KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI-GHANA

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF WOOD SCIENCE AND TECHNOLOGY

PHYSICO - CHEMICAL PROPERTIES AND NATURAL DURABILITY WITHIN TWO VARIETIES OF *Borassus aethiopum*

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PHYSICO-CHEMICAL PROPERTIES AND NATURAL DURABILITY WITHIN TWO VARIETIES OF *Borassus aethiopum*

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OF

MSc. WOOD SCIECE AND TECHNOLOGY

FACULTY OF RENEWABLE NATURAL RESOURCES,

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

DECLARATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

Many commercial Ghanaian timber species are over-exploited and threatened with extinction due to current pressure on traditional timbers. The need to investigate the potential utilization for NonTimber Forest Products (NTFPs) to ascertain their possible utilization is important. Some physical and chemical properties, and the natural durability within two varieties of *Borassus aethiopum* harvested from Kobreso were investigated. Moisture content at green state ranged between 59.03 % (for periphery of the base) and 129.42 % (at core of the crown) for the male, and 56.38 % and

137.98 % respectively for the female. At the dry state, the male respectively recorded 12.19 % and 12. 94 % and also 12.29 % for the female and 12.85 % at the same sites. The density also ranged from 450.00kg/m^3 (at the core of crown) and 960.50 kg/m^3 (at periphery of base) for the male, and 423.50 kg/m^3 and 1026.50 kg/m^3 respectively for the female at green state. The male, at dry state, respectively recorded 264.00kg/m^3 and 827kg/m^3 and also 219.50kg/m^3 for the female and 754.50kg/m^3 at the same sites. Longitudinal swelling and shrinkage ranged from 0.22-0.48 % and 1.11-3.69 % respectively along the male and 0.22-0.52 % and 1.32-3.94 % for female. Tangential swelling and shrinkage similarly was 0.62-2.23 % and 1.75-4.04 % respectively for male and 0.692.21 % and 2.24-3.13 % for female. Radial swelling and shrinkage increased from 2.54-4.76 % and 2.41-3.54 % respectively for male while 2.14-4.66 % and 2.34-3.40 % along the female. Generally, volumetric swelling and shrinkage had a range of 2.88-6.99 % and 5.88-10.68 % respectively along the male with the female having 4.01-6.23 % and 6.82- 9.22 %. The male and female peripheries at base obtained greater total extractive (4.41 % and 3.25 % respectively), lignin (36.88 % and 39.53 %), alpha-cellulose (40.09 % and 37.01 %) and holocellulose (74.44 % and 75.23 %). Contrary, the core of crown had lowest total extractive (1.81 % and 1.83 % for male and female respectively), lignin (29.31 % and 28.60 %) and alpha-cellulose (28.02 % and 24.40 %) while the core of middle recorded least holocellulose (62.64 % and 62.62 %). Hemi-cellulose ranged from 32.59-41.93 % and 31.61-46.09 % for male and female respectively. The core of base for male gained lowest (31.61%) with core of crown for female having greatest (46.09%). The ash and mass loss for the male also ranged from 0.65-3.39 % and 4.17-100 % respectively likewise 0.85-5.64 % and 4.07-100 % for female. The core of crown for female recorded greater ash (5.64 %) with the periphery of base having least (0.65 %). For mass loss, both the core of crown for male and female obtained greatest (100 %) whilst periphery of the female recorded the least (4.07 %). The lignin, alpha-cellulose and holocellulose correlated strongly with the mass loss. Generally, the peripheries at the base and middle within the two varieties were durable and could be utilized for structural and exterior works. The cores of the base and middle could be also very useful for minor artifacts. The usage of *B. aethiopum* in the timber industry could reduce pressure on primary wood species and forest degradation as a result of excessive logging for the traditional timber species.

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DEDICATION

To my God who has seen me through all these years, and to my children (Richard Kofi Kyei Acheampong and Mary Pearl Acheampomaa), I dedicate this work.

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ABBREVIATIONS AND SYMBOLS

The following abbreviations and symbols were used in the document.

ASTM	American Society of Testing and Materials
BS	British Standard of Testing Small Clear Samples
Df	Degree of Freedom
FSP	Fibre Saturation Point
P – Value	Probability Value
MC	Moisture Content
MS	Mean Sum of Squares
SS	Sum of Squares
BP	Periphery of base
BC	Core of base
MP	Periphery of middle **MC**
	Core of middle
CP	Periphery of crown
CC	Core of crown

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

The United Nations Food and Agricultural Organization (FAO) (2006) defined forests as land with a tree canopy cover of more than 10% and an area of more than half a hectare. Forest resources such as timber and non-timber forest products are of great importance to millions of people, especially those whose livelihood largely depends on them. They also play vital roles in maintaining the ecological balance and environmental make-up of our world (Danso, 2010). Forests resources in Ghana is changing as a result of excessive logging and that some of the wellknown tree species will no longer exist in sufficient quantities to be useful commercially as a result of too much selective felling of the preferred timber species (Hubbell *et al*., 1999).

Wood has always served man and contributed decisively to his survival all through the development of civilization, as the raw material for several products including furniture, flooring, sleepers, dowels and bridges compared to other competitive materials such as metals, cement (concrete) and plastics (Tsoumis,1991). Most of the economic indigenous forest timbers such as *Milicia excelsa* and M. *regia*, the Mahoganies (*Khaya* and *Entandrophragma* species), *Pericopsis elata, Nauclea diderrichii* and *Triplochiton scleroxylon* have drastically reduced over the past decades due to unsustainable agriculture, wanton logging, wildfires, firewood collection and charcoal production, mining, population pressure, poorly defined land and resource tenureand market failures, international trade, and imposition of economic programs such as the Structural

Adjustment Program (Appiah *et al.* 2009).

Winandy (1994) revealed that forest resources (such as wood) are an extremely versatile material with a range of physical, chemical, mechanical and natural durability properties among the species. As a construction material, wood is strong, light, flexible and easily worked with. In contrast to other

structural materials (such as brick, metal, concrete and plastics), wood which is a renewable material can be produced and transported with little energy consumed (Koch, 1971). Wood physical properties are referred to as quantitative characteristics of wood and its behaviour that affect its appearances rather than applied forces (Winandy, 1994).The most studied physical properties for determining the wood end uses comprise density, wood-water relations, shrinkage, swelling and colour (Bowyer *et al.,* 2003). Among the physical factors, wood density influences the termite's ability to fragment the wood mechanically with its mandibles whereas the moisture content drives the termite towards the wood (Bultman and Southwell, 1976).

Wood chemistry is very important in determining its utilization potentials (Li 2004). Wood chemical composition varies with tree part (root, stem, or branch), type of wood (i. e., normal, or reaction) geographic location, climate, and soil conditions. There are two major chemical components in wood: lignin (18–35%) and carbohydrate (65–75%). Various studies such as Manasrah (2008) and Reiniati (2009) have investigated into chemical composition of wood but systematic and thorough research on a commercially importance of *B. aethiopum* is needed in determining its potential utilization for various products. The chemical compositions of wood usually reveal the nature of the wood.

Wood mechanical properties refers to its ability to carry applied load or forces (Haygreen and Bowyer, 1996). They indicated that mechanical properties are usually the most important characteristics of wood products to be used in structural applications. They largely determine the fitness of wood for structural and building purposes and there is hardly a single use of wood that does not depend at least to some degree on one or more of its mechanical properties (Kollmann and

Cote, 1968).Hence, a basic knowledge of the mechanical properties of timber is essential, if it is to be used efficiently.

Natural durability of wood is its natural resistance to damage by subterranean termites, decay fungi and other soil micro-organisms. Thus, it is important to consider when timber is to be used for outdoors. Some timbers have had their natural durability tested in the laboratory and in the field (Antwi-Boasiako, 2004) but more works need to be done on more timber species in order to widen the data base and increase the pool of timber resources to choose from when considering wood for utilization in construction and provide useful information on their possible end-uses as well as important predictions on product service life (Gambetta *et al.*, 2004). The physical, mechanical, and chemical properties of wood are probably interdependent and affect wood resistance to termites (Shanbhag, 2013). It is therefore essential to determine some of these properties to assess its potential utilization of Non–Timber Forest Products (NTFPs) such as *B. aethiopum.*

1.2 Problem Statement

Ghana was richly endowed with forest resources which were vital for her development. Originally, the forests covered about 36% (84,000 km^2) of the total land area (Rice and Counsell, 1993; EU, 2006). Timber, which is the major market based forest product, is the fourth largest contributor to Ghana's foreign exchange earnings aside minerals, cocoa and tourism (Marfo, 2010). The formal timber industry accounts for 11% of foreign exchange earnings and contributes about 6% to Gross Domestic Product (GDP) and directly employs about 100, 000 people (Marfo, 2010). Due to the high demand for Ghana's tropical timber, large volumes of it have been harvested over the past century making it one of the major export earners for the country.

Appiah *et al.* (2009) estimated the total revenue loss to Ghana from illegal logging operations, including chainsaw milling at GH¢ 40.5 million per year, equivalent to about 2% of GDP. The geometric rate about 2% p.a. at which the once evergreen forests of Ghana are fast diminishing at the expense of forest communities' livelihoods and development is very alarming, especially with regard to meeting the needs of future generations (Tropenbos International-Ghana, 2007).

Due to the constant decline in timber volumes caused by over exploitation, the emphasis is now on other sources to supplement the revenue from timber. An alternative to timber production with a potential revenue generation would be seen as welcome news to reverse the negative impact of its over-exploitation on the environment. This alternative is seen in Non-Timber Forest Products (NTFPs), which is in abundance and untapped in large quantities (Howard, 2011). Chamberlain *et al.* (2000) defined NTFPs as any product other than timber that is derived from forests. They may be gathered in the wild or produced in forest plantations and agro forestry schemes. Large volumes of NTFPs abound in the country's forests which include: canes, *B. aethiopum*, bamboos, rattans, fruits and nuts, resins, and a host of other palms and grasses. (Jatau, 2008) also reported that several species with commercial potential are not used. In view of this, the need has arisen for investigations into the promotion and marketing of Ghana's NTFPs as a means of reducing the over exploitation and dependence on the preferred species. For these NTFPs (e.g. *B. aethiopum*) to be used as substitutes and accepted on the market it is very essential to understand their physical, mechanical and chemical properties as well as natural durability and how they perform in service.

B. aethiopum is in abundance in Ghana but underutilized for commercial activities. Its prudent utilization promotion would boost Ghana's wood industry and reduce pressure on the dwindling primary timber species as every part of *B. aethiopum*could serve any of the socio-cultural, economic and environmental needs of human kind (Jatau, 2008). Native intelligence and observation have

revealed that *B. aethiopum* is strong and versatile in its utilization. It is widely utilized in other countries in Asia and South America for household utilities such as containers, chopsticks, fishing poles, cricket boxes and chairs. It has also been widely used in building applications such as flooring, fences, housing roofs, trusses, bridges, beams and lintels but it has minimal usage in Ghana (Ayarkwa, 1997).

1.3 Objectives of the Study

(a) Main objective:

To determine the physical and chemical properties and natural durability within the male and female types of *B. aethiopum*.

(b) Specific objective:

1. To determine the swelling and shrinkage (dimensional stability) properties of the two varieties of *B. aethiopum.*
2. To determine the chemical properties of the two varieties of *B. aethiopum.*
3. To assess the natural durability of the two varieties of *B. aethiopum.*

CHAPTER TWO

LITERATURE REVIEW

2.1. Wood as a Structural Material

Embers (2000) defined wood as ‘‘the hardest, fibrous substance that is found beneath the bark of the stems and branches in both trees and shrubs’’. It has successfully been utilized as building material and other constructional works for thousands of years due to its availability, easy to use, great insulating and strength properties (Gonzalez, 2007). Wood is a unique material in which the chemical

composition, anatomical features, physical and mechanical properties as well as natural durability are interrelated (Chowdhury *et al.*, 2007). Ali (2011) reported that wood is a living organism with a great variability in structure and properties. The variability exists as inter- and intra-tree variation and also between growing stands. The environmental conditions are one important source of wood anatomical structure variability, which influences the physical, chemical and natural durability properties.

Generally, wood is considered as dimensionally unstable, subject to decay by fungi, destruction by insects and marine borers and is easily burned. It is not often realized that the difficulty being faced in its use is due to lack of proper understanding of its properties rather than defects in the timber itself (Shrivastava, 1997). Wood species can be grouped into two: hardwoods (angiosperm) and softwoods (gymnosperm). It is also made up of a number of substances such as cellulose (40-50%), hemi-cellulose (20-30%), lignin (18-30%), ash (0.1-1; 5%) and accumulated extractives (210; 40%) (Rowell *et. al*., 2005, Gonzalez, 2007, Ndlovu, 2007). Wood properties vary from species to species, from one position to another in the tree, from one tree to another grown in the same locality, and between trees grown in one locality and those grown in another (Antwi-Boasiako, 2004).

Gryc *et al.* (2007) reported that wood in comparison with other competitive materials offers many advantages including being a renewable resource, it provides a very high strength and elasticity given its weight, it has good thermal insulating properties, can be easily shaped, it is ecologically recyclable and has indisputable aesthetic qualities. However, it also has some disadvantages; one of them is being hygroscopic, which induces shape changes. The differences in wood quality exist between samples taken from same species from different geographical areas and even from different parts of the same tree (Antwi-Boasiako, 2004; Quartey, 2009). In order to use wood very efficiently, a comprehensive knowledge of the structure of wood, its physical, mechanical, chemical and

durability behavior, and the causes of variability, as they affect its utilization form the basis of the present and potential utilization (Panshin and de Zeeuw, 1980).

2.2 Non-Timber Forest Products (NTFPs)

Wong (2000) referred to Non-Timber Forest Products (NTFPs) as products with the exception of timber, harvested from a forest ecosystem. NTFPs could also be all tangible animal and plant products other than industrial wood, coming from natural forests, including managed secondary forests and enriched forests (Ros-Tonen *et al.,* 1998). They can be classified into four general product lines: edibles, specialty wood products, floral greens, and medicinal and dietary supplements (Hammett and Chamberlain, 1998). NTFPs require special management and monitoring considerations in order to ensure the long-term viability of species and to minimize adverse social and ecological impacts. They are important to industrialized as well as developing economies. Chamberlain *et al.* (2000) observed that NTFPs are often viewed as a marginal activity in industrialized countries; in reality the trade of these products provides significant economic benefits to many rural households and communities. Some NTFPs are internationally traded while others are critical subsistence resources in many rural economies. NTFPs harvest may produce fewer negative impacts on forest ecosystems than timber harvesting and can provide an array of social and economic benefits, particularly to community forest operations.

2.3. *B. aethiopum* in Perspective

B. aethiopum (mart) is a dioecious palm tree of African origin, of the family of Palmae or Arecaceae (Jatau, 2008). It is an unbranched palm, which grows up to 20m high and characterized by a crown up to 8m wide. Young palms are covered with dry leaf stalks, showing gradually fading leaf scars. Trees over 25 years old have a swelling of the trunk at 12-15m above the ground (at 2/3 of the

height); bark is pale- grey in older palms and is more or less smooth. Leaves are very large, fan shaped, bluish-green, 15-30cm, up to 3.5m long, including petiole which is marked with sharp, black thorns; leaflets symmetric at the base. A report by Millennium Seed Bank Project (2007) revealed that *B. aethiopum* is a solitary, pleonanthic (does not die after flowering) palm. The tallest of the African palms, it can reach 30m in height, but is typically 7-20m. The straight trunk is dark grey, 40-50 cm in diameter; with a bulge up to 80cm across above the middle (this bulge usually develops after 25 years growth). The leaf bases leave a scar on the surface of the trunk. The leaves are dark bluish-green, palmate, markedly petiolate and arranged in dense terminal tufts. Mature trees have between 10 and 40 living leaves, arranged in three spiral rows.

The many-folded leaf blades are typically 1.5 to 3.6 m long.

The petioles are up to 3m long, 15cm wide at the base and narrow to 7.5cm towards the top. The petioles are concave above and convex below, edged with curved teeth. Flowers are unisexual. The male inflorescence is 0.8 to 1.8 m long, with 3-6 partial inflorescences that are 5 m long. The female inflorescence is usually unbranched, and 1.3 to 2.6m long, with larger flowers of 2 x 3m. The flowers are tightly set in the axil of abstracts. Flowers comprise three free external tepals and three internal petals attached at the base (Bayton *et al.,* 2006). Eaia (1983) explained that a cross section through *B. aethiopum* stem shows three layers: the dermal (periphery), sub-dermal (core) and central (pith) zones. Although it was described first in India in 1753 and only much later in Africa but botanists believed that it originated from Africa. Byton *et al.* (2007) further stressed that five species are recognized: *B. aethiopum* from Africa and Madagascar, *B. akeassii* from West and Central Africa, *B. madagascariensis* from Madagascar, *B. flabellifer* from South and Southeast Asia and *B. heineanus* from Papua New Guinea. In English it is variously referred to as African fan palm, African palmyra palm, deleb palm, ron palm, toddy palm, black rhun palm, ronier palm (from the

French) and others. It also has names in African languages. It is known in Nigerian, among the Yoruba, Igbo, Hausa and Ga as Agbon-eye, Ubiri, Giginya and Kengera respectively (Jatau, 2008). In Ghana, they are given names by various tribes such as 'Maakube' by the Akan, Malekwe by Nzema, Agor by Ewes and Konga by Moshis and Wiedzo by the Ga (Asafu – Adjaye *et al.*, 2012).

2.4. Ecology and Distribution of *B. aethiopum*

B. aethiopum is a non–timber tree which grows in the transition and savanna zones of Ghana and West Africa. It may also be found in marshy areas and by stream sides in the savanna areas and also transitional and savanna areas of the semi-arid and sub-humid tropics in West Africa, from Senegal to Nigeria and the belts southwards from Sudan to Mozambique and Transvaal. Thus, it is common in Kenya, Burkina Faso, Mali, Congo, Cote- d'voire, Ethiopia, Gambia, Guinea, Guinea Bissau, Liberia, Benin, Sierra-Leone, South Africa, Tanzania, Togo, Uganda, Zambia and Zimbabwe (Ayarkwa, 1997).

Millennium Seed Bank Project (2007) reported that *B. aethiopum* is cultivated in India, Southeast Asia, Malaysia and also in Hawaii and Florida. It grows in great abundance on riverine flats and coastal plains, and in open secondary forest, dense forest borders and in savannah drier areas where it is restricted to grassland with high ground water table, or along water courses (annual rainfall of 500-1000 mm). It thrives in temporary flooded areas, often forming dense stands. It is irregular, but widely distributed, typically found at altitudes of up to 400 m, but up to 1200m in East Africa. It is abundant and characteristic in all types of savannah of the region, occurring at low altitudes along rivers and in coastal woodlands. It can tolerate high temperatures and will grow in areas with rainfall less than 500mm p.a. if the groundwater table is high. Agbitor (2005) stressed that *B. aethiopum* also occurs in wetter parts of the coastal areas and grassland, particularly east of the Volta Region of Ghana.

2.5 Taxonomy of *B. aethiopum*

The taxonomy of African *Borassus* L. (Coryphoideae: Borasseae) has been the subject of some controversy since the first African species, *B. aethiopum* was described by Bayton *et al.* (2006). They however, reported that the eminent palm botanist Beccari recognized two varieties within *B. aethiopum*: *B. aethiopum* var. *bagamojensis* from East Africa and *B. aethiopum* var. *senegalensis* from West Africa (Bayton *et al.,* 2006). Generally, *B. aethiopum* is of two main varieties. They are of male and female types. The male *B. aethiopum* bears flowers but does not produce fruits. The female *B. aethiopum* bear fruits every 8 months and produces between 50 and 150 fruits weighing between 50 to 175 kg, depending on the size of the fruits. The edible fruits of *B. aethiopum* are gathered in tightened bunches, containing each two to three cores surrounded by a fibrous flesh. They are ovoid or smooth globulous and fibrous drupes, from 15cm to 20cm in diameter. Their color, when at maturity, is yellow, orange or slightly reddish. A sweet, viscous and scented juice is extracted from the ripe fruit, with fibrous mesocarp, which is used in the production of millet flurry or in the preparation of wafers of millet. The pulp, seeds, hypocotyl and sap are very useful in various forms for human consumption (Ahmed *et al.,* 2010).

2.6. General importance of *B. aethiopum*

B. aethiopum is a multipurpose palm, providing multi-functional importance to mankind. Every part of the *B. aethiopum* can serve any of our socio-cultural, economic and environmental needs. The tree is an attractive palm and has been planted for amenity purposes along highways and is recommended for strategic places such as government buildings, libraries, schools, parks and museums (Fairchild Tropical Garden Reports, 2002). Borassus palm (*B. aethiopum*) is a monocotyledon palmae species that serves as a potential source of raw material for the furniture and

construction industries (Ayarkwa, J. 1997). It is also used in areas like medicine, food, and beverage and for industrial products. The roots, shoots and fruits are also utilized for medicinal purposes. The powdered root when mixed with sheep butter is used to treat sore throat and bronchitis; palm wines from it are considered an aphrodisiac and stimulant (FAO, 1988).

B. aethiopum is locally used in Ghana for firewood, stakes in farming, walking sticks, canoes, doors, chairs, fences, flooring, ceiling and other constructional purposes usually in the rural areas. Ecological, Eco-developmental use of *B. aethiopum* for effective and efficient purification of the environment because it acts as oxygen banks and eliminate air pollutants, for abating or moderating temperature, noise and wind by planting trees as environmental screens, thus affecting the microclimate, for harboring wildlife, for maintaining biodiversity and for conserving energy. Millennium Seed Bank project (2007)identified that almost all parts of *B. aethiopum* are used for producing food, oils, timber, dyes, fibre, wine, and raw materials (from leaves) for mats and baskets. The dark brown, coarsely fibrous wood is a highly prized timber; it is very resistant to termites and fungi, and is used in carpentry, construction and also for household articles. The leaves are said to be an aphrodisiac and the sap is reported to have many uses such as being fermented into toddy which can be converted into alcohol, vinegar or sugar (Johnson, 1998).

The fruits are eaten as a food supplement; both the fruit pulp and seeds are edible. The fruit is made into soft drinks, while the sap is fermented into palm wine usually used during traditional ceremonies. However, excessive tapping kills the plant (Johnson, 1998). Structurally, Ayarkwa (1997) revealed that the wood is commonly used in Wattle and Daub construction, wall plates, rafters, ridges, king posts, lintels, fences and local bridges in several towns and villages in the transitional and savanna zones of Ghana where they are readily available.

2.7. Physical properties of *B. aethiopum*

The versatility of wood is demonstrated by a wide variety of its products; which is a result of a spectrum of desirable physical properties among the many species of wood (Bowyer *et al.*, 2003). Wood is a hygroscopic and porous material and as such, depending on the external conditions, it can either absorb or release water. The absorption and release of moisture on the hygroscopicity level are accompanied in wood by the process of swelling and shrinkage respectively. The anisotropic properties of wood are manifested through different degrees of swelling and shrinkage in the individual anatomic directions (Niemz, 1993). The physical properties of *B. aethiopum* such as density, MC and dimensional stability usually show variations in height (Asafu - Adjaye*et al.*, 2012, Ayarkwa, 1997).

2.7.1. Moisture content of *B. aethiopum*

Water is naturally present in all parts of a tree and permeates the wood structure. It commonly makes up more than half the weight of a living tree, a fresh log or wet chips. Moisture in wood is found as water vapour, free water in the cell lumens and cavities and as bound water within the cell walls (Choong and Achmadi 1991). The moisture content (MC) at which the cell walls are fully saturated with bound water but no free water occurs in the structure is designated as Fibre Saturation Point (FSP). The amount of free water depends on porosity of the wood 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. Although the ratio between the main structural compounds varies, the maximum amount of bound water in wood of various species changes in a narrow interval of 25-30%. Moisture has great impact on wood durability and service life because it is a prerequisite of vital importance for the wood destroying organisms (Siau, 1995).

Wood MC is one of the many variables that affect the performance and utilization of wood. The amount of water present in wood does not only influences its strength, stiffness and mode of failure, but also affects its dimensions, susceptibility to fungal attack, workability as well as ability to accept adhesives and finishes (Kollman and Cotê 1968). Quartey (2009) reported that woodexchanges moisture with air; the amount and direction of the exchange (gain or loss) depends on the relative humidity and temperature of the air and the current amount of water in the wood.

This moisture relationship has an important influence on wood properties and performance.

Romulo and Arancon (1997) found MC to be negatively correlated with the basic density at the green and dry states (i.e. MC decreased with increase in basic density) *vice versa* and explained that the amount of MC in coconut stems increased with increasing stem height and decreased from the periphery to the core, and ranged from 50% at the periphery of its base to 400% at the core of its crown.For timber species, Shupe *et al.* (1995) reported that MC of heartwood and sapwood at the green and dry states varied with height, whilst Chowdhury *et al.* (2007) noticed that such variability is dependent on the tree species, portion of log, site, genetic variation and the environment. Dinwoodie (2000) also stated that it might be correlated with the season of the year when the tree was felled.MC of palms (Date palm, Oil palm, *B. aethiopum*, etc.) decrease linearly from the crown to the base and from the periphery to the core (Faith, 2014) as was also observed from this study.

2.7.2. Density of *B. aethiopum*

Wood density is an important property to consider since its stiffness, strength and shrinkage properties are all dependent on the density. Lignin and hemi-cellulose are material constituents of wood that absorb water and swell, which affects its volume and the weight and determines its density

(Stenius, 2000). Dinwoodie (2000) explains that density, like many other properties of timber, is extremely variable. Density usually decreases with height in the stem of a tree (Donaldson *et al.*, 1995). Wood density also influences the yield and quality of solid wood products and wood-based composites (Gryc *et al.*, 2007). It is an important property for both solid wood and fiber products from conifers and hardwoods. It is affected by the cell wall thickness, the cell diameter, the early wood to latewood ratio and the chemical content of the wood.

Panshin and de Zeeuw (1980) reported that density is a general indicator of cell size and a good predictor of strength, stiffness, and ease of drying, machining, hardness and various papermaking properties. According to Quartey (2009) density affects wood shrinkage and swelling, machinability, surface texture and micro-smoothness, gluability, penetrability of fluids and gases, and in other respects, it governs the degradation of wood by chemicals, fire and microorganisms.

In particular, the strength of wood and its stiffness are affected by changes in the density. TEDB (1994) reported that at 12% MC, density of wood is classified as very heavy, heavy, mediumheavy, medium, light medium and light. The classification reveals that light density species are soft, less durable and less strong with the very heavy, heavy and medium-heavy density species exhibiting greater level of strength, natural durability and toughness. The technical limits between the classification are: very heavy density is 900kg/m^3 or more, heavy density between 725kg/m^3 and 900kg/m^3, medium heavy 575kg/m^3 and 725kg/m^3, medium 450kg/m^3 and 575kg/m^3, light medium 350kg/m^3 and 450kg/m^3, light 350kg/m^3 or less; TEDB (1994). This classification aids in gaining general idea of the nature of timber species usually in service. Wood density is important as an index of wood quality and is considered to be one of the most important indices of timber strength properties (Stenius, 2000). The higher the wood density, the lower the degradation (Shanbhag, 2013). The density of *B. aethiopum* increased from the periphery of the base to the core of the crown.

2.7.3. Shrinkage and Swelling of *B. aethiopum*

Shrinkage occurs when wood loses moisture from cell walls, while swelling takes place when it gains water (Bowyer *et al*., 2003; Hernandez, 2007). As an anisotropic material, wood shrinks and swells most in the tangential direction, about half as much across the radial direction and insignificantly along the longitudinal direction (Kollmann and Côté, 1984; Simpson and Ten Wolde, 1999). Wood shrinkage upon drying depends on several variables, including specific gravity, rate of drying and size of the wood. The combined effects of radial and tangential shrinkage can distort the shape of the wood. Shrinkage and swelling can also contribute to checks, warping, splitting and overall performance problems that make wood products less useful (Winandy, 1994). The dimensional changes of wood are related to the chemical composition and extractive content but also to fiber morphology and tissue proportions.

Gryc *et al.* (2007) reported that the magnitude of shrinkage and swelling is affected by the amount of moisture gained or lost by wood when the moisture content fluctuates between 0ºC and Fiber Saturation Point. Kollman and Côté (1968) explained that shrinkage differs in three different directions (Longitudinal, Tangential and Radial) due to the influence of wood rays and different arrangements of fibrils on cell walls. The volumetric shrinkage and swelling properties are affected by several wood factors such as heartwood to sapwood ratio or the fibrillar angle on the S_2 layer. However, the most important parameter affecting wood shrinkage is the wood density. In general, the factors that affect shrinkage and swelling are MC, density, and content of extractives, mechanical stresses, and abnormalities in wood structure. The amount of shrinkage or swelling that occurs is

approximately proportional to the change in moisture content. The greater the density of wood, the less is its shrinkage and swelling, because denser (heavier) woods usually contain less moisture in their cell walls.

2.8. Chemical Composition of wood

The chemical composition of wood cannot be defined precisely for a given tree species or even for a given tree. According to Reiniati (2009), wood is comprise of three principal structural polymers: cellulose (40-50%), hemi-celluloses (20–30%) and lignin (20-30%), in addition to low molecular weight organic compounds called extractives (2-10%). These chemical components vary between wood and even within wood of the same species (Reiniati, 2009). In different wood species, however, their relative composition varies greatly, and the chemical composition of wood varies quantitatively among tree species. Manasrah (2008) also maintained that the major chemical constituents of all wood species are a polymeric matrix of structural components: carbohydrates (mainly cellulose and hemi-celluloses) and lignin together with smaller amounts of pectic substances. Two thirds of the dry wood is composed of polysaccharides; cellulose and various hemi-celluloses.

2.8.1. Total extractives of *B. aethiopum*

Wood extractives are polyphenols found in the heartwood of some tree species (FAO, 1986; Syofuna, 2006). Extractive in wood consists of materials that are soluble in organic and inorganic solvents and that are not part of the wood substance. Extractives are non-structural substances usually associated with heartwood and exudates that give wood its distinct smell, color and durability properties. The classes of wood extractive functions are diverse, for example, they may provide energy or protect trees from microbiological or insect attack. They include (1) terpenes, found in

relatively high amounts in the resin ducts of pines, and can be used to make turpentine; (2) resin acids which can be used to make rosin size; (3) triglycerides and fatty acids, which can be used for soaps and (4) phenolic compounds.

These extractives result from series of chemical processes that occur as the cells in the sapwood gradually senescent. Jelokava and Sindler (1997) revealed that extractives in wood are made up of numerous components that can be isolated from wood using non-polar and polar solvents. Natural durability of individual wood species against biotic factors depends mainly on the chemical structure and amount of extractives present, the higher the proportion of extractives, the greater the durability of the heartwood (Syofuna, 2006). The presence of these extractives in sufficient amounts prevents or minimizes the severity of attack by destructive organisms if the extractives are toxic or repellent. The toxic substances vary from species to species and in their chemical properties so that different solvent systems will effectively extract different toxins in different species (Eaton and Hale, 1993).

Wood extractives also include water soluble substances thus covering essentially all wood components other than cellulose, hemi-cellulose and lignin (Syofuna, 2006). The amount of extractives in wood is highly variable and can range from 3-30% by weight depending on the tree species (Haygreen and Bowyer, 1996). Rowell *et al.* (2005) also revealed that extractive content usually ranges from 2-10% by dry weight but can represent up to 40% in some wood species.
There is, however, a general decrease in extractives content with increase in tree height (Walker, 1993) and from the pith to the bark. Wood extractives can be classified according to their morphological site and function in the tree (Syofuna, 2006).

Organic substances such as gums, fats, resins, sugars, oils, starches, and tannins vary by species, from less than 1% in some poplars to approximately 10% in redwood based on oven-dry wood weight (Reiniati, 2009). They are known to be present in different cell types in the heartwood of one wood or that of different extractives may be present in the same cell type in different parts of the same wood. Extractives affect wood color, odor, decay resistance, density, flammability, and moisture absorption (Syofuna, 2006). Wood with less extractive can hold more water in the cell walls, and therefore extractives influence dimensional stability, shrinkage, and solvent uptake. It can therefore be stated that the darker the coloration of the heartwood, the higher will be its natural durability (Stirling and Morris, 2006). Extractives may be hydrophobic or hydrophilic; that is, they may be soluble in organic solvents or water. Extractives can also act as mechanical barriers to fungal hyphae, may reduce wood wettability, contribute to reduced equilibrium moisture content and its depletion can result in declining durability (Taylor *et al*., 2003; Stirling and Morris, 2006).

2.8.2. Lignin content of *B. aethiopum*

Lignin is an encrusting, amorphous, hydrophobic polymer that binds wood cells together and is responsible for giving rigidity to the cell wall. According to Gellerstedt *et al.* (2009), lignin is aromatic polymer that binds together the cellulose microfibrils and hemi-cellulose fixating them towards each other. It is however known to serve as ‘‘glue’’ that holds the tree together. Softwoods usually contain 20-30% lignin, while hardwoods contain lesser amounts (18-25%). The greater amount of lignin and total phenolic contents ensure higher resistance of attack against termites (Shanbhag, 2013).

Softwood lignin is composed of guaiacyl units, while hardwood lignins contain guaiacyl and syringyl units (Gonzalez, 2007). Lignin, principally located in the compound middle lamellae, binds with

hemi-celluloses covalently (Bowyer *et al.*, 2003), providing rigidity to the cells and improving dimensional stability, due to its relative hydrophobicity compared to that of polysaccharides. Although the highest concentration of lignin is found in the middle lamella, the secondary fiber wall contains 70% of the lignin but in lower concentrations. Lignin content adds to the natural durability. It also decreases the permeation of water through the cell walls of the xylem, thereby playing an intricate role in the transport of water and nutrients. Finally, lignin is important function in plant‘s natural defenses against degradation by impeding penetration of destructive enzymes through the cell wall (Syafii *et al.*, 1998).

2. 8.3. Alpha-cellulose of *B. aethiopum*

Alpha-cellulose is the most abundant polymer in nature. It is the principal ingredient of woody plants, which makes the diversity of its applications range from housing structures to paper and textile production. Arguably, it is one of the most influential chemical compounds in the history of human culture (Kontturi, 2003). Gonzalez (2007) stated that cellulose is the main constituent of wood carbohydrates and forms the structural framework of the cell, making up 40-50% of total components in wood and drives the termites towards the wood. It is however revealed that cellulose, the major component of papermaking fibers, contributes 40-45% of the wood‘s dry weight. Located primarily in the secondary cell wall, cellulose polymers are composed of long linear chains of D-glucose linked by ß-1, 4-glycosidic bonds of glucose in a $^4C_1$ chain conformation with equatorially oriented substituent. As a major constituent, it is a reinforcing material in the cell wall that contributes greatly to the stiffness and mechanical strength of wood (Bowyer *et al.*, 2003).

Quartey (2009) stated that wood is the richest source of cellulose. Cellulose and its derivatives are used in various applications and have become inevitable for man. Cellulose, in the form of wood, is the oldest source of energy which when exposed to an atmosphere of constant temperature and

humidity, ultimately attains a moisture content that remains constant so long as these conditions are unaltered. As it is an insoluble substance in most solvents including strong alkali, it is hard to separate cellulose from the wood in pure form because cellulose is closely integrated with lignin and hemi-celluloses (Pettersen, 1984). Quartey (2009) also revealed that it is insoluble in water and most common solvents; the poor solubility is attributed primarily to the strong intra-molecular and intermolecular hydrogen bonding between the individual chains. Despite its poor solubility characteristics, cellulose is used in a wide range of applications including composites, netting, upholstery, coatings; paper (Bowyer *et al.*, 2003).

2.8. 4. Hemi-cellulose of *B. aethiopum*

Gonzalez (2007) revealed that hemi-cellulose is the matrix substance between the cellulose microfibrils and is composed of heterogeneous branched monosaccarides, whose major components are D-glucose, D-mannose, D-galactose, D-xylose, L-arabinose, L-rhamnose, Dglucoronic acid and 4-O-methyl-D-glucoronic acid. They are one of the main polymeric constituents of biomass such as woods. The content of hemi-celluloses represents 20-30% of the dry weight of wood; the wood hemi-celluloses consist of variety of linkages and branching types depending on the wood tissues. Hardwoods, softwoods, grasses and straws are the major sources of hemi-celluloses. The typical content of hemi-cellulose in softwoods is 25-30% and 30-35% in hardwoods. In woody plants, they constitute approximately one-fourth to one third of the total organic material present. Around 80% of the biomass on earth is lignocellulosic materials. Hemicelluloses are colorless and relatively stable carbohydrate polymers. They are heteroglycans containing various types of sugar units, arranged in different proportions and with different structures. The amount and type of hemi-cellulose depends on the kind of wood. Hemi-celluloses are important in maintaining cohesion between the wood polymers within the cell wall, since cellulose has no affinity toward lignin and vice versa (Bowyer *et al.*, 2003). It is often considered to be the component most susceptible to biological degradation

because its heteromorphic nature and side chains make it more accessible to enzymatic attack (Curling *et al.,* 2001).

According to Manasrah (2008), several economic and environmental benefits can be obtained from utilization of wood and crop residue of hemi-celluloses. Organic acids such as acetic acid, methane, monosaccharide, sugar alcohols solvents alternatives to petroleum-derived chemicals and dyes are the potential products that can be made from hemicelluloses. Many potentially useful applications of hemicelluloses are as raw materials for food additives, thickeners, emulsifiers, adhesives, binder, anti-tumor agents and adsorbents that have attracted attention in the past few years. The hemi-cellulosic gums usually have nutritional, medicinal and health product applications. Furthermore, guar gum has large market in various areas in textile, paper, and explosives, cosmetic and mining industries.

2.8.6. Ash Content of *B. aethiopum*

Ash generally refers to inorganic substances such as silicates, sulfates, carbonates or metal ions (Li, 2004). Wood ash is the inorganic and organic residue remaining after the combustion of wood or unbleached wood fibre. The physical and chemical properties of wood ash vary significantly depending on many factors. The ash content and chemical composition vary among tree species and also depend on soil type and climate (Ndlovu, 2007). Temperate-climate wood yields 0.1-1.0% ash, while tropical and sub-tropical wood yield up to 5%. Hardwoods in general contain more ashes than softwoods (Ndlovu, 2007).

Etiegni and Campbell (1990) published that ash has small particle size (an average of 230μm) and low density. Ndlovu (2007) revealed some importance of ash. It is thrown into an outside hole-dug

or pit toilets to reduce bad smell from the latrine, is spread on the land as part of fertilizing the soil, used as tooth paste, to white wash homes and use as a replacement of liquid bath soap to wash dishes and shine sauce pans. Wood ash is very useful as wood insect repellent, polish and abrasive cleaner.

2.9. Natural Durability of Wood

Natural durability of wood refers to its resistance against attack by wood-decay organisms, such as fungi, insects or marine organisms under conditions that favor such attack (Morrell, 2008). Li (2004) revealed that durability against mould, fungal and borer attack is strongly associated with its chemical composition. Wong *et al.* (2005) further stated that natural durability normally refers to the heartwood of timber species, except for those species with no differentiation between heartwood and sapwood. Natural durability varies between wood species and is explained mainly by the composition and amount of wood extractives. Extractive deposits formed during the conversion of sapwood to heartwood often make the heartwood of some species more durable since generally greater heartwood extractive content imparts higher decay resistance of wood species (Pometti *et al.*, 2010). Jelokava and Sindler (2001) also reported that natural durability of individual wood species against biotic factors depends mainly on the chemical structure and amount of extractives present.

Other factors that have been reported to influence the durability of wood include:

- Lignin content; timbers with higher lignin content have greater durability
- Density; where timbers with a greater density are normally more durable (Antwi –Boasiako and Pitman, 2009). Denser timbers have reduced void volume which reduces the rate of gaseous diffusion and therefore the rate of decay.

The principal biological agents that degrade wood are bacteria, fungi, insects (termites and beetles) and marine borers (Tsunoda, 1990; Highley, 1999). Naturally, durable wood has been used successfully in many hazardous environments due, in part, to the toxicity of extractives against

biological agents that cause deterioration and to a low inherent permeability (Archer and Lebow, 2006). Hinterstoisser *et al.* (2000) noted that the content of extractives play a key role in the prediction of the durability of wood. The concentration of extractives varies among species, between individual trees of the same species and within a single tree. Hwang *et al*. (2007) suggested that heartwood provided enhanced protection against bio-deterioration, despite the limited uptake of preservatives in heartwood compared with sapwood.

2.10 Causes of Biodegradation of Wood

Biodegradation of wood results due to the activities of decay and some insects of which termites are the primary agents; wood decay is primarily enzymatic activities of micro-organisms such as fungi. A wood decay fungus has the ability to digest wood causing it to rot. The decay causes damage to timber which leads to great economic losses. Fungal attack causes rotting of wood by means of fungi which lives on and within wood and slowly digesting the cell wall materials leading to softening and decaying of the wood. Wood decay fungi obtain nourishment by digesting cell walls, thus causing deterioration of wood.

Naturally, decay occurs in untreated wood in direct contact with ground, cement or concrete or exposed to a source of moisture such as rain, seepage, plumbing leaks or condensations. Certain conditions are known to favour the occurrences of decay. The major ones include: an adequate supply of oxygen, a favorable temperature (15-40°C), moisture in excess of Fiber Saturation Point (FSP) (25-30%), a suitable source of energy and nutrients (i.e. the wood) and an absence of antagonistic influence of other fungi. Mohebby (2003) indicated that wood decay fungi require wood MC in excess FSP to propagate, that is, fungal growth below FSP (absence of lumen water) is greatly retarded and that below 20% wood MC development is completely inhibited.

2.10. 1. Types of Decay

Wood decay can be defined as the microbiological degradation of wood (Scheffer, 1973). The damage of wood by fungi is essentially caused by the degradation of the cell wall by fungi, which decreases wood properties and substantially reduces wood use (Schmidt, 2006). Various types of decay are known to adversely affect living wood and wood in use. Brown rot, soft rot and white rot are known for this effect (Scheffer, 1973).

Kent and Culen (2005) stated that white rot fungi are able to fragment the major structural polymers of wood and other lignocelluloses, lignin, cellulose, and hemi-cellulose and further metabolize the fragments. The hyphae of fungi rapidly invade wood cells and lie along the lumen walls where they secret the enzyme to depolymerize the hemi cellulose, cellulose and fragmentation of lignin. The white rot fungi degrade wood by removing cellulose, hemi-cellulose and lignin more or less simultaneously. This is more dangerous and harmful than brown rot since it affects all the contents of cell wall thus causing accidental collapse and damages (Schmidt, 2006). Fungi producing this type of wood decay (white rot) belong to basidiomycetes. They are common in nature and particularly active in forest ecosystems bringing about extensive decay of stumps and debris left over from tree harvest. Hardwood species are more susceptible to white rot attack than softwood species, and untreated timbers are more readily attacked than preservative-treated timbers (Kent and Culen, 2005).

Toughness and weight loss are known to be the most sensitive indicators of the degree of wood deterioration caused by decay. Various negative effects are observed and experienced due to unexpected changes in the wood properties after decay infestations. These changes include the following: Weight loss, Strength loss, Reduction in volume, Reduction in caloric value, increased permeability and discoloration http://www.cals.ncsu.edu/course/pp318/profiles/decay/decay.ht).

2.11. Termites

Termites are wood degrading insects and they attack wood in different ways depending on the species of the termites. Termites are found in a wide range of terrestrial environments and are distributed throughout the warmer regions of the world (Nunes and Nobre, 2001). A report by Lee and Ryu (2003) explained that termites inhabit approximately 70% of the world tropical and subtropical regions extending to some areas in the temperate region. There are now over 2700 species of termites described from 282 genera but these can be grouped into four major categories according to their nesting habitats and association with moisture. These are damp wood, dry wood, subterranean and arboreal termites (Haverty *et al.*, 2005). Water is essential for termite survival, however, only few termite species demand a minimum moisture content of the wood they attack, since they either utilize independent water sources in the soil or physiologically compensate low moisture contents by metabolic water production (Lee and Ryu, 2003).

Termite feeding habits are important for nutrient and energy recycling in tropical ecosystems where they are abundant (Peralta *et al.*, 2003). They are more hazardous to wooden structures and contents. Generally, they eat anything with cellulose; hence thrive on anything with cellulose including live and dead wood. Termites are among the few insects capable of utilizing cellulose as food but do not secrete cellulase; bear symbiotic intestinal protozoa in their gut that carry out the digestion of cellulose. Under natural conditions, termites feed on roots of grasses, decaying vegetable matter, living trees and dry wood. Termites are therefore grouped as follow:

2.11.1. Damp Wood Termites

Damp wood termites, as the name implies, generally infest wood with high moisture content. Quartey (2009) explained that damp wood termites (also called wet wood termites) live and feed on very moist wood especially stumps and fallen trees on the forest floor. The colonies of damp wood

termites are exclusively wood dwellings with most species not requiring contact with the soil. They always eat across the grain, consuming both spring and summer wood and makes chambers of interconnected galleries inside the wood.

2.10.2 Subterranean Termites

Subterranean termites are social insects that live in colonies consisting of many individuals. The colonies are composed of workers, soldiers and reproductives. The workers, have no wings, are whitish in color and are very numerous (Gold *et al.,* 1999; Koehler and Tucker, 2003). Soldiers are wingless and white in color with large brown heads and mandibles. They defend the colony against insects that attack the colony. King and queen termites perform the reproductive functions of the colony (Gold *et al.,* 1999). Subterranean termites feed on wood or other items that contain cellulose, such as paper, grass, fiberboard and some fabrics derived from cotton or plant fibers (Gold *et al.,* 1999; Koehler and Tucker, 2003).

Perrott (2003) stated they are very successful because they are social insects and live in large family groups and work together for the good of the colony. Lee *et al.* (2007) also confirmed that they are very successful insects they are crypto biotic (their nests and foraging activities are concealed beneath the soil, within wood, and inside mud tubes). They may be detected by the presence of winged reproductives mud tubes and wood damage (Gold *et al.,* 1999). They readily attack both sound and decaying timbers in contact with the ground and can also extend their attack to roofing timbers in high buildings. They are responsible for most of the severe termite damage to structural timbers and cause severest structural weakening at the ground lines of poles, bridge timbers, towers and in the foundation members of buildings (Kollman and Côte, 1984; Ofori, 1994).

2.11. 3. Dry Wood Termites:

Dry wood termites (Family: Kalotermitidae) are found commonly on most continents. They do not require contact with moisture or soil in order to survive. Quartey (2009) revealed that they nest entirely in timber above ground. Dry wood termite species vary in their ecology and biology. They infest dry, sound wood, including structural lumber, as well as dead limbs of native trees, shade and orchard trees, utility poles, posts, and lumber in storage. Dry wood termites have a low moisture requirement and can tolerate dry conditions for prolonged periods. They do not connect their nests to the soil. Piles of their faecal pellets, which are distinctive in appearance, may be a clue to their presence (Ibach, 1999).

A published report by Kollman and Côte (1984) explained that dry wood termites attack buildings, poles, fences and other structures made of seasoned wood. They live entirely in the timber on which they feed, often hollowing large timber but leaving a thin sheet for protection. Attack, once begun, takes place largely within the timber and may be well advanced before being recognized. *Cryptotermes havilandi* is the most common dry wood species in Ghana and occurs mainly along the coast, but was reported once found in the Ashanti Region (Quartey, 2009).

2. 11. 4. Arboreal Termites

Arboreal termites (also called mound builders) are capable of building earthen towers 8m or more in height above the ground. Their presence is indicated by mounds found commonly in Africa, Australia, Southeast Asia and parts of South America. The size of a mound also indicates their population size (Diehl *et al.*, 2005).

2.12. Visual Durability Rating

The natural durability rating of a timber species is a rating of the timber's natural resistance to attack by wood destroying fungi and wood destroying insects. The sapwood of all timber species has poor resistance and so the natural durability rating applies only to the heartwood of a timber species (Timber Users Guide 1-Timber, Durability and External Applications, 2012). The rating is based on the testing of stakes and poles imbedded or inserted in the ground and on expert opinion of historical performance. The rating is not intended to predict a precise life expectancy for a species-because of the variability within a species and the differences in conditions between sites and applications where the timber species might be used.

However, the natural durability ratings of heartwood for above ground use and for in-ground contact use, do provide a broad comparison between species; Timber Users Guide 1 - Timber, Durability and External Applications (2012). There are four classes of durability rating. For each of the four classes, there is an expected service life range. The above ground ranges are different from the in-ground contact ranges. The relevant Australian Standard AS 5604 provides natural durability ratings for a large number of species in several categories including lyctid susceptibility, termite resistance, in ground contact durability, outside above ground durability and marine borer resistance. Class 1 rated species is the most durable, class 2 species are durable, class 3 species are moderately durable and class 4 species the least durable.

CHAPTER THREE

MATERIALS AND METHODS

3.1. The Study Location

The research was conducted at the Wood Science Department Workshop, The General Chemical Laboratory and Durability Test field of the Faculty of Renewable Natural Resources (FRNR) at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi.

3.2. Wood Sample Collection

Two matured males and females of *B. aethiopum* were harvested from Kobreso (Semi- arid forest zone in the Offinso North District of Ashanti Region) in Ghana on the 27th October, 2011(Plate

3.1).

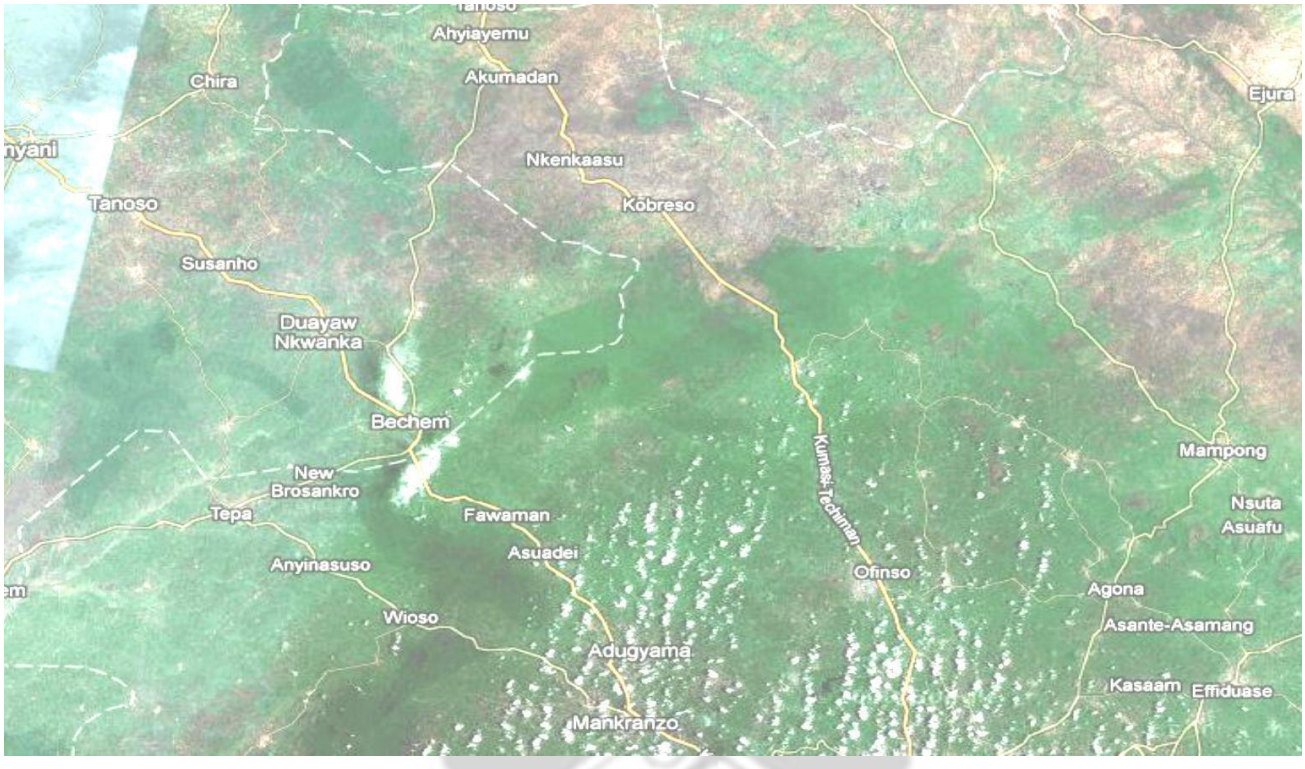

Plate 3.1.Map of the collection site of samples (arrow shows sampling site, Kobreso)

The range of diameter of the *B. aethiopum* was between 0.20 m to 0.50 m at the breast height of 1.5m above ground level with a height range of 15-20 m. Each sample (110cm) of *B. aethiopum was* taken from three main portions: 2.4m of the base portion from ground, 10.6m of the middle portion and 18.8m of the crown portion from the ground.

3.3. Determination of Physical Properties of *B. aethiopum*

3.3.1. Moisture Content

The samples for moisture content (MC) measured 20 x 20 x 20 mm were determined using the oven dry method (Panshin *et al*., 1980). The sawn discs (samples) were oven – dried at 103 ± 2 °C, cooled in desiccators until constant weight were attained. MC of the samples was expressed as the percentage of the oven dry weight of the wood:

$$MC\% = \frac{(W_1 - W_o)}{W_o} \times 100$$

W_o (1)

Where,

W_1 = initial weight of samples (g).

W_0 = oven–dry weight of samples (g).

3.3.2. Swelling of *B. aethiopum*

Wood samples were prepared from defect-free, air-dried (at 12% MC) wood of *B. aethiopum* measuring 152mm (Longitudinal), 76mm (Tangential) and 5mm (Radial) for their swelling properties based on ASTM D 1037-06(24), (2006) (Plate 3.2).

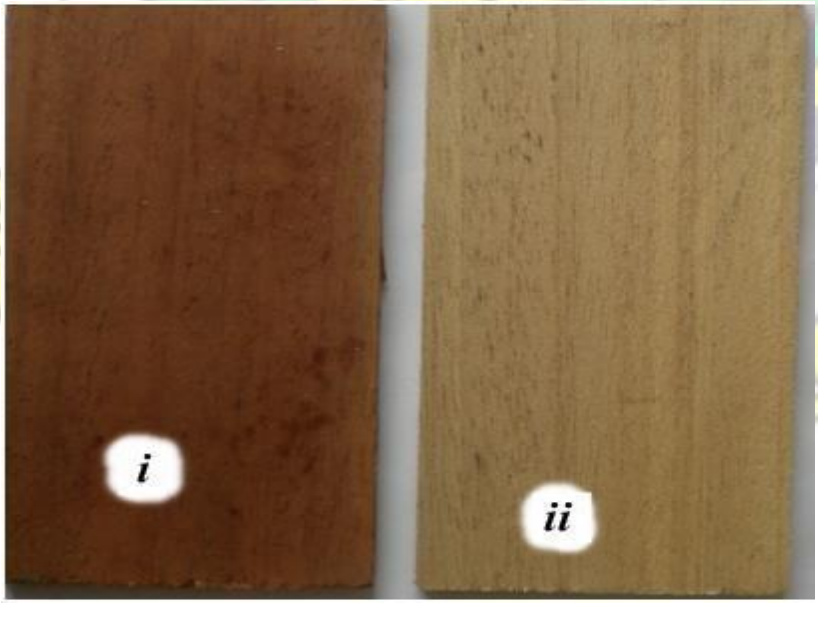

Plate 3.2: Wood samples for swelling test ('i' from the periphery;

'ii' from the core)

The samples for the swelling determination were equally taken from the base, middle and crown portions of *B. aethiopum*. The water-soak test method was used for evaluating the moisture absorption and swelling properties. Base on the measurement of dimensional change of each specimen immersed in water for 24 hours at room temperature (25 °C) and conditioning at 50% RH. The points where the measurements were to be made were marked and subsequent measurements were made at the same location. Measurements of the longitudinal, tangential and radial dimensions were made within 30 minutes upon removal of each sample from the water to prevent loss of water from the wood. Swellings in the longitudinal, tangential and radial directions were calculated separately using the formula by Kollman and Côté (1984):

$$\text{Swelling} = \frac{Wda - Wdb}{Wdb} \times 100 \qquad (2)$$

Where:

Wda = Wood dimension after immersion

Wdb = Wood dimension before immersion

Volumetric swelling for each stake was determined from its longitudinal, tangential and radial faces (Mantanis *et al.*, 1994) as:

$$\text{Volumetric swelling (\%)} = \frac{Sl \times St \times Sr - Dl \times Dt \times Dr}{Dl \times Dt \times Dr} \times 100 \qquad (3)$$

Where;

S_l = Longitudinal dimensions of stakes in swollen condition

S_t = Tangential dimensions of stakes in swollen condition

S_r = Radial dimensions of stakes in swollen condition

D_l= Longitudinal dimensions of stakes in dry condition

D_t = Tangential dimensions of stakes in dry condition

D_r = Radial dimensions of stakes in dry condition

3.3.3. Basic density and shrinkage of *B. aethiopum*

The samples for the basic density and shrink age determination were equally taken from the base, middle and crown portions of *B. aethiopum*. The test specimens were cut from these sections with the dimensions of 20 × 20 × 20 mm, according to Panshin *et al.* (1980) used for measuring basic density, shrinkage, and moisture content. The specimens were soaked in distilled water for 72hrs to ensure that their moisture content was above the fiber saturation point, and then their dimensions were measured in all three principal directions (longitudinal, tangential and radial), with a digital caliper to the nearest 0.001mm. The specimens were weighed to the nearest 0.001g for saturated weight and the saturated volume was calculated based on these dimension measurements. Finally, the samples were oven-dried at 103±2°C. After cooling in desiccators, the oven-dry weights of the specimen were measured. Basic density and shrinkage properties were calculated using the following equations:

$$D_b = \frac{M^o}{V_s} 100 \quad (4)$$

Where:

D_b = the basic density of the specimen

M_0 = the oven-dry weight of the specimen

V_s= the saturated volume of the specimen

$$\beta_L = \frac{L_s - L_o}{L_s} \times 100 \quad (5)$$

$$\beta_T = \frac{T_s - T_o}{T_s} \times 100 \quad (6)$$

$$\beta_R = \frac{R_s - R_o}{R_s} \times 100 \quad (7)$$

$$Bv = B_L + B_T + B_R \quad (8)$$

Where:

B_L = longitudinal shrinkage of the specimen

B_R = radial shrinkage of the specimen

B_T = tangential shrinkage of the specimen

B_V = volumetric shrinkage of the specimen

L_S = longitudinal dimensions of the saturated specimens

R_S = radial dimensions of the saturated specimens

T_S = tangential dimensions of the saturated specimens

L_0 = longitudinal dimensions of the dried specimens

R_0 = radial dimensions of the dried specimens

T_0 = tangential dimensions of the dried specimens

3.4 Chemical analysis within *B. aethiopum*

The various samples for the chemical analysis were prepared and air-dried to 12%, placed in a Wiley mill and ground. Each sample was placed in a shaker with sieves to pass through a 40 mesh sieve (425µm) yet retained on a 60 mesh sieve (250µm) and stored for chemical analyses. All tests were

conducted under the standards of American Society for Testing and Materials (ASTM) as presented in Table 3.1.

Table 3.1 Standard used for the chemical analysis of *B. aethiopum*

Total extractives	ASTMD 1105 – 96 (Reapproved 2007)
Lignin	ASTMD 1106 – 96 (Reapproved 2007)
Holocellulose	ASTMD 1104 – 96 (Reapproved 2007)
Alpha – cellulose	ASTMD 1103 – 60 (Reapproved 1976)
Ash content	ASTMD 1102 – 84 (Reapproved 2007)

Each test was conducted in 3 replicates. Both the lignin and holocellulose content tests were performed with extractive free *B. aethiopum* while alpha-cellulose test was carried out with air - dried holocellulose. The total extractive and ash content determination were however performed using unextracted wood samples.

3.4.1 Determination of Total Extractives

The extraction apparatus for this analysis consisted of a Soxhlet extraction flask connected on the top end of a reflux condenser and joined at the bottom to a boiling flask (Figure 3.3). A 2g powdered, oven-dried sample was placed into a cellulose extraction thimble, plugged with a small amount of cotton at the top of the thimble and placed in a Soxhlet extraction flask. The boiling round bottom flask contained a 2:1 solution of 95% ethanol and acetone and was placed on a heating mantle. The sample was extracted until the solvent siphoned over colourles. After extraction, all the remaining

solution was transferred to the boiling flask, which was heated on a heating mantle until the solution evaporated. The flask was oven-dried at 103±2ºC, cooled in a desiccator and weighed until a constant weight was obtained.

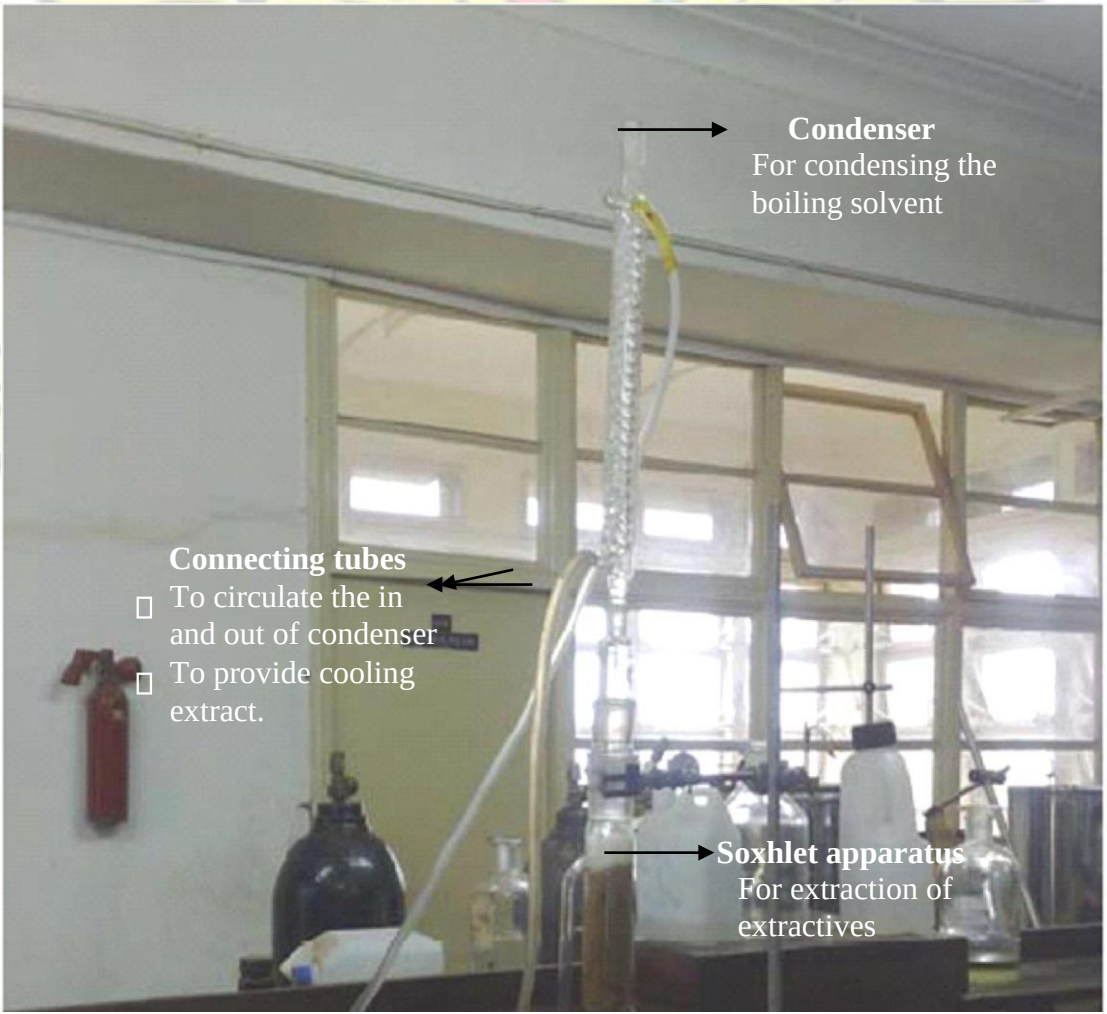

Figure 3.3 Soxhlet Extraction Apparatus for the extraction of powdered *B. aethiopum* samples at FRNR (KNUST) Chemical laboratory

The total extractive of *B. aethiopum* at each stem position was calculated as:

$$\text{Total extractives (\%)} = \frac{W_2}{W_1} \times 100 \quad (9)$$

Where,

W_1 = weight of original oven- dried wood (g).

W_2 = weight of oven - dry extraction residue (g).

3.4.2. Preparation of Extractive Free Material

An amount of 10g air-dried *B. aethiopum* ground sample that passed through a number 60 (250µm) sieves and retained by number 80 (180µm) sieve was placed in an extraction thimble ensuring that it did not extend above the level of the top of the siphon tube. The sample was extracted for 4 hours with alcohol-acetone mixture (1:2) in the Soxhlet extraction apparatus. The excess solvent was removed with suction and 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 (about 200ml) 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 200ml of hot water as was done for alcohol for 4 hours. The material after hot water extraction was air-dried thoroughly and used as extractive-free material for the determination of lignin, cellulose and alpha-cellulose.

3.4.3 Determination of Lignin within *B. aethiopum*

A 1g oven-dried sample of extractive-free *B. aethiopum* was placed in a 150ml beaker and 15ml 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 20ºC. The specimen was transferred by washing with 560 ml of distilled water into a 1,000 ml Erlenmeyer flask, diluting the concentration of the sulphuric acid to three percent. The apparatus was placed in a boiling water bath for 4 hours. The flask was removed from the water bath and the insoluble material allowed to settle overnight. The contents of the flasks were filtered by vacuum suction into a fritted-glass crucible of known weight. The residue was then washed free of acid with 500ml of hot distilled water and then ovendried at 103 ± 2ºC. The crucible was cooled in a desiccator and weighed to constant weight.

Determination of lignin content was:

$$\text{Lignin content (\%)} = \frac{W_2}{W_1} \times 100 \quad (10)$$

Where,
W_1= Weight of oven – dried unextracted wood (g).

W_2 = Weight of oven–dried lignin (g).

3.4.4 Determination of alpha–cellulose within *B. aethiopum*

Air-dried holocellulose material from each part of the stem was first obtained as described in 3.4.5 and placed in a 250ml Erlenmeyer flask with a small watch glass cover. The sample was treated with a total of 25ml of 17.5% NaOH within 45 minutes. First, 10ml portion of the 17.5% NaOH was added to the sample, thoroughly mixed and placed in a water bath maintained at 20 °C. The sample was 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 5ml portion was added and thoroughly mixed. Five minutes later, the next 5 ml portion was also added followed by the addition of the last 5ml portion and thorough mixing 15 minutes after the addition of the first portion. The mixture was allowed to stand at 20 °C in the water bath for 30 minutes, making the total of 45minutes NaOH treatment.

Following the NaOH treatment, 33ml of distilled water previously maintained at 20 °C was added to the mixture and the content of the beaker thoroughly mixed and allowed to stand at 20 °C for 1 hour. The contents of the flask were filtered through vacuum suction into a fritted-glass crucible of known weight. The residue was washed first with 100ml of 8.3% NaOH, then with distilled water and treated with 15ml of 10% acetic acid for 3 minutes. The residue was washed free of acid with distilled water. The crucible was oven-dried at 103 ± 2ºC, cooled in a desiccator, and weighed until a constant weight was obtained. The alpha-cellulose content in *B. aethiopum* was determined as:

$$\text{Alpha–cellulose (\%)} = \frac{W_2}{W_1} \times 100 \quad (11)$$

Where,

W_1= Weight of original oven – dried wood (g).

W_2= Weight of oven - dried alpha - celloluse (g).

3.4.5. Determination of holocellulose within *B. aethiopum*

A 2g sample of air-dried extractive-free *B. aethiopum* from each section was placed into a 250ml flask. The specimen was then treated with a mixture of 180ml of distilled water, 8.6g of sodium acetate, 6.6g of sodium chlorite and 5.7ml of ethanoic acid. The sample - solution mixture was covered with a glass cover and placed in water bath maintained at 60ºC for 4 hours. The content of the flask was filtered into a coarse porous fritted - glass crucible of known weight. The residue was then washed with distilled water and the crucible and its content dried in an oven at 103 ± 2ºC, cooled in a desiccator and weighed until a constant weight was reached. The determination of the holocellulose content in *B. aethiopum* was as follows:

$$\text{Holocellulose content} = \frac{W_2}{W_1} \times 100 \quad (12)$$

Where,

W_1 = weight of oven – dried extractive – free wood (g).

W_2= weight of oven – dried holocellulose (g).

3.4.6 Determination of Ash content within *B. aethiopum*

Empty crucibles were ignited in a muffle furnace at 600ºC, cooled in a desiccator, and weighed to the nearest 0.1mg. A 2g sample of air-dried *B. aethiopum* was put in the crucibles to determine the weight of the crucibles and the specimen. The crucibles and their contents were placed in a drying oven at 103 ± 2ºC, cooled in desiccator and weighed until the weights were constant. The crucibles and their contents were then placed in the muffle furnace and ignited until all the carbon was eliminated. They were then 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 580-600ºC. The crucibles with their contents were then removed to a desiccator and the cover replaced loosely, cooled and weighed. The heating was repeated until the weight after cooling was constant to within 0.2g. The ash content was calculated as:

$$\text{Ash (\%)} = \frac{W_1}{W_2} 100 \quad (13)$$

Where:

W_1= Weight of ash

W_2 = Weight of oven dry sample

3.5 Preparation of the test Specimens for Natural Durability Test

Dry boles of *B. aethiopum* were sawn into billets in two main directions (Radial and axial). Various samples were critically examined to ensure that they were free from natural and artificial defects. Samples were taken specifically from the two sections (the periphery and the core) of the three portions (base, middle and crown) of the wood for their natural durability analysis (EN 252, 1989). The samples were further ripped after conversion from the periphery and core sections of the three portions of the converted sections and were air-dried for one month. They were planed into 25x 50

x 500 mm. Ten samples each from the periphery and the core sections of the bottom, middle and the crown of the individual harvested *B. aethiopum* varieties were tested.

3.5.1 Graveyard Test for Natural Durability determination

Stakes (25x 50 x 500mm) from both the periphery and the core sections were weighed before and after tagging to determine their weights before their insertion in the experimental field. A leveled and well drained test field was prepared at FRNR Experimental Farm (KNUST). The plot was demarcated into four equal blocks. Each block contains sixty randomly selected samples. The specimens were carefully inserted such that two-thirds of their lengths were above the ground (Figure 3.4):

Figure 3.4. *B. aethiopum* stakes inserted in the test field for natural durability determination at FRNR (KNUST) Experimental Farm

The samples were inserted in the ground for a period of one year. Monthly inspections of inserted stakes were done to determine the nature of attacks for a year after which they were exhumed.

3.5.2 Visual Durability Rating of Inserted *B. aethiopum* Specimens

Visual durability rating was conducted during the period of insertion monthly purposely to determine the nature of attack by bio-degraders in accordance with EN 252 (1989) (Table 3.2).

Table 3.2 Visual Durability Rating (EN 252, 1989)

Rating	Description	Definition
0	Sound	No evidence of attack by bio – degraders
1	Slight attack	Limited evidence of attacks by bio – degraders
2	Moderate attack	Significant evidence of attack by bio– degraders
3	Severe attack	Strong evidence of attacks by bio - degraders
4	Failure	Total failure of samples

3.5.3 Determination of Percentage mass loss of *B. aethiopum*

The exhumed samples were-dried at 25 °C for 72 hours after which the soil particles were brushed off with a hard bristle brush. Each sample was weighed and kept in an oven at 103±2ºC for 24 hours and reweighed. The corrected oven-dried (M_1) was determined by the formula:

$$\text{Corrected oven dry weight } (M_1) = \frac{(100 \square M_2)}{(100 \square \%MC)} \quad (14)$$

Where,

M_2 = weight before insertion

% MC = percentage moisture content after insertion

The percentage mass loss of each sample after insertion was also calculated as:

$$\text{Mass loss (\%)} = \frac{M_1 - M_f}{M_1} \times 100 \quad (15)$$

Where:

M_1 = the corrected oven – dried weight

M_f = the final oven –dried weight

The rating used for the determination of weight loss according to Eaton and Hale (1993) was: 0–5% = very durable,

6–10% = durable,

11–40% = moderately durable,

41–100% = non-durable.

3.7 Statistical analysis

After the data had been obtained from the sample tests, Single Factor One-way Analysis of Variance (ANOVA) of Microsoft Office Excel 2007 was employed to determine the significant difference ($P<0.05$) between treatments within each bole. Turkey's Multiple Comparison Test was used to test the statistical significance of each pair of means for the various physical, chemical and natural durability properties within the bole for each variety.

CHAPTER FOUR

4.0. Results

4.1 Physical Test

4.1. 1. Moisture content within the stem of *B. aethiopum* at the green state

Along the periphery, the base of the male *B. aethiopum* recorded the lowest MC (59.03%) and the greatest at its crown (89.63%) at the green state. The core also recorded the lowest MC at its base (61.51%) but greatest at its crown (129.42%) (Table 4.1). Similarly, the female recorded greatest MC at its crown (85.90%) and lowest at its base (56.38%) for the periphery while the core also recorded greatest MC of 137.98% at the crown and lowest at the base (71.96%). Thus, the sections of the core of each variety recorded greater MC than its corresponding periphery (Table 4.1). ANOVA (Appendices B1 and B2) showed significant differences ($p<0.05$) within the stem positions of the two varieties. T–test (Appendix C1) showed Significant differences ($p<0.05$) at the middle and crown cores as well as the periphery of the crown.

Table 4.1 Moisture content within the stems of two *B. aethiopum* varieties at the green state

Stem position		Moisture content (%)	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	59.03^{d}	56.34^{D}
	Middle	60.14^{d}	62.26^{D}

	Crown	89.63[b]	85.90[B]
	Base	61.51[d]	71.96[C]
Core	Middle	66.28[c]	74.47[C]
	Crown	129.42[a]	137.98[A]
Overall		**77.68**	**81.49**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**3.34**	**8.28**

4.1.2. Moisture content within the stem of *B. aethiopum* at the dry state

Along the periphery, the base of the male recorded the lowest value (12.19%) and the greatest at its crown (12.52%) at the dry state. Its core recorded the lowest (12.35%) at the base and the greatest at the crown (12.94%) (Table 4.2). The base of the female also recorded the lowest MC (12.29%) but greatest at its crown (12.51%) at the periphery. The core recorded the lowest value (12.44%) at its base but greatest at the crown (12.85%). The male peripheries recorded wider MC range (12.19-12.52%) than the female variety (12.29-12.51%) at the dry state while the core portions of the male also recorded greater range (12.35-12.94%) than the female counterpart (12.44-12.85%). Generally, MC at the dry state for the cores at each position was greater than the peripheries for each variety. Significant differences in MC ($P<0.05$) exist within the stem positions of the two varieties at the dry state (Appendices B3 andB4; Table 4.2) while T-test (Appendix C2) show significant differences ($p<0.05$) between their middle and crown peripheries.

Table 4.2 Moisture content within the stems of the two *B. aethiopum* varieties at the dry state

Stem position		**Moisture content (%)**	
Radial	**Axial**	**Variety Male**	**Female**
Periphery	Base	12.19^{d}	12.29^{C}
	Middle	12.33^{cd}	12.35^{BC}
	Crown	12.52^{bc}	12.51^{AB}
Core	Base	12.35^{cd}	12.44^{BC}
	Middle	12.65^{ab}	12.53^{A}
	Crown	12.94^{a}	12.85^{A}
Overall		**12.50**	**12.50**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**0.30**	**0.17**

4.1.3. Density within the stem of *B. aethiopum* at the green state

The male *B. aethiopum* recorded the greatest density at green state at the base (960.50kg/m^3) and the lowest at the crown (496.00kg/m^3) along the periphery. Similarly, the core recorded the greatest value of 783.00 kg/m^3 at the base but lowest at its crown (450.00kg/m^3) (Table 4.3). Along the periphery, the female recorded greatest value of 1026.50kg/m^3 at its base and lowest at the crown (525.00kg/m^3) whilst the core also recorded greatest density at the base (666.00kg/m^3) and lowest at its crown (423.50kg/m^3). Thus, the peripheries and cores of the two varieties recorded a decreasing trend in density from the base to the crown with significant differences ($p<0.05$) between them (Table 4.3; Appendices B5 and B6). T-test (Appendix C3) showed Significant differences ($p<0.05$) at the middle periphery as well as the base, middle, and crown cores. The density showed variations from the periphery of the base to the core of the crown (Table 4. 3).

Table 4.3 Density within the stems of the two *B. aethiopum* at the green state

Stem position		**Density (kg/m^3)**	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base Middle	960.50^{a}	1026.50^{A}
		912.50^{a}	724.50^{B}
	Crown	469.00^{c}	525.00^{C}
		783.00^{b}	666.00^{B}
Core	Base Middle	737.00^{b}	481.00^{CD}
	Crown	450.00^{c}	423.50^{D}
Overall		**718.67**	**641.08**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**64.00**	**73.10**

4.1.4 Density within the stem of *B. aethiopum* at the dry state

Along the periphery, the crown of the male variety recorded the lowest value (315.50kg/m^3) but greatest at the base (827.00kg/m^3) at the dry state. Similarly, its core recorded the lowest value at the crown (264.00kg/m^3) but greatest at the base (451.50kg/m^3). Along the periphery of the female variety, the crown recorded the lowest density of 280.50kg/m^3 but greatest at its base (754.50kg/m^3). The core also recorded the lowest value of 219.50kg/m^3 at its crown and the greatest at the base (424.50kg/m^3). The two varieties recorded a general trend of increased in values from the crown to base for both the peripheries and the cores.

Table 4.4 and Appendix B8 depicted Significant differences ($p<0.05$) but Appendix B7 observed no Significant difference within the stem positions of the two varieties whilst T-test (Appendix C4) also showed Significant differences ($p<0.05$) between the middle periphery as well as middle and crown cores.

Table 4.4 Density within the stem of *B. aethiopum* varieties at the dry state

Stem position		**Density (kg/m^3)**	
Radial	**Axial**	**Variety Male**	**Female**
Periphery	Base Middle	827.00^{a}	754.50^{A}
		746.50^{b}	506.00^{B}
	Crown	315.50^{d}	280.50^{E}
		451.50^{c}	424.50^{C}
Core	Base Middle	447.00^{c}	244.50^{DE}
	Crown	264.00^{e}	219.50^{E}

Overall	**508.58**	**404.92**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**51.00**	**48.20**

4.2. Dimensional stability

4.2.1 Swelling within *B. aethiopum*

4.2.1.1 Longitudinal swelling

The male *B. aethiopum* recorded the greatest swelling at its middle periphery (0.48%) and lowest (0.22%) at crown periphery (Table 4.5). The core also recorded greatest value of 0.36% at its base and crown with the lowest at the middle (0.28%). The male peripheries and cores recorded no significant difference ($p<0.05$) in swelling along the stem positions (Table 4.5). The core of the female recorded the greatest value at its crown (0.52%) but lowest at the base (0.22%) whilst their peripheries recorded greatest value at the crown (0.48%) and lowest (0.22%) at its middle. There was inconsistent trend from the base to the crown for the peripheries but consistent for the cores. No Significant difference ($p>0.05$) occurred within the stem positions of the male variety (Appendix B9) but Significant difference was observed for the female variety (Appendix B10) whilst T-test (Appendix C5) also showed significant differences ($p<0.05$) at the periphery of the crown and of the base core.

Table 4.5 Longitudinal swelling within the stem of *B. aethiopum*

Stem position		**Longitudinal swelling (%)**	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	0.24^{a}	0.30^{BC}
	Middle	0.48^{a}	0.22^{C}
	Crown	0.22^{a}	0.48^{BC}

	Base	0.36[a]	0.22[C]
Core	Middle	0.28[a]	0.28[C]
	Crown	0.36[a]	0.52[A]
Overall		**0.32**	**0.34**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**0.47**	**0.18**

4.2.1.2 Tangential Swelling

Table 4.6 showed that the male *B. aethiopum* recorded the greatest swelling of 1.68% at the base and lowest (0.62%) at the core along the periphery whilst the core recorded greatest (2.23%) at the crown and lowest (1.07%) at the middle. Similarly, the female counterpart recorded the greatest tangential swelling of 1.65% at the base and lowest at its crown (0.69) along the periphery. The core also recorded the lowest value at the middle (1.15%) but greatest (2.21%) at the base. Significant differences ($p<0.05$) exist within the stem positions of the two varieties (Table 4.6; Appendices B11 and B12) whilst T- test for the two varieties depicted no significant differences ($p<0.05$) (Appendix C6)

Table 4.6 Tangential swelling within the stem of *B. aethiopum* varieties

Stem position		**Tangential swelling (%)**	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	1.68[ab]	1.65[AB]
	Middle	1.18[bc]	1.38[B]
	Crown	0.62[c]	0.69[C]
Core	Base	1.60[b]	2.21[A]
	Middle	1.07[bc]	1.15[BC]
	Crown	2.23[a]	1.72[AB]

Overall	**1.40**	**1.47**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**0.62**	**0.59**

4.2.1.3 Radial Swelling

The periphery along the male *B. aethiopum* recorded the greatest radial swelling at the middle (3.37%) and lowest (2.54) at its base. The core also recorded greatest value of 4.76% at its base but lowest at its middle (2.84%) (Table 4.7). Similarly, the periphery along the female variety also recorded greatest value at its middle (2.97%) and lowest at the base (2.14%) while the core recorded greatest value of 4.66% at the middle and lowest at its crown (2.68%). Table 4.7; Appendices B13 and B14 for the two varieties showed significant differences (P <0.05) within their stem positions whilst T-test (Appendix C7) also revealed significant differences (p<0.05) between the base, middle and crown cores.

Table 4.7 Radial swelling within the stem of *B. aethiopum* varieties

Stem position		**Radial swelling (%)**	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	2.54^{c}	2.14^{C}
	Middle	3.37_{bc}	2.97^{B}
	Crown	3.05_{bc}	2.38_{BC}
Core	Base	4.76^{a}	2.59_{BC}
	Middle	2.84^{bc}	4.66^{A}
	Crown	3.69^{b}	2.68^{C}
Overall		**3.38**	**2.90**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**0.98**	**0.70**

4.2.1.4 Volumetric swelling

Table 4.8 showed that along the periphery of the male *B. aethiopum,* the greatest value was recorded at its base (4.76%) but lowest at the middle (2.88%). The core also recorded greatest value at the base (6.99%) and lowest at the middle and crown (4.14%). Similarly, the periphery of the female *B. aethiopum* also recorded the greatest value at its middle (4.75%) and lowest at the crown (4.01%) whilst the core also recorded the greatest value of 6.23% at the middle but lowest at its crown (4.79%). Generally, the cores of the two varieties recorded greatest swelling values than their peripheries with significant differences ($p<0.05$) within them (Table 4.8; Appendices B15 and B16) whilst T-test for the two varieties (Appendix C8) also showed significant differences ($p<0.05$) at the middle periphery as well as the base and middle cores. The core sections swelled more than the peripheral zones of the two varieties (Table 4.8).

Table 4.8 Volumetric swelling within the stem of *B. aethiopum* varieties

Stem position		**Volumetric swelling (%)**	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	4.76^{b}	4.51_{AB}
	Middle	2.88^{c}	4.75^{B}
	Crown	3.82_{bc}	4.01^{B}
Core	Base	6.99^{a}	5.22_{AB}
	Middle	4.14^{b}	6.23^{A}
	Crown	4.14^{b}	4.79^{B}
Overall		**4.46**	**4.92**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**1.06**	**1.25**

4.2.2 Shrinkage within *B. aethiopum*

4. 2.2.1. Longitudinal shrinkage

The periphery along the male *B. aethiopum* recorded the greatest shrinkage at its crown (2.79%) and the lowest (1.11%) at the base. The core also recorded greatest value of 3.69% at the middle but lowest at the base (2.32%) (Table 4.9). The male peripheries recorded an increasing trend from the base to the crown whilst the core proved otherwise. Similarly, the periphery of the female also recorded greatest value at the middle (2.86%) and lowest at its base (1.32%) whilst the core recorded greatest value of 3.94% at the crown but lowest at its middle (2.94%). The peripheries and their cores recorded inconsistent trend for the female variety. Generally, the peripheries of the two varieties recorded fewer values than their core counterpart. Significant differences (P<0.05) exist within the stem positions of the two varieties (Table 4.9; Appendices B17 and B18) whilst T-test (Appendix C9) also showed significant differences (p<0.05) between the base core and middle periphery.

Table 4.9 Longitudinal shrinkage within the stem of *B. aethiopum* varieties

Stem position		**Longitudinal shrinkage (%)**	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	1.11^{c}	1.32^{C}
	Middle	1.91_{bc}	2.86_{AB}
	Crown	2.79_{ab}	2.67^{B}
Core	Base	2.32^{b}	3.48_{AB}
	Middle	3.69^{a}	2.94_{AB}

	Crown	3.35[a]	3.94[A]
Overall		**2.53**	**2.87**
***Values in the same column with same letter are not significantly different (P<0.05)**			
LSD		**0.99**	**1.11**

4.2.2.2 Tangential shrinkage

The periphery along the male *B. aethiopum* recorded the greatest value of 3.50% at its middle and crown and lowest (1.75%) at the base. The core also recorded greatest value at its crown (4.04%) but lowest at the middle (2.93%). The male peripheries recorded an increasing trend in shrinkage from the base to the crown with their cores recording otherwise (Table 4.10). Similarly, the female variety also recorded greatest value along the periphery at its middle and crown (3.13%) and lowest (2.24%) at the base. The core recorded greatest value at its crown (2.75%) and lowest of 2.24% at the base. The peripheries and their cores of the female variety recorded an increasing trend from the base to the crown respectively. Significant difference ($p<0.05$) exist within the male variety but not the female variety (Appendices B19 and B20) whilst T-test for the two varieties (Appendix C10) also revealed significant differences ($p<0.05$) between the base and crown peripheries with their cores.

Table 4.10 Tangential shrinkage within the stem of *B. aethiopum* varieties

Stem position		**Tangential shrinkage (%)**	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	1.75[c]	2.24[B]
	Middle	3.50[ab]	3.13[A]
	Crown	3.50[ab]	3.13[A]

	Base	3.57_{ab}	2.47_{AB}
Core	Middle	2.93^{b}	2.70^{B}
	Crown	4.04^{a}	2.75_{AB}
Overall		**3.22**	**2.73**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**0.64**	**0.77**

4. 2.2.3 Radial shrinkage

The male *B. aethiopum* recorded the greatest shrinkage at its crown (3.04%) and lowest (2.41%) at the base. Similarly, the core also recorded greatest value at the middle (3.54%) but lowest of 3.01% at the base. The male peripheries showed an increasing trend in shrinkage from the base to the crown with their cores depicting otherwise (Table 4.11). The female variety also recorded the greatest value at its base (3.27%) but lowest at its crown (2.34%) along the periphery. The core recorded greatest value of 3.40% at the middle and lowest at the crown (2.53%). The female peripheries recorded a decreasing trend in shrinkage from the base to the crown but their cores revealed otherwise. Generally, the core of each variety shrunk more than their periphery counterpart. ANOVA (Appendices B21 and B22) depicted no significant differences for the male *B. aethiopum* but the female variety showed significant differences (P<0.05) whilst T-test (Appendix C11) showed significant differences (p<0.05) between the crown core as well as the base and crown peripheries.

Table 4.11 Radial shrinkage within the stem of *B. aethiopum*

Stem position		**Radial shrinkage (%)**	
Radial	**Axial**	**Variety**	
		Male	**Female**

Periphery	Base	2.41[b]	3.27[A]
	Middle	2.84[ab]	2.76[AB]
	Crown	3.04[ab]	2.34[C]
Core	Base	3.01[ab]	3.16[AB]
	Middle	3.54[a]	3.40[A]
	Crown	3.42[a]	2.53[BC]
Overall		**3.04**	**2.91**
***Values in the same column with same letter are not significantly different (P<0.05)**			
LSD		**0.81**	**0.71**

4. 2.2.4 Volumetric Shrinkage

Table 4.12 showed that the male variety recorded the greatest shrinkage along the periphery at its crown (9.93%) and lowest at the base (5.88%) while the core also recorded greatest value at the crown (10.68%) but the lowest (8.17%) at the middle. The peripheries of the female variety also recorded the greatest value at its middle (8.40%) but lowest at the base (6.82%) likewise the core also recorded greatest value of 9.22% at the crown and lowest at its middle (8.92%). The peripheries of the two *B. aethiopum* varieties recorded an increasing trend in shrinkage from the base to the crown while their cores proved otherwise. Table 4.12; Appendices B23 and B24 revealed Significant differences ($p<0.05$) within the stem positions of the two varieties whilst T-test for volumetric shrinkage of the two varieties (Appendix C12) also showed significant differences ($p<0.05$) between the base and crown peripheries

Table 4.12 Volumetric Shrinkage within the stem of *B. aethiopum*

Stem position	**Volumetric shrinkage (%)**

Radial	Axial	Variety	
		Male	Female
Periphery	Base	5.88^{d}	6.82^{C}
	Middle	9.43^{b}	8.40$_{AB}$
	Crown	9.93^{b}	7.01$_{BC}$
Core	Base	8.63^{c}	9.08^{A}
	Middle	8.17^{c}	8.92^{A}
	Crown	10.68^{a}	9.22^{A}
Overall		**8.79**	**8.24**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD **0.72** **1.42**

4.3 Chemical Analysis

4.3.1 Total extractives within the stem of *B. aethiopum*

The male variety recorded the greatest total extractives at its base (4.41%) and lowest at the crown (2.38%) along the periphery likewise the core with 2.62% and (1.83%) respectively (Table 4.13). Similarly, the periphery of the female *B. aethiopum* recorded the greatest amount of extractives at its base (3.25%) and the lowest at the crown (2.04%). The core recorded the greatest at the base (2.95%) but lowest at its crown (1.81%). The peripheries and their cores of the two varieties recorded a decreasing trend from the base to the crown. Thus, the peripheries of the two varieties recorded greatest values than their cores. Significant differences ($p<0.05$) in total extractives exist within the stem positions of each variety (Table 4.13; Appendices B25 and B26) likewise T-test for total extractives for the two *B. aethiopum* varieties (Appendix C13) also showed significant differences ($P <0.05$) at the base periphery.

Table 4.13 Total extractives content within the stem of *B. aethiopum*

Stem position		Total extractives (%)	
Radial	**Axial**	**Variety Male**	**Female**
Periphery	Base Middle	4.41^{a}	3.25^{A}
		3.06^{b}	3.08_{AB}
	Crown	2.38^{c}	2.04^{D}
Core	Base Middle	2.62^{c}	2.95^{B}
		2.35^{c}	2.35^{C}
	Crown	1.83^{d}	1.81^{E}
Overall		**2.78**	**2.58**
***Values in the same column with same letter are not significantly different (P<0.05)**			
LSD		**0.34**	**0.23**

4.3.2 Lignin content within the stem of *B. aethiopum*

The male and female *B. aethiopum* recorded greatest lignin content at the peripheries of their bases (36.88% and 39.53% respectively) and lowest at their crowns (32.83% and 29.06% respectively) (Table 4.14). Peripheries and cores of the two varieties depicted a decreasing trend in lignin content from the base to the crown with significant differences ($p<0.05$) between them. Generally, the lignin content of the peripheries was greater than their cores for each variety. Significant differences ($P<0.05$) within their stem positions are given in

Appendices B27 and B28 whilst T-test for the two *B. aethiopum* varieties (Appendix C14) also showed significant differences ($p<0.05$) at the middle periphery as well as the middle and crown cores.

Table 4.14 Lignin content within the stem of *B. aethiopum* varieties

Stem position		Lignin (%)	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	36.88[a]	39.53[A]
	Middle	35.98[b]	36.31[B]
	Crown	32.83[d]	29.06[D]
Core	Base	34.13[c]	35.63[B]
	Middle	33.90[c]	33.59[C]
	Crown	29.31[e]	28.60[D]
Overall		**33.84**	**33.79**
***Values in the same column with same letter are not significantly different (P<0.05)**			
LSD		**0.74**	**0.79**

4.3.3 Alpha - cellulose content within the stem of *B. aethiopum*

Table 4.15 showed that the male *B. aethiopum* recorded greatest alpha-cellulose content (40.09%) at the base and lowest (29.53%) at its crown along the periphery likewise the core with 34.20% and 28.02% respectively. Along the periphery of the female, the base also recorded the greatest value (37.01%) and lowest at its crown (25.97%) whilst the core recorded greatest (36.10%) at the base and lowest at its crown (24.40%). The peripheries as well as the cores all recorded decreasing trends from the bases to the crowns. Significant differences ($p<0.05$) exist within their stem positions (Table 4.15; Appendices B29 and B30) likewise Ttest (AppendixC15) also showed significant differences ($p<0.05$) at the base and crown peripheries as well as their cores.

Table 4.15 Alpha-cellulose within the stem of *B. aethiopum*

Stem position		Alpha- cellulose (%)	
Radial	**Axial**	**Variety**	
		Male	**Female**

	Base	40.09[a]	37.01[A]
Periphery	Middle	34.11[b]	35.38[C]
	Crown	29.53[c]	25.97[E]
	Base	34.20[b]	36.10[B]
Core	Middle	30.05[c]	29.36[D]
	Crown	28.02[d]	24.40[E]
Overall		**32.67**	**31.37**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**1.01**	**0.66**

4.3.4 Hemi-cellulose content within the stem of *B. aethiopum*

The periphery along the stem positions of the male variety recorded the greatest hemi-cellulose (39.39%) at its middle and lowest (32.94%) at the crown. The core also recorded greatest value of 41.93% at the crown but lowest (32.59%) at its middle. The base and crown cores recorded greater values than their peripheries counterpart but the middle showed otherwise (Table 4.16).

The female variety also recorded greatest amount of hemi-cellulose along the periphery at its base (38.22%) and lowest (37.78%) at the crown but the core recorded its greatest value of 46.09% at the crown and lowest (31.61%) at the base. The two varieties recorded significant differences ($p<0.05$) within their stem positions from the base to the crown (Table 4.16; Appendices B31 and B32) while T-test (Appendix C16) also show significant differences ($p<0.05$) at the base, middle and crown peripheries as well as the base and crown cores.

Table 4.16 Hemi-cellulose within the stem of *B. aethiopum*

Stem position		**Hemi-cellulose (%)**	
Radial	**Axial**	**Variety Male**	**Female**

	Base	34.35^{c}	38.22^{B}
Periphery	Middle	39.39^{b}	33.02^{C}
	Crown	32.94$_{cd}$	37.78^{B}
	Base	38.30^{b}	31.61^{D}
Core	Middle	32.59^{d}	33.26^{C}
	Crown	41.93^{a}	46.09^{A}
Overall		**36.58**	**36.66**

***Values in the same column with same letter are not significantly different (P<0.05)**

LSD	**1.74**	**1.26**

4.3.5 Holocellulose content within the stem of *B. aethiopum*

The male recorded the greatest holocellulose content of 74.44% at the base and lowest at its crown (62.47%) along the periphery likewise the core with 72.50% at the base and 62.64% at the middle (Table 4.17). Similarly, the female variety also recorded greatest holocellulose content at its base (75.23%) and lowest at the crown (63.75%) and the core recording greatest value of 70.49% at the crown but lowest at its middle (62.62%). The peripheries and cores of the two varieties recorded a decreasing trend in holocellulose from the base to the crown except the periphery of the crown and the core of the crown of female variety which proved otherwise. Significant differences ($p<0.05$) exist within the stem positions of the two varieties (Table 4.17; Appendices B33 and B34) whilst T-test (Appendix C17) also showed significant differences ($p<0.05$) between the base core and middle periphery.

Table 4.17 Holocellulose content within the stem of *B. aethiopum*

Stem position	**Holocellulose (%)**

Radial	Axial	Variety Male	Female
Periphery	Base	74.44[a]	75.23[A]
	Middle	73.50[ab]	68.40[C]
	Crown	62.47[d]	63.75[D]
Core	Base	72.50[b]	68.22[C]
	Middle	62.64[d]	62.62[E]
	Crown	69.95[d]	70.49[D]
Overall		**69.25**	**68.12**
***Values in the same column with same letter are not significantly different (P<0.05)**			
LSD		**1.30**	**1.16**

4.3.6 Ash content within the stem of *B. aethiopum*

Table 4.18 showed that the male *B. aethiopum* recorded greatest ash content at its crown (2.45%) and lowest at the base (0.65%) along the periphery while the core also recorded its greatest at the crown (3.39%) but lowest at the base (1.31%). Similarly, the female variety also recorded greatest amount of ash content at its crown (2.83%) and lowest at the base (0.85%) of the peripheries likewise the core with 5.64% and 1.49% respectively. Generally, the peripheries and the cores of the two varieties recorded an increasing trend in ash content from the base to the crown (Table 4.18). Significant differences (P<0.05) within the stem positions of the two varieties were observed (Table 4.18; Appendices B23 and B24) whilst T-test (Appendix C18) for ash content also showed significant differences (p<0.05) at middle core. The peripheral portions recorded less ash content then the core sections (Table 4.18)

Table 4.18 Ash Content within the stem of *B. aethiopum* varieties

Stem position		Ash (%)	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	0.65^{d}	0.85^{D}
	Middle	1.44^{c}	1.98^{C}
	Crown	2.45^{b}	2.83^{B}
Core	Base	1.31^{c}	1.49^{CD}
	Middle	1.58^{c}	2.94^{B}
	Crown	3.39^{a}	5.64^{A}
Overall		**1.80**	**2.62**
***Values in the same column with same letter are not significantly different (P<0.05)**			
LSD		**0.52**	**0.76**

4.4 Durability Test

4.4.1 Mass loss within the stem of *B. aethiopum*

Table 4.19 showed that the male *B. aethiopum* recorded greatest mass loss at the crown of the periphery (92.56%) and lowest at its counterpart base (4.17%) which showed more durability. Similarly, the core recorded greatest value of 100.00% at the crown and lowest at the base 9.62%. The crown of the female periphery also recorded greatest mass loss (92.00%) and lowest at the base (4.07%). The crown of the core also was least durable and recorded greatest mass loss (100.00%) but lowest at the base (29.11%). The peripheries with their cores for the two varieties all recorded an increasing trend in mass loss from the base to the crown with significant differences ($p<0.05$) among them (Appendices B37 and B38.) likewise T-test for (AppendixC19) for mass loss also showed significant differences at the middle periphery as well as the middle and crown cores.

Table 4.19 Mass loss within the stem of *B. aethiopum*

Stem position		**Mass loss (%)**	
Radial	**Axial**	**Variety** Male	Female
Periphery	Base	4.17^{c}	4.07^{D}
	Middle	7.97^{c}	8.26^{D}
	Crown	92.56^{a}	92.00^{A}
Core	Base	9.62^{c}	29.11^{C}
	Middle	55.95^{b}	59.89^{B}
	Crown	100.00^{a}	100.00^{A}
Overall		**45.05**	**48.89**
***Values in the same column with same letter are not significantly different (P<0.05)**			
LSD		**42.28**	**57.04**

4.4.2 Visual Durability rating within the stem of *B. aethiopum* varieties

Table 4.20 showed that the male and female degraded most and recorded greatest visual durability rating at their crowns (4.00) but lowest at their bases (0.00) in their peripheries which depict more durability. The core also recorded greatest value (4.00) at their crowns and lowest at their bases (1.30 and 1.45) respectively. Thus, the peripheries and cores of the two varieties recorded a decreasing trend in visual durability from the base to the crown. Significant differences ($p<0.05$) exist within their stem positions (Table 4.20; Appendices B39 and B40) likewise T-test (Appendix C20) also showed significant differences ($p<0.05$) between the base, middle and crown peripheries as well as the crown core. The peripheral portions of the two varieties were least attacked by the termites than the core sections (Table 4.20).

Table 4.20 Visual durability within the stem of *B. aethiopum*

Stem position		Visual durability	
Radial	**Axial**	**Variety**	
		Male	**Female**
Periphery	Base	0.00^{e}	0.00^{E}
	Middle	0.00^{e}	0.00^{E}
	Crown	4.00^{a}	4.00^{A}
Core	Base	1.30^{c}	1.45^{C}
	Middle	2.70^{b}	2.70^{B}
	Crown	4.00^{a}	4.00^{A}
Overall		**2.00**	**2.03**
***Values in the same column with same letter are not significantly different (P<0.05)**			
LSD		**0.41**	**0.46**

4.5 Relationship between mass loss and some wood characteristics

Male mass loss had strong positive correlation with dry density for periphery of middle (r = 0.7770), lignin (r = 0.9933) and alpha-cellulose (r = 0.8860) for core of base and hemicellulose for core of middle (r = 0.9400). A negative relationship however existed between mass loss and holocellulose for periphery of crown (r = -0.9977) (Appendices D 2, 3, 4 and 5). There were no correlations between mass loss and dry density for periphery of base (r= 0.05061), total extractives for core of middle (r = -0.03136), holocellulose for periphery of base (r = -0.04152) and ash content for core of middle (r = -0.01254) (Appendices D 1 and 4). For female variety, Mass loss recorded strong positive correlation with lignin for periphery of middle (r= 0.9935) and ash content (r= 0.7667) for periphery of crown of female. However, strongly negative correlations were obtained between mass loss and alpha-cellulose (r= 0.9993) and mass loss and

holocellulose (r= -0.9958) for periphery of crown (Appendices D 8 and 10). No correlations were found between mass loss and density for periphery of base (r= 0.01668) and also mass loss and total extractives for core of middle (r= 0.02281) (Appendices D 6 and 9).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

It is apparent that many NTFPs with commercial potentials are not used due to lack of or inadequate information about their potential utilization (Bih, 2006). Identifying their potential utilization would ensure their conservation and sustainable development of the nation‘s forest resources including timber for the maintenance of environmental quality and the perpetual flow of optimum benefits to all segments of the society (Bih, 2006). This would also contribute to the reduction of the over-exploitation and dependence on some preferred timber species (Chamberlain *et al;* 2000). For NTFPs (e.g. *B. aethiopum*) to be useful as substitutes and also accepted in the timber market, it is essential to understand their physical, chemical properties, natural durability and other characteristics as well as their performance in service.

5.2 Physical properties of *B. aethiopum*

5.2.1 Moisture content

The strength properties of wood samples are associated with their MC (Kollmann and Côté 1968). Simpson and Ten Wolde (1999) similarly reported the same about hardwoods with their MC in the sapwood usually greater than (or about equal to) that of their heartwood at the green and dry states. A study on oil palm trunk by Lim and Khoo (1986) further revealed a gradual

increase in MC along its trunk height and towards the central region, with the outer and lower zones having far less values than the inner and upper zones. Bakar *et al*. (1998) stated the same for the trunk of oil palms. They further explained that for the trunk height, there was a tendency for MC to increase from the bottom to the crown of the oil palm tree and predicted that it was influenced by the effect of earth gravity, where the water distribution to the higher part of the trunk requires higher caviler pressure.

The current study for the two varieties of *B. aethiopum* revealed similar trends with the bases recording less MC through the middle to the crown at both green and dry states. Their peripheries also recorded less MC than the core sections in consonance with earlier works by

Lim and Khoo (1986), Shupe *et al.* (1995), Romulo and Arancon (1997), Bakar *et al*. (1998), Dinwoodie (2000) and Chowdhury *et al.* (2007). The implications for the trend were that portions of the two varieties with less MC would have minimum dimensional changes and greater densities than portions with greater MC. These could contribute to greater strength properties as portions with less MC (peripheries) were more durable than their cores with less MC. The peripheries shrunk and swelled with decreasing or increasing MC respectively, which could make them very useful in the timber industry since durable wood are mostly recommended for structural works including roofing, flooring, sleepers, bridges, paneling (Gillah *et al.* 2007).

5.1.2 Density within *B. aethiopum*

Some timbers exhibit greater density variation than others. However, wood density decreases towards the inner of the stem and over the stem height at both the green and dry states (Fathi, 2014). In sitka spruce, density is very great at the heartwood, which then decreases from the sapwood to the pith (Harvald and Olesen, 1987). Petty *et al.* (1990) also found density in sitka

spruce to be relatively the same along the bole at the green and dry states. Ayarkwa (1997) found the density at the periphery of *B. aethiopum* at 12% MC to be 670kg/m^3, whilst Asafu - Adjaye*et al.* (2012) reported 793.3kg/m^3. The current study recorded 827.00kg/m^3, 764.50kg/m^3, 315.50kg/m^3 at 12% MC respectively for the base, middle and crown peripheries for the male, and 451.50kg/m^3, 447.00kg/m^3 and 264.00kg/m^3 respectively for the cores. The female also recorded 754.50kg/m^3, 506.00kg/m^3, 280.50kg/m^3 respectively for the peripheries with their cores having 424.50kg/m^3, 244.50kg/m^3 and 219.50kg/m^3.

Thus, there was a general decrease from the base to the crown for the two varieties. Ayarkwa (1997) and Asafu - Adjaye*et al.* (2012) did not report about the variety of *B. athioupum* they worked on but the differences with their works and the current study could be attributed to the ages, varieties of *B. aethiopum* they studied and or soil and climatic conditions as their samples and the current study samples were not harvested from identical environment. Wood density usually decreases with height in the stem of a tree (Donaldson *et al;* 1995); greater at the base at the green and dry states due to the greater compaction of the base tissues exerted by overlapping cells along the bole than the tree crown. Bakar *et al.* (1998) observed a great variation of density at different parts of oil palm stem and explained that it values ranged from 200 to 600 kg/m^3 with an average of 370 kg/m^3. Lim and Khoo (1986) explained that the density of oil palm trunk decreases linearly with the trunk height and towards the centre of the trunk similar to the trend for the two varieties of *B. aethiopum*. This was reflected in the clear distinction for the hardness and weight between the outer and inner sections as well as the butt and upper regions of the trunk. Similarly, Prayitno (1995) as well as Romulo and Arancon (1997) identified the base of the oil and coconut palm trunks having greater density, followed by the middle and the top at a

range of 100kg/m^3–900kg/m^3. The present values also range 264.00kg/m^3–827.00kg/m^3 and 219.25kg/m^3–754.50kg/m^3 for the male and female

respectively.

Apparently, the densities for the peripheries at the base of the two varieties and the periphery of the middle for the male were greater than what was reported for *B. aethiopum* by Ayarkwa (1997) and Bakar *et al.* (1998) likewise the periphery of the base for male being greater than Asafu - Adjaye*et al.* (2012)report. The mean basic density (at 12% MC) for the two varieties also decreased from their peripheries to the cores, which confirmed the report by Boding and Jane (1982) that wood from different parts of a tree show differences in density. This variation, according to Panshin and de Zeeuw (1980) and Lim and Khoo (1986), existed horizontally (from the pith to the sapwood) and vertically (from the base to crown) of the tree. The radial and axial change in density for the two varieties is likely to be associated with the presence of greater amount of total extractives, lignin content, the number and distribution of vascular bundles, the dimension (diameter) as well as thickness of the cell walls of the bundles and the cell wall thickness of the ground parenchyma within the peripheral zones from the base to the crown than their cores (Fathi, 2014). This is in agreement with the report by Sulc (1984), Brown *et al.* (1952), and Fathi (2014) that wood density has positive correlation with extractive, lignin, vascular bundles as well as durability.

Peripheries of the two varieties have greater density than their cores but the base and middle periphery of the male recorded greater density than that of the periphery of the base and middle for the female variety. Their other sections recorded low densities. Similarly, FAO (1985) and TEDB (1994) reported that at 12% MC, wood should be graded high (very heavy), medium and low densities having values above 500kg/m^3, 350-500kg/m^3 and less than 350kg/m^3 respectively.

They added that only high density timber are usually durable and acceptable for structural and exterior purposes such as roofing, sleepers and bridges with the medium and less density timbers being applicable for minor constructional and interior works. The current study observed greater density at the periphery of the base and middle of the two varieties, medium density at the cores of the base and middle of the male variety as well as the core of the base for the female variety but the peripheries and cores of the crown as well as the core of the middle of the two varieties recorded low densities. The implication is that the peripheries of the base of the two varieties could be used for structural works with the medium density portions being useful for minor works.

5.2.3 Dimensional stability within the stem of *B. aethiopum*

5.2.3.1 Swelling

Swelling of wood in liquids is of fundamental importance in the context of commercial processes including the usage of wood (Mantanis *et al.,* 1994). Gryc *et al.* (2007) explained that the dimensional changes regarding swelling of wood are smallest in the longitudinal direction (0.1-0.4%) unlike tangential direction (3-6%) and radial direction (6-12%). Thus, Kollman and Côté (1984) reported that wood swells insignificantly along the longitudinal direction. The male variety recorded horizontal, tangential and radial swelling in the ranges of 0.22-0.65%, 0.62-2.23% and 2.54-4.76% respectively, their volumetric swelling was between 2.89-6.99%. The female also recorded 0.22-0.52%, 0.69-2.21% and 2.14-4.66% respectively with volumetric swelling of 4.01-6.23%. The two varieties recorded less horizontal swelling but greater radial swelling. Their peripheries also recorded minimum swelling than the cores from the base to the crown. This gives an implication that the peripheries of the two varieties have

greater density, less MC and could be useful externally as they have less moisture absorption properties.

(Mantanis *et al.*, 1994) found that swelling of wood is dependent on the chemical composition, such as water-soluble extractives and lignin content. It has definite influence on the cell wall structure and subsequently affects the wood swelling. A study by Fathi (2014) on oil palm, coconut palm and date palm trunks revealed that wood swells with decreasing or increasing MC. The peripheries of the two varieties recorded greater total extractive, lignin and an increasing trend of MC from the base to the crown. The greater extractive content tends to result in lower FSP and less swelling because less water will be absorb, whilst greater lignin content also would make the wood very compact to contain less Moisture (Fathi, 2014) which could influence much swelling of the peripheries than their core counterparts

5.2.3.2 Shrinkage

Shrinkage generally increased from tree base to crown and from the inner wood (heartwood) to outer wood (sapwood) of most timber species (Shupe *et al.* 1995). This increase from inner to outer wood is published by Shupe *et al.* (1995) for yellow poplar. Koubaa *et al.* (1998) reported increase in dimensional changes along the tangential surfaces of some hybrid poplar clones and concluded that dimensions of inner wood shrank less than the outer wood in both radial and tangential directions, which could be attributed to greater amount of total extractive, lignin and less MC for the inner wood and the increase in specific gravity from the inner to the outer wood. This pattern correlates with earlier findings by Seralde (2006) who also attributed variability in dimensional changes to decrease in specific gravity along the trunk of coconut, date and oil palms due to variations in total extractive, lignin and MC.

The shrinkage for oil palm wood at various zones and height by Walker *et al.* (1996) showed the volumetric shrinkage of 10.3-22.8%. However, a study by Erwinsyah (2008) on oil palms showed that the shrinkage in the central zone was about 19.6% with a range between 13-23%, while the shrinkage for the inner and peripheral zones was about 16.7% (range 11-20%) and 16.8% (range 10-23%) respectively. The volumetric shrinkage of oil palm wood in central zones was identified to be greater than the inner and peripheral zones (Walker *et al;* 1993). The male *B. aethiopum* showed longitudinal, tangential and radial shrinkage ranges of 1.75-4.04%, 1.11-3.69% and 2.41-3.54% respectively with their volumetric shrinkage being 5.88-10.68%. The female also recorded 1.32-3.94%, 2.24-3.13% and 2.34-3.27% respectively, and volumetric shrinkage of 6.82-9.22 % (Table 4.12). Compared with earlier works on palms and wood by Walker et al. (1993; 1995), Erwinsyah (2008), Shupe *et al*. (1995), Koubaa *et al*. (1998) and Seralde (2006), the peripheral zones of the two varieties of *B. aethiopum* recorded less shrinkage values than their cores from the base to the crown. This trend could be due to the greater density which is believe to provide small void volume to absorb and release moisture, the greater amount of total extractives, which tend to decrease FSP with less shrinking since less moisture would be lost in the cell wall, greater lignin content which cemented the wood together and less amount of MC at the peripheries than the core zones, which have a definite influence on the shrinkage of the cell wall structure and subsequently affect the wood shrinkage (Mantanis *et al.*, 1994; Yamamoto and Hong, 1994).

5.3. Chemical properties of *B. aethopum*

5.3.1 Total extractives

The total extractives and their composition vary greatly among different wood species and also within their parts. Heartwood contains greater amount than the sapwood (Hillis, 1978). There is considerable variation in the distribution of extractives throughout the wood of a given tree (Adam, 2009). The amount of total extractives in wood is highly variable and can range from 3-30% by weight depending on the tree species (Haygreen and Bowyer, 1996) as was observed by this study. Rowell *et al.* (2005) noted that they usually range from 2-10% by dry weight and up to 40% in some timbers, whilst a study on oil palm trunk by Halimahton and Ahmed (1990) gave 8.07% based on the dry weight of its trunk.

Comparing the total extractives content of *B. aethiopum* to earlier works by Halimahton and Ahmed (1990), Haygreen and Bowyer (1996) and Rowell *et al.* (2005), the male and female recorded 1.83-4.41% and 1.81-3.25% respectively from the core of the crown to the periphery of the base which confirms the range reported in wood by Haygreen and Bowyer (1996) and Rowell *et al.* (2005). The peripheries from the bottom to the crown of the two *B. aethiopum* recorded greater total extractives than their cores. The presence of these extractives in sufficient amounts would prevent or minimize the severity of attack by destructive organisms (e.g. termites), which are exemplified in their peripheries being more resistant to biodegraders (i.e. being more durable) and having less dimensional changes than their cores (Syofuna, 2006; Quartey, 2009).

5.3.2 Lignin content

The peripheries of the two varieties recorded greater lignin content than their cores with gradual decrease in value from the base to the crown (Table 4.14). Gonzalez (2007) noted that the amount of lignin in wood usually decreased from the heartwood to the sapwood and from the base to the crown. Halimahton and Ahmad (1990) observed that lignin content in oil palm stem was fairly or evenly distributed throughout the tree except that the core was slightly deficient in the component, whilst the peripheries of the base and middle contained an excessive amount. Li (2004) noted that the base, middle and crown outer layers of bamboo had greatest lignin content.

Lignin values of 20-26% place bamboo at the high end of the normal range of 11-27% reported for non-woody biomass (Bagby 1971), which closely resemble the ranges reported for softwoods (24-37%) and hardwoods (17-30%) (Fengel 1984; Dence 1992). Gellerstedt *et al.* (2009) also reported that softwoods usually contain lignin content of 20-30%, with hardwoods having less amounts (18-25%). Results for the two varieties of *B. aethiopum* contrast with earlier ranges of lignin content observed by Bagby (1971), (Fengel 1984; Dence 1992), Li (2004) and Gellerstedt *et al.* (2009), *B. aethiopum* recorded greater amount, which decreased from the base to the crown and from the peripheries to the cores. These could contribute greatly to greater strength properties and resistance to bio-degraders at the periphery of base than the crown and cores.

5.3.3 Alpha-cellulose

Gonzalez (2007) and Reiniati (2009) reported that the amount of alpha-cellulose in wood is between 40-50% of the dry wood weight but Khunrong (2008) reported 37.14% for oil palm trunk. Bakar *et al.* (1998) and Fathi (2014) identified gradual decrease in alpha-cellulose from

the periphery to the core for oil, date and coconut palm trunks. The alpha-cellulose content of coconut and oil palms wood was 42% and 29.2% respectively similar to those of most wood species compared to those in softwoods (40-52%) and hardwoods (38-56%) (Rydholm, 1965). A decreasing trend of 28.02-40.09% and 24.40-37.01% were recorded for the male and female varieties from the peripheries of the base to cores of the crown respectively (Table 4.15). Comparing this with reports by Rydholm (1965), Bakar *et al.* (1998) Gonzalez (2007), Khunrong (2008) and Reniati (2009), the periphery of the male base recorded a little above 40% which is in consonance with the range (40-52%; 38-56%) identified by Rydholm (1965) for softwoods and hardwoods. The rest of the stem positions of the two varieties recorded less range of between 24.40-37.01%. This gradual decrease along the peripheries as well as their cores is similar to earlier reports by Bakar *et al.* (1998), Khunrong (2008) and Fathi (2014). Being the principal food for termites, wood structures that contain excessive alpha-cellulose and MC are avidly consumed and destroyed by termites (Peralta *et al;* 2003). Apparently, the amount of alpha-cellulose and excessive MC at the core portions within the two varieties of *B. aethiopum* could be factors that attracted biodegrades (termites) to attack the core sections making them less durable than the peripheries.

5.3.4 Hemi-cellulose

The hemi-cellulose content for the male and female ranged from 32.59-41.93% and 31.6146.09% respectively (Table 4.16). The core at the base for the male recorded greater value than the periphery, whilst the core of the middle and crown of the female also recorded greater values than their peripheries Gonzalez (2007) observed that hemi-cellulose in softwoods range from 25-

30% and that of hardwoods 30-35%; whilst a study by Khunrong (2008) on oil palm trunk reported (31.73%). In contrast, some portions (core of middle, periphery of base and crown for the male variety as well as periphery of middle, base and core of middle) of the *B. aethiopum* recorded values within the range (30-35%) identified by Gonzalez (2007) for hardwoods with the rest (middle periphery, base and crown cores of the male variety as well as crown core as well as base and crown peripheries of the female variety) having greater values than that reported. However, all the recorded values for the two varieties were greater than that observed by Khunrong (2008) for oil palm trunk (31.73%) with the exception of the core of the female base. Bowyer *et al.* (2003) reported that the amount and type of hemi-cellulose within timber species depend on the kind of wood and the position along the stem and this was apparently observed within the male and female *B. aethiopum* of this study. Alpha-cellulose, hemi-cellulose and greater MC within the core portions of the two varieties could serve as a source of food for bio-degraders which could easily attract termites to degrade the wood at where they are mostly occupied as similarly reported by Koehler and Tucker (2003).

5.3.5 Holocellulose

Holocellulose content for the male and female *B. aethiopum* was between 62.64 -74.44 % and 62.62 -75.23 % respectively (Table 4.17). Their cores generally recorded lower values than their peripheries. Hindi *et al.* (2010) found *Leucaena leucocephala* and *Moringa perigrina* woods to have 70.82% and 59.64% respectively, whilst Khunrong (2008) found the content within the stem of oil palm trunk as 68.87%. However, Wahab *et al.* (2013) reported that the holocellulose content in bamboo was 74-85%, softwood (67%) and hardwood (75%). Similarly, Li (2004) and Poulter and Hopewell (2010) observed that the outer zones of coconut have the highest

holocellulose content of 66.7% which decreases from its outer to inner zones along the wood. Similarly, results for the current study agreed with the report by Li (2004) and Poulter and Hopewell (2010) on oil palm wood, as their peripheries (outer zones) recorded greater values (62.47-74.44 %; 63.75-75.23 %) than their cores (62.64-72.50 %; 62.62-70.49 %) for the male and female respectively. Holocellulose is one of the glucose components of wood, which together with greater amount of MC attracts bio-degraders (such as termites). The greater amount of holocellulose and excessive MC within a given wood species could be factors, which assist bio-degraders (termites) in destroying wood species. The implication is that the core portions of the two varieties recorded some amount of holocellulose with greater MC, which could rendered the core sections less durable than the peripheries.

5.3.6 Ash content

Ndlovu (2007) reported that temperate-climate woods yield 0.1-1.0% ash, while tropical and sub-tropical woods yield up to 5%. Campbell (1990) explained that on the average, the burning of wood results in about 6-10% ashes. Ash content is highly variable within tree; it is greatest at the pith and decrease to the bark (Imbeah 1998). A study by Halimahton and Ahmad (1990) on oil palm trunk observed the ash content to be similar throughout the trunk in the range of 3.0-3.3%. The peripheries of the two varieties of *B. aethiopum* recorded lower ash content than their cores with gradual decrease in value from the base to crown (Table 4.18). Bakar *et al.* (1998), working on oil palm trunk, also concluded that ash content was greater at the inner zones (cores) than at the peripheral zones. The male and female varieties recorded ash content ranges of 0.65–3.39% and 0.85–5.64% from the base to the crown of the peripheries and cores along the stem positions respectively which is in line with earlier works on oil palm by Halimahtonand

Ahmad (1990) and Bakar *et al.* (1998). This could account for the peripheries having greater densities, total extractives, lignin, less MC, dimensional changes and mass loss than their cores.

5.4.1 Natural durability within the stem of *B. aethiopum*

Natural durability of wood depends on many factors including the chemical structure and total extractives to the extent that the greater the proportion of toxic extractives, the greater the durability of the wood (Antwi-Boasiako *et al*., 2010). Within a species, timbers can vary in termite-resistance among species, from tree to tree and within the same tree (Antwi-Boasiako, 2004). In addition, the termite-resistance of timber exposed above the ground may be superior to its resistance in the ground (Johnson *et al.,* 2006). Other factors that have been reported to influence the durability of wood include lignin and ash content. Timbers with greater lignin or less ash content have greater durability. Those with greater densities are also often but not always more durable (Antwi–Boasiako and Pitman, 2009).

Generally, the peripheries within the two varieties of *B. aethiopum* recorded greater total extractives, lignin content, and densities with less MC, ash content, dimensional changes, mass loss and visual durability rating than their cores from the base to the crown. These observations from the current study are in consonance with the earlier works cited by Keating *et al.*(1982), Eaton and Hale (1993), Quartey (2009), Antwi–Boasiako and Pitman (2009) and AntwiBoasiako *et al*. (2010) that durability of individual wood species depend on the amount of extractives and lignin content as well as some physical properties like density, dimensional changes and the mass loss. The implication of this is that the peripheries of the two varieties of *B. aethiopum* are more

durable than their cores and could be more useful for structural works such as roofing, bridges construction and paneling than their cores.

5.4.2 Factors that influence natural durability within B. *aethiopum*

The physico-chemical properties of the two varieties observed to influence natural durability include MC, density, dimensional stability, total extractives, lignin and ash content as well as mass loss. MC of wood is an essential variable in the identification of wood natural durability to enhance its utilization (Kollmann and Côté 1968). Moisture in wood attracts bio-degraders to attack the wood. Thus, the amount of MC within a given timber species could determine the wood natural durability. The two *B. aethiopum* varieties of this study recorded greater MC at their cores than the peripheries from the base to the crown which made sections with less MC (peripheries) least attacked by termites than where MC greatly concentrated. Another important factor is density of wood. It decreases with tree height and governs the degradation of individual timber species (Donaldson *et al;* 1995; Antwi-Boasiako and Pitman, 2009). Yamamoto and Hong (1994) reported a good correlation between wood densities and durability by explaining that wood with greater density has better durability due to small void volume which is believe to reduce diffusion of gasses through the wood, thereby likely reducing the attack by bio-degraders and this was apparently observed from this study at the peripheral zones. However, Antwi-Boasiako and Pitman, 2009 found out that this is not always so since durability, they report depends on several factors such as total extractive, lignin and ash.

Moreover, the dimensional stability of wood can be influenced greatly by MC, density and chemical composition of timber species (Gryc *et al*; 2007). They explained that wood with

greater MC has the potential to swell more than those with less MC. Similarly, less dense wood also shrunk greater than heavy density wood and *vice versa*. The peripheries of the two varieties swelled less than their cores, whilst the cores shrunk more than the peripheries, similar to the report by Gryc *et al*. (2007). The extractives and lignin content were greater with the ash being less at the peripheral zones than the cores which could influence the natural durability as well as dimensional stability at the peripheral zones than the cores. Chemical composition of wood has great impact on natural durability of timber species. Reports by several authors such as Wong *et al;* 1983, Suttie and Orsler 1996; Syafii *et al;* 1988; Li, 2004, and Syofuna, 2006 about the influence of chemical composition of wood on natural durability against bio-deteriogens comprise the total extractive content and type (Suttie and Orsler 1996; Syofuna, 2006), the lignin content and type (Syafii *et al;* 1988), the ash content (Li, 2004) and the type of wood (Wong *et al;* 1983). The greater amount of extractives and lignin content within timber, increase durability of wood while the less ash content within wood, the more its durability (Hillis, 1978; Campbell, 1990) as was identified for the peripheries of the base and middle within the two varieties of this study. The alpha-cellulose, hemi-cellulose and holocellulose components of wood serve as wood carbohydrates which make wood mostly susceptible to biological degradation (Curling *et al;* 2001). These were greater at the peripheries than the cores which could have made those portions least durable. However, the greatest influences at the peripheral zones by total extractives; lignin, density and less ash content as well as the mass loss influenced the natural durability of the two varieties at the peripheries.

Generally, the physical, mechanical and chemical properties of wood are interdependent and results in variability in wood characteristics, which ultimately cause variability in resistance of wood against termites (Peralta *et al;* 2004). These variabilities in physico-chemical properties

were observed among the peripheries and cores of the two varieties. The peripheral zones were identified superior to termites' resistance (more durable) than the cores and are recommended for constructional usage to boost the timber industry so as to reduce over- exploitation and dependency on the primary timber species.

CHAPTER SIX

6.0 Conclusion and Recommendations

6.1 Conclusion

Moisture content (MC) along the male and female *B. aethiopum* was greatest at the core of crown (129.42% and 137.98% respectively) but least at the periphery of base (59.03% and 56.34%) at green state. The trend was similar at the dry state for the core of crown (12.94% and 12.85%) and periphery of base (12.19% and 12.29%).

Density at the green state was greater at the periphery of base for male (960.50 kg/m^3) and female (1026.50 kg/m^3) than the core of crown (450.00 kg/m^3 and 423.50 kg/m^3 respectively). At the dry state, it rated as 827.00 kg/m^3 (male) and 754.50 kg/m^3 (female) at periphery of base and 264.00 kg/m^3 (male) and 219.50 kg/m^3 (female) for core of crown.

Longitudinal swelling and shrinkage ranged from 0.22-0.48% and 1.11-3.69% respectively along the male and 0.22-0.52% and 1.32-3.94% for female. Generally, the core of crown for the female swelled more (0.52%) with core of base (0.22%) and periphery of middle (0.22%) for the female and periphery of crown for male (0.22%) swelling the least. The core of crown for the female recorded the greatest longitudinal shrinkage (3.94%) whilst periphery of the base for the male recorded the least (1.11%). Tangential swelling and shrinkage was 0.622.23% and 1.75-4.04% respectively for male and 0.69-2.21% and 2.24-3.13% for female. The greatest tangential swelling and shrinkage were observed for the core of crown for the male
(2.23% and 4.04% respectively) whilst the least was recorded by periphery of crown for male (0.62%) and periphery of base for male (1.75%) respectively. Radial swelling and shrinkage rated as 2.54-4.76% and 2.41-3.54% respectively for male and 2.14-4.66% and 2.34-3.40% for female. The core of base for the male swelled more (4.76%) with periphery of base for the female swelling the least (2.14%). In terms of shrinkage, the core of middle for male recorded the greatest radial shrinkage (3.54%) whilst periphery of the base for female recorded the least (2.34%). Volumetric swelling and shrinkage also ranged from 2.88-6.99% and 5.88-10.68% respectively along the male and 4.01-6.23% and 7.01-9.22% for female. The core of base for male swelled more (6.99%) with periphery of middle swelling the least (2.88%). The periphery

of base for the male recorded the least volumetric shrinkage (5.88%) with the core of the crown for male recording the greatest (10.68%).

However, the periphery of the base for both male and female recorded greater total extractive (4.41% and 3.25% respectively), lignin (36.88% and 39.53%), alpha-cellulose (40.09% and 37.01%) and holocellulose (74.44 % and 75.23 %). On the other hand, the core of crown recorded the lowest total extractive (1.83% and 1.81% for male and female respectively), lignin (29.31% and 28.60%) and alpha-cellulose (28.02% and 24.40%) while the core of middle recorded least holocellulose (62.64 % and 62.62 %). Hemi-cellulose generally ranged from 32.59-41.93% and 31.61-46.09% for male and female respectively. The core of base for female gained less (31.61%) with the core of crown for female having greatest (46.09%). The ash content and mass loss along the male also ranged from 0.65-3.39% and 4.17-100% respectively and 0.85-5.64% and 4.07-100% for the female. The core of crown for the female had greater ash content (5.64%) while the periphery of base for male had the least (0.65%). For mass loss, both the core of crown for the male and female obtained the greatest (100%) whilst the periphery of the female recorded the least (4.07%). Generally, the peripheries within the two varieties of *B. aethiopum* recorded greater values from the base to the crown for density (at green and dry states), total extractives, lignin, alpha-cellulose as well as holocellulose. However, less MC (at green and dry states), dimensional stability, ash content, hemi-cellulose as well as mass loss and visual durability rating was observed at the peripheries than the cores. A significant correlation was found between lignin, alpha-cellulose, hemi-cellulose of the two varieties and degradation by termites. The greater the lignin content contributes greatly to the higher strength properties and lower mass loss (more durable) (Fiath, 2014). Similarly, higher amount of alpha-cellulose and holocellulose

drives the termites towards the wood. The two varieties observed strong correlation between lignin, alpha-cellulose, holocellulose and mass loss. The peripheries of the base and middle of the two varieties are recommended for structural and exterior works such as roofing, furniture and bridge construction due to natural durability properties. This could minimize pressure on primary wood species and reduce forest degradation.

RECOMMENDATIONS

- The periphery of the base and middle *B. aethiopum* could be employed for structural works such as furniture, roofing and bridge construction as a result of their physicochemical and natural durability properties.
- The core portions at the base and middle could be employed for light works such as stools, cork for bottling, pencils, and packaging due to their density, swelling and shrinkage properties, chemical composition (lignin, alpha-cellulose, hemi-cellulose, holocellulose and extractives) and natural durability
- The two varieties were harvested from one study area. Their properties (including strength) using species harvested from different geographic locations could be examined.

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APPENDICES

Appendix A1: Moisture Content values for Male and Female *B. aethiopum* at the green state

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	59.414	61.672
2	BP	2	59.407	51.141
3	BP	3	60.010	58.533
4	BP	4	58.495	55.581
5	BP	5	59.516	58.230
6	BP	6	59.077	57.862
7	BP	7	59.164	50.790
8	BP	8	58.423	62.598
9	BP	9	58.184	53.193
10	BP	10	58.635	54.243
11	BC	1	64.000	63.088
12	BC	2	56.604	80.048
13	BC	3	61.538	53.361
14	BC	4	59.189	65.625
15	BC	5	55.023	73.439
16	BC	6	64.576	90.486
17	BC	7	64.910	60.870
18	BC	8	60.654	74.129
19	BC	9	63.190	87.669
20	BC	10	65.391	70.868

21	MP	1	60.767	60.514
22	MP	2	58.242	56.551
23	MP	3	63.172	55.949
24	MP	4	61.445	78.571
25	MP	5	57.547	46.897
26	MP	6	58.753	64.925
27	MP	7	60.016	55.844
28	MP	8	60.514	75.287
29	MP	9	60.624	59.057
30	MP	10	60.310	68.975
31	MC	1	68.340	62.778
32	MC	2	69.274	79.908
33	MC	3	62.708	67.673
34	MC	4	64.093	91.706
35	MC	5	66.405	57.607
36	MC	6	63.488	97.543
37	MC	7	67.788	80.908
38	MC	8	67.450	61.382
39	MC	9	65.923	73.170
40	MC	10	67.317	72.021
41	CP	1	89.714	84.000
42	CP	2	80.837	81.126
43	CP	3	96.432	77.615
44	CP	4	92.957	80.932
45	CP	5	89.321	84.871
46	CP	6	90.346	83.837
47	CP	7	92.709	89.347
48	CP	8	86.182	93.642
49	CP	9	90.736	90.612
50	CP	10	87.082	92.982
51	CC	1	124.000	125.424
52	CC	2	122.000	133.048
53	CC	3	139.609	140.252
54	CC	4	138.182	126.198
55	CC	5	120.000	136.145
56	CC	6	128.387	149.143
57	CC	7	134.358	141.358
58	CC	8	126.728	143.169
59	CC	9	128.635	142.075
60	CC	10	132.301	142.991

Appendix A2: Moisture content values for Male and Female *B. aethiopum* at the dry state

Obs	STEM POSITION	REPLICATE	MALE	
			MALE	**FEMALE**
1	BP	1	12.150	12.120
2	BP	2	12.230	12.205
3	BP	3	12.140	12.460
4	BP	4	12.490	12.300
5	BP	5	12.045	12.115
6	BP	6	12.315	12.330
7	BP	7	12.100	12.255
8	BP	8	12.230	12.480
9	BP	9	12.180	12.345
10	BP	10	12.050	12.240
11	BC	1	12.450	12.305
12	BC	2	12.520	12.455
13	BC	3	12.530	12.585
14	BC	4	12.540	12.530
15	BC	5	12.870	12.400
16	BC	6	12.315	12.430
17	BC	7	12.040	12.340
18	BC	8	12.535	12.300
19	BC	9	12.610	12.670
20	BC	10	12.775	12.295
21	MP	1	12.540	12.695
22	MP	2	12.890	12.160
23	MP	3	12.700	12.495
24	MP	4	12.820	12.435
59	CC	9		
60	CC	10		

				FEMALE
25	MP	5	12.540	12.295
26	MP	6	12.865	12.365
27	MP	7	12.745	12.275
28	MP	8	12.760	12.120
29	MP	9	12.615	12.305
30	MP	10	14.890	12.370
31	MC	1	12.105	12.530
32	MC	2	12.555	12.345
33	MC	3	12.175	12.710
34	MC	4	11.800	12.200
35	MC	5	12.350	12.490
36	MC	6	12.685	12.600
37	MC	7	12.405	12.385
38	MC	8	12.385	12.570
39	MC	9	12.660	12.480
40	MC	10	12.170	12.760
41	CP	1	12.220	12.535
42	CP	2	12.465	12.620
43	CP	3	12.180	12.350
44	CP	4	12.350	12.520
45	CP	5	12.345	12.555
46	CP	6	12.450	12.610
47	CP	7	12.325	12.460
48	CP	8	12.085	12.425
49	CP	9	12.530	12.425
50	CP	10	12.395	12.555
51	CC	1	12.750	12.975
52	CC	2	12.780	12.400
53	CC	3	12.595	12.120
54	CC	4	12.570	12.295
55	CC	5	12.740	12.955
56	CC	6	12.555	12.220
57	CC	7	12.560	12.500
58	CC	8	12.920	12.515
59	CC	9		
60	CC	10		

			MALE	FEMALE
			12.385	12.750
			12.605	12.530

Appendix A3: Density values for Male and Female *B. aethiopum* at the green state

Obs	STEM POSITION	REPLICATE		
1	BP	1	975	865
2	BP	2	920	895
3	BP	3	930	885
4	BP	4	975	890
5	BP	5	990	1160
6	BP	6	985	1240
7	BP	7	1015	1300
8	BP	8	935	885
9	BP	9	935	1210
10	BP	10	945	935
11	BC	1	690	675
12	BC	2	685	705
13	BC	3	810	610
14	BC	4	685	660
15	BC	5	770	590
16	BC	6	905	635
59	CC	9		
60	CC	10		

				FEMALE
17	BC	7	830	630
18	BC	8	805	715
19	BC	9	855	710
20	BC	10	795	730
21	MP	1	810	740
22	MP	2	755	705
23	MP	3	980	720
24	MP	4	830	715
25	MP	5	1070	780
26	MP	6	1050	675
27	MP	7	795	715
28	MP	8	1010	720
29	MP	9	1045	725
30	MP	10	775	750
31	MC	1	665	490
32	MC	2	670	435
33	MC	3	760	400
34	MC	4	670	530
35	MC	5	780	540
36	MC	6	785	460
37	MC	7	645	500
38	MC	8	800	505
39	MC	9	805	505
40	MC	10	790	445
41	CP	1	520	615
42	CP	2	480	605
43	CP	3	455	545
44	CP	4	510	520
45	CP	5	450	510
46	CP	6	510	510
47	CP	7	555	495
48	CP	8	470	500
49	CP	9	555	475
50	CP	10	455	475
51	CC	1	390	430
59	CC	9		
60	CC	10		

			MALE	FEMALE
52	CC	2	425	400
53	CC	3	425	350
54	CC	4	465	405
55	CC	5	405	430
56	CC	6	475	450
57	CC	7	485	440
58	CC	8	490	445
			485	430
			455	445

Appendix A4: Density values for Male and Female *B. aethiopum* at the dry state

Obs	STEM POSITION	REPLICATE	MALE	
1	BP	1	800	685
2	BP	2	745	645
3	BP	3	805	635
4	BP	4	875	670
5	BP	5	885	840
6	BP	6	895	830
7	BP	7	830	885
8	BP	8	850	690
9	BP	9	745	905
10	BP	10	840	760
11	BC	1	470	410
12	BC	2	470	485
13	BC	3	445	445
14	BC	4	460	455
59	CC	9		
60	CC	10		

				FEMALE
15	BC	5	520	410
16	BC	6	460	365
17	BC	7	425	440
18	BC	8	445	420
19	BC	9	415	395
20	BC	10	405	420
21	MP	1	695	510
22	MP	2	685	550
23	MP	3	710	605
24	MP	4	675	450
25	MP	5	855	505
26	MP	6	830	435
27	MP	7	640	470
28	MP	8	835	550
29	MP	9	890	490
30	MP	10	650	495
31	MC	1	420	230
32	MC	2	430	250
33	MC	3	450	230
34	MC	4	465	210
35	MC	5	405	330
36	MC	6	400	230
37	MC	7	375	255
38	MC	8	520	230
39	MC	9	530	245
40	MC	10	475	235
41	CP	1	350	295
42	CP	2	440	290
43	CP	3	350	350
44	CP	4	350	355
45	CP	5	340	250
46	CP	6	265	250
47	CP	7	250	255
48	CP	8	275	250
49	CP	9	265	260
59	CC	9		
60	CC	10		

			MALE	FEMALE
50	CP	10	270	250
51	CC	1	250	245
52	CC	2	265	225
53	CC	3	270	200
54	CC	4	290	200
55	CC	5	275	215
56	CC	6	285	230
57	CC	7	240	210
58	CC	8	255	235
			250	225
			260	210

Appendix A5: Longitudinal swelling values for Male and Female *B. aethiopum.*

Obs	**STEM POSITION**	**REPLICATE**		
1	BP	1	0.385	0.305
2	BP	2	0.525	0.275
3	BP	3	0.140	0.285
4	BP	4	0.140	0.295
5	BP	5	0.270	0.345
6	BP	6	0.275	0.210
7	BP	7	0.165	0.350
8	BP	8	0.150	0.295
59	CC	9		
60	CC	10		

				FEMALE
9	BP	9	0.160	0.295
10	BP	10	0.150	0.370
11	BC	1	0.220	0.230
12	BC	2	0.285	0.280
13	BC	3	0.680	0.545
14	BC	4	0.410	0.260
15	BC	5	0.225	0.100
16	BC	6	0.180	0.215
17	BC	7	0.290	0.195
18	BC	8	0.340	0.055
19	BC	9	0.630	0.150
20	BC	10	0.320	0.135
21	MP	1	0.390	0.060
22	MP	2	0.265	0.210
23	MP	3	0.470	0.430
24	MP	4	0.185	0.200
25	MP	5	0.250	0.455
26	MP	6	0.240	0.045
27	MP	7	0.305	0.095
28	MP	8	0.260	0.265
29	MP	9	0.090	0.240
30	MP	10	0.050	0.220
31	MC	1	0.270	0.245
32	MC	2	0.230	0.470
33	MC	3	0.420	0.120
34	MC	4	0.275	0.175
35	MC	5	0.175	0.425
36	MC	6	0.165	0.215
37	MC	7	0.435	0.240
38	MC	8	0.415	0.305
39	MC	9	0.195	0.310
40	MC	10	0.245	0.285
41	CP	1	0.210	0.510
42	CP	2	0.270	0.200
59	CC	9		
60	CC	10		

			MALE	FEMALE
43	CP	3	0.355	0.660
44	CP	4	0.300	0.530
45	CP	5	0.065	0.530
46	CP	6	0.120	0.730
47	CP	7	0.070	1.025
48	CP	8	0.340	0.200
49	CP	9	0.395	0.165
50	CP	10	0.075	0.220
51	CC	1	0.180	0.865
52	CC	2	0.250	0.395
53	CC	3	0.440	0.235
54	CC	4	0.665	1.280
55	CC	5	0.355	0.300
56	CC	6	0.325	0.595
57	CC	7	0.120	0.615
58	CC	8	0.325	0.285
			0.445	0.420
			0.510	0.160
59	CC	9		
60	CC	10		

Appendix A6: Tangential swelling values for Male and Female *B. aethiopum.*

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	2.410	0.830
2	BP	2	2.080	1.750
3	BP	3	1.320	1.735
4	BP	4	3.325	1.580
5	BP	5	2.285	2.000
6	BP	6	2.335	2.135
7	BP	7	1.090	1.855
8	BP	8	0.790	2.285
9	BP	9	0.710	1.460
10	BP	10	0.465	0.830
11	BC	1	1.995	2.015
12	BC	2	2.350	2.130
13	BC	3	1.090	3.085
14	BC	4	1.520	2.580
15	BC	5	2.095	2.320
16	BC	6	2.290	1.145
17	BC	7	0.535	1.990
18	BC	8	1.075	1.455
19	BC	9	2.005	2.610
20	BC	10	1.005	2.760
21	MP	1	1.220	0.805
22	MP	2	0.580	0.795
23	MP	3	0.675	1.235
24	MP	4	1.575	0.205
25	MP	5	0.845	2.305
26	MP	6	1.675	0.415
27	MP	7	1.460	2.030
28	MP	8	0.325	2.070
29	MP	9	0.350	1.680
30	MP	10	2.090	2.280
31	MC	1	0.990	1.310
32	MC	2	1.305	1.320
33	MC	3	1.050	1.525
34	MC	4	1.030	0.360
35	MC	5	1.095	1.655
60	CC	10		

			MALE	FEMALE
36	MC	6	1.250	1.405
37	MC	7	0.460	1.400
38	MC	8	1.065	1.055
39	MC	9	1.055	0.905
40	MC	10	1.370	0.555
41	CP	1	1.190	0.165
42	CP	2	0.915	1.140
43	CP	3	0.865	0.225
44	CP	4	0.215	0.700
45	CP	5	0.805	1.250
46	CP	6	0.345	0.780
47	CP	7	0.115	0.265
48	CP	8	0.525	0.160
49	CP	9	0.505	0.195
50	CP	10	0.730	2.020
51	CC	1	1.765	2.220
52	CC	2	0.930	1.235
53	CC	3	0.875	1.335
54	CC	4	3.590	3.370
55	CC	5	2.945	0.360
56	CC	6	1.535	1.940
57	CC	7	1.510	2.745
58	CC	8	2.875	0.955
59	CC	9	2.505	1.430
			3.805	1.630

Appendix A7: Radial swelling values for Male and Female *B. aethiopum*.

Obs	STEM POSITION	REPLICATE		
1	BP	1	2.445	2.230
59	CC	9		
60	CC	10		

			MALE	FEMALE
2	BP	2	3.790	1.580
3	BP	3	3.315	2.905
4	BP	4	2.755	1.935
5	BP	5	3.245	2.740
6	BP	6	1.130	2.340
7	BP	7	2.815	2.300
8	BP	8	2.095	1.525
9	BP	9	2.495	1.220
10	BP	10	1.330	2.630
11	BC	1	5.195	2.725
12	BC	2	4.540	3.125
13	BC	3	4.105	2.590
14	BC	4	3.430	2.815
15	BC	5	5.640	2.275
16	BC	6	4.525	1.965
17	BC	7	6.925	2.195
18	BC	8	5.885	3.425
19	BC	9	2.670	2.850
20	BC	10	4.700	1.925
21	MP	1	3.960	1.980
22	MP	2	2.740	3.345
23	MP	3	3.020	2.195
24	MP	4	4.140	2.000
25	MP	5	4.085	2.380
26	MP	6	4.195	2.410
59	CC	9		
60	CC	10		

			MALE	FEMALE
27	MP	7	4.420	2.755
28	MP	8	2.160	5.145
29	MP	9	2.830	3.450
30	MP	10	2.115	4.030
31	MC	1	2.410	2.460
32	MC	2	2.955	6.850
33	MC	3	2.935	4.240
34	MC	4	2.520	5.080
35	MC	5	2.965	5.100
36	MC	6	4.660	5.265
37	MC	7	3.750	3.640
38	MC	8	2.085	4.470
39	MC	9	2.130	4.570
40	MC	10	2.005	4.890
41	CP	1	4.190	3.045
42	CP	2	2.980	1.480
43	CP	3	3.325	3.195
44	CP	4	4.910	1.665
45	CP	5	4.270	3.450
46	CP	6	2.620	2.555
47	CP	7	1.925	2.220
48	CP	8	1.805	1.730
49	CP	9	1.810	2.675
50	CP	10	2.685	1.810
51	CC	1	3.590	2.775
52	CC	2	4.345	2.255
53	CC	3	2.555	3.235
54	CC	4	1.075	1.920
55	CC	5	4.570	2.310
59	CC	9		
60	CC	10		

			MALE	FEMALE
56	CC	6	3.475	3.130
57	CC	7	2.720	3.480
58	CC	8	3.190	2.970
			4.980	2.650
			6.405	2.110

Appendix A8: Volumetric swelling values for Male and Female *B. aethiopum.*

Obs	**STEM POSTION**	**REPLICATE**		
1	BP	1	5.26500	3.565
2	BP	2	6.51000	5.725
3	BP	3	4.86500	4.075
4	BP	4	4.81000	4.385
5	BP	5	5.87500	5.385
6	BP	6	4.81500	4.920
7	BP	7	4.11500	4.185
8	BP	8	3.02500	4.035
9	BP	9	3.39000	4.275
10	BP	10	4.92000	4.540
11	BC	1	7.59000	4.980
12	BC	2	7.28000	5.830
13	BC	3	5.96500	6.190
14	BC	4	5.34000	5.700
15	BC	5	8.09000	4.670
16	BC	6	7.10000	5.525
17	BC	7	7.60000	4.560
18	BC	8	5.62500	4.510
19	BC	9	9.25000	5.380
20	BC	10	6.07500	4.805
21	MP	1	3.58500	2.865
22	MP	2	2.23000	4.400
59	CC	9		
60	CC	10		

			MALE	FEMALE
23	MP	3	2.83500	4.010
24	MP	4	1.81500	4.200
25	MP	5	3.86000	5.295
26	MP	6	3.18500	2.835
27	MP	7	3.58500	4.405
28	MP	8	2.18500	7.655
29	MP	9	3.65000	5.630
30	MP	10	1.91500	6.150
31	MC	1	3.76000	4.105
32	MC	2	4.54000	8.410
33	MC	3	4.45000	5.540
34	MC	4	3.86500	5.640
35	MC	5	4.32500	10.100
36	MC	6	4.25500	7.195
37	MC	7	5.02000	7.470
38	MC	8	4.61500	2.950
39	MC	9	3.39000	5.815
40	MC	10	3.21500	5.075
41	CP	1	5.56500	3.735
42	CP	2	4.18500	1.895
43	CP	3	5.16500	2.235
44	CP	4	4.40000	3.595
45	CP	5	5.16500	5.300
46	CP	6	3.22500	5.810
47	CP	7	2.08000	7.105
48	CP	8	2.68000	2.645
49	CP	9	2.32500	3.675
50	CP	10	3.44500	4.085
51	CC	1	3.53000	4.920
59	CC	9		
60	CC	10		

			MALE	FEMALE
52	CC	2	3.61667	3.610
53	CC	3	2.60000	4.640
54	CC	4	3.61333	6.690
55	CC	5	6.82333	2.975
56	CC	6	2.32333	4.895
57	CC	7	2.91667	6.995
58	CC	8	3.14333	4.255
			5.39000	4.415
			7.43000	4.500

Appendix A9: Longitudinal shrinkage values for Male and Female *B. aethiopum.*

Obs	**STEM POSITION**	**REPLICATE**		
1	BP	1	1.330	1.020
2	BP	2	1.000	1.660
3	BP	3	1.185	0.580
4	BP	4	1.125	0.515
5	BP	5	1.230	0.835
6	BP	6	1.345	2.990
7	BP	7	1.220	1.100
8	BP	8	1.465	1.910
9	BP	9	0.680	0.410
10	BP	10	0.505	2.135
11	BC	1	3.415	2.050
12	BC	2	1.715	4.345
13	BC	3	1.525	3.590
59	CC	9		
60	CC	10		

			MALE	FEMALE
14	BC	4	2.560	6.235
15	BC	5	2.610	2.895
16	BC	6	2.430	3.450
17	BC	7	2.005	2.660
18	BC	8	2.790	2.580
19	BC	9	1.815	3.615
20	BC	10	2.340	3.325
21	MP	1	2.045	3.550
22	MP	2	2.245	1.860
23	MP	3	1.475	2.700
24	MP	4	1.575	2.360
25	MP	5	1.605	3.895
26	MP	6	0.780	1.770
27	MP	7	1.560	1.700
28	MP	8	3.465	3.940
29	MP	9	1.875	4.785
30	MP	10	2.455	2.030
31	MC	1	8.495	3.655
32	MC	2	2.470	4.360
33	MC	3	7.310	2.190
34	MC	4	2.735	3.765
35	MC	5	2.575	2.655
36	MC	6	2.785	0.670
37	MC	7	2.720	5.145
38	MP	8	2.845	2.310
39	MP	9	2.400	1.800
40	MP	10	2.545	2.855
41	CP	1	3.390	1.775
42	CP	2	2.400	2.010
59	CC	9		
60	CC	10		

			MALE	FEMALE
43	CP	3	2.770	1.845
44	CP	4	2.580	1.355
45	CP	5	2.320	3.835
46	CP	6	3.145	2.010
47	CP	7	2.640	1.950
48	CP	8	2.510	4.585
49	CP	9	2.880	4.650
50	CP	10	3.275	2.730
51	CC	1	2.525	7.525
52	CC	2	2.590	3.730
53	CC	3	2.690	2.435
54	CC	4	2.310	2.795
55	CC	5	4.185	4.655
56	CC	6	4.485	5.095
57	CC	7	1.860	3.535
58	CC	8	4.650	2.025
			4.595	2.670
			3.590	4.890
59	CC	9		
60	CC	10		

			MALE	FEMALE

Appendix A10: Tangential shrinkage values for Male and Female *B. aethiopum.*

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	1.065	1.225
2	BP	2	1.180	2.095
3	BP	3	0.895	1.960
4	BP	4	1.885	3.130
5	BP	5	2.140	1.410
6	BP	6	2.045	2.505
7	BP	7	2.280	2.860
8	BP	8	2.255	2.920
9	BP	9	2.245	2.070
10	BP	10	1.550	2.215
11	BC	1	3.180	1.490
12	BC	2	3.110	2.425
13	BC	3	3.425	0.620
14	BC	4	3.980	1.625
15	BC	5	3.810	3.660
16	BC	6	3.810	3.820
17	BC	7	3.770	3.050
18	BC	8	3.655	2.320
19	BC	9	3.675	3.025
20	BC	10	3.285	2.700
21	MP	1	3.615	3.215
22	MP	2	2.435	2.375
23	MP	3	4.330	2.715
24	MP	4	1.550	2.975
25	MP	5	3.875	2.620
26	MP	6	4.460	1.995
27	MP	7	3.020	2.845
59	CC	9		
60	CC	10		

28	MP	8	4.045	3.310
29	MP	9	5.050	5.170
30	MP	10	2.630	4.100
31	MC	1	2.840	1.600
32	MC	2	3.300	3.765
33	MC	3	3.305	4.025
34	MC	4	2.490	1.460
35	MC	5	2.715	2.545
36	MC	6	3.285	1.915
37	MC	7	3.055	2.860
38	MC	8	2.960	5.085
39	MC	9	2.515	1.700
40	MC	10	2.850	2.060
41	CP	1	4.025	1.355
42	CP	2	4.000	1.700
43	CP	3	3.330	1.700
44	CP	4	2.995	1.420
45	CP	5	2.970	2.380
46	CP	6	3.285	3.205
47	CP	7	3.445	2.800
48	CP	8	3.035	2.410
49	CP	9	3.010	2.265
50	CP	10	3.050	3.025
51	CC	1	4.925	3.105
52	CC	2	3.735	2.795
53	CC	3	3.230	3.125
54	CC	4	5.580	3.755
55	CC	5	2.470	2.480
56	CC	6	4.975	2.595
57	CC	7	3.805	2.365
58	CC	8	2.605	2.000
59	CC	9	5.425	2.850
			3.625	2.445

Appendix A11: Radial shrinkage values for Male and Female *B aethiopum.*

Obs	**STEM POSITION**	**REPLICATE**		
1	BP	1	1.955	3.210
60	CC	10		

			MALE	FEMALE
2	BP	2	1.730	3.370
3	BP	3	2.080	3.890
4	BP	4	2.275	3.385
5	BP	5	2.245	3.945
6	BP	6	2.315	1.815
7	BP	7	2.585	2.390
8	BP	8	2.710	2.900
9	BP	9	3.415	3.125
10	BP	10	2.825	4.660
11	BC	1	2.215	2.225
12	BC	2	2.710	2.770
13	BC	3	4.815	3.660
14	BC	4	2.125	2.420
15	BC	5	2.590	3.540
16	BC	6	4.015	3.470
17	BC	7	2.140	2.925
18	BC	8	3.290	3.725
19	BC	9	3.330	4.500
20	BC	10	2.825	2.350
21	MP	1	1.340	2.780
22	MP	2	2.285	3.170
23	MP	3	3.270	3.450
24	MP	4	5.145	1.980
25	MP	5	4.075	3.030
26	MP	6	1.830	2.810
59	CC	9		
60	CC	10		

27	MP	7	3.800	1.530
28	MP	8	1.915	3.045
29	MP	9	1.980	2.780
30	MP	10	2.720	2.985
31	MC	1	1.830	2.960
32	MC	2	4.085	2.355
33	MC	3	2.855	5.860
34	MC	4	5.760	4.410
35	MC	5	2.270	2.465
36	MC	6	4.165	2.730
37	MC	7	3.900	2.720
38	MC	8	4.290	2.610
39	MC	9	3.665	5.650
40	MC	10	2.580	2.280
41	CP	1	2.515	2.050
42	CP	2	2.440	2.440
43	CP	3	2.285	2.010
44	CP	4	2.495	2.335
45	CP	5	2.920	1.940
46	CP	6	2.785	3.635
47	CP	7	3.165	1.950
48	CP	8	4.095	2.115
49	CP	9	3.140	2.425
50	CP	10	4.555	2.540
51	CC	1	3.415	2.435
52	CC	2	3.125	2.470
53	CC	3	4.615	2.640
54	CC	4	2.355	2.375
55	CC	5	3.520	2.930
56	CC	6	4.050	2.910
57	CC	7	3.730	1.900
58	CC	8	3.945	2.340
			2.940	2.855
			2.480	2.450

Appendix A12: Volumetric shrinkage values for Male and Female *B. aethiopum.*

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
60	CC	10		

			MALE	FEMALE
1	BP	1	5.310	5.460
2	BP	2	4.650	7.125
3	BP	3	5.175	6.430
4	BP	4	6.220	7.010
5	BP	5	6.235	6.185
6	BP	6	6.090	7.310
7	BP	7	6.370	6.350
8	BP	8	6.870	7.730
9	BP	9	6.115	5.600
10	BP	10	5.780	9.010
11	BC	1	7.850	5.760
12	BC	2	9.480	9.540
13	BC	3	8.750	7.870
14	BC	4	7.715	10.280
15	BC	5	8.525	10.095
16	BC	6	9.875	9.650
17	BC	7	7.630	8.835
18	BC	8	9.295	8.840
19	BC	9	9.045	11.140
20	BC	10	8.135	8.805
21	BC	1	10.830	8.245
22	BC	2	8.960	7.405
23	BC	3	9.075	8.865
24	BC	4	10.265	7.315
25	BC	5	11.555	10.345
26	BC	6	8.575	6.575
27	BC	7	8.380	6.075
28	BC	8	9.930	10.300
29	BC	9	8.910	9.770
59	CC	9		
60	CC	10		

30	BC	10	7.810	9.110
31	MC	1	8.165	8.655
32	MC	2	8.165	8.370
33	MC	3	8.165	12.085
34	MC	4	8.165	9.630
35	MC	5	8.165	7.660
36	MC	6	8.165	5.735
37	MC	7	8.165	10.725
38	MC	8	8.165	10.005
39	MC	9	8.165	9.130
40	MC	10	8.165	7.200
41	CP	1	9.930	5.180
42	CP	2	9.930	6.155
43	CP	3	9.930	5.370
44	CP	4	9.930	5.105
45	CP	5	9.930	6.155
46	CP	6	9.930	8.850
47	CP	7	9.930	6.700
48	CP	8	9.930	8.965
49	CP	9	9.930	9.335
50	CP	10	9.930	8.295
51	CC	1	10.875	13.065
52	CC	2	9.450	8.995
53	CC	3	10.535	8.200
54	CC	4	10.240	8.925
55	CC	5	10.170	10.065
56	CC	6	12.010	10.600
57	CC	7	9.395	7.800
58	CC	8	11.570	6.370
59	CC	9	12.960	8.375
			9.625	9.790
60	CC	10		

Appendix A13: Total extractives values for Male and Female *B aethiopum.*

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	4.480	3.225
2	BP	2	4.265	3.235
3	BP	3	4.490	3.290
4	BC	1	2.775	2.925
5	BC	2	2.350	3.025
6	BC	3	2.720	2.910
7	MP	1	3.085	3.130
8	MP	2	3.055	2.955
9	MP	3	3.045	3.150
10	MC	1	2.260	2.565
11	MC	2	2.250	2.150
12	MC	3	2.550	2.320
13	CP	1	2.035	2.125
14	CP	2	2.555	2.110
15	CP	3	2.560	1.885
16	CC	1	2.020	1.700
17	CC	2	1.730	1.965
18	CC	3	1.740	1.770

Appendix 14: Lignin content values for Male and Female *B aethiopum.*

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	36.345	39.530
2	BP	2	37.420	39.530
3	BP	3	36.885	39.530
4	BC	1	33.830	35.630
5	BC	2	34.270	35.630
6	BC	3	34.290	35.630
7	MP	1	36.150	35.995
8	MP	2	35.430	36.360
9	MP	3	36.360	36.570
10	MC	1	33.900	33.900
11	MC	2	34.095	33.715
12	MC	3	33.710	33.140
13	CP	1	33.140	29.380
14	CP	2	32.945	28.420
15	CP	3	32.395	29.380
16	CC	1	29.145	28.740
17	CC	2	29.890	27.750
18	CC	3	28.905	29.310

Appendix A15: Alpha-cellulose values for Male and Female *B. aethiopum.*

Obs	STEM POSITION	TREATMENT	MALE	FEMALE
1	BP	1	40.895	36.890
2	BP	2	40.335	37.395
3	BP	3	39.045	36.750
4	BC	1	33.705	36.515
5	BC	2	34.260	35.570
6	BC	3	34.625	36.210
7	MP	1	34.175	34.745
8	MP	2	34.180	35.795
9	MP	3	33.960	35.595
10	MC	1	29.885	29.110
11	MC	2	30.590	29.345
12	MC	3	29.660	29.635
13	CP	1	28.695	25.780
14	CP	2	30.025	26.135
15	CP	3	29.860	26.000
16	CC	1	28.285	24.200
17	CC	2	27.840	24.280

18	CC	3	27.920	24.710

Appendix A16: Hemi-cellulose values for Male and Female *B aethiopum.*

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	33.550	37.495
2	BP	2	33.505	37.460
3	BP	3	35.980	39.700
4	BC	1	39.275	31.895
5	BC	2	38.425	32.105
6	BC	3	37.205	30.825
7	MP	1	40.035	33.285
8	MP	2	40.015	32.920
9	MP	3	38.130	32.845
10	MC	1	32.400	33.210
11	MC	2	32.890	33.055
12	MC	3	32.490	33.505
13	CP	1	34.085	37.205
14	CP	2	32.640	38.320
15	CP	3	32.105	37.825
16	CC	1	41.840	46.025
17	CC	2	42.545	46.785
18	CC	3	41.415	45.450

Appendix A17: Holocellulose values for Male and Female *B aethiopum.*

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	74.445	74.385
2	BP	2	73.840	74.855
3	BP	3	75.025	76.425
4	BC	1	72.980	68.410
5	BC	2	72.685	67.675
6	BC	3	71.830	67.035
7	MP	1	74.210	68.030
8	MP	2	74.195	68.715
9	MP	3	72.090	68.440
10	MC	1	62.285	62.320
11	MC	2	63.480	62.400
12	MC	3	62.150	62.140
13	CP	1	62.780	62.985
14	CP	2	62.665	64.455
15	CP	3	61.965	63.825
16	CC	1	70.125	70.225
17	CC	2	70.385	71.065
18	CC	3	69.335	70.160

Appendix A18: Ash content values for Male and Female *B. aethiopum.*

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	0.555	0.570
2	BP	2	0.830	0.840
3	BP	3	0.560	1.130
4	BC	1	1.400	1.390
5	BC	2	1.395	1.395
6	BC	3	1.120	1.675
7	MP	1	1.305	1.670
8	MP	2	1.425	2.025
9	MP	3	1.585	2.250
10	MC	1	1.680	3.135
11	MC	2	1.675	2.550
12	MC	3	1.380	3.135
13	CP	1	1.985	2.300
14	CP	2	2.825	3.460
15	CP	3	2.540	2.715
16	CC	1	3.115	5.885

17	CC	2	3.115	6.145
18	CC	3	3.945	4.885

Appendix A20: Data for natural durability (mass loss) of Male and Female *B. aethiopum*.

Obs	STEM POSITION	REPLICATE	MALE	FEMALE
1	BP	1	3.595	8.785
2	BP	2	5.095	1.060
3	BP	3	5.045	2.570
4	BP	4	5.140	8.900
5	BP	5	3.320	2.235
6	BP	6	4.685	0.840
7	BP	7	5.900	5.225
8	BP	8	1.935	2.520
9	BP	9	3.310	6.990
10	BP	10	3.705	1.555
11	BC	1	4.875	7.865
12	BC	2	11.895	11.575
13	BC	3	11.295	16.630
14	BC	4	7.110	54.965
15	BC	5	9.300	57.950
16	BC	6	8.015	52.285
17	BC	7	11.440	8.240
18	BC	8	6.945	55.720
19	BC	9	10.985	13.860
20	BC	10	14.335	11.960
21	MP	1	3.605	7.050
22	MP	2	7.425	9.040
23	MP	3	3.310	10.770
24	MP	4	9.270	3.870
25	MP	5	14.615	10.770
26	MP	6	6.905	6.835
27	MP	7	3.015	5.025
28	MP	8	15.300	3.880
29	MP	9	12.105	19.460
30	MP	10	4.140	5.915
31	MC	1	33.350	63.555
32	MC	2	69.115	57.765
33	MC	3	51.170	100.000
34	MC	4	100.000	7.745
35	MC	5	69.545	100.000
36	MC	6	58.165	100.000
37	MC	7	27.190	56.950
38	MC	8	56.320	57.575
39	MC	9	73.075	25.445

40	MC	10	21.560	29.890
41	CP	1	100.000	100.000
42	CP	2	100.000	51.545
43	CP	3	100.000	100.000
44	CP	4	100.000	100.000
45	CP	5	100.000	100.000
46	CP	6	100.000	100.000
47	CP	7	61.465	100.000
48	CP	8	64.145	100.000
49	CP	9	100.000	100.000
50	CP	10	100.000	68.420
51	CC	1	100.000	100.000
52	CC	2	100.000	100.000
53	CC	3	100.000	100.000
54	CC	4	100.000	100.000
55	CC	5	100.000	100.000
56	CC	6	100.000	100.000
57	CC	7	100.000	100.000
58	CC	8	100.000	100.000
59	CC	9	100.000	100.000
60	CC	10	100.000	100.000

Appendix A21: Data for natural durability (visual rating) of Male and Female *B. aethiopum.*

Obs	**STEM POSITION**	**REPLICATE**	**MALE**	**FEMALE**
1	BP	1	0.0	0.0
2	BP	2	0.0	0.0
3	BP	3	0.0	0.0
4	BP	4	0.0	0.0
5	BP	5	0.0	0.0
6	BP	6	0.0	0.0
7	BP	7	0.0	0.0
8	BP	8	0.0	0.0
9	BP	9	0.0	0.0
10	BP	10	0.0	0.0
11	BC	1	1.0	0.5
12	BC	2	1.5	1.0
13	BC	3	1.5	1.5
14	BC	4	1.0	2.0
15	BC	5	1.5	1.5
16	BC	6	1.5	2.0
17	BC	7	1.0	1.0
18	BC	8	1.0	1.0
19	BC	9	1.0	2.0
20	BC	10	2.0	2.0

21	MP	1	0.0	0.0
22	MP	2	0.0	0.0
23	MP	3	0.0	1.0
24	MP	4	0.0	1.0
25	MP	5	0.0	1.0
26	MP	6	0.0	1.0
27	MP	7	0.0	1.0
28	MP	8	0.0	1.0
29	MP	9	0.0	1.0
30	MP	10	0.0	1.0
31	MC	1	2.0	2.0
32	MC	2	3.0	1.0
33	MC	3	4.0	4.0
34	MC	4	4.0	2.0
35	MC	5	3.0	4.0
36	MC	6	2.0	4.0
37	MC	7	2.0	2.0
38	MC	8	2.0	2.0
39	MC	9	4.0	3.0
40	MC	10	1.0	3.0
41	CP	1	4.0	4.0
42	CP	2	4.0	4.0
43	CP	3	4.0	4.0
44	CP	4	4.0	4.0
45	CP	5	4.0	4.0
46	CP	6	4.0	4.0
47	CP	7	4.0	4.0
48	CP	8	4.0	4.0
49	CP	9	4.0	4.0
50	CP	10	4.0	4.0
51	CC	1	4.0	4.0
52	CC	2	4.0	4.0
53	CC	3	4.0	4.0
54	CC	4	4.0	4.0
55	CC	5	4.0	4.0
56	CC	6	4.0	4.0
57	CC	7	4.0	4.0
58	CC	8	4.0	4.0
59	CC	9	4.0	4.0
60	CC	10	4.0	4.0

APPENDIX B1: ANOVA for the Moisture content within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	38668.25123	7733.65025	558.73	<.0001
Error	54	747.43644	13.84142		
Corrected Total	59	39415.68767			

***Significant difference at p<0.05**

APPENDIX B2: ANOVA for the Moisture content within the stem of female *B. aethiopum*.

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	43509.14132	8701.82826	102.08	<.0001
Error	54	4603.15776	85.24366		
Corrected Total	59	48112.2908			

***Significant difference at p<0.05**

APPENDIX B3: ANOVA for the Moisture content within the stem of male *B. aethiopum* at dry state

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Model	5	3.62769708	0.72553942	6.46	<.0001
Error	54	6.06806750	0.11237162		
Corrected Total	59	9.69576458			

***Significant difference at p<0.05**

APPENDIX B4: ANOVA for the Moisture content within the stem of female *B. aethiopum* at dry state

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.47920833	0.09584167	3.18	<0.0138
Error	54	1.62781500	0.03014472		
Corrected Total	59	2.10702333			

***Significant difference at p<0.05**

APPENDIX B5:ANOVA for density within the stem of male *B. aethiopum* at the green state

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	222.170333	44.434067	87.30	<.0001
Error	54	2748.4500	5.08972		
Corrected Total	59	2470.620333			

***Significant difference at p<0.05**

APPENDIX B6: ANOVA for density within the stem of female *B. aethiopum* at the green state

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	242.569708	48.513942	72.93	<.0001
Error	54	3592.0750	6.65199		
Corrected Total	59	3834.644708			

***Significant difference at p<0.05**

APPENDIX B7:ANOVA for the density within the stem of male *B .aethiopum* at dry state

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	189.196117	37.839223	1.20<0.3233	
Error	54	1707.806438	31.626045		
Corrected Total	59	1897.002555			

***Significant difference at p<0.05**

APPENDIX B8: ANOVA for the density within the stem of female *B. aethiopum* at dry state

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	208.402208	41.680442	1.44	<.0001
Error	54	35.920750	6.65199		
Corrected Total	59	244.322958			

***Significant difference at p<0.05**

APPENDIX B9: ANOVA for the Longitudinal Swelling within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1.24936708	0.24987342	0.90	<0.4848
Error	54	14.91083750	0.27612662		
Corrected Total	59	16.16020458			

***Significant difference at p<0.05**

APPENDIX B10: ANOVA for the Longitudinal Swelling within the stem of female *B. aethiopum*.

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.83566833	0.16713367	4.04	<0.0034
Error	54	2.23247500	0.04134213		
Corrected Total	59	3.06814333			

***Significant difference at p<0.05**

APPENDIX B11: ANOVA for the Tangential Swelling within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	15.78368833	3.15673767	6.57	<.0001

Error	54	25.93185500	0.48021954	
Corrected Total	59	41.71554333		

***Significant difference at p<0.05**

APPENDIX B12: ANOVA for the Tangential swelling within the stem of female *B. aethiopum*

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	13.59705333	2.71941067	6.35	<0.0001
Error	54	23.13834000	0.42848778		
Corrected Total	59	36.73539333			

***Significant difference at p<0.05**

APPENDIX B13: ANOVA for Radial Swelling within the stem of male *B. aethiopum*.

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	31.05666208	6.21133242	5.24	0.0005
Error	54	63.96709250	1.18457579		
Corrected Total	59	95.02375458			

***Significant difference at p<0.05**

APPENDIX B14: ANOVA for the Radial Swelling within the stem of female *B. aethiopum*

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	40.78219500	8.15643900	13.30	<.0001
Error	54	33.11557000	0.61325130		
Corrected Total	59	73.89776500			

***Significant difference at p<0.05**

APPENDIX B15: ANOVA for the Volumetric Swelling within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	95.8859086	19.1771817	13.82	<.0001
Error	54	74.9417015	1.3878093		
Corrected Total	59	170.8276101			

***Significant difference at p<0.05**

APPENDIX B16: ANOVA for the Volumetric Swelling within the stem of female *B. aethiopum*.

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	28.5152450	5.7030490	2.94	0.0202
Error	54	104.6696950	1.9383277		
Corrected Total	59	133.1849400			

***Significant difference at p<0.05**

APPENDIX B17: ANOVA for the Longitudinal Shrinkage within the stem of male *B. aethiopum*.

Dependent Variable : MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	5	45.2960283	9.0592057	7.5	<.0001
Error	54	65.203395	1.2074703		
Corrected Total	59	110.4994233			

***Significant difference at p<0.05**

APPENDIX B18: ANOVA for the Longitudinal Shrinkage within the stem of female *B. aethiopum*

Dependent Variable : FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	5	39.6042221	7.9208444	5.14	0.0006
Error	54	83.2776525	1.5421788		
Corrected Total	59	122.8818746			

***Significant difference at p<0.05**

APPENDIX B19: ANOVA for the Tangential Shrinkage within the stem of male *B. aethiopum*.

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	31.03630375	6.20726075	12.17	<.0001
Error	54	27.54761750	0.51014106		
Corrected Total	59	58.58392125			

***Significant difference at p<0.05**

APPENDIX B 20: ANOVA for the Tangential Shrinkage within the stem of male *B. aethiopum*

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	6.01502375	1.20300475	1.64	0.1660
Error	54	39.68984750	0.73499718		
Corrected Total	59	45.70487125			

***Significant difference at p<0.05**

APPENDIX B 21: ANOVA for the Radial Shrinkage within the stem of male *B. aethiopum*.

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	8.27791000	1.65558200	2.03	0.0887
Error	54	43.99875000	0.81479167		
Corrected Total	59	52.27666000			

***Significant difference at p<0.05**

APPENDIX B22: ANOVA for the Radial Shrinkage within the stem of female *B. aethiopum*.

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	9.22760833	1.84552167	2.93	0.0205
Error	54	33.98393500	0.62933213		
Corrected Total	59	43.21154333			

***Significant difference at p<0.05**

APPENDIX B23: ANOVA for the Volumetric Shrinkage within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	141.6689021	28.3337804	44.28	<.0001
Error	54	34.5563025	0.6399315		
Corrected Total	59	176.2252046			

***Significant difference at p<0.05**

APPENDIX B24: ANOVA for the Volumetric Shrinkage within the stem of female *B. aethiopum.*

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	56.7704300	11.3540860	4.50	0.0017
Error	54	136.2675300	2.5234728		
Corrected Total	59	193.0379600			

***Significant difference at p<0.05**

APPENDIX B25: ANOVA for the Total extractive content within the stem of male *B. aethiopum*.

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Model	5	12.03204583	2.40640917	66.49	<.0001
Error	12	0.43431667	0.03619306		
Corrected Total	17	12.46636250			

***Significant difference at p<0.05**

APPENDIX B26: ANOVA for the Total extractive content within the stem of male *B. aethiopum*

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	5.32132361	1.06426472	65.76	<.0001
Error	12	0.19420000	0.01618333		
Corrected Total	17	5.51552361			

***Significant difference at p<0.05**

APPENDIX B27: ANOVA for the Lignin content within of male *B. aethiopum*.

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	106.3407958	21.2681592	122.17	<.0001
Error	12	2.0890667	0.1740889		
Corrected Total	17	108.4298625			

***Significant difference at p<0.05**

APPENDIX B28: ANOVA for the Lignin content within the stem of female *B. aethiopum*.

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Model	5	276.0783278	55.2156656	282.67	<.0001
Error	12	2.3440667	0.1953389		
Corrected Total	17	278.4223944			

***Significant difference at p<0.05**

APPENDIX B29: ANOVA for the Alpha–cellulose within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	293.7330000	58.7466000	180.97	<.0001
Error	12	3.8953500	0.3246125		
Corrected Total	17	297.6283500			

***Significant difference at p<0.05**

APPENDIX B30: ANOVA for the Alpha –cellulose within the stem of female *B. aethiopum*

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	456.1451000	91.2290200	655.50	<.0001
Error	12	1.6701000	0.1391750		
Corrected Total	17	457.8152000			

***Significant difference at p<0.05**

APPENDIX B31: ANOVA for the Hemi – cellulose within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	220.9532667	44.1906533	46.29	<.0001
Error	12	11.3561333	0.9546778		
Corrected Total	17	232.4094000			

***Significant difference at p<0.05**

APPENDIX B32: ANOVA for the Hemi – cellulose within the stem of female *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	482.7846000	85.7569200	172.31	<.0001
Error	12	5.9724500	0.4977042		
Corrected Total	17	434.7570500			

***Significant difference at p<0.05**

APPENDIX B33: ANOVA for the Holocellulose content within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Model	5	437.0151167	87.4030233	162.61	<.0001
Error	12	6.4498833	0.5374903		
Corrected Total	17	443.4650000			

***Significant difference at p<0.05**

APPENDIX B34: ANOVA for the Holocellulose content within the stem of female *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	327.6595569	65.5319114	154.20	<.0001
Error	12	5.0998167	0.4249847		
Corrected Total	17	332.7593736			

***Significant difference at p<0.05**

APPENDIX B35: ANOVA for the Ash content within the stem of male *B. aethiopum*.

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	14.12154028	2.82430806	33.11	<.0001
Error	12	1.02356667	0.08529722		
Corrected Total	17	15.14510694			

***Significant difference at p<0.05**

APPENDIX B36: ANOVA Ash content within the stem of male *B. aethiopum*.

Dependent Variable: FEMALE

Sum of

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	5	42.27415694	8.45483139	46.43	<.0001
Error	12	2.18526667	0.18210556		
Corrected Total	17	44.45942361			

***Significant difference at p<0.05**

APPENDIX B37: ANOVA for the Mass loss within the stem of male *B. aethiopum.*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	96968.3571	19393.6714	137.03	<.0001
Error	54	7642.3664	141.5253		
Corrected Total	59	104610.7235			

***Significant difference at p<0.05**

APPENDIX B38: ANOVA for the mass loss within the stem of female *B. aethiopum*

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	86425.9032	17285.1806	54.03	<.0001
Error	54	17276.6094	319.9372		
Corrected Total	59	103702.5127			

***Significant difference at p<0.05**

APPENDIX B39: ANOVA for the Visual durability rating within the stem of male *B. aethiopum*

Dependent Variable: MALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	169.8000000	33.9600000	163.74	<.0001
Error	54	11.2000000	0.2074074		
Corrected Total	59	181.0000000			

***Significant difference at p<0.05**

APPENDIX B40: ANOVA for the Visual durability rating within the stem of female *B. aethiopum*

Dependent Variable: FEMALE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	140.8208333	28.1641667	105.43	<.0001
Error	54	14.4250000	0.2671296		
Corrected Total	59	155.2458333			

***Significant difference at p<0.05**

APPENDIX C1: T-test for MC within the male and female *B. aethiopum* at the green state

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	24.91	(-91.14, 41.32)	0.42
Base Core	34.81	(-1.44, 71.06)	0.06
Middle Periphery	17.30	(-46.23, 11.63)	0.21
Middle Core	70.08	(-81.22, -58.94)	0.00*
Crown Periphery	70.08	(-81.22, -58.94)	0.00*
Crown Core	22.88	(4.10, 41.65)	0.02*

*** Significant difference (p<0.05)**

APPENDIX C2: T-test for MC within the male and femal e *B. aethiopum* at the dry state

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.09	(-0.02, 0.20)	0.10
Base Core	0.04	(-0.19, 0.12)	0.60

Middle Periphery	0.59	(-1.10,-0.07)	0.03*
Middle Core	0.18	(-0.04, 0.39)	0.09
Crown Periphery	0.17	(0.09, 0.26)	0.00*
Crown Core	0.12	(-0.34, 0.10)	0.24

***Significant difference (p<0.05)**

APPENDIX C3: T-test for density within male and femal

e B. *aethiopum* varieties at the green state

Position in stem	Mean Density (kg/m^3)	Confidence Interval (CI)	P - Value
Base Periphery	70.00	(-0.05, 0.18)	0.23
Base Core	120.00	(-0.19,-0.05)	0.00*
Middle Periphery	190.00	(-0.28,-0.09)	0.00*
Middle Core	260.00	(-0.31,-0.20)	0.00*
Crown Periphery	30.00	(-0.02,0.08)	0.20
Crown Core	30.00	(-0.05,4.28)	0.05*

*** Significant difference (p<0.05)**

APPENDIX C4: T – test for density for male and female B. *aethiopum* at the dry state

Position in stem	Means (kg/m^3)	Confidence Interval (CI)	P - Value
Base Periphery	72.50	(-0.1510, 6.03E-03)	0.07
Base Core	27.00	(-0.0600, 6.01E-03)	0.10
Middle Periphery	240.50	(-0.3190, -0.1620)	0.00*
Middle Core	202.50	(-0.2524, -0.1526)	0.00*
Crown Periphery	35.00	(-0.709, 9.26E-04)	0.06
Crown Core	44.50	(-0.0628, -0.0262)	0.00*

*** Significant difference (p<0.05)**

APPENDIX C5:T-test for longitudinal swelling within male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.07	(-0.17, 0.04)	0.19
Base Core	0.14	(0.03, 0.25)	0.02*
Middle Periphery	0.43	(-0.47, 1.33)	0.31
Middle Core	3.50	(-0.13, 0.13)	0.95
Crown Periphery	0.26	(-0.52, 1.38)	0.05*
Crown Core	0.15	(-0.10, 0.41)	0.20

***Significant difference (p<0.05)**

APPENDIX C6: T-test for tangential swelling of male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.04	(-0.70, 0.77)	0.92
Base Core	0.61	(-1.31, 0.08)	0.08
Middle Periphery	0.20	(-0.89,0.49)	0.52
Middle Core	0.08	(-0.47, 0.30)	0.64
Crown Periphery	0.07	(-0.55, 0.40)	0.75
Crown Core	0.51	(-0.44, 1.46)	0.25

*** Significant difference (p<0.05)**

APPENDIX C7: T – test for radial swelling of male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.40	(-0.15, 0.35)	0.26
Base Core	2.17	(-3.17,-1.17)	0.01*
Middle Periphery	0.40	(-0.90, 1.70)	0.51
Middle Core	1.81	(-2.75,-0.88)	0.00*
Crown Periphery	0.40	(-1.15,0.35)	0.26
Crown Core	2.17	(-3.17,-1.17)	0.00*

*** Significant difference (p<0.05)**

APPENDIX C8: volumetric swelling of male and female B. *aethiopum*

Positions in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.09	(-0.76,0.58)	0.77
Base Core	1.78	(-2.81,0.74)	0.00*
Middle Periphery	1.86	(0.50, 3.22)	0.01*
Middle Core	2.09	(0.66, 3.52)	0.01*
Crown Periphery	0.19	(-1.53, 1.90)	0.81
Crown Core	0.65	(-1.20, 2.50)	0.45

*** Significant difference (p<0.05)**

APPENDIX C9:T–test for longitudinal shrinkage of male and female B. *aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.21	(-0.41, 0.82)	0.47
Base Core	1.15	(0.11, 2.19)	0.03*
Middle Periphery	0.95	(0.18, 1.73)	0.02*

Middle Core	0.75	(-2.59, 1.10)	0.38
Crown Periphery	0.12	(-1.09, 0.86)	0.79
Crown Core	0.95	(0.18, 1.73)	0.39

*** Significant difference (p<0.05)**

APPENDIX C10: T – test for tangential shrinkage of male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.49	(-0.92,-0.06)	0.03*
Base Core	1.10	(0.43, 1.76)	0.05*
Middle Periphery	0.37	(-0.52, 1.26)	0.37
Middle Core	0.23	(-0.55,1.01)	0.52
Crown Periphery	1.09	(0.44, 1.74)	0.00*
Crown Core	1.26	(0.65, 1.93)	0.00*

*** Significant difference (p<0.05)**

APPENDIX C11:T-test for radial shrinkage of male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.86	(-1.54,0.12)	0.01*
Base Core	0.15	(0.68, 0.37)	0.52
Middle Periphery	0.08	(-1.04,1.20)	0.88
Middle Core	0.14	(-1.06,1.35)	0.08
Crown Periphery	0.70	(0.06,1.33)	0.04*
Crown Core	0.89	(0.35, 1.42)	0.01*

*** Significant difference (p<0.05)**

APPENDIX C 12: T – test for volumetric shrinkage of male and female B. *aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.94	(0.10, 1.78)	0.03*
Base Core	0.45	(-0.58,1.48)	0.35
Middle Periphery	1.03	(-2.11, 0.05)	0.06
Middle Core	0.76	(-0.55, 2.06)	0.22
Crown Periphery	2.92	(-4.12, -1.71)	0.00*
Crown Core	1.47	(-3.04,0.11)	0.06

*** Significant difference (p<0.05)**

APPENDIX C13: T-test for total extractives within male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	1.16	(0.87,1.45)	0.00*
Base Core	0.34	(-1.06, 0.39)	0.18
Middle Periphery	0.02	(-0.28,0.25)	0.81
Middle Core	8.33	(-0.69, 0.70)	0.96
Crown Periphery	0.34	(-0.63, 1.32)	0.27
Crown Core	0.02	(-0.68,0.72)	0.92

*** Significant difference (p<0.05)**

APPENDIX C14: T-test for lignin content of male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.07	(-0.15, 6.03)	0.07
Base Core	0.03	(-0.06, 6.01)	0.10
Middle Periphery	0.24	(-0.32, -0.16)	0.00*
Middle Core	0.20	(-0.25, -0.15)	0.00*
Crown Periphery	0.04	(-0.07, 9.26)	0.06
Crown Core	0.05	(-0.06, -0.03)	0.00*

*** Significant difference (p<0.05)**

APPENDIX C15:T-test for alpha-cellulose content within male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	3.08	(0.94, 5.23)	0.03*
Base Core	1.90	(-3.89, 0.08)	0.05*
Middle Periphery	1.27	(-2.79, 0.24)	0.07
Middle Core	0.68	(-0.85, 2.21)	0.20
Crown Periphery	3.56	(2.18, 4.93)	0.01*
Crown Core	3.62	(2.52,4.71)	0.01*

*** Significant difference (p<0.05)**

APPENDIX C16: T-test for hemi-cellulose content within male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	3.87	(-4.20,-3.54)	0.00*
Base Core	6.69	(5.21, 8.17)	0.00*
Middle Periphery	6.38	(3.99, 8.76)	0.01*
Middle Core	0.66	(-1.77,0.44)	0.12
Crown Periphery	4.84	(-8.54,-1.14)	0.03*
Crown Core	4.15	(-4.42,-3.89)	0.00*

*** Significant difference (p<0.05)**

APPENDIX C17:T-test for holocellulose content within male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.79	(-2.67,1.10)	0.21
Base Core	4.79	(4.25, 5.34)	0.00*
Middle Periphery	5.10	(1.86, 8.35)	0.02*
Middle Core	0.35	(-1.22, 1.92)	0.45
Crown Periphery	1.29	(-3.61,1.04)	0.14
Crown Core	0.54	(-1.49,0.42)	0.14

*** Significant difference (p<0.05)**

APPENDIX C18:T-test for ash content within male an l female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	0.20	(-1.00, 0.60)	0.40
Base Core	0.18	(-0.99,0.62)	0.43
Middle Periphery	0.54	(-0.94,-0.15)	0.27
Middle Core	1.36	(-2.47,-0.25)	0.03*
Crown Periphery	0.38	(-0.96, 0.21)	0.11
Crown Core	2.25	(-5.08, 0.58)	0.08

*** Significant difference (p<0.05)**

APPENDIX C19:T-test for mass loss of male and female *B. aethiopum*

Position in stem	Means (%)	Confidence Interval (CI)	P - Value
Base Periphery	4.44	(-14.25, 5.38)	0.33
Base Core	0.03	(-0.03, 6.01)	0.10
Middle Periphery	0.24	(-0.32, -0.16)	0.00*
Middle Core	0.20	(-0.25, -0.15)	0.00*
Crown Periphery	0.04	(-0.07, 9.26)	0.06
Crown Core	0.05	(-0.06,-0.03)	0.00*

*** Significant difference (p<0.05)**

APPENDIX C20:T-test for visual durability rating within the stem of *B. aethiopum*

Position in stem	Means	Confidence Interval (CI)	P - Value
Base Periphery	0.00	(0.00, 0.00)	0.00*
Base Core	0.15	(-0.53,0.23)	0.40
Middle Periphery	0.80	(-1.10,-0.50)	0.00*
Middle Core	0.00	(-1.01, 1.01)	1.00
Crown Periphery	0.00	(0.00, 0.00)	0.00*
Crown Core	0.00	(0.00, 0.00)	0.00*

*** Significant difference (p<0.05)**

APPENDIX D 1: Relationship between mass loss and some wood characteristics at the periphery of male base

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	-0. 05061	No correlation
	Total extractives	-0.4913	Weak negative correlation
	Lignin	0.8816	Strong positive correlation
	Alpha-cellulose	-0.7131	Strong positive correlation
	Hemi-cellulose	0.4603	Weak positive correlation
	Holocellulose	-0.04152	No correlation
	Ash content	0.5387	Moderate positive correlation

APPENDIX D 2: Relationship between mass loss and some wood characteristics at the core of male base

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	-0.4853	Weak negative correlation
	Total extractives	-0.6594	Moderate negative correlation
	Lignin	0.9933	Strong positive correlation
	Alpha-cellulose	0.8860	Strong positive correlation
	Hemi-cellulose	-0.7625	Strong negative correlation
	Holocellulose	-0.6411	Moderate negative correlation
	Ash content	-0.4458	weak negative correlation

APPENDIX D 3: Relationship between mass loss and some wood characteristics at the periphery of male middle

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	0.7770	Strong positive correlation
	Total extractives	-0.2150	Weak negative correlation
	Lignin	-0.9884	Strong negative correlation
	Alpha-cellulose	0.5711	moderate positive correlation
	Hemi-cellulose	0.5470	moderate positive correlation
	Holocellulose	0.5495	moderate positive correlation
	Ash content	-0.1461	Weak negative correlation

APPENDIX D 4: Relationship between mass loss and some wood characteristics at the core of male middle

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	0.2771	Weak positive correlation
	Total extractives	-0.03136	No correlation
	Lignin	0.5082	moderate positive correlation
	Alpha-cellulose	0.7279	Strong positive correlation
	Hemi-cellulose	0.9400	Strong positive correlation
	Holocellulose	0.8174	Strong positive correlation
	Ash content	-0.01254	No correlation

APPENDIX D 5: Relationship between mass loss and some wood characteristics at the periphery of male crown

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	-0.6796	Strong negative correlation
	Total extractives	0.5598	Moderate positive correlation
	Lignin	-0.9815	Strong negative correlation
	Alpha-cellulose	0.4546	Weak positive correlation
	Hemi-cellulose	-0.7514	Strong negative correlation
	Holocellulose	-0.9977	Strong negative correlation
	Ash content	0.2433	Weak positive correlation

APPENDIX D 6: Relationship between mass loss and some wood characteristics at the periphery of female base

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	0.01668	No correlation
	Total extractives	-0.4631	Weak negative correlation
	Lignin	-	-
	Alpha-cellulose	-0.4805	Weak negative correlation
	Hemi-cellulose	-0.3188	Weak negative correlation
	Holocellulose	-0.5311	Moderate negative correlation

	Ash content	-0.7454	Strong negative correlation

APPENDIX D 7: Relationship between mass loss and some wood characteristics at the core of female base

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	-0.2826	Weak negative correlation
	Total extractives	-0.2071	Weak negative correlation
	Lignin	-	-
	Alpha-cellulose	-0.2312	Weak negative correlation
	Hemi-cellulose	-0.8316	Strong negative correlation
	Holocellulose	-0.9918	Strong negative correlation
	Ash content	0.9131	Strong positive correlation

APPENDIX D 8: Relationship between mass loss and some wood characteristics at the periphery of female middle

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	0.1826	Weak positive correlation
	Total extractives	0.05300	No correlation
	Lignin	0.9935	Strong positive correlation
	Alpha-cellulose	0.7878	Strong positive correlation
	Hemi-cellulose	-0.9482	Strong negative correlation
	Holocellulose	0.6266	moderate positive correlation
	Ash content	0.9961	Strong positive correlation

APPENDIX D 9: Relationship between mass loss and some wood characteristics at the core of female middle

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	0.4440	Weak positive correlation
	Total extractives	0.02281	No correlation
	Lignin	-0.9351	Strong negative correlation
	Alpha-cellulose	0.8310	Strong positive correlation
	Hemi-cellulose	0.9761	Strong positive correlation
	Holocellulose	-0.9841	Strong negative correlation

	Ash content	0.6055	Moderate positive correlation

APPENDIX D 10: Relationship between mass loss and some wood characteristics at the periphery of female crown

X Variable	Y Variable	Pearson correlation (r)	Interpretation
Mass loss	Dry density	-0.4104	Weak negative correlation
	Total extractives	0.2273	Weak positive correlation
	Lignin	0.7667	Strong positive correlation
	Alpha-cellulose	-0.9993	Strong negative correlation
	Hemi-cellulose	-0.9941	Strong negative correlation
	Holocellulose	-0.9958	Strong negative correlation
	Ash content	-0.9440	Strong negative correlation