Africa's woodlands for energy and construction. In: M. Lawes, H. Eeley, C.M. Shakleton and B. Geach, Editors, Indigenous forests and woodlands in South Africa: policy people and practice. University of Kwazula-Natal Press, Piertermaritzburg (2004), pp 337-366.

Sillman S. (2003). "Tropospheric ozone and photochemical smog, in B. Sherwood Lollar, ed., Treatise on Geochemistry, Environmental Geochemistry, Ch. 11, Elsevier, Vol. 9, 2003. http://www.TreatiseOnGeochemistry.com

Simpson, W. and Tenwolde A. (1999). Physical properties and moisture relations of wood. Wood handbook: wood as an engineering material. Madison, WI: USDA Forest Service, Forest Products Laboratory, 1999. General technical report FPL GTR-113: Pages 1-3, 24.

Saenger, P. and Snedaker, S. C. (1993). Pantropical trends in mangrove above-ground biomass and annual litterfall. *Oecologia,* 96, 293-299.

Spalding, M.; Kainuma, M.; Collins, L. (2010). World Atlas of Mangroves. A collaborative project of ITTO, ISME, FAO, UNEP-WCMC, UNESCO-MAB, UNU-INWEH and TNC. London (UK): Earthscan, London. 319 pp. Data layer from the World Atlas of Mangroves. In Supplement to: Spalding et al. (2010a). Cambridge (UK): UNEP World Conservation Monitoring Centre. URL: data.unep-wcmc.org/datasets/22.

Stöd, R., Verkasalo, E., and Heinonen, J. (2016). Quality and Bending Properties of Sawn Timber from Commerical Thinnings of Scot pine (sylvestrish L.). Baltic Forestry 22(1):148 – 162.

Stöd, R., Verkasalo, E., and Heinonen, J. (2016). Quality and Bending Properties of Sawn Timber from Commerical Thinnings of Scot pine (sylvestrish L.). Baltic Forestry 22(1):148 – 162.

Syafii, W., Samejima, M. and Yoshimoto, T. (1987). The Role of Extractives in Decay Resistance of Ulin Wood (*Eusideroxylonzwageri* T. et B.). Bull. *Tokyo Univ. For*., 77. Pp.1-8.

Syafii, W., Samejima, M. and Yoshimoto, T. (1988a). The Role of Lignin on Decay Resistance of Ulin (*Eusideroxylon zwageri* T.*etal* B.) to Wood-rotting Fungi. *Bull. Tokyo Univ. For.,* 79: 119-126.

Syafii, W., Samejima, M. and Yoshimoto, T. (1988b). The Effect of Lignin Structure on Decay Resistance of Some Tropical Hardwoods. *Bull. Tokyo Univ. For*., 80: 69-77.

Syafii, W., Samejima, M. and Yoshimoto, T. (1998). The Effect of Lignin Structure on Decay Resistance of some Tropical Hardwoods.*Bull. Tokyo Univ. For.,* 80:69-77.

Syafii, W., Samejima, M. and Yoshimoto, T. (1998). The Role of Lignin on Decay Resistance of Ulin (*Eusideroxylon zwageri* T. *et*B.) to Wood-rotting Fungi.*Bull. Tokyo Univ. For.,* 79:119-126

TEDB. (1994). The Tropical Timbers of Ghana. Timber Export Development Board, Takoradi.5-6 and 40pp.

Telmo C. Lousada J., & Moreira N. (2010). Proximate Analysis, Backwards Stepwise Regression between Gross Calorific Value, Ultimate and Chemical Analysis of Wood, Bio resources Technology, 101 (11), 3808-15

Tillman, D. A. (1978). Wood as energy resource, Academic Press Elsevier

Tomlinson, P. B (1986). The botany of mangroves. Cambridge University Press, Cambridge. ISBN 0-521-25567-8.

Tomlinson, P. B. (1995). The Botany of Mangroves-Cambridge Tropical Biology Series, Cambridge University Press.

Tsoumis, G. (1991). Science and Technology of Wood: Structure, Properties and Utilization. Van Nostrand Reinhold New York 160-174pp.

Twilley, R.R, R. Zimmerman, L. Solorzano, V.Rivera-Monroy, A. Bodero, R. Zambrano, M. Pozo, V. Garcia, K. Loot, R. Garcia, W. Cardenas, N. Gaibor, J. Espinoza, and J. Lynch. (1990). 'The importance of mangroves in sustaining fisheries and controlling water quality in coastal ecosystems', Interim Report, U.S. Agency for International Development, Program in Science and Technology Cooperation, Washington, D.C.

Upton, D. A. J., and Attah, A. (2003). Commercial timbers of Ghana – The potential for lesser used species. Forestry Commission of Ghana, Accra. 6p

USDA Forest Service. (1999). Wood handbook. Wood as an engineering material. General Technical Report FPL-113. USDA Forest Service, Forest Products Laboratory, Madison, p56.

Van Loo, S., Koppejan, J., (2002). Handbook of biomass combustion and Co-firing; Bioenergy task 32; International Energy Agency (IEA): Amsterdam, Netherlands.

Vetimane, J. E., (2010). Anatomy, Drying Behaviour and Mechanical Properties of lesser used wood species from Mozambique, Uppsala.

Werkelin, J., Lindberg, D., Boström, D., Skrifvars, B. J., Hupa, M., (2011). Ash-forming elements in four Scandinavian wood species part 3: Combustion of five spruce samples, Biomass and Bioenergy, 35: 725–733.

White, R. H. (1987). Effect of lignin content and extractive on the higher heating valve of wood. Wood and fibre Science. 19:446 – 452.

Winandy, J. E. (1994). Wood properties. Arntzen, F. A. C. J. Encyclopedia of Agricultural Sciences. Orlando. Pp.156-172.

Wood Floors Online. (2009). How moisture affects wood flooring products Wood Floors. Online.com, Inc., Jacksonville, Fl32210. Retrieved from http://www.woodfloorsonline.com/techtalk/woodwatterI. (Accessed: 02/03/14).

Yang, J. L. and Evans, R. (2003). Prediction of MOE of eucalypt wood from microfibril angle and density. Holz als Roh-und Werkstoff 61: 449-452pp.

Zelalem Getahun, Pradeep Poddar, and Omprakash Sahu. (2014). The Influence of Physical and Mechanical properties on Quality of wood produced from Pinus Patula Tree Grown at Arsi Forest. Department of Wood Technology, Adam University (CE) Adam Ethiopia. Department of Chemical Engineering, Wollo University (SW) Kombolcha, Ethiopia Correspondence Author Email: ops0121@gmail.com; Tel: +251933520653.

Zule and Dolenc (2012): Distribution of Mineral Substances in Different Wood Tissues... DRVNA INDUSTRIJA *63 (1) 19-25 (2012)* 19 Janja Zule, Jožica Dolenc1 Distribution of Mineral Substances in Different Wood Tissues of European Larch (*Larix decidua* Mill.) pp. 19 – 25.

Zziwa, A., Kaboggoza, J. R. S., Mwakali, J. A., Banana, A. Y., and Kyeyune, R. K. (2006). Physical and mechanical properties of some less utilised tropical timber tree species growing in Uganda. Uganda Journal of Agricultural Sciences 12 (1): 29-37.

APPENDICES

Appendix A1: Data for Moisture Content of *L. racemosa* from Central (C) and Western (W) Regions Along (B, M, T) and across (S, H) the Stem

	CBH	CBS	CMH	CMS	CTH	CTS	WBH	WBS	WMH	WMS	WTH	WTS
	29.07	31.74	33.84	43.36	42.95	46.64	28.13	30.68	34.60	32.81	44.06	25.71
	24.86	32.69	32.30	34.41	33.11	45.71	39.69	32.68	33.39	29.63	37.65	35.61
	31.56	31.22	26.37	33.21	38.20	45.66	28.02	33.20	33.63	33.33	37.59	37.99
	24.02	32.72	26.37	34.57	44.44	49.78	28.19	32.17	32.24	29.17	36.75	37.52
	27.56	34.54	34.07	32.01	40.16	42.56	26.82	30.80	31.90	30.53	36.50	33.82
	29.14	34.17	35.19	32.12	37.21	42.74	26.31	32.00	34.51	31.16	40.33	33.67
	28.21	29.45	31.63	31.65	42.46	42.27	25.68	28.68	32.44	28.64	41.26	31.52
	29.05	30.46	28.34	31.39	44.22	41.80	25.27	29.78	33.74	36.55	45.76	36.25
	25.93	33.14	34.16	31.58	30.77	31.83	27.82	31.57	42.17	36.99	42.00	35.11
	32.22	31.61	31.53	33.93	34.18	25.81	39.93	31.08	28.68	38.34	43.14	32.94
	30.66	35.02	33.84	33.54	36.77	36.80	36.74	29.64	34.16	35.47	28.90	34.88
	32.26	30.13	27.55	36.10	33.75	26.53	33.96	29.55	26.84	29.75	28.70	38.26
	33.51	32.54	28.76	33.60	36.48	30.85	37.17	27.96	29.11	33.69	26.88	36.21
	32.50	30.97	29.26	33.26	36.14	35.93	35.45	32.58	26.67	37.86	29.00	39.72
	30.97	27.85	33.93	29.26	33.39	38.26	30.32	30.07	33.78	33.61	31.29	33.72
	30.97	27.85	32.84	29.26	33.39	38.26	30.32	30.07	33.78	33.61	31.29	33.72
	32.81	28.87	32.74	30.24	37.62	29.87	34.27	29.76	37.83	35.58	31.20	36.17
	30.71	28.55	30.55	30.09	37.62	30.78	33.59	32.44	36.08	37.75	29.88	39.96
	33.69	32.67	28.55	29.92	37.63	26.06	39.81	29.35	27.09	34.43	30.09	33.98
	33.33	29.85	33.03	30.63	37.64	28.50	33.78	30.03	32.36	33.43	27.55	39.11
	30.11	31.87	31.78	30.24	37.58	36.76	33.80	30.92	32.27	39.24	35.51	35.80
AVERAGE	**30.11**	**31.50**	**31.51**	**32.76**	**37.62**	**36.76**	**32.24**	**30.75**	**32.67**	**33.90**	**35.20**	**35.40**

Appendix A2: Data for Basic Density of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

CBH	CBS	CMH	CMS	CTH	CTS	WBH	WBS	WMH	WMS	WTH	WTS
609.85	646.19	594.20	539.81	622.76	585.64	652.76	593.14	628.21	687.24	591.72	572.50
635.40	641.51	584.95	663.08	604.86	600.05	634.72	679.94	612.90	606.94	616.63	571.75
632.44	622.29	617.54	661.12	612.00	648.65	675.29	696.13	596.11	615.12	593.02	569.02
627.77	648.80	589.23	576.22	628.19	635.61	663.06	612.46	589.40	604.63	590.70	573.88

623.98	650.22	592.41	539.06	606.87	643.99	681.48	600.91	535.21	615.38	607.61	621.96
620.07	626.14	633.02	551.89	602.31	633.25	622.06	626.04	625.81	660.79	612.86	570.77
615.48	637.29	583.03	545.77	607.26	640.59	626.97	620.77	622.84	630.14	609.47	574.15
613.38	638.95	645.36	528.26	605.46	644.14	650.12	597.80	619.32	594.00	607.61	584.46
632.52	607.18	649.14	573.59	609.54	627.96	625.14	595.94	615.83	608.95	584.36	577.08
632.77	614.77	644.94	542.82	617.80	561.89	641.67	718.91	593.47	601.17	600.64	567.67
631.28	620.30	639.18	627.81	620.91	598.09	642.83	712.95	597.91	587.18	610.51	620.86
631.08	609.00	643.35	606.35	613.94	585.66	627.18	675.40	619.98	572.46	604.30	575.46
631.72	624.73	643.93	652.22	646.27	566.63	632.55	600.54	624.06	600.24	622.28	571.43
626.88	605.99	647.19	650.78	622.99	584.01	618.05	608.85	622.07	593.71	597.00	598.01
626.88	606.31	599.26	673.01	661.71	568.42	626.85	680.85	618.09	617.22	604.73	612.74
634.05	625.13	644.30	648.82	622.72	605.92	634.76	600.92	616.00	588.37	604.48	588.74
626.88	614.69	648.15	618.99	646.53	576.05	632.91	600.00	609.17	581.07	593.09	594.92
627.55	618.32	644.32	635.09	635.57	598.84	631.87	600.23	624.32	593.68	589.91	567.73
631.38	609.91	647.12	633.33	646.70	581.67	618.93	628.74	656.08	612.24	621.59	578.08
625.62	620.02	625.82	659.02	624.44	561.69	622.09	605.47	650.05	604.92	646.90	626.81
626.85	**624.39**	**625.82**	**606.35**	**622.94**	**602.44**	**638.07**	**632.80**	**613.84**	**608.77**	**605.47**	**585.90**

Appendix A3: Data for MOR of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

CBH	CBS	CMH	CMS	CTH	CTS	WBH	WBS	WMH	WMS	WTH	WTS
56.31	51.2	49.7	60.2	54.16	56.47	60.4	52.7	49.17	50.89	64.63	34.13
60.57	56.9	52.2	64.8	49.98	56.24	56.5	49.68	46.21	46.96	54.73	23.25
51.04	60.7	50.1	63.73	48.02	57.01	60.16	41.53	53.3	40.46	64.2	25.25
58.77	55.4	49.1	62.57	50.59	59.34	60.44	47.27	51.34	39.37	67.22	35.87
56.67	56.0	48.9	63.57	50.69	56.78	56.18	42.47	49.98	45	59.9	45.15
57.47	58.0	50	62.97	55.71	57.168	57.36	53.16	55.42	44.7	56.12	34.88
59.81	59.8	51.8	63.49	57.13	59.46	51.14	49.86	48.77	44.42	59.79	39.41
58.11	57.3	50.7	64.34	51.98	57.73	55.44	39.89	50.96	48.02	52.89	31.25
54.43	52.8	48.2	62.45	44.38	54.88	52.47	40.32	52.55	42.31	57.26	30.23
53.53	52.3	49.3	61.6	44.25	56.61	56.68	46.32	50.86	44.68	59.64	33.27
75.38	59.9	64.9	39.26	57.66	48.02	61.23	61.48	59.83	46.7	49.08	55.71
77.17	64.5	70.2	40.17	59.18	43.83	59.23	59.96	65.82	49.35	52.38	57.37
89.38	60.7	65.1	38.83	56.66	44.25	75.04	55.6	59.53	54.06	54.21	57.37
81.68	57.4	67.9	37.98	59.36	43.15	67.79	62.42	60.69	48.47	54.43	59.75

78.16	56.5	67	39.06	60.23	44.813	66.32	60.37	76.73	47.56	49.83	61.98
80.35	59.8	69.2	41.16	58.62	45.97	70.79	56.66	59.34	46.96	59.62	54.85
85.82	60.2	67.3	40.28	59.13	49.23	60.62	55.34	73.24	46.32	61.71	64.01
82.13	62.0	68	39.83	59.86	47.89	67.23	59.06	65.53	49.2	54.43	54.73
74.88	59.4	65.7	37.07	58.11	40.57	61.23	58.96	68.29	47.37	49.93	57.99
78.57	57.6	64.8	37.96	57.38	40.39	65.52	58.87	65.44	48.44	53.96	58.05
68.51	**57.9**	**58.5**	**51.07**	**54.65**	**50.99**	**61.09**	**52.6**	**58.15**	**46.56**	**56.8**	**45.73**

Appendix A4: Data for MOE of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

CBH	CBS	CMH	CMS	CTH	CTS	WBH	WBS	WMH	WMS	WTH	WTS
7858	6995	7895	4820	6242	5979	7626	5980	4431	3640	3155	5418
8305	7173	7920	9252	6795	6037	7653	7059	3651	3398	2918	4750
7616	7134	8092	4997	6846	5841	6070	6148	4049	4476	3468	4914
8122	7068	7865	9036	6757	6149	6146	6184	4459	4628	3683	4734
6033	6989	8030	5553	6286	5896	7437	6090	3507	3538	4886	4596
7587	7072	7960	6732	6585	5981	6960	5656	3944	4303	2435	5316
7581	7079	7964	6736	6591	5991	7041	6059	4325	4530	3171	5225
7593	7073	7966	6733	6595	5973	6832	5326	4071	4662	3972	5587
7585	7068	7953	6728	6580	5975	6970	6062	4072	4146	3461	5067
7580	7064	7957	6727	6570	5980.4	6971	6063	8636	4147	3462	5068
9797	6071	5621	8296	8098	7226	7902	7112	9424	7928	8936	5420
8718	8710	5738	8030	6931	7363	8644	6850	9120	6647	9424	5967
9022	6850	5874	7954	7742	6819	8723	7940	7897	7362	9120	6206
9543	6795	5923	8349	7591	6976	7951	6928	9020	6939	8897	6662
9828	6372	5438	8164	7864	6878	7857	7685	8927	7927	9204	6366
8471	6946	5719	8159	7923	7059	8116	7372	9247	6899	9027	4530
9230	6957	5722	8167	7692	7061	8773	7777	8462	7797	8647	6254
9236	6966	5730	8163	7699	7045	7505	7413	8841	7233	8462	5937
9248	6961	5714	8149	7677	7043	8183	7414	8842	7341	8964	5917
9203	6944	5706	8152	7701	7052.4	8184	7640	4202	7342	8965	5918
8408	**7014**	**6839**	**7445**	**7138**	**6516.2**	**7577.2**	**6738**	**6456.4**	**5744**	**6213**	**5492.6**

Appendix A5: Data for CPG of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

CBH	CBS	CMH	CMS	CTH	CTS	WBH	WBS	WMH	WMS	WTH	WTS
28.95	30.6	23.6	15.73	27.32	27.62	26.99	24.73	26.32	33.2	29.32	18.25
23.84	27.8	20.84	17.48	25.8	18.91	31.35	25.37	24.12	31.93	27.6	20.95

29.35	31.48	24.66	26.28	28.88	18.15	35.03	23.21	21.11	25.78	25.65	18.09
27.85	27.5	29.02	17.23	27.37	22.13	29.68	24.55	24.83	26.46	27.77	12.96
31.93	28.55	22.08	19.5	26.7	23.67	36.3	23.75	29.73	25.55	30.47	16.54
27.37	24.23	21.95	23.39	27.9	16.15	36.68	26.05	28.42	26.4	26.08	12
28.22	27.95	23.69	20	27.77	21.11	30.9	29.46	23.18	24.48	28.32	12.57
29.13	31.15	24.19	24.95	24.7	23.06	26.4	30.43	25.82	26.76	25.95	19.85
28.84	28.66	23.82	20.57	27.06	22.13	37.15	30.28	22.36	27.8	26.22	13.45
26.69	28.64	23.06	20.57	27.05	18.09	36.7	26.15	29.1	26.88	27.35	18.35
32.32	31.4	31.55	40.12	33.13	35.05	27.9	24.11	33.55	27.53	29.43	20.32
35.72	33.95	35.15	33.7	29.77	29.95	30.82	25.8	33.92	23.43	28.41	26.03
33.75	32.97	31.88	32.33	20.69	33.95	25.32	25.7	35.57	22.45	36.28	23.2
35.7	31.38	35.68	32.6	26.22	36.45	28.52	25.05	31	26.8	34.55	23.19
32.5	32.8	33.42	32.56	25.69	34.25	25.85	27.05	34	23.03	27.96	27.28
27.13	32.5	36.32	34.262	27.1	31.05	24.79	26.03	32.17	26.53	33.65	27.8
37.72	33.87	34.3	35.33	28.69	29.98	29.23	22.28	30.3	22.36	27.4	26.25
33.55	32.91	34.043	34.87	27.56	32.95	25.35	29.85	33.92	22.34	27.58	27.45
32.32	31.13	33.01	33.65	25.51	31.55	34.05	28.28	32.1	28.18	29	22.5
34.77	32.09	35.07	33.19	26.64	34.35	27.53	28.6	32.57	23.64	23.96	22.92
30.88	**30.58**	**28.87**	**27.42**	**27.08**	**27.03**	**30.33**	**26.34**	**29.20**	**26.08**	**28.65**	**20.50**

Appendix A6: Data for Lignin Content of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

SAMPLE ID	R1 (%)	R2 (%)	R3 (%)	AVERAGE (%)
CBS	11.23	10.93	11.08	11.08
CBH	12.00	10.91	11.46	11.46
CMS	11.28	10.35	10.82	10.82
CMH	12.06	10.32	11.19	11.19
CTS	10.71	10.97	10.84	10.84
CTH	10.41	10.26	10.34	10.34
WBS	14.88	14.81	14.85	14.85
WBH	16.16	16.61	16.39	16.39
WMS	13.93	14.54	14.24	14.24
WMH	14.80	13.52	14.16	14.16
WTS	12.48	12.09	12.28	12.28
WTH	12.10	12.61	12.36	12.36

Appendix A7: Data for Cellulose of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

SAMPLE ID	R 1 (%)	R 2 (%)	R 3 (%)	AVERAGE (%)
CBH	23.84	22.87	23.36	**23.36**
CBS	23.51	22.13	22.82	**22.82**
CMH	23.10	23.73	23.42	**23.42**
CMS	28.00	31.69	29.85	**29.85**
CTH	27.31	26.26	26.79	**26.79**
CTS	28.09	30.69	29.39	**29.39**
WBH	25.32	26.02	25.67	**25.67**
WBS	25.13	26.66	25.90	**25.90**
WMH	22.47	29.24	25.86	**25.86**
WMS	29.57	31.69	30.63	**30.63**
WTH	30.26	30.17	30.22	**30.22**
WTS	28.48	28.62	28.55	**28.55**

Appendix A8: Data for Ash Content of *L. racemosa* from Central (C) and Western (W) regions along (B, M, T) and across (S, H) the stem

SAMPLE ID	R1 (%)	R2 (%)	R3 (%)	AVERAGE (%)
CBS	3.04	3.55	3.29	**3.29**
CBH	3.14	3.30	3.22	**3.22**
CMS	2.45	2.40	2.42	**2.42**
CMH	2.44	2.25	2.35	**2.35**
CTS	2.65	2.79	2.72	**2.72**
CTH	2.69	2.75	2.72	**2.72**
WBS	2.79	2.69	2.74	**2.74**
WBH	2.70	2.70	2.70	**2.70**
WMS	2.85	2.09	2.47	**2.47**
WMH	2.80	2.75	2.77	**2.77**
WTS	2.93	3.03	2.98	**2.98**
WTH	2.80	2.99	2.89	**2.89**

Appendix A9: Data for Organic Carbon of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

SAMPLE ID	R1 (%)	R2 (%)	R3 (%)	AVERAGE %)
CBS	31.92	31.92	31.92	**31.92**
CBH	31.14	31.1	31.12	**31.12**
CMS	30.29	30.35	30.32	**30.32**
CMH	31.11	31.13	31.12	**31.12**
CTS	30.7	30.74	30.72	**30.72**
CTH	31.53	31.51	31.52	**31.52**
WBS	31.53	31.51	31.52	**31.52**
WBH	31.54	31.65	31.59	**31.59**
WMS	31.92	31.92	31.92	**31.92**
WMH	30.28	30.36	30.32	**30.32**
WTS	30.7	30.74	30.72	**30.72**
WTH	30.33	30.31	30.32	**30.32**

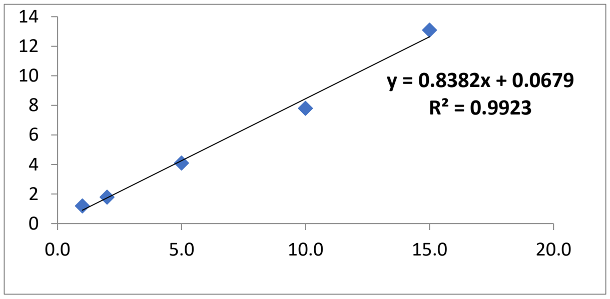
Appendix A10: Data for Nitrogen Content of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

SAMPLE ID	R1 (mg/Kg)	R2 (mg/Kg)	R3 (mg/Kg)	AVERAGE (mg/Kg)
CBS	215.91	202.07	208.99	**208.99**
CBH	228.60	247.05	237.82	**237.82**
CMS	253.58	262.76	258.17	**258.17**
CMH	221.92	246.71	234.31	**234.31**
CTS	336.26	351.36	343.81	**343.81**
CTH	249.46	264.19	256.82	**256.82**
WBS	205.10	204.99	205.04	**205.04**
WBH	187.32	200.80	194.06	**194.06**
WMS	202.43	207.37	204.90	**204.90**
WMH	233.47	187.61	210.54	**210.54**
WTS	262.82	251.50	257.16	**257.16**
WTH	221.67	234.67	228.17	**228.17**

Appendix A11: Data for Potassium Content of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

Triplicate Analysis of Potassium in Wood Samples

Std. Av. Conc. (mg/L }	Av. Meter Reading (M.R)
1.0	1.2
2.0	1.8
5.0	4.1
10.0	7.8
15.0	13.1



SAMPLE ID	Meter Readings (M.R.) M. R. 1	M. R. 2	M. R. 3	CONC. 1 (mg / L)	CONC. 2 (mg / L)	CONC. 3 (mg / L)	CONC. 1 (mg/Kg)	CONC. 2 (mg/Kg)	CONC. 3 (mg/Kg)	Average (mg/Kg)
CBH	11.60	11.70	11.65	14.10	14.221	14.160	704.951	711.064	708.007	**708.007**
CBS	14.60	14.50	14.55	17.77	17.644	17.705	888.325	882.213	885.269	**885.269**
CMH	12.60	12.70	12.65	15.32	15.444	15.383	766.076	772.188	769.132	**769.132**
CMS	22.70	22.50	22.60	27.67	27.424	27.546	1383.435	1371.210	1377.323	**1377.323**
CTH	19.60	19.80	19.70	23.88	24.123	24.001	1193.949	1206.174	1200.061	**1200.061**
CTS	16.30	16.50	16.40	19.85	20.089	19.967	992.237	1004.462	998.350	**998.350**
WBH	11.00	11.10	11.05	13.37	13.488	13.427	668.276	674.389	671.333	**671.333**
WBS	22.90	23.00	22.95	27.91	28.035	27.974	1395.660	1401.773	1398.716	**1398.716**
WMH	10.80	10.90	10.85	13.12	13.243	13.182	656.051	662.164	659.108	**659.108**
WMS	8.50	8.60	8.55	10.31	10.432	10.370	515.465	521.577	518.521	**518.521**
WTH	11.50	11.40	11.455	13.98	13.855	13.916	698.839	692.726	695.782	**695.782**
WTS	9.80	9.70	9.75	11.90	11.776	11.837	594.927	588.814	591.870	**591.870**

Appendix A12: Data for Phosphorus Content of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

SAMPLE ID	R1 (mg/Kg)	R2 (mg/Kg)	R3 (mg/Kg)	AVERAGE (mg/Kg)
CBS	0.009	0.037	0.065	**0.037**
CBH	0.031	0.138	0.245	**0.138**
CMS	0.027	0.158	0.290	**0.158**
CMH	0.038	0.231	0.425	**0.231**
CTS	0.031	0.161	0.290	**0.161**
CTH	0.020	0.132	0.245	**0.132**
WBS	0.042	0.256	0.470	**0.256**
WBH	0.033	0.240	0.447	**0.240**
WMS	0.033	0.184	0.335	**0.184**
WMH	0.043	0.002	0.043	**0.029**
WTS	0.038	0.231	0.425	**0.231**
WTH	0.013	0.073	0.133	**0.073**

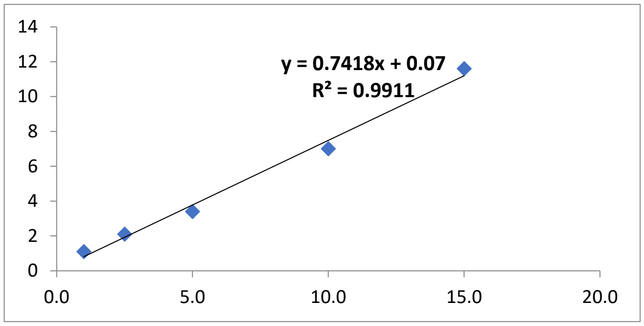
Appendix A13: Data for Calcium Content of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

SAMPLE ID	R1 (mg/Kg)	R2 (mg/Kg)	R3 (mg/Kg)	AVERAGE (mg/Kg)
CBH	347.67	336.05	336.05	**339.92**
CBS	548.84	531.40	531.40	**537.21**
CMH	197.67	206.98	206.98	**203.88**
CMS	384.88	377.33	377.33	**379.84**
CTH	160.47	162.21	162.21	**161.63**
CTS	84.88	81.98	81.98	**82.95**
WBH	358.14	347.09	347.09	**350.78**
WBS	608.14	594.19	594.19	**598.84**
WMH	593.02	481.98	481.98	**518.99**
WMS	440.70	429.07	429.07	**432.95**
WTH	223.26	219.19	219.19	**220.54**
WTS	140.70	144.77	144.77	**143.41**

Appendix A14: Data for Sodium Content of *L. racemosa* from Central (C) and Western (W) Regions along (B, M, T) and across (S, H) the Stem

Triplicate Analysis of Sodium in Wood Samples

Std. Av. Conc. (mg/L }	Av. Meter Reading (M.R)
1.0	1.1
2.5	2.1
5.0	3.4
10.0	7
15.0	11.6



SAMPLE ID	Meter Readings (M.R.) M. R. 1	M. R. 2	M. R. 2	CONC. 1 (mg / L)	CONC. 2 (mg / L)	CONC. 3 (mg / L)	CONC. 1 mg/Kg	CONC. 2 mg/Kg	CONC. 3 mg/Kg	Average mg/Kg
CBH	10.80	10.70	10.75	14.480	14.345	14.413	724.022	717.274	720.648	**720.648**
CBS	12.40	12.30	12.35	16.640	16.505	16.572	831.984	825.236	828.610	**828.610**
CMH	10.80	10.60	10.70	14.480	14.211	14.345	724.022	710.526	717.274	**717.274**
CMS	13.30	13.40	13.35	17.854	17.989	17.922	892.713	899.460	896.086	**896.086**
CTH	13.80	13.70	13.75	18.529	18.394	18.462	926.451	919.703	923.077	**923.077**
CTS	12.60	12.50	12.55	16.910	16.775	16.842	845.479	838.731	842.105	**842.105**
WBH	14.90	15.00	14.95	20.013	20.148	20.081	1000.675	1007.422	1004.049	**1004.049**
WBS	17.50	17.60	17.55	23.522	23.657	23.590	1176.113	1182.861	1179.487	**1179.487**
WMH	16.50	16.60	16.55	22.173	22.308	22.240	1108.637	1115.385	1112.011	**1112.011**
WMS	16.00	16.20	16.10	21.498	21.768	21.633	1074.899	1088.394	1081.646	**1081.646**
WTH	14.90	14.80	14.85	20.013	19.879	19.946	1000.675	993.927	997.301	**997.301**
WTS	15.70	15.60	15.65	21.093	20.958	21.026	1054.656	1047.908	1051.282	**1051.282**

Appendix B1: Tukey's multiple comparison test for MC of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95.00% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	-1.395	-5.111 to 2.321	No	ns
BH vs. MH	-1.406	-5.122 to 2.310	No	ns
BH vs. MS	-2.648	-6.364 to 1.068	No	ns
BH vs. TH	-7.509	-11.22 to -3.792	Yes	****
BH vs. TS	-6.649	-10.37 to -2.933	Yes	****
BS vs. MH	-0.01102	-3.727 to 3.705	No	ns
BS vs. MS	-1.253	-4.970 to 2.463	No	ns
BS vs. TH	-6.114	-9.830 to -2.398	Yes	****
BS vs. TS	-5.254	-8.971 to -1.538	Yes	***
MH vs. MS	-1.242	-4.959 to 2.474	No	ns
MH vs. TH	-6.103	-9.819 to -2.387	Yes	****
MH vs. TS	-5.243	-8.960 to -1.527	Yes	***
MS vs. TH	-4.860	-8.577 to -1.144	Yes	**
MS vs. TS	-4.001	-7.717 to -0.2849	Yes	*
TH vs. TS	0.8594	-2.857 to 4.576	No	ns
WESTERN				
BH vs. BS	1.490	-2.226 to 5.206	No	ns
BH vs. MH	-0.4361	-4.152 to 3.280	No	ns
BH vs. MS	-1.660	-5.376 to 2.056	No	ns
BH vs. TH	-2.964	-6.681 to 0.7517	No	ns
BH vs. TS	-3.160	-6.876 to 0.5565	No	ns
BS vs. MH	-1.926	-5.642 to 1.790	No	ns
BS vs. MS	-3.150	-6.866 to 0.5664	No	ns
BS vs. TH	-4.454	-8.170 to -0.7381	Yes	**
BS vs. TS	-4.649	-8.366 to -0.9333	Yes	**
MH vs. MS	-1.224	-4.940 to 2.492	No	ns
MH vs. TH	-2.528	-6.245 to 1.188	No	ns
MH vs. TS	-2.724	-6.440 to 0.9926	No	ns
MS vs. TH	-1.304	-5.021 to 2.412	No	ns
MS vs. TS	-1.500	-5.216 to 2.217	No	ns
TH vs. TS	-0.1952	-3.911 to 3.521	No	ns

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	30.11	31.50	-1.395	1.293	20	20	1.526	228.0
BH vs. MH	30.11	31.51	-1.406	1.293	20	20	1.538	228.0
BH vs. MS	30.11	32.76	-2.648	1.293	20	20	2.896	228.0
BH vs. TH	30.11	37.62	-7.509	1.293	20	20	8.213	228.0
BH vs. TS	30.11	36.76	-6.649	1.293	20	20	7.273	228.0
BS vs. MH	31.50	31.51	-0.01102	1.293	20	20	0.01205	228.0
BS vs. MS	31.50	32.76	-1.253	1.293	20	20	1.371	228.0
BS vs. TH	31.50	37.62	-6.114	1.293	20	20	6.687	228.0

BS vs. TS	31.50	36.76	-5.254	1.293	20	20	5.747	228.0
MH vs. MS	31.51	32.76	-1.242	1.293	20	20	1.359	228.0
MH vs. TH	31.51	37.62	-6.103	1.293	20	20	6.675	228.0
MH vs. TS	31.51	36.76	-5.243	1.293	20	20	5.735	228.0
MS vs. TH	32.76	37.62	-4.860	1.293	20	20	5.316	228.0
MS vs. TS	32.76	36.76	-4.001	1.293	20	20	4.376	228.0
TH vs. TS	37.62	36.76	0.8594	1.293	20	20	0.9400	228.0
WESTERN								
BH vs. BS	32.24	30.75	1.490	1.293	20	20	1.629	228.0
BH vs. MH	32.24	32.67	-0.4361	1.293	20	20	0.4770	228.0
BH vs. MS	32.24	33.90	-1.660	1.293	20	20	1.816	228.0
BH vs. TH	32.24	35.20	-2.964	1.293	20	20	3.242	228.0
BH vs. TS	32.24	35.40	-3.160	1.293	20	20	3.456	228.0
BS vs. MH	30.75	32.67	-1.926	1.293	20	20	2.106	228.0
BS vs. MS	30.75	33.90	-3.150	1.293	20	20	3.445	228.0
BS vs. TH	30.75	35.20	-4.454	1.293	20	20	4.872	228.0
BS vs. TS	30.75	35.40	-4.649	1.293	20	20	5.085	228.0
MH vs. MS	32.67	33.90	-1.224	1.293	20	20	1.339	228.0
MH vs. TH	32.67	35.20	-2.528	1.293	20	20	2.765	228.0
MH vs. TS	32.67	35.40	-2.724	1.293	20	20	2.979	228.0
MS vs. TH	33.90	35.20	-1.304	1.293	20	20	1.427	228.0
MS vs. TS	33.90	35.40	-1.500	1.293	20	20	1.640	228.0
TH vs. TS	35.20	35.40	-0.1952	1.293	20	20	0.2135	228.0

Appendix B2: Tukey's multiple comparison test for Density of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	-1.444	-26.06 to 23.17	No	ns
BH vs. MH	-3.905	-28.52 to 20.71	No	ns
BH vs. MS	16.59	-8.028 to 41.21	No	ns
BH vs. TH	-2.879	-27.50 to 21.74	No	ns
BH vs. TS	20.51	-4.114 to 45.12	No	ns
BS vs. MH	-2.461	-27.08 to 22.16	No	ns
BS vs. MS	18.04	-6.584 to 42.65	No	ns
BS vs. TH	-1.434	-26.05 to 23.18	No	ns
BS vs. TS	21.95	-2.669 to 46.57	No	ns
MH vs. MS	20.50	-4.123 to 45.12	No	ns
MH vs. TH	1.027	-23.59 to 25.65	No	ns
MH vs. TS	24.41	-0.2084 to 49.03	No	ns
MS vs. TH	-19.47	-44.09 to 5.150	No	ns
MS vs. TS	3.914	-20.70 to 28.53	No	ns
TH vs. TS	23.38	-1.235 to 48.00	No	ns
WESTERN				

BH vs. BS	-5.266	-29.89 to 19.35	No	ns
BH vs. MH	46.90	22.28 to 71.52	Yes	****
BH vs. MS	24.03	-0.5930 to 48.65	No	ns
BH vs. TH	18.96	-5.663 to 43.58	No	ns
BH vs. TS	27.33	2.709 to 51.95	Yes	*
BS vs. MH	52.16	27.54 to 76.78	Yes	****
BS vs. MS	29.29	4.673 to 53.91	Yes	**
BS vs. TH	24.22	-0.3967 to 48.84	No	ns
BS vs. TS	32.59	7.975 to 57.21	Yes	**
MH vs. MS	-22.87	-47.49 to 1.748	No	ns
MH vs. TH	-27.94	-52.56 to -3.322	Yes	*
MH vs. TS	-19.57	-44.19 to 5.050	No	ns
MS vs. TH	-5.070	-29.69 to 19.55	No	ns
MS vs. TS	3.302	-21.32 to 27.92	No	ns
TH vs. TS	8.372	-16.25 to 32.99	No	ns

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	622.9	624.4	-1.444	8.566	20	20	0.2385	228
BH vs. MH	622.9	626.8	-3.905	8.566	20	20	0.6448	228
BH vs. MS	622.9	606.4	16.59	8.566	20	20	2.739	228
BH vs. TH	622.9	625.8	-2.879	8.566	20	20	0.4753	228
BH vs. TS	622.9	602.4	20.51	8.566	20	20	3.385	228
BS vs. MH	624.4	626.8	-2.461	8.566	20	20	0.4063	228
BS vs. MS	624.4	606.4	18.04	8.566	20	20	2.978	228
BS vs. TH	624.4	625.8	-1.434	8.566	20	20	0.2368	228
BS vs. TS	624.4	602.4	21.95	8.566	20	20	3.624	228
MH vs. MS	626.8	606.4	20.50	8.566	20	20	3.384	228
MH vs. TH	626.8	625.8	1.027	8.566	20	20	0.1695	228
MH vs. TS	626.8	602.4	24.41	8.566	20	20	4.030	228
MS vs. TH	606.4	625.8	-19.47	8.566	20	20	3.214	228
MS vs. TS	606.4	602.4	3.914	8.566	20	20	0.6463	228
TH vs. TS	625.8	602.4	23.38	8.566	20	20	3.861	228
WESTERN								
BH vs. BS	632.8	638.1	-5.266	8.566	20	20	0.8694	228
BH vs. MH	632.8	585.9	46.90	8.566	20	20	7.743	228
BH vs. MS	632.8	608.8	24.03	8.566	20	20	3.967	228
BH vs. TH	632.8	613.8	18.96	8.566	20	20	3.130	228
BH vs. TS	632.8	605.5	27.33	8.566	20	20	4.512	228
BS vs. MH	638.1	585.9	52.16	8.566	20	20	8.612	228
BS vs. MS	638.1	608.8	29.29	8.566	20	20	4.836	228
BS vs. TH	638.1	613.8	24.22	8.566	20	20	3.999	228
BS vs. TS	638.1	605.5	32.59	8.566	20	20	5.381	228
MH vs. MS	585.9	608.8	-22.87	8.566	20	20	3.776	228
MH vs. TH	585.9	613.8	-27.94	8.566	20	20	4.613	228
MH vs. TS	585.9	605.5	-19.57	8.566	20	20	3.231	228
MS vs. TH	608.8	613.8	-5.070	8.566	20	20	0.8370	228
MS vs. TS	608.8	605.5	3.302	8.566	20	20	0.5452	228
TH vs. TS	613.8	605.5	8.372	8.566	20	20	1.382	228

Appendix B3: Tukey's Multiple Comparison Test for MOR of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95.00% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	10.60	2.877 to 18.32	Yes	**
BH vs. MH	10.02	2.295 to 17.74	Yes	**
BH vs. MS	17.45	9.725 to 25.17	Yes	****
BH vs. TH	13.86	6.138 to 21.58	Yes	****
BH vs. TS	17.52	9.801 to 25.24	Yes	****
BS vs. MH	-0.5818	-8.302 to 7.138	No	ns
BS vs. MS	6.849	-0.8716 to 14.57	No	ns
BS vs. TH	3.261	-4.459 to 10.98	No	ns
BS vs. TS	6.925	-0.7954 to 14.65	No	ns
MH vs. MS	7.431	-0.2897 to 15.15	No	ns
MH vs. TH	3.843	-3.877 to 11.56	No	ns
MH vs. TS	7.507	-0.2135 to 15.23	No	ns
MS vs. TH	-3.588	-11.31 to 4.133	No	ns
MS vs. TS	0.07617	-7.644 to 7.797	No	ns
TH vs. TS	3.664	-4.057 to 11.38	No	ns
WESTERN				
BH vs. BS	8.492	0.7722 to 16.21	Yes	*
BH vs. MH	2.939	-4.782 to 10.66	No	ns
BH vs. MS	14.53	6.806 to 22.25	Yes	****
BH vs. TH	4.290	-3.430 to 12.01	No	ns
BH vs. TS	15.43	7.708 to 23.15	Yes	****
BS vs. MH	-5.554	-13.27 to 2.166	No	ns
BS vs. MS	6.034	-1.686 to 13.75	No	ns
BS vs. TH	-4.202	-11.92 to 3.518	No	ns
BS vs. TS	6.936	-0.7848 to 14.66	No	ns
MH vs. MS	11.59	3.868 to 19.31	Yes	***
MH vs. TH	1.352	-6.368 to 9.072	No	ns
MH vs. TS	12.49	4.769 to 20.21	Yes	****
MS vs. TH	-10.24	-17.96 to -2.516	Yes	**
MS vs. TS	0.9015	-6.819 to 8.622	No	ns
TH vs. TS	11.14	3.417 to 18.86	Yes	***

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	68.51	57.91	10.60	2.686	20	20	5.579	228.0
BH vs. MH	68.51	58.50	10.02	2.686	20	20	5.273	228.0
BH vs. MS	68.51	51.07	17.45	2.686	20	20	9.185	228.0

BH vs. TH	68.51	54.65	13.86	2.686	20	20	7.296	228.0
BH vs. TS	68.51	50.99	17.52	2.686	20	20	9.225	228.0
BS vs. MH	57.91	58.50	-0.5818	2.686	20	20	0.3063	228.0
BS vs. MS	57.91	51.07	6.849	2.686	20	20	3.606	228.0
BS vs. TH	57.91	54.65	3.261	2.686	20	20	1.717	228.0
BS vs. TS	57.91	50.99	6.925	2.686	20	20	3.646	228.0
MH vs. MS	58.50	51.07	7.431	2.686	20	20	3.912	228.0
MH vs. TH	58.50	54.65	3.843	2.686	20	20	2.023	228.0
MH vs. TS	58.50	50.99	7.507	2.686	20	20	3.952	228.0
MS vs. TH	51.07	54.65	-3.588	2.686	20	20	1.889	228.0
MS vs. TS	51.07	50.99	0.07617	2.686	20	20	0.04010	228.0
TH vs. TS	54.65	50.99	3.664	2.686	20	20	1.929	228.0
WESTERN								
BH vs. BS	61.09	52.60	8.492	2.686	20	20	4.471	228.0
BH vs. MH	61.09	58.15	2.939	2.686	20	20	1.547	228.0
BH vs. MS	61.09	46.56	14.53	2.686	20	20	7.648	228.0
BH vs. TH	61.09	56.80	4.290	2.686	20	20	2.259	228.0
BH vs. TS	61.09	45.66	15.43	2.686	20	20	8.123	228.0
BS vs. MH	52.60	58.15	-5.554	2.686	20	20	2.924	228.0
BS vs. MS	52.60	46.56	6.034	2.686	20	20	3.177	228.0
BS vs. TH	52.60	56.80	-4.202	2.686	20	20	2.212	228.0
BS vs. TS	52.60	45.66	6.936	2.686	20	20	3.651	228.0
MH vs. MS	58.15	46.56	11.59	2.686	20	20	6.101	228.0
MH vs. TH	58.15	56.80	1.352	2.686	20	20	0.7118	228.0
MH vs. TS	58.15	45.66	12.49	2.686	20	20	6.575	228.0
MS vs. TH	46.56	56.80	-10.24	2.686	20	20	5.389	228.0
MS vs. TS	46.56	45.66	0.9015	2.686	20	20	0.4746	228.0
TH vs. TS	56.80	45.66	11.14	2.686	20	20	5.864	228.0

Appendix B4: Tukey's Multiple Comparison Test for MOE of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95.00% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	1393	116.9 to 2670	Yes	*
BH vs. MH	963.0	-313.6 to 2240	No	ns
BH vs. MS	1568	291.9 to 2845	Yes	**
BH vs. TH	1270	-6.989 to 2546	No	ns
BH vs. TS	1892	615.0 to 3168	Yes	***
BS vs. MH	-430.5	-1707 to 846.1	No	ns
BS vs. MS	175.0	-1102 to 1452	No	ns
BS vs. TH	-123.9	-1400 to 1153	No	ns
BS vs. TS	498.1	-778.4 to 1775	No	ns

MH vs. MS	605.5	-671.1 to 1882	No	ns
MH vs. TH	306.6	-970.0 to 1583	No	ns
MH vs. TS	928.6	-348.0 to 2205	No	ns
MS vs. TH	-298.9	-1575 to 977.7	No	ns
MS vs. TS	323.1	-953.4 to 1600	No	ns
TH vs. TS	622.0	-654.5 to 1899	No	ns
WESTERN				
BH vs. BS	839.3	-437.2 to 2116	No	ns
BH vs. MH	1121	-155.7 to 2397	No	ns
BH vs. MS	1833	556.5 to 3110	Yes	***
BH vs. TH	1364	87.81 to 2641	Yes	*
BH vs. TS	2085	808.1 to 3361	Yes	****
BS vs. MH	281.5	-995.0 to 1558	No	ns
BS vs. MS	993.8	-282.8 to 2270	No	ns
BS vs. TH	525.0	-751.5 to 1802	No	ns
BS vs. TS	1245	-31.24 to 2522	No	ns
MH vs. MS	712.2	-564.3 to 1989	No	ns
MH vs. TH	243.5	-1033 to 1520	No	ns
MH vs. TS	963.8	-312.8 to 2240	No	ns
MS vs. TH	-468.7	-1745 to 807.8	No	ns
MS vs. TS	251.5	-1025 to 1528	No	ns
TH vs. TS	720.3	-556.3 to 1997	No	ns

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q
CENTRAL							
BH vs. BS	8408	7014	1393	444.1	20	20	4.437
BH vs. MH	8408	7445	963.0	444.1	20	20	3.066
BH vs. MS	8408	6839	1568	444.1	20	20	4.994
BH vs. TH	8408	7138	1270	444.1	20	20	4.042
BH vs. TS	8408	6516	1892	444.1	20	20	6.023
BS vs. MH	7014	7445	-430.5	444.1	20	20	1.371
BS vs. MS	7014	6839	175.0	444.1	20	20	0.5572
BS vs. TH	7014	7138	-123.9	444.1	20	20	0.3944
BS vs. TS	7014	6516	498.1	444.1	20	20	1.586
MH vs. MS	7445	6839	605.5	444.1	20	20	1.928
MH vs. TH	7445	7138	306.6	444.1	20	20	0.9762
MH vs. TS	7445	6516	928.6	444.1	20	20	2.957
MS vs. TH	6839	7138	-298.9	444.1	20	20	0.9516
MS vs. TS	6839	6516	323.1	444.1	20	20	1.029
TH vs. TS	7138	6516	622.0	444.1	20	20	1.980
WESTERN							
BH vs. BS	7577	6738	839.3	444.1	20	20	2.672
BH vs. MH	7577	6456	1121	444.1	20	20	3.569
BH vs. MS	7577	5744	1833	444.1	20	20	5.837
BH vs. TH	7577	6213	1364	444.1	20	20	4.344
BH vs. TS	7577	5493	2085	444.1	20	20	6.638

BS vs. MH	6738	6456	281.5	444.1	20	20	0.8965
BS vs. MS	6738	5744	993.8	444.1	20	20	3.164
BS vs. TH	6738	6213	525.0	444.1	20	20	1.672
BS vs. TS	6738	5493	1245	444.1	20	20	3.965
MH vs. MS	6456	5744	712.2	444.1	20	20	2.268
MH vs. TH	6456	6213	243.5	444.1	20	20	0.7753
MH vs. TS	6456	5493	963.8	444.1	20	20	3.069
MS vs. TH	5744	6213	-468.7	444.1	20	20	1.492
MS vs. TS	5744	5493	251.5	444.1	20	20	0.8010
TH vs. TS	6213	5493	720.3	444.1	20	20	2.293

Appendix B5: Tukey's Multiple Comparison Test for CPG of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95.00% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	0.3043	-3.825 to 4.434	No	ns
BH vs. MH	2.015	-2.114 to 6.145	No	ns
BH vs. MS	3.467	-0.6631 to 7.596	No	ns
BH vs. TH	3.805	-0.3248 to 7.935	No	ns
BH vs. TS	3.855	-0.2750 to 7.984	No	ns
BS vs. MH	1.711	-2.419 to 5.841	No	ns
BS vs. MS	3.162	-0.9674 to 7.292	No	ns
BS vs. TH	3.501	-0.6291 to 7.630	No	ns
BS vs. TS	3.550	-0.5793 to 7.680	No	ns
MH vs. MS	1.451	-2.679 to 5.581	No	ns
MH vs. TH	1.789	-2.340 to 5.919	No	ns
MH vs. TS	1.839	-2.290 to 5.969	No	ns
MS vs. TH	0.3384	-3.791 to 4.468	No	ns
MS vs. TS	0.3881	-3.742 to 4.518	No	ns
TH vs. TS	0.04979	-4.080 to 4.179	No	ns
WESTERN				
BH vs. BS	3.991	-0.1392 to 8.120	No	ns
BH vs. MH	1.123	-3.007 to 5.252	No	ns
BH vs. MS	4.251	0.1208 to 8.380	Yes	*
BH vs. TH	1.680	-2.450 to 5.809	No	ns
BH vs. TS	9.830	5.700 to 13.96	Yes	****
BS vs. MH	-2.868	-6.998 to 1.262	No	ns
BS vs. MS	0.2600	-3.870 to 4.390	No	ns
BS vs. TH	-2.311	-6.441 to 1.819	No	ns
BS vs. TS	5.839	1.709 to 9.969	Yes	***
MH vs. MS	3.128	-1.002 to 7.258	No	ns

MH vs. TH	0.5570	-3.573 to 4.687	No	ns
MH vs. TS	8.707	4.577 to 12.84	Yes	****
MS vs. TH	-2.571	-6.701 to 1.559	No	ns
MS vs. TS	5.579	1.449 to 9.709	Yes	**
TH vs. TS	8.150	4.020 to 12.28	Yes	****

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	30.88	30.58	0.3043	1.437	20	20	0.2995	228.0
BH vs. MH	30.88	28.87	2.015	1.437	20	20	1.984	228.0
BH vs. MS	30.88	27.42	3.467	1.437	20	20	3.412	228.0
BH vs. TH	30.88	27.08	3.805	1.437	20	20	3.745	228.0
BH vs. TS	30.88	27.03	3.855	1.437	20	20	3.794	228.0
BS vs. MH	30.58	28.87	1.711	1.437	20	20	1.684	228.0
BS vs. MS	30.58	27.42	3.162	1.437	20	20	3.112	228.0
BS vs. TH	30.58	27.08	3.501	1.437	20	20	3.445	228.0
BS vs. TS	30.58	27.03	3.550	1.437	20	20	3.494	228.0
MH vs. MS	28.87	27.42	1.451	1.437	20	20	1.428	228.0
MH vs. TH	28.87	27.08	1.789	1.437	20	20	1.761	228.0
MH vs. TS	28.87	27.03	1.839	1.437	20	20	1.810	228.0
MS vs. TH	27.42	27.08	0.3384	1.437	20	20	0.3330	228.0
MS vs. TS	27.42	27.03	0.3881	1.437	20	20	0.3820	228.0
TH vs. TS	27.08	27.03	0.04979	1.437	20	20	0.04900	228.0
WESTERN								
BH vs. BS	30.33	26.34	3.991	1.437	20	20	3.928	228.0
BH vs. MH	30.33	29.20	1.123	1.437	20	20	1.105	228.0
BH vs. MS	30.33	26.08	4.251	1.437	20	20	4.184	228.0
BH vs. TH	30.33	28.65	1.680	1.437	20	20	1.653	228.0
BH vs. TS	30.33	20.50	9.830	1.437	20	20	9.675	228.0
BS vs. MH	26.34	29.20	-2.868	1.437	20	20	2.823	228.0
BS vs. MS	26.34	26.08	0.2600	1.437	20	20	0.2559	228.0
BS vs. TH	26.34	28.65	-2.311	1.437	20	20	2.275	228.0
BS vs. TS	26.34	20.50	5.839	1.437	20	20	5.747	228.0
MH vs. MS	29.20	26.08	3.128	1.437	20	20	3.079	228.0
MH vs. TH	29.20	28.65	0.5570	1.437	20	20	0.5482	228.0
MH vs. TS	29.20	20.50	8.707	1.437	20	20	8.570	228.0
MS vs. TH	26.08	28.65	-2.571	1.437	20	20	2.530	228.0
MS vs. TS	26.08	20.50	5.579	1.437	20	20	5.491	228.0
TH vs. TS	28.65	20.50	8.150	1.437	20	20	8.022	228.0

Appendix B6: Tukey's Multiple Comparison Test for Lignin Content of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	0.3750	-0.6489 to 1.399	No	ns
BH vs. MH	0.2650	-0.7589 to 1.289	No	ns
BH vs. MS	0.6400	-0.3839 to 1.664	No	ns
BH vs. TH	1.120	0.09612 to 2.144	Yes	*
BH vs. TS	0.6150	-0.4089 to 1.639	No	ns
BS vs. MH	-0.1100	-1.134 to 0.9139	No	ns
BS vs. MS	0.2650	-0.7589 to 1.289	No	ns
BS vs. TH	0.7450	-0.2789 to 1.769	No	ns
BS vs. TS	0.2400	-0.7839 to 1.264	No	ns
MH vs. MS	0.3750	-0.6489 to 1.399	No	ns
MH vs. TH	0.8550	-0.1689 to 1.879	No	ns
MH vs. TS	0.3500	-0.6739 to 1.374	No	ns
MS vs. TH	0.4800	-0.5439 to 1.504	No	ns
MS vs. TS	-0.02500	-1.049 to 0.9989	No	ns
TH vs. TS	-0.5050	-1.529 to 0.5189	No	ns
WESTERN				
BH vs. BS	1.540	0.5161 to 2.564	Yes	**
BH vs. MH	2.227	1.203 to 3.250	Yes	****
BH vs. MS	2.150	1.126 to 3.174	Yes	****
BH vs. TH	4.030	3.006 to 5.054	Yes	****
BH vs. TS	4.102	3.078 to 5.126	Yes	****
BS vs. MH	0.6865	-0.3374 to 1.710	No	ns
BS vs. MS	0.6100	-0.4139 to 1.634	No	ns
BS vs. TH	2.490	1.466 to 3.514	Yes	****
BS vs. TS	2.562	1.538 to 3.586	Yes	****
MH vs. MS	-0.07650	-1.100 to 0.9474	No	ns
MH vs. TH	1.804	0.7796 to 2.827	Yes	***
MH vs. TS	1.876	0.8516 to 2.899	Yes	***
MS vs. TH	1.880	0.8561 to 2.904	Yes	***
MS vs. TS	1.952	0.9281 to 2.976	Yes	****
TH vs. TS	0.07200	-0.9519 to 1.096	No	ns

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								

BH vs. BS	11.46	11.08	0.3750	0.3311	3	3	1.601	24
BH vs. MH	11.46	11.19	0.2650	0.3311	3	3	1.132	24
BH vs. MS	11.46	10.82	0.6400	0.3311	3	3	2.733	24
BH vs. TH	11.46	10.34	1.120	0.3311	3	3	4.783	24
BH vs. TS	11.46	10.84	0.6150	0.3311	3	3	2.626	24
BS vs. MH	11.08	11.19	-0.1100	0.3311	3	3	0.4698	24
BS vs. MS	11.08	10.82	0.2650	0.3311	3	3	1.132	24
BS vs. TH	11.08	10.34	0.7450	0.3311	3	3	3.182	24
BS vs. TS	11.08	10.84	0.2400	0.3311	3	3	1.025	24
MH vs. MS	11.19	10.82	0.3750	0.3311	3	3	1.601	24
MH vs. TH	11.19	10.34	0.8550	0.3311	3	3	3.651	24
MH vs. TS	11.19	10.84	0.3500	0.3311	3	3	1.495	24
MS vs. TH	10.82	10.34	0.4800	0.3311	3	3	2.050	24
MS vs. TS	10.82	10.84	-0.02500	0.3311	3	3	0.1068	24
TH vs. TS	10.34	10.84	-0.5050	0.3311	3	3	2.157	24
WESTERN								
BH vs. BS	16.39	14.85	1.540	0.3311	3	3	6.577	24
BH vs. MH	16.39	14.16	2.227	0.3311	3	3	9.509	24
BH vs. MS	16.39	14.24	2.150	0.3311	3	3	9.182	24
BH vs. TH	16.39	12.36	4.030	0.3311	3	3	17.21	24
BH vs. TS	16.39	12.28	4.102	0.3311	3	3	17.52	24
BS vs. MH	14.85	14.16	0.6865	0.3311	3	3	2.932	24
BS vs. MS	14.85	14.24	0.6100	0.3311	3	3	2.605	24
BS vs. TH	14.85	12.36	2.490	0.3311	3	3	10.63	24
BS vs. TS	14.85	12.28	2.562	0.3311	3	3	10.94	24
MH vs. MS	14.16	14.24	-0.07650	0.3311	3	3	0.3267	24
MH vs. TH	14.16	12.36	1.804	0.3311	3	3	7.702	24
MH vs. TS	14.16	12.28	1.876	0.3311	3	3	8.010	24
MS vs. TH	14.24	12.36	1.880	0.3311	3	3	8.029	24
MS vs. TS	14.24	12.28	1.952	0.3311	3	3	8.336	24
TH vs. TS	12.36	12.28	0.07200	0.3311	3	3	0.3075	24

Appendix B7: Tukey's Multiple Comparison Test for Cellulose of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	0.5350	-2.681 to 3.751	No	ns
BH vs. MH	0.06000	-3.276 to 3.156	No	ns
BH vs. MS	-6.490	-9.706 to -3.274	Yes	****
BH vs. TH	-3.430	-6.646 to - 0.2137	Yes	*
BH vs. TS	-6.035	-9.251 to -2.819	Yes	****
BS vs. MH	-0.5950	-3.811 to 2.621	No	ns
BS vs. MS	-7.025	-10.24 to -3.809	Yes	****
BS vs. TH	-3.965	-7.181 to -	Yes	**

		0.7487		
BS vs. TS	-6.570	-9.786 to -3.354	Yes	****
MH vs. MS	-6.430	-9.646 to -3.214	Yes	****
MH vs. TH	-3.370	-6.586 to - 0.1537	Yes	*
MH vs. TS	-5.975	-9.191 to -2.759	Yes	****
MS vs. TH	3.060	-0.1563 to 6.276	No	ns
MS vs. TS	0.4550	-2.761 to 3.671	No	ns
TH vs. TS	-2.605	-5.821 to 0.6113	No	ns
WESTERN				
BH vs. BS	-0.2250	-3.441 to 2.991	No	ns
BH vs. MH	-0.1850	-3.401 to 3.031	No	ns
BH vs. MS	-4.960	-8.176 to -1.744	Yes	***
BH vs. TH	-4.545	-7.761 to -1.329	Yes	**
BH vs. TS	-2.880	-6.096 to 0.3363	No	ns
BS vs. MH	0.04000	-3.176 to 3.256	No	ns
BS vs. MS	-4.735	-7.951 to -1.519	Yes	**
BS vs. TH	-4.320	-7.536 to -1.104	Yes	**
BS vs. TS	-2.655	-5.871 to 0.5613	No	ns
MH vs. MS	-4.775	-7.991 to -1.559	Yes	**
MH vs. TH	-4.360	-7.576 to -1.144	Yes	**
MH vs. TS	-2.695	-5.911 to 0.5213	No	ns
MS vs. TH	0.4150	-2.801 to 3.631	No	ns
MS vs. TS	2.080	-1.136 to 5.296	No	ns
TH vs. TS	1.665	-1.551 to 4.881	No	ns

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	23.36	22.82	0.5350	1.040	3	3	0.7274	24
BH vs. MH	23.36	23.42	-0.06000	1.040	3	3	0.08157	24
BH vs. MS	23.36	29.85	-6.490	1.040	3	3	8.823	24
BH vs. TH	23.36	26.79	-3.430	1.040	3	3	4.663	24
BH vs. TS	23.36	29.39	-6.035	1.040	3	3	8.205	24
BS vs. MH	22.82	23.42	-0.5950	1.040	3	3	0.8089	24
BS vs. MS	22.82	29.85	-7.025	1.040	3	3	9.551	24
BS vs. TH	22.82	26.79	-3.965	1.040	3	3	5.391	24
BS vs. TS	22.82	29.39	-6.570	1.040	3	3	8.932	24
MH vs. MS	23.42	29.85	-6.430	1.040	3	3	8.742	24
MH vs. TH	23.42	26.79	-3.370	1.040	3	3	4.582	24
MH vs. TS	23.42	29.39	-5.975	1.040	3	3	8.123	24
MS vs. TH	29.85	26.79	3.060	1.040	3	3	4.160	24
MS vs. TS	29.85	29.39	0.4550	1.040	3	3	0.6186	24
TH vs. TS	26.79	29.39	-2.605	1.040	3	3	3.542	24
WESTERN								
BH vs. BS	25.67	25.90	-0.2250	1.040	3	3	0.3059	24
BH vs. MH	25.67	25.86	-0.1850	1.040	3	3	0.2515	24
BH vs. MS	25.67	30.63	-4.960	1.040	3	3	6.743	24
BH vs. TH	25.67	30.22	-4.545	1.040	3	3	6.179	24
BH vs. TS	25.67	28.55	-2.880	1.040	3	3	3.915	24
BS vs. MH	25.90	25.86	0.04000	1.040	3	3	0.05438	24
BS vs. MS	25.90	30.63	-4.735	1.040	3	3	6.437	24
BS vs. TH	25.90	30.22	-4.320	1.040	3	3	5.873	24

BS vs. TS	25.90	28.55	-2.655	1.040	3	3	3.610	24
MH vs. MS	25.86	30.63	-4.775	1.040	3	3	6.492	24
MH vs. TH	25.86	30.22	-4.360	1.040	3	3	5.928	24
MH vs. TS	25.86	28.55	-2.695	1.040	3	3	3.664	24
MS vs. TH	30.63	30.22	0.4150	1.040	3	3	0.5642	24
MS vs. TS	30.63	28.55	2.080	1.040	3	3	2.828	24
TH vs. TS	30.22	28.55	1.665	1.040	3	3	2.264	24

Appendix B8: Tukey's Multiple Comparison Test for Organic Carbon of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	-0.8000	-0.8616 to -0.7384	Yes	****
BH vs. MH	0.0	-0.06155 to 0.06155	No	ns
BH vs. MS	0.8000	0.7384 to 0.8616	Yes	****
BH vs. TH	-0.4000	-0.4616 to -0.3384	Yes	****
BH vs. TS	0.4000	0.3384 to 0.4616	Yes	****
BS vs. MH	0.8000	0.7384 to 0.8616	Yes	****
BS vs. MS	1.600	1.538 to 1.662	Yes	****
BS vs. TH	0.4000	0.3384 to 0.4616	Yes	****
BS vs. TS	1.200	1.138 to 1.262	Yes	****
MH vs. MS	0.8000	0.7384 to 0.8616	Yes	****
MH vs. TH	-0.4000	-0.4616 to -0.3384	Yes	****
MH vs. TS	0.4000	0.3384 to 0.4616	Yes	****
MS vs. TH	-1.200	-1.262 to -1.138	Yes	****
MS vs. TS	-0.4000	-0.4616 to -0.3384	Yes	****
TH vs. TS	0.8000	0.7384 to 0.8616	Yes	****
WESTERN				
BH vs. BS	0.07333	0.01178 to 0.1349	Yes	*
BH vs. MH	1.273	1.212 to 1.335	Yes	****
BH vs. MS	-0.3267	-0.3882 to -0.2651	Yes	****
BH vs. TH	1.273	1.212 to 1.335	Yes	****
BH vs. TS	0.8733	0.8118 to 0.9349	Yes	****
BS vs. MH	1.200	1.138 to 1.262	Yes	****
BS vs. MS	-0.4000	-0.4616 to -0.3384	Yes	****
BS vs. TH	1.200	1.138 to 1.262	Yes	****
BS vs. TS	0.8000	0.7384 to 0.8616	Yes	****
MH vs. MS	-1.600	-1.662 to -1.538	Yes	****
MH vs. TH	6.358e-007	-0.06155 to 0.06155	No	ns

MH vs. TS	-0.4000	-0.4616 to -0.3384	Yes	****
MS vs. TH	1.600	1.538 to 1.662	Yes	****
MS vs. TS	1.200	1.138 to 1.262	Yes	****
TH vs. TS	-0.4000	-0.4616 to -0.3384	Yes	****

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	31.12	31.92	-0.8000	0.01991	3	3	56.83	24
BH vs. MH	31.12	31.12	0.0	0.01991	3	3	0.0	24
BH vs. MS	31.12	30.32	0.8000	0.01991	3	3	56.83	24
BH vs. TH	31.12	31.52	-0.4000	0.01991	3	3	28.42	24
BH vs. TS	31.12	30.72	0.4000	0.01991	3	3	28.42	24
BS vs. MH	31.92	31.12	0.8000	0.01991	3	3	56.83	24
BS vs. MS	31.92	30.32	1.600	0.01991	3	3	113.7	24
BS vs. TH	31.92	31.52	0.4000	0.01991	3	3	28.42	24
BS vs. TS	31.92	30.72	1.200	0.01991	3	3	85.25	24
MH vs. MS	31.12	30.32	0.8000	0.01991	3	3	56.83	24
MH vs. TH	31.12	31.52	-0.4000	0.01991	3	3	28.42	24
MH vs. TS	31.12	30.72	0.4000	0.01991	3	3	28.42	24
MS vs. TH	30.32	31.52	-1.200	0.01991	3	3	85.25	24
MS vs. TS	30.32	30.72	-0.4000	0.01991	3	3	28.42	24
TH vs. TS	31.52	30.72	0.8000	0.01991	3	3	56.83	24
WESTERN								
BH vs. BS	31.59	31.52	0.07333	0.01991	3	3	5.210	24
BH vs. MH	31.59	30.32	1.273	0.01991	3	3	90.46	24
BH vs. MS	31.59	31.92	-0.3267	0.01991	3	3	23.21	24
BH vs. TH	31.59	30.32	1.273	0.01991	3	3	90.46	24
BH vs. TS	31.59	30.72	0.8733	0.01991	3	3	62.04	24
BS vs. MH	31.52	30.32	1.200	0.01991	3	3	85.25	24
BS vs. MS	31.52	31.92	-0.4000	0.01991	3	3	28.42	24
BS vs. TH	31.52	30.32	1.200	0.01991	3	3	85.25	24
BS vs. TS	31.52	30.72	0.8000	0.01991	3	3	56.83	24
MH vs. MS	30.32	31.92	-1.600	0.01991	3	3	113.7	24
MH vs. TH	30.32	30.32	6.358e-007	0.01991	3	3	4.517e-005	24
MH vs. TS	30.32	30.72	-0.4000	0.01991	3	3	28.42	24
MS vs. TH	31.92	30.32	1.600	0.01991	3	3	113.7	24
MS vs. TS	31.92	30.72	1.200	0.01991	3	3	85.25	24
TH vs. TS	30.32	30.72	-0.4000	0.01991	3	3	28.42	24

Appendix B9: Tukey's Multiple Comparison Test for Ash Content of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	-0.07300	-0.4368 to 0.2908	No	ns
BH vs. MH	0.8725	0.5087 to 1.236	Yes	****
BH vs. MS	0.7975	0.4337 to 1.161	Yes	****
BH vs. TH	0.5025	0.1387 to 0.8663	Yes	**
BH vs. TS	0.5030	0.1392 to 0.8668	Yes	**
BS vs. MH	0.9455	0.5817 to 1.309	Yes	****
BS vs. MS	0.8705	0.5067 to 1.234	Yes	****
BS vs. TH	0.5755	0.2117 to 0.9393	Yes	***
BS vs. TS	0.5760	0.2122 to 0.9398	Yes	***
MH vs. MS	-0.07500	-0.4388 to 0.2888	No	ns
MH vs. TH	-0.3700	-0.7338 to -0.006226	Yes	*
MH vs. TS	-0.3695	-0.7333 to -0.005726	Yes	*
MS vs. TH	-0.2950	-0.6588 to 0.06877	No	ns
MS vs. TS	-0.2945	-0.6583 to 0.06927	No	ns
TH vs. TS	0.0005000	-0.3633 to 0.3643	No	ns
WESTERN				
BH vs. BS	-0.04050	-0.4043 to 0.3233	No	ns
BH vs. MH	-0.07350	-0.4373 to 0.2903	No	ns
BH vs. MS	0.2310	-0.1328 to 0.5948	No	ns
BH vs. TH	-0.1935	-0.5573 to 0.1703	No	ns
BH vs. TS	-0.2800	-0.6438 to 0.08377	No	ns
BS vs. MH	-0.03300	-0.3968 to 0.3308	No	ns
BS vs. MS	0.2715	-0.09227 to 0.6353	No	ns
BS vs. TH	-0.1530	-0.5168 to 0.2108	No	ns
BS vs. TS	-0.2395	-0.6033 to 0.1243	No	ns
MH vs. MS	0.3045	-0.05927 to 0.6683	No	ns
MH vs. TH	-0.1200	-0.4838 to 0.2438	No	ns
MH vs. TS	-0.2065	-0.5703 to 0.1573	No	ns
MS vs. TH	-0.4245	-0.7883 to -0.06073	Yes	*
MS vs. TS	-0.5110	-0.8748 to -0.1472	Yes	**
TH vs. TS	-0.08650	-0.4503 to 0.2773	No	ns

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	3.220	3.293	-0.07300	0.1177	3	3	0.8775	24

BH vs. MH	3.220	2.347	0.8725	0.1177	3	3	10.49	24
BH vs. MS	3.220	2.422	0.7975	0.1177	3	3	9.586	24
BH vs. TH	3.220	2.717	0.5025	0.1177	3	3	6.040	24
BH vs. TS	3.220	2.717	0.5030	0.1177	3	3	6.046	24
BS vs. MH	3.293	2.347	0.9455	0.1177	3	3	11.37	24
BS vs. MS	3.293	2.422	0.8705	0.1177	3	3	10.46	24
BS vs. TH	3.293	2.717	0.5755	0.1177	3	3	6.918	24
BS vs. TS	3.293	2.717	0.5760	0.1177	3	3	6.924	24
MH vs. MS	2.347	2.422	-0.07500	0.1177	3	3	0.9015	24
MH vs. TH	2.347	2.717	-0.3700	0.1177	3	3	4.447	24
MH vs. TS	2.347	2.717	-0.3695	0.1177	3	3	4.441	24
MS vs. TH	2.422	2.717	-0.2950	0.1177	3	3	3.546	24
MS vs. TS	2.422	2.717	-0.2945	0.1177	3	3	3.540	24
TH vs. TS	2.717	2.717	0.0005000	0.1177	3	3	0.006010	24
WESTERN								
BH vs. BS	2.699	2.739	-0.04050	0.1177	3	3	0.4868	24
BH vs. MH	2.699	2.772	-0.07350	0.1177	3	3	0.8835	24
BH vs. MS	2.699	2.468	0.2310	0.1177	3	3	2.777	24
BH vs. TH	2.699	2.892	-0.1935	0.1177	3	3	2.326	24
BH vs. TS	2.699	2.979	-0.2800	0.1177	3	3	3.366	24
BS vs. MH	2.739	2.772	-0.03300	0.1177	3	3	0.3967	24
BS vs. MS	2.739	2.468	0.2715	0.1177	3	3	3.263	24
BS vs. TH	2.739	2.892	-0.1530	0.1177	3	3	1.839	24
BS vs. TS	2.739	2.979	-0.2395	0.1177	3	3	2.879	24
MH vs. MS	2.772	2.468	0.3045	0.1177	3	3	3.660	24
MH vs. TH	2.772	2.892	-0.1200	0.1177	3	3	1.442	24
MH vs. TS	2.772	2.979	-0.2065	0.1177	3	3	2.482	24
MS vs. TH	2.468	2.892	-0.4245	0.1177	3	3	5.103	24
MS vs. TS	2.468	2.979	-0.5110	0.1177	3	3	6.142	24
TH vs. TS	2.892	2.979	-0.08650	0.1177	3	3	1.040	24

Appendix B10: Tukey's Multiple Comparison Test for Nitrogen Content of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	0.02883	0.004984 to 0.05267	Yes	*
BH vs. MH	0.003509	-0.02034 to 0.02735	No	ns
BH vs. MS	-0.02035	-0.04419 to 0.003495	No	ns
BH vs. TH	-0.01900	-0.04285 to 0.004842	No	ns
BH vs. TS	-0.1060	-0.1298 to -0.08215	Yes	****
BS vs. MH	-0.02532	-0.04916 to -0.001475	Yes	*
BS vs. MS	-0.04918	-0.07302 to -0.02533	Yes	****
BS vs. TH	-0.04783	-0.07168 to -0.02399	Yes	****
BS vs. TS	-0.1348	-0.1587 to -0.1110	Yes	****
MH vs. MS	-0.02386	-0.04770 to -1.371e-005	Yes	*

MH vs. TH	-0.02251	-0.04636 to 0.001333	No	ns
MH vs. TS	-0.1095	-0.1333 to -0.08566	Yes	****
MS vs. TH	0.001347	-0.02250 to 0.02519	No	ns
MS vs. TS	-0.08564	-0.1095 to -0.06180	Yes	****
TH vs. TS	-0.08699	-0.1108 to -0.06314	Yes	****
WESTERN				
BH vs. BS	-0.01098	-0.03483 to 0.01286	No	ns
BH vs. MH	-0.01648	-0.04033 to 0.007364	No	ns
BH vs. MS	-0.01084	-0.03468 to 0.01300	No	ns
BH vs. TH	-0.03411	-0.05795 to -0.01026	Yes	**
BH vs. TS	-0.06310	-0.08695 to -0.03926	Yes	****
BS vs. MH	-0.005497	-0.02934 to 0.01835	No	ns
BS vs. MS	0.0001440	-0.02370 to 0.02399	No	ns
BS vs. TH	-0.02312	-0.04697 to 0.0007203	No	ns
BS vs. TS	-0.05212	-0.07596 to -0.02827	Yes	****
MH vs. MS	0.005640	-0.01820 to 0.02949	No	ns
MH vs. TH	-0.01763	-0.04147 to 0.006217	No	ns
MH vs. TS	-0.04662	-0.07047 to -0.02278	Yes	****
MS vs. TH	-0.02327	-0.04711 to 0.0005763	No	ns
MS vs. TS	-0.05226	-0.07611 to -0.02842	Yes	****
TH vs. TS	-0.02899	-0.05284 to -0.005148	Yes	*

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	0.2378	0.2090	0.02883	0.007712	3	3	5.287	24
BH vs. MH	0.2378	0.2343	0.003509	0.007712	3	3	0.6435	24
BH vs. MS	0.2378	0.2582	-0.02035	0.007712	3	3	3.732	24
BH vs. TH	0.2378	0.2568	-0.01900	0.007712	3	3	3.485	24
BH vs. TS	0.2378	0.3438	-0.1060	0.007712	3	3	19.44	24
BS vs. MH	0.2090	0.2343	-0.02532	0.007712	3	3	4.643	24
BS vs. MS	0.2090	0.2582	-0.04918	0.007712	3	3	9.018	24
BS vs. TH	0.2090	0.2568	-0.04783	0.007712	3	3	8.771	24
BS vs. TS	0.2090	0.3438	-0.1348	0.007712	3	3	24.72	24
MH vs. MS	0.2343	0.2582	-0.02386	0.007712	3	3	4.375	24
MH vs. TH	0.2343	0.2568	-0.02251	0.007712	3	3	4.128	24
MH vs. TS	0.2343	0.3438	-0.1095	0.007712	3	3	20.08	24
MS vs. TH	0.2582	0.2568	0.001347	0.007712	3	3	0.2470	24
MS vs. TS	0.2582	0.3438	-0.08564	0.007712	3	3	15.70	24
TH vs. TS	0.2568	0.3438	-0.08699	0.007712	3	3	15.95	24
WESTERN								
BH vs. BS	0.1941	0.2050	-0.01098	0.007712	3	3	2.014	24
BH vs. MH	0.1941	0.2105	-0.01648	0.007712	3	3	3.022	24
BH vs. MS	0.1941	0.2049	-0.01084	0.007712	3	3	1.988	24
BH vs. TH	0.1941	0.2282	-0.03411	0.007712	3	3	6.255	24
BH vs. TS	0.1941	0.2572	-0.06310	0.007712	3	3	11.57	24
BS vs. MH	0.2050	0.2105	-0.005497	0.007712	3	3	1.008	24
BS vs. MS	0.2050	0.2049	0.0001440	0.007712	3	3	0.02641	24
BS vs. TH	0.2050	0.2282	-0.02312	0.007712	3	3	4.241	24
BS vs. TS	0.2050	0.2572	-0.05212	0.007712	3	3	9.557	24
MH vs. MS	0.2105	0.2049	0.005640	0.007712	3	3	1.034	24

MH vs. TH	0.2105	0.2282	-0.01763	0.007712	3	3	3.233	24
MH vs. TS	0.2105	0.2572	-0.04662	0.007712	3	3	8.549	24
MS vs. TH	0.2049	0.2282	-0.02327	0.007712	3	3	4.267	24
MS vs. TS	0.2049	0.2572	-0.05226	0.007712	3	3	9.584	24
TH vs. TS	0.2282	0.2572	-0.02899	0.007712	3	3	5.317	24

Appendix B11: Tukey's Multiple Comparison Test for Potassium Content of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	-177.3	-187.5 to -167.1	Yes	****
BH vs. MH	-61.12	-71.33 to -50.92	Yes	****
BH vs. MS	-669.3	-679.5 to -659.1	Yes	****
BH vs. TH	-492.1	-502.3 to -481.8	Yes	****
BH vs. TS	-290.3	-300.5 to -280.1	Yes	****
BS vs. MH	116.1	105.9 to 126.3	Yes	****
BS vs. MS	-492.1	-502.3 to -481.8	Yes	****
BS vs. TH	-314.8	-325.0 to -304.6	Yes	****
BS vs. TS	-113.1	-123.3 to -102.9	Yes	****
MH vs. MS	-608.2	-618.4 to -598.0	Yes	****
MH vs. TH	-430.9	-441.1 to -420.7	Yes	****
MH vs. TS	-229.2	-239.4 to -219.0	Yes	****
MS vs. TH	177.3	167.1 to 187.5	Yes	****
MS vs. TS	379.0	368.8 to 389.2	Yes	****
TH vs. TS	201.7	191.5 to 211.9	Yes	****
WESTERN				
BH vs. BS	-727.4	-737.6 to -717.2	Yes	****
BH vs. MH	12.22	2.018 to 22.43	Yes	*
BH vs. MS	152.8	142.6 to 163.0	Yes	****
BH vs. TH	-24.45	-34.66 to -14.24	Yes	****
BH vs. TS	79.46	69.26 to 89.67	Yes	****
BS vs. MH	739.6	729.4 to 749.8	Yes	****
BS vs. MS	880.2	870.0 to 890.4	Yes	****
BS vs. TH	702.9	692.7 to 713.1	Yes	****
BS vs. TS	806.8	796.6 to 817.1	Yes	****
MH vs. MS	140.6	130.4 to 150.8	Yes	****
MH vs. TH	-36.67	-46.88 to -26.47	Yes	****
MH vs. TS	67.24	57.03 to 77.44	Yes	****
MS vs. TH	-177.3	-187.5 to -167.1	Yes	****
MS vs. TS	-73.35	-83.56 to -63.14	Yes	****
TH vs. TS	103.9	93.71 to 114.1	Yes	****

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF

CENTRAL								
BH vs. BS	708.0	885.3	-177.3	3.301	3	3	75.94	24
BH vs. MH	708.0	769.1	-61.12	3.301	3	3	26.19	24
BH vs. MS	708.0	1377	-669.3	3.301	3	3	286.7	24
BH vs. TH	708.0	1200	-492.1	3.301	3	3	210.8	24
BH vs. TS	708.0	998.3	-290.3	3.301	3	3	124.4	24
BS vs. MH	885.3	769.1	116.1	3.301	3	3	49.75	24
BS vs. MS	885.3	1377	-492.1	3.301	3	3	210.8	24
BS vs. TH	885.3	1200	-314.8	3.301	3	3	134.9	24
BS vs. TS	885.3	998.3	-113.1	3.301	3	3	48.44	24
MH vs. MS	769.1	1377	-608.2	3.301	3	3	260.6	24
MH vs. TH	769.1	1200	-430.9	3.301	3	3	184.6	24
MH vs. TS	769.1	998.3	-229.2	3.301	3	3	98.20	24
MS vs. TH	1377	1200	177.3	3.301	3	3	75.94	24
MS vs. TS	1377	998.3	379.0	3.301	3	3	162.4	24
TH vs. TS	1200	998.3	201.7	3.301	3	3	86.41	24
WESTERN								
BH vs. BS	671.3	1399	-727.4	3.301	3	3	311.6	24
BH vs. MH	671.3	659.1	12.22	3.301	3	3	5.237	24
BH vs. MS	671.3	518.5	152.8	3.301	3	3	65.47	24
BH vs. TH	671.3	695.8	-24.45	3.301	3	3	10.47	24
BH vs. TS	671.3	591.9	79.46	3.301	3	3	34.04	24
BS vs. MH	1399	659.1	739.6	3.301	3	3	316.9	24
BS vs. MS	1399	518.5	880.2	3.301	3	3	377.1	24
BS vs. TH	1399	695.8	702.9	3.301	3	3	301.1	24
BS vs. TS	1399	591.9	806.8	3.301	3	3	345.7	24
MH vs. MS	659.1	518.5	140.6	3.301	3	3	60.23	24
MH vs. TH	659.1	695.8	-36.67	3.301	3	3	15.71	24
MH vs. TS	659.1	591.9	67.24	3.301	3	3	28.80	24
MS vs. TH	518.5	695.8	-177.3	3.301	3	3	75.94	24
MS vs. TS	518.5	591.9	-73.35	3.301	3	3	31.42	24
TH vs. TS	695.8	591.9	103.9	3.301	3	3	44.52	24

Appendix B12: Tukey's Multiple Comparison Test for Phosphorus Content of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	0.001446	-0.003233 to 0.006124	No	ns
BH vs. MH	-0.009326	-0.01400 to -0.004647	Yes	****
BH vs. MS	-0.002022	-0.006701 to 0.002656	No	ns
BH vs. TH	-0.009438	-0.01412 to -0.004759	Yes	****
BH vs. TS	-0.006581	-0.01126 to -0.001902	Yes	**
BS vs. MH	-0.01077	-0.01545 to -0.006093	Yes	****

BS vs. MS	-0.003468	-0.008147 to 0.001211	No	ns
BS vs. TH	-0.01088	-0.01556 to -0.006205	Yes	****
BS vs. TS	-0.008026	-0.01270 to -0.003348	Yes	***
MH vs. MS	0.007304	0.002625 to 0.01198	Yes	***
MH vs. TH	-0.0001120	-0.004791 to 0.004567	No	ns
MH vs. TS	0.002745	-0.001933 to 0.007424	No	ns
MS vs. TH	-0.007416	-0.01209 to -0.002737	Yes	***
MS vs. TS	-0.004558	-0.009237 to 0.0001202	No	ns
TH vs. TS	0.002857	-0.001821 to 0.007536	No	ns
WESTERN				
BH vs. BS	-0.001573	-0.006252 to 0.003106	No	ns
BH vs. MH	0.01479	0.01011 to 0.01946	Yes	****
BH vs. MS	0.008951	0.004273 to 0.01363	Yes	****
BH vs. TH	0.02108	0.01640 to 0.02575	Yes	****
BH vs. TS	0.01090	0.006220 to 0.01558	Yes	****
BS vs. MH	0.01636	0.01168 to 0.02104	Yes	****
BS vs. MS	0.01052	0.005846 to 0.01520	Yes	****
BS vs. TH	0.02265	0.01797 to 0.02733	Yes	****
BS vs. TS	0.01247	0.007793 to 0.01715	Yes	****
MH vs. MS	-0.005835	-0.01051 to -0.001156	Yes	**
MH vs. TH	0.006289	0.001610 to 0.01097	Yes	**
MH vs. TS	-0.003888	-0.008566 to 0.0007909	No	ns
MS vs. TH	0.01212	0.007445 to 0.01680	Yes	****
MS vs. TS	0.001947	-0.002731 to 0.006626	No	ns
TH vs. TS	-0.01018	-0.01485 to -0.005498	Yes	****

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	0.01381	0.01236	0.001446	0.001513	3	3	1.351	24
BH vs. MH	0.01381	0.02314	-0.009326	0.001513	3	3	8.716	24
BH vs. MS	0.01381	0.01583	-0.002022	0.001513	3	3	1.890	24
BH vs. TH	0.01381	0.02325	-0.009438	0.001513	3	3	8.821	24
BH vs. TS	0.01381	0.02039	-0.006581	0.001513	3	3	6.150	24
BS vs. MH	0.01236	0.02314	-0.01077	0.001513	3	3	10.07	24
BS vs. MS	0.01236	0.01583	-0.003468	0.001513	3	3	3.241	24
BS vs. TH	0.01236	0.02325	-0.01088	0.001513	3	3	10.17	24
BS vs. TS	0.01236	0.02039	-0.008026	0.001513	3	3	7.502	24
MH vs. MS	0.02314	0.01583	0.007304	0.001513	3	3	6.826	24
MH vs. TH	0.02314	0.02325	-0.0001120	0.001513	3	3	0.1047	24
MH vs. TS	0.02314	0.02039	0.002745	0.001513	3	3	2.566	24
MS vs. TH	0.01583	0.02325	-0.007416	0.001513	3	3	6.931	24
MS vs. TS	0.01583	0.02039	-0.004558	0.001513	3	3	4.260	24
TH vs. TS	0.02325	0.02039	0.002857	0.001513	3	3	2.671	24

Appendix B13: Tukey's Multiple Comparison Test for Calcium Content of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	-197.3	-246.0 to -148.6	Yes	****
BH vs. MH	136.0	87.32 to 184.8	Yes	****
BH vs. MS	-39.92	-88.65 to 8.804	No	ns
BH vs. TH	178.3	129.6 to 227.0	Yes	****
BH vs. TS	257.0	208.3 to 305.7	Yes	****
BS vs. MH	333.3	284.6 to 382.1	Yes	****
BS vs. MS	157.4	108.6 to 206.1	Yes	****
BS vs. TH	375.6	326.9 to 424.3	Yes	****
BS vs. TS	454.3	405.5 to 503.0	Yes	****
MH vs. MS	-176.0	-224.7 to -127.2	Yes	****
MH vs. TH	42.25	-6.478 to 90.97	No	ns
MH vs. TS	120.9	72.20 to 169.7	Yes	****
MS vs. TH	218.2	169.5 to 266.9	Yes	****
MS vs. TS	296.9	248.2 to 345.6	Yes	****
TH vs. TS	78.68	29.96 to 127.4	Yes	***
WESTERN				
BH vs. BS	-248.1	-296.8 to -199.3	Yes	****
BH vs. MH	-168.2	-216.9 to -119.5	Yes	****
BH vs. MS	-82.17	-130.9 to -33.44	Yes	***
BH vs. TH	130.2	81.51 to 179.0	Yes	****
BH vs. TS	207.4	158.6 to 256.1	Yes	****
BS vs. MH	79.84	31.12 to 128.6	Yes	***
BS vs. MS	165.9	117.2 to 214.6	Yes	****
BS vs. TH	378.3	329.6 to 427.0	Yes	****
BS vs. TS	455.4	406.7 to 504.2	Yes	****
MH vs. MS	86.05	37.32 to 134.8	Yes	***
MH vs. TH	298.4	249.7 to 347.2	Yes	****
MH vs. TS	375.6	326.9 to 424.3	Yes	****
MS vs. TH	212.4	163.7 to 261.1	Yes	****
MS vs. TS	289.5	240.8 to 338.3	Yes	****
TH vs. TS	77.13	28.41 to 125.9	Yes	***

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	339.9	537.2	-197.3	15.76	3	3	17.70	24
BH vs. MH	339.9	203.9	136.0	15.76	3	3	12.21	24
BH vs. MS	339.9	379.8	-39.92	15.76	3	3	3.583	24
BH vs. TH	339.9	161.6	178.3	15.76	3	3	16.00	24
BH vs. TS	339.9	82.95	257.0	15.76	3	3	23.06	24
BS vs. MH	537.2	203.9	333.3	15.76	3	3	29.91	24

BS vs. MS	537.2	379.8	157.4	15.76	3	3	14.12	24
BS vs. TH	537.2	161.6	375.6	15.76	3	3	33.70	24
BS vs. TS	537.2	82.95	454.3	15.76	3	3	40.77	24
MH vs. MS	203.9	379.8	-176.0	15.76	3	3	15.79	24
MH vs. TH	203.9	161.6	42.25	15.76	3	3	3.791	24
MH vs. TS	203.9	82.95	120.9	15.76	3	3	10.85	24
MS vs. TH	379.8	161.6	218.2	15.76	3	3	19.58	24
MS vs. TS	379.8	82.95	296.9	15.76	3	3	26.64	24
TH vs. TS	161.6	82.95	78.68	15.76	3	3	7.061	24
WESTERN								
BH vs. BS	350.8	598.8	-248.1	15.76	3	3	22.26	24
BH vs. MH	350.8	519.0	-168.2	15.76	3	3	15.10	24
BH vs. MS	350.8	432.9	-82.17	15.76	3	3	7.374	24
BH vs. TH	350.8	220.5	130.2	15.76	3	3	11.69	24
BH vs. TS	350.8	143.4	207.4	15.76	3	3	18.61	24
BS vs. MH	598.8	519.0	79.84	15.76	3	3	7.165	24
BS vs. MS	598.8	432.9	165.9	15.76	3	3	14.89	24
BS vs. TH	598.8	220.5	378.3	15.76	3	3	33.95	24
BS vs. TS	598.8	143.4	455.4	15.76	3	3	40.87	24
MH vs. MS	519.0	432.9	86.05	15.76	3	3	7.722	24
MH vs. TH	519.0	220.5	298.4	15.76	3	3	26.78	24
MH vs. TS	519.0	143.4	375.6	15.76	3	3	33.70	24
MS vs. TH	432.9	220.5	212.4	15.76	3	3	19.06	24
MS vs. TS	432.9	143.4	289.5	15.76	3	3	25.98	24
TH vs. TS	220.5	143.4	77.13	15.76	3	3	6.922	24

Appendix B14: Tukey's Multiple Comparison Test for Sodium Content of *L. racemosa* from Central and Western Regions along the Stem

Number of families	2
Number of comparisons per family	15
Alpha	0.05

Tukey's multiple comparisons test	Mean Diff.	95% CI of diff.	Significant?	Summary
CENTRAL				
BH vs. BS	-108.0	-118.4 to -97.53	Yes	****
BH vs. MH	3.374	-7.058 to 13.81	No	ns
BH vs. MS	-175.4	-185.9 to -165.0	Yes	****
BH vs. TH	-202.4	-212.9 to -192.0	Yes	****
BH vs. TS	-121.5	-131.9 to -111.0	Yes	****
BS vs. MH	111.3	100.9 to 121.8	Yes	****
BS vs. MS	-67.48	-77.91 to -57.04	Yes	****
BS vs. TH	-94.47	-104.9 to -84.04	Yes	****
BS vs. TS	-13.50	-23.93 to -3.064	Yes	**
MH vs. MS	-178.8	-189.2 to -168.4	Yes	****
MH vs. TH	-205.8	-216.2 to -195.4	Yes	****
MH vs. TS	-124.8	-135.3 to -114.4	Yes	****

MS vs. TH	-26.99	-37.42 to -16.56	Yes	****
MS vs. TS	53.98	43.55 to 64.41	Yes	****
TH vs. TS	80.97	70.54 to 91.40	Yes	****
WESTERN				
BH vs. BS	-175.4	-185.9 to -165.0	Yes	****
BH vs. MH	-108.0	-118.4 to -97.53	Yes	****
BH vs. MS	-77.60	-88.03 to -67.17	Yes	****
BH vs. TH	6.748	-3.684 to 17.18	No	ns
BH vs. TS	-47.23	-57.66 to -36.80	Yes	****
BS vs. MH	67.48	57.04 to 77.91	Yes	****
BS vs. MS	97.84	87.41 to 108.3	Yes	****
BS vs. TH	182.2	171.8 to 192.6	Yes	****
BS vs. TS	128.2	117.8 to 138.6	Yes	****
MH vs. MS	30.36	19.93 to 40.80	Yes	****
MH vs. TH	114.7	104.3 to 125.1	Yes	****
MH vs. TS	60.73	50.30 to 71.16	Yes	****
MS vs. TH	84.35	73.91 to 94.78	Yes	****
MS vs. TS	30.36	19.93 to 40.80	Yes	****
TH vs. TS	-53.98	-64.41 to -43.55	Yes	****

Test details	Mean 1	Mean 2	Mean Diff.	SE of diff.	N1	N2	q	DF
CENTRAL								
BH vs. BS	720.6	828.6	-108.0	3.374	3	3	45.25	24
BH vs. MH	720.6	717.3	3.374	3.374	3	3	1.414	24
BH vs. MS	720.6	896.1	-175.4	3.374	3	3	73.54	24
BH vs. TH	720.6	923.1	-202.4	3.374	3	3	84.85	24
BH vs. TS	720.6	842.1	-121.5	3.374	3	3	50.91	24
BS vs. MH	828.6	717.3	111.3	3.374	3	3	46.67	24
BS vs. MS	828.6	896.1	-67.48	3.374	3	3	28.28	24
BS vs. TH	828.6	923.1	-94.47	3.374	3	3	39.60	24
BS vs. TS	828.6	842.1	-13.50	3.374	3	3	5.657	24
MH vs. MS	717.3	896.1	-178.8	3.374	3	3	74.95	24
MH vs. TH	717.3	923.1	-205.8	3.374	3	3	86.27	24
MH vs. TS	717.3	842.1	-124.8	3.374	3	3	52.33	24
MS vs. TH	896.1	923.1	-26.99	3.374	3	3	11.31	24
MS vs. TS	896.1	842.1	53.98	3.374	3	3	22.63	24
TH vs. TS	923.1	842.1	80.97	3.374	3	3	33.94	24
WESTERN								
BH vs. BS	1004	1179	-175.4	3.374	3	3	73.54	24
BH vs. MH	1004	1112	-108.0	3.374	3	3	45.25	24
BH vs. MS	1004	1082	-77.60	3.374	3	3	32.53	24
BH vs. TH	1004	997.3	6.748	3.374	3	3	2.828	24
BH vs. TS	1004	1051	-47.23	3.374	3	3	19.80	24
BS vs. MH	1179	1112	67.48	3.374	3	3	28.28	24
BS vs. MS	1179	1082	97.84	3.374	3	3	41.01	24
BS vs. TH	1179	997.3	182.2	3.374	3	3	76.37	24

BS vs. TS	1179	1051	128.2	3.374	3	3	53.74	24
MH vs. MS	1112	1082	30.36	3.374	3	3	12.73	24
MH vs. TH	1112	997.3	114.7	3.374	3	3	48.08	24
MH vs. TS	1112	1051	60.73	3.374	3	3	25.46	24
MS vs. TH	1082	997.3	84.35	3.374	3	3	35.36	24
MS vs. TS	1082	1051	30.36	3.374	3	3	12.73	24
TH vs. TS	997.3	1051	-53.98	3.374	3	3	22.63	24