KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF WOOD SCIENCE AND TECHNOLOGY

THE VARIABILITY BETWEEN THE STRENGTH AND SOME PHYSICAL PROPERTIES OF *ALLANBLACKIA PARVIFLORA* FOR FURNITURE PRODUCTION

BY

KWAKU ANTWI

B.Ed. (HONS)

NOVEMBER, 2012

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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 have been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

In Ghana, many of our traditional wood species are over exploited and threatened to extinction. The utilization of other lesser-used and lesser known wood species needs to be looked at urgently as a possibility of increasing the wood resource base. And a successful expansion of the resource base is dependent on adequate knowledge of the properties of the lesser-used species such as *Allanblackia parviflora* which can be a good substitute to the dwindling species. It was against this background that the strength and some physical properties of *Allanblackia parviflora* trees were determined to predict the suitability of the species for furniture production and as a structural raw material for downstream production of wood products. Three *Allanblackia parviflora* trees were extracted from a cocoa farm a moist semi-deciduous forest at Powuako near Ayanfuri in Western Region because of the known age of trees from plantation. Logs from the trees were converted to boards. One-half of the boards were used in the green state for the determination of the green moisture content, basic density and the mechanical tests. And the other half, air dried for mechanical tests. Mechanical strength test specimens were prepared and tested in accordance with the British Standard BS 373: 1957. Mean green moisture content was 81.19%. Mean basic density was 539.00kg/m^3. The range of mean strength values in N/mm^2 in the 'green' [and dry (12 % mc)] conditions for the three wood species were as follows: - Modulus of Rupture: 50.00 - 56.00 [85.00 - 94.00], Modulus of Elasticity: 6,387.00-6,951.00 [8,287.00 - 8,875.00], compression parallel to grain: 24.00-28.00 [13.00-14.00] and shear parallel to grain 6.83-7.74 [9.62-10.82]. Mean ratios of dry to 'green' MOR and MOE were 1.68 and 1.28. *Allanblackia parviflora* wood can be used for furniture production. In finding the variations among and within the three trees of *Allanblackia parviflora*, there are differences but these differences are not significant (p-value >0.001) among the tree. But for variations within tree-sawn planks [heart to sap division 1, 2, 3] indicates that, the strength of division one (1) and two (2) are higher than division three (3).Almost all strength tests conducted shows a consistent trend that, the heartwood portion of each division is slightly stronger in terms of resistance to failure than its corresponding sapwood portion. Based on the strength tests results, division one (1) and two (2) can be described as the heartwood portion and division three (3) as sapwood portion. Comparing the strength of

Allanblackia parviflora to an existing classification (grade), strength is 'medium' in *Allanblackia parviflora* wood. And this predicts the suitability of *Allanblackia parviflora* wood for furniture production. It is recommended that, other strength and physical properties such as hardness, cleavage and shrinkage tests are determined to obtain detailed information about the species in order to further predict their performance as structural raw materials for furniture production. Indeed, it is a good substitute to the dwindling (scarlet star) species, and will increase the wood resource base. It should be considered as exploitable raw material base for timber industries by stakeholders in wood industry.

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CHAPTER ONE

Introduction

1.1 Background of the study

Ghana has considerable wealth in tropical hardwood timber resources. There are about 680 different species of trees in the forest reserves of Ghana. Approximately 420 of these tree species attain timber size and therefore, are of potential economic value. About 126 of them occur in sufficient volumes to be considered exploitable as a raw material base for the timber industries (Ghartey, 1989). However, about 90% of the country's wood exports are covered by only 10 species (Jayanetti, 1999), and only 4 species contribute roughly 60% of the total production (Upton & Atta, 2003). The lesser-used species (LUS) occur in abundance in the forest, but increased harvesting must be on a sustainable basis to ensure continued harvesting potential.

Several years ago, Unilever became interested in using *Allanblackia* oil as a substitute for palm oil to produce commercial products such as margarine and soaps, as its physical and nutritional properties offer great potential for many products. As a result, Unilever has assisted FORIG to establish *Allanblackia* nursery at its Fumasua site in Kumasi. And currently the nursery covers 60 by 60 metres land area. One half of the nursery is screened by 50% shade netting supported by treated teak poles. The other half is under natural shade.

Also FORIG has adopted a scientific way of raising seedlings that are disease free. To achieve this aim, FORIG has constructed a Green House facility for raising vulnerable seeds for mass plantation purpose. The planting project will contribute to biodiversity conservation through the use of *Allanblackia* tree in forest landscape restoration programmes and agro forestry systems. Although the tree has frequently been used as a shade tree in cocoa farms, the increasing use of shade-tolerant hybrid cocoa is leading to the disappearance of these shade trees from farms. Now, the project will help provide cocoa farmers with an economic incentive to maintain these trees and inter-plant *Allanblackia* seedlings between their cocoa trees, until they are fully matured as timber for harvesting.

Allanblackia parviflora, an evergreen tree widely distributed in tropical forest in Ghana belongs to the family Guttiferae (Thompson, 1980). A tree up to 30m high, bark reddish brown, furrowed, stringy, stem blotchy-white (Thompson ,1980). This tree can be described as a hardwood (pored timber) because it bears flowers, its seeds are encased in fruit, it has a broad leaves and branches usually grow out at different levels, at the most two at the same level.

There are about half-dozen varieties of *Allanblackia* trees in tropical Africa. *Palviflora*, *Floribunda*, *Gabonensis, Stuhlmannii, Ulngurensis* are some of the varieties of *Allanblackia* tree. In Ghana it is known by various local names as Apesedua/Okusidua (Asante) Okisidwe (Denkyira), Suankyi (Wassa), Sonkyi (Nzema)

Most farmers from about four regions in Ghana have started commercial plantations of *Allanblackia parviflora* tree purposely for extraction of oil for both local and foreign market. Field planting started in early 2007. The project is establishing community nurseries at Appeasuman (near Bogoso), Afosu, Sureso (nearAsankragua), New Edubiase, Offinso, and Twifo Praso where farmers can have access training on how to plant *Allanblackia* seedling and will also be supplied to farmers, from these sites. It takes *Allanblackia* seeds 10 to 18 months to germinate and 10 years to bear fruits if it is not grafted or budded but to reduce fruit bearing period, seedlings produced would have to be grafted to start bearing fruits in a shorter period of time estimated at 4 years.

1.2 Statement of the problem

The increase in the material need of the growing human population has put much pressure on the world's forest resources so much that its effect on the environment is palpable and in controvertible Haygreen and Bowyer (1996).

The annual rate of forest degradation in Ghana is estimated to be 1.7% due to continuous and uncontrolled exploitation of the economic timber species, which is a threat to Ghana's forests, contributing to the rapid depletion of the plant genetic resources. (Oteng-Amoako *et al.,*1998).

The demand for wood in Ghana is increasing at an alarming rate such that the Annual Allowable Cut (AAC) of one Million m^3 is insufficient. Currently, the annual extraction of logs by the saw mills is estimated to be nearly 3.7 million m^3 (Anon, 2006). This poses a lot of problems to the forest in that demands of the wood industry and consequently, forcing the saw-mills to close down especially those in Ashanti Region.

Many of our traditional species are overexploited and threatened to extinction. The utilization of other lesser-used species needs to be looked at urgently as a possibility of increasing the wood resource base. And a successful expansion of the resource base is dependent on adequate knowledge of the properties of the lesser-used species such as *Allanblackia parviflora* which can be a good substitute to known and the dwindling (scarlet star) species.

Promoting LUS will release the pressure off the few primary timber species such as Odum, Wawa, Kusia, Asanfona, and Kyere, Again, it will reduce the cost of sawmilling operations and also ensure a more balanced usage of the entire natural forest product .These can help keep timber industries in business in the face of economic extensions of primary species.

As a result, the development and efficient utilization of *Allanblackia parviflora* tree which hitherto have not been commercially utilized industrially but is abundant in Ghana and are on plantations now could assist in arresting the current wood supply problems, expand the wood resource base, and also be a further source of income for farmers in the future.

In many uses wood is put, the wood is required to resist loads. It is therefore expedient to examine its behaviour when subjected to many forces or stresses before it can be recommended for use. And therefore mechanical tests and other tests such as extractive content, cell-wall thickness are conducted or designed almost exclusively to obtain data for predicting the performance of the wood material in use. (Bodig and Jayne, 1982)

1.3 Objectives/Research

The main objective of the study is ‘to determine the strength/mechanical properties and some physical properties and to assess *Allanblackia parviflora* tree’s suitability for furniture production.’

The specific objectives are;

- To determine the physical properties such as moisture content, basic density along the bole of each *Allanblackia parviflora* tree felled.
- To determine the mechanical properties such as static bending (MOR and MOE), compression and shear parallel to grain for within and among tree variation of *Allanblackia parviflora*.
- To compare the determined properties with an existing grades. And properties of three traditional wood species to know its suitability for furniture production.

1.4 Limitation

The acquisition and transportation of logs were very expensive. Equipment and tools were not readily available when needed. The researcher had to go for equipment in other institutions. Lack of sponsorship created a lot of financial difficulties to the researcher.

CHAPTER TWO

Literature Review

2.1 Wood as a structural material

Wood is a heterogeneous conglomeration of large numbers of very small elements of cells (Brown, 1988). The cavities of these cells in a dry condition are at least, largely occupied by air (Jane, 1956). According to Brown (1988), wood is basically a porous mass of tube like material held together by amorphous molecules of lignin and, depending upon species and types, containing various chemicals, minerals, gums, silica. It is an extremely complex substance whose versatility is unparalleled by any other material (Panshin *et al.*, 1964).

2.2 Significance of wood as a structural material

Eaton and Hale (1993) have said that throughout the course of history wood has remained one of the most important natural resources available to man and is found in every area of modern existence. According to FAO (1993), the world demand for timber and wood products has been growing at 1 to 2% per year and the total world production of industrial timber in 1990 was about 1,600 million cubic metres.

Wood is a structurally sound material and compares favourably with concrete, steel, stone, and a variety of other product/material. Wood in its natural state can be used for many forms of construction (Jayanetti, 1999). As a construction material, wood is strong, light, durable, and flexible and easily worked with. In contrast to the substitutes for wood in structural purposes such as brick, metal, concrete and plastics, wood can be produced and transported with little energy consumed and the products are renewed (Madson,2004).

According to Eaton and Hale (1993), the properties of solid wood and the structural durability of certain species of timber have provided man with a material, which has performed many functions including use as a building material for shelter. Bodig and Jayne (1982) also noted that in North America during the 1970s more wood products were used for construction than all other materials combined. Furthermore, the present world consumption of timber alone is equal to the world's annual production of steel and iron.

2.3 Factors affecting strength properties of wood

There are a great many factors affecting the strength of timbers and the nature of the material is such that widely differing results can be obtained from differing specimens of the same species (Taylor, 1991).

2.3.1 Moisture Content (MC)

The moisture content of a piece of wood is defined as the mass of water in the piece expressed as the percentage of the oven-dry mass of the wood. It has influence on all the strength properties of wood (Dinwoodie and Desch, 1996).

Panshin and de Zeeuw (1980) said that below the fibre saturation point, most of the strength properties vary inversely with the MC of the wood. Below the fibre saturation point shrinkage or swelling occurs, the increasing or reducing cohesion and stiffness (Kollmann and Cote, 1984). Panshin and de Zeeuw (1980) explain that, above the fibre saturation point, strength properties are constant with changes with MC. Thus free liquid water filling the coarser capillaries in vessels, tracheid and other elements of the wooden tissues does not affect strength (Kollmann and Cote, 1984).

According to Panshin *et al.,* (1964), the variations in strength of wood, due to changes in moisture content, are expressed as percentages of change of a given strength property for each 1% change in moisture content. For example the Modulus of Rupture value (**R**) at 12% moisture content represents 63% of the strength of oven dry wood, and **R** at 8% moisture content is 73%. Ishengoma and Nagoda (1991) have also reported that for a given change in moisture content below fibre saturation point, changes in strength properties are not the same. The average change in wood strength properties for 1% change in moisture content is given in *Table 2.1.* Small clear specimens thoroughly air dried (i.e. 12% moisture content) have practically twice the strength in bending and endwise compression of the same material when unseasoned. When kiln dried 5% moisture content the increase in strength may be threefold.

***Table 2.1*: The average Increase (or Decrease) in value of various strength properties affected by decreasing (or increasing) 1% Moisture Content when at about 12%**

Property	Percent (%)
Static Bending	
Fibre stress at elastic limit	6
Modulus of rupture	4
Modulus of elasticity	2
Work to elastic limit	8
Work to maximum load	-1
Impact Bending	
Fibre stress at elastic limit	4
Work to elastic limit	5
Height of hammer drop causing complete failure	-3
Compression parallel to grain	
Fibre stress at elastic limit	5
Crushing strength	4

Compression perpendicular to grain	
Fibre stress at elastic limit	6
Hardness-end	3
Hardness-side	1
Shear strength parallel to grain	4
Tension perpendicular to grain	1

Source: Desch (1996) in Ishengoma and Nagoda (1991)

Moisture content (MC) is a factor that influences almost all the strength properties of wood (Desch and Dinwoodie, 1996)

2.3.2 Density

The basic density of wood sample is related to its strength properties (Stalnaker and Harris, 1989). It was therefore essential that, this physical property of three *Allanblackia parviflora* wood be determined. Also the density of wood is a good index of its properties as long as the wood is clear, straight grained, and free from defects.

However, density values are also affected by the presence of gums, resins, and extractives which add to their weight and contribute little to mechanical properties (Lavers, 1983; Green *et al.*, 1999).

2.3.3 Specific Gravity (SG)

Tsoumis (1991) has defined specific gravity of wood as the ratio of the density of wood to the density of water. It is also called relative density. Moisture content influences density both in changing the total weight of the wood and in bringing about swelling and shrinkage below the fibre saturation point. For this reason, oven-dry weight is often related to the volume of a piece of wood at a specific MC. Calculated this way the property is normally termed “normal specific gravity” because it is expressed as the ratio of the assumed density of water (Metten, 1986).

The specific gravity of wood, because it is a measure of solid cell wall substance, is the best index that exists for predicting the strength properties of wood (Panshin and de Zeeuw, 1980). Results of strength tests according to Stalnaker and Harris (1989) show that strength properties S are related to SG in the form:

$$S = k\,(SG)^{n} \qquad \text{………………………………}2.2$$

Where *S* is any one of the strength properties, *k* is proportionality constant differing for each strength property and *n* is an exponent that defines the shape of the curve representing the relationship (Panshin and de Zeeuw, 1980).

However, in structural design, equation of this type has limited value since so many other factors such as extractive, cell size also affect wood strength, and it is the combination of all these factors that controls the actual strength of any member (Stalnaker and Harris, 1989).

Dinwoodie and Desch (1996) have stressed that some strength properties show a very marked correlation with density, and compression strength parallel to grain, bending strength and hardness fall into this category. However, shear and tensile strengths and cleavage although are influenced by density (specific gravity) are determined much more either by the cellular arrangement of the wood, or by the fine structure of the cell wall.

2.3.4 Anisotropic Behaviour of Wood

A material, which has different physical properties in the directions of various structural axes, is said to be anisotropic. The cell wall exhibits definite anisotropy because of the structural organization of the materials composing it (Panshin and de Zeeuw, 1980).

Strength properties depend on the anisotropy of wood (Illstron, 1994). Compressive, tensile and shear strengths vary widely between longitudinal and the lateral directions in wood. For example, the ratio of compression parallel to grain to the compression perpendicular to grain varies from a minimum of 4 in hardwoods, containing thick-walled fibres with small diameters, to a maximum of 12 in thin-walled tracheae in conifers. This means that wood is 4-12 times stronger in compression parallel to grain than it is perpendicular to grain (Panshin and de Zeeuw, 1980).

2.3.5 Cross Grain

Cross grain, a defect limited to wood (Bodig and Jayne, 1982) occurs when the longitudinal axis of the cells is not parallel to the edge of a piece of wood (Illstron, 1994). Hoadley (1990) explained that cross grain is measured quantitatively as slope of grain, taken as the ratio of unit of deviation across the grain to the corresponding distance along the grain.

The fibre deviation from a line parallel to the sides of the wood (cross grain) reduces strength because wood is much weaker across the grain than parallel to it (Wilcox *et al.*, 1991). Strength properties in directions ranging from parallel to perpendicular to the fibres can be approximated using Hankinson formula below.

$$N=P\sin^2\vartheta+Q\cos^2\vartheta \qquad \text{2.3}$$

In this equation, N represents the strength property at angle θ from the fibre direction, Q is the strength across the grain, P is strength parallel to the grain, and N is an empirically determined constant. Compression strength appears least affected by this characteristic. Bending and tensile strengths are drastically affected. Modulus of rupture, for example, is reduced by about 20% by the slope of 1:10 and by 45% by a slope of 1:5 (Anon, USDA, 1974).

2.3.6 Knots

Knots are formed by the change of wood structure that occurs where limbs grow from the main stem of the tree (Illstron, 1994).

Bodig and Jayne (1982) have indicated that knots introduce heterogeneity and therefore have major influence on the mechanical properties of wood. According to Hoadley (1990), they reduce strength in two ways. Firstly, the knot itself has abnormal cell structure that runs at an angle to the surrounding grain direction, and an encased knot is not connected to the surrounding tissue. Furthermore, the area around the knot usually contains cross grain that result in severe strength reduction.

Tensile strength is affected most by the knot but compression strength parallel to grain is reduced too. The amount of reduction depends on where the knot is located on the beam (wood) across the section (Illstron, 1994). Bodig and Jayne (1982) have, however, observed that not every property is adversely affected by the presence of knots. Overall strength and stiffness in compression perpendicular to grain as well as in shear along the grain benefit from the presence of knot.

2.3.7 Tension wood

Tension wood is usually formed on the upper side of leaning stems or branches of hardwoods, but a few kinds of trees form tension wood on the lower side (Onaka, 1949). Depending on its intensity, tension wood according to Tsoumis (1991) has higher density than normal wood. The higher density may be explained on the basis of thicker walls of gelatinous fibres. When tensions wood is present, the normal relationships of strength and moisture content and density do not apply.

Information on mechanical properties of this subnormal wood is quite incomplete (Panshin and de Zeeuw, 1980); few data are available. The available data suggest that compression strength both parallel and perpendicular to grain, modulus of rupture, modulus of elasticity in bending, and shear strength of tension wood are all lower than those of normal wood below the fibre saturation point (Bodig and Jayne, 1982).

2.3.8 Juvenile wood

Juvenile wood refers to a typical wood form around the pith during the first few years of growth (Hoadley, 2000). It is especially pronounced in trees with unusually fast initial growth. In plantation-grown conifers, which grow quickly due to lack of competition, juvenile-wood formation often continues for 15 or more years, forming a core several inches in diameter. In other cases, however, juvenile wood is either restricted to a few rings adjacent to the pith or is virtually nonexistence (Hoadley, 1990). The transition from juvenile wood to mature wood is gradual in some cases, abrupt in others. Juvenile wood may be lower than normal in density, especially in conifers. In some cases there are pronounced, differences in cell size the relative arrangement of cells or their microscopic appearance (Tsoumis, 1990). Wood from the first few growth rings should be compared to mature wood to get a sense of how different juvenile wood can be. In an unidentified piece or sample, mature wood should be examined whenever possible.

2.4 Mechanical properties of wood

The strength and resistance to deformation of a material such as wood are referred to as its mechanical properties (Haygreen and Bowyer, 1996). The strength of wood according to Desch and Dinwoodie (1996) refers to its ability to resist applied (load) forces that could lead to its failure. Failure is also the maximum stress that the wood sample will endure (Illstron, 1994). Haygreen and Bowyer (1996) reported that resistance to deformation determines the amount the wood is compressed, distorted, or bent under applied load.

In contrast to metals and other materials of homogeneous structure, wood exhibits different mechanical properties in different growth directions and therefore, it is mechanically anisotropic (Tsoumis, 1991)

2.5 Methods of determining strength properties of wood

Mechanical tests are designed almost exclusively to obtain data for predicting the performance of materials in use. Two distinctly different methods are in use to characterize the properties of wood. These are tests of small, clear, defect-free specimens and tests on timber and structural sizes (Bodig and Jayne, 1982). Only the first method is considered here.

2.5.1Test of Small Specimens of Wood

This method is valid for characterizing new timbers and for strict academic comparison of wood from different species. The method utilizes in a standardized procedure small, clear, straight-grained pieces of wood, which represent maximum quality that can be obtained. As such, the test specimens are not representative of timber actually being used without the application of a number of reducing factors. However, the method does afford the direct comparison of wood from different species. (Dinwoodie, and Desch, 1996).

2.6 Strength properties of wood

Some of the various strength properties of wood that are determined are:

- Static Bending

- Compression Parallel to Grain
- Compression Perpendicular to Grain
- Shear Parallel to Grain
- Tension Parallel to Grain
- Tension Perpendicular to Grain
- Modulus of Elasticity.

Of these, the first four are used intensively and the others receive limited use (Bodig and Jayne, 1982).

2.6.1 Bending Strength

Wilcox *et al.,* (1991) defined bending strength of wood as "an index of the maximum load a bending member can be expected to support before failing, weighted for the effects of span, width and depth". Bending strength results from a combination of all the three primary strengths (compression, shear and tension); they cause flexure or bending in the wood (Panshin *et al.*, 1964).

The bending strength of wood according to Dinwoodie and Desch (1996), usually presented as modulus of rupture (*MOR*) is the equivalent stress in the extreme fibres of specimen at a point of failure. *MOR* is calculated from the following equation (Kollmann and Cote, 1984):

$$MOR = \frac{3PL}{2wh^2} \qquad \text{.........................2.1}$$

Where,

P is the load in N

L is the span in mm

w is the width in mm and

h is height/depth in mm

2.6.2 Modulus of Elasticity (MOE)

Hooke's Law states, the ratio of stress to strain for a given piece of wood within the elastic range is a Constant. The ratio is called the modulus of elasticity. Also known as Young's Modulus and usually abbreviated as MOE or simply E, this ratio equals the stress divided by the resulting strain. It can be calculated by choosing any set of values of stress and resulting strain, although the stress and strain values at the proportional limit are conventionally used (Hoadley, 2000).The relative slope of the stress-strain curve, as indicated by the modulus of elasticity, E, gives a measure of a relative stiffness; the steeper the slope, the higher the 'E' value and stiffer the wood. Moreover, the higher the E value, the lower the deformation under a given load. Hoadley,(1990).

2.6.3 Compression Parallel to Grain

When a force or load tends to shorten or crush a wood, there is said to be compressive stress and the strength of wood is said to be compressive strength (Panshin *et al.*, 1964). Wilcox *et al.,* (1991) have also stated that, compression strength parallel to grain indicates maximum load that each square millimetre of wood can be expected to support as a column with the load being applied to the end grain, in the grain direction. The compressive strength is obtained by dividing the load to failure by cross-sectional area (Dinwoodie and Desch, 1996).

2.6.4 Shear Parallel to Grain

Panshin *et al.,* (1964) stated that shear strength of wood results when one portion of the wood slides over the other on application of external load. According to Bodig and Jayne (1982) because of the extremely high shear resistant across the grain, shear testing of wood is restricted to failure in the longitudinal direction only. Shear strength is determined by dividing the maximum load by the shear area (Dinwoodie and Desch, 1996).

2.6.5 Variability in Strength Properties of Wood

The strength property of wood species is known to vary widely. Some indication of the spread of property values is therefore desirable (Green *et al.,* (1999). The strength property is statistically normally distributed, with mean F_{mean} and standard deviation σn-1 (Sunley, 1968; Ocloo, 1985; CEN; 2002)

Ideally, the weakest strength value for the species should be used, but in practice the 'characteristic strength' is given. The European Standard EN 12511 (CEN, 2002) for determining the characteristic value uses the 5% point of exclusion for the mean bending strength of the test specimens. For the mechanical strength property of small clear specimens, statistically, this reduced characteristic strength value at the 5% point of exclusion is

$$Po5 = f\ mean - 1.96\ \sigma n\text{-}1,$$

Where

F mean = mean

σn-1 = standard Deviation.

2.7 Some standards (grades) for physical and mechanical test.

2.7.1 Ratio of dry to green grades, Ghana and USA.

Ghanaian hardwood (mean)	1.20 – 1.61	1.13 – 1.39	1.4 – 1.75	1.39 – 1.71
USA hardwood (mean)	1.20 – 2.10	1.11- 1.52	1.61 – 260	1.13 – 1.82

Dry means 12% moisture content source: American Society for Testing and Materials (ASTM, 2008).

2.7.2 TEDB (1994) has classified strength of species based on the MOE at 12% moisture Content as follows: Medium to very high classification indicate that the tree can be used for construction, flooring, stairs, furniture and cabinet works, boats, canoes, panelling and mouldings.

'Very High' → [19,000 N/mm^2 and more]

'High' → [14,000 N/mm^2 – 19,000 N/mm^2]

'Medium' → [11,000 N/mm^2 – 14,000 N/mm^2]

'Low' → [below 9,000 N/mm^2]

2.7.3 Based on Bolza and Keating (1972)

Wood species that falls within the MOR ranges S2-S4 predicts the wood uses as carvings, artifacts, construction, bridges, sleepers, furniture, mouldings, and musical instruments.

S2 → [MOR of 134 N/mm^2 and more]

S3 → [MOR of 114 N/mm^2 - 134 N/mm^2]

S4 → [MOR of 93.7 N/mm^2 -114 N/mm^2]

2.7.4 TEDB (1994) Weight classification. The weight of a species is a broad guide to its performance. Lighter weight species are softer, less durable and less strong. Heavy species can exhibit high level of strength, and toughness.

To assist in gaining a general idea of the nature of a species, the descriptions provide the average weight of that species when dried to 12-15% moisture content. In practice there is always variation. Wood species with very high to light-medium classification predicts the tree uses as construction , furniture, panelling, moulding, frames, trims, sleepers, floorings, vehicle and truck bodies.

Weight (kg per m^3) at 12-15% moisture content.

Light → 350 or less

Light-Medium 350 → 450

Medium → 450 – 575

Medium-Heavy → 575 – 725

Heavy → 725 – 900

Very Heavy → 900 or higher

CHAPTER THREE

Materials and Methods

3.1 Introduction

This chapter describes materials and methodology used for the research. The researcher describes the study area, wood sample collection, tree height and divisions showing points where test samples were collected, how surfaces of each billet was marked for sawing, preparation of test specimen for strength and physical properties, methods of determining some strength and physical properties of wood, test sample dimensions and formula used for the strength properties of wood and statistical analysis.

3.2 The study area

Three trees of *Allanblackia parviflora* were extracted from a cocoa farm in a moist semi-deciduous forest at Powuako near Ayanfuri in the Wassa Amanfi East District of Western Region of Ghana.

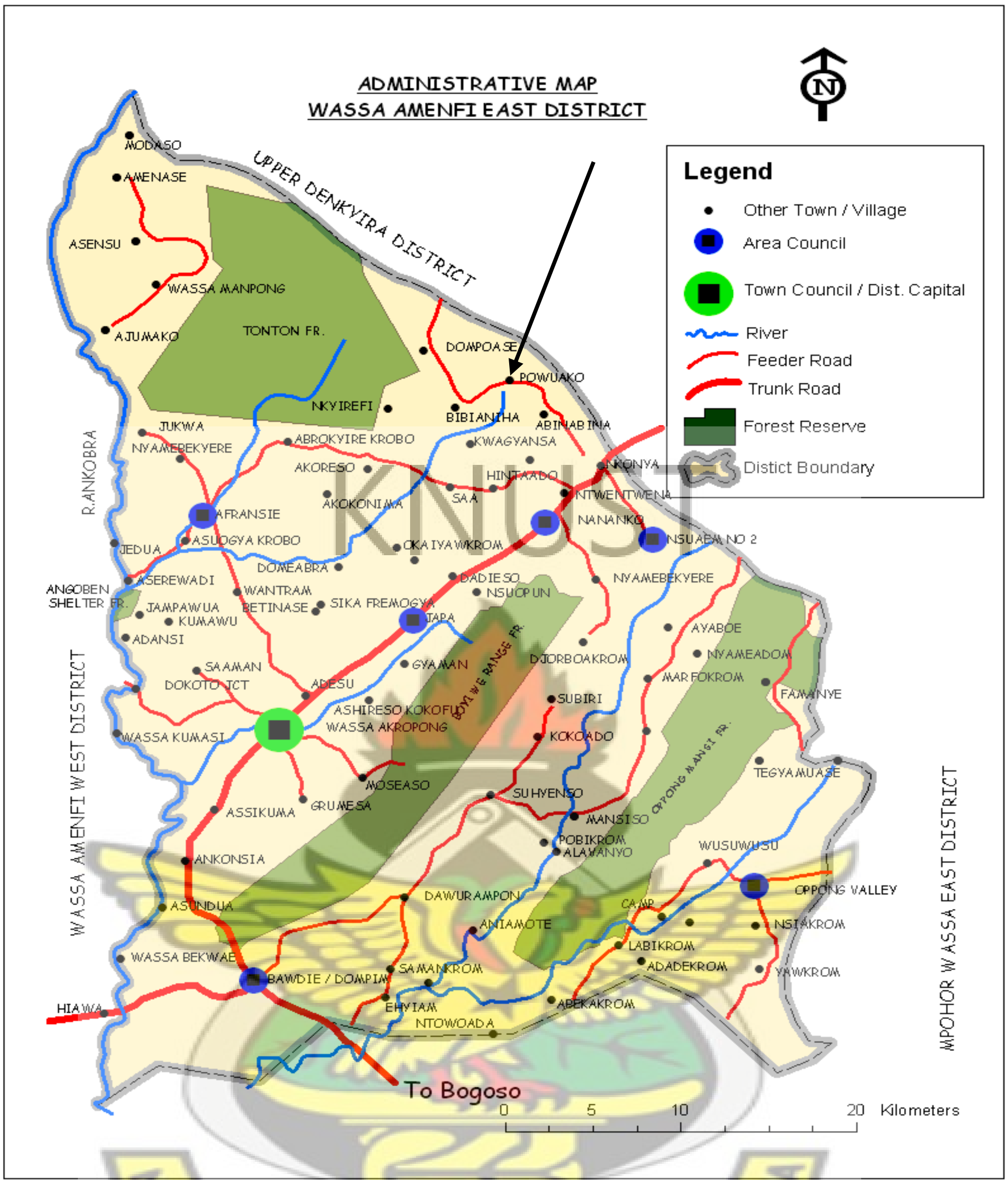


Figure 3.1 **Map of study area**. (Source: www.ghanadistricts.com)

The District is located in the middle part of the Western Region of Ghana. It lies between latitudes 5, 30` N, 6, 15` N, longitudes 1, 45` W, and 2, 11` W. It has an estimated total land area of about 16000 square kilometres; about 8% of the size of the region. It is bounded to the west by Wassa Amenfi West; to the East by Mpohor Wassa East, to the North by Upper and Lower Denkyira and to the south by Wassa West District.

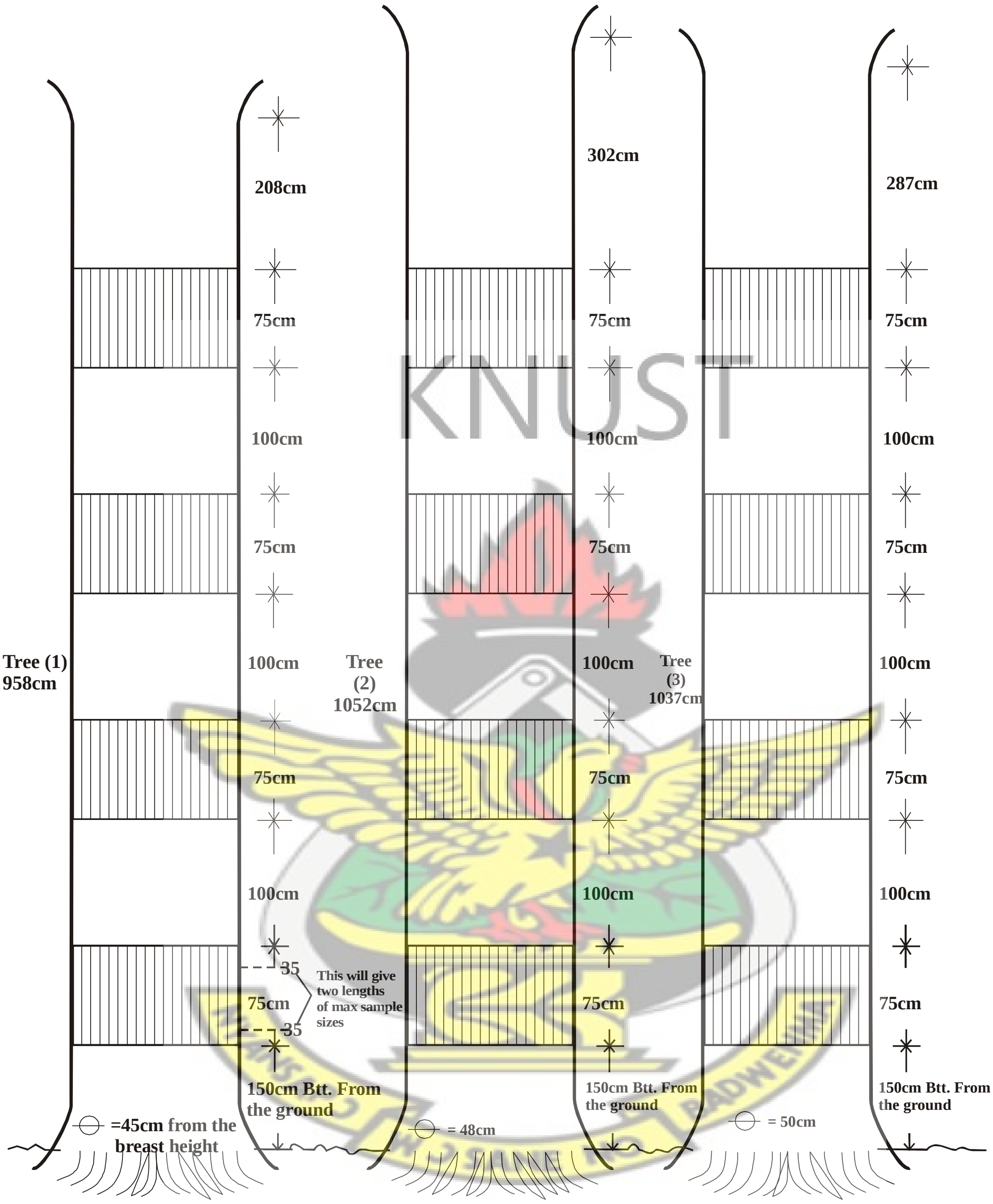
The wood samples were prepared at the wood science Department workshop, Faculty of Renewable Natural Resource (FRNR) of KNUST – Kumasi in the Ashanti Region. Moisture content and basic density determined were carried out at the Timber Mechanics and Engineering Laboratory, Forestry Research Institute of Ghana (FORIG) of Council for Scientific and Industrial Research (CSIR).

Strength properties of the wood samples compression parallel to grain, modulus of rupture and modulus of elasticity were determined at the Mechanical Engineering Department of the Kwame Nkrumah University of Science and Technology (KNUST) Kumasi. And shear parallel to grain test was carried out at the Timber Mechanics and Engineering Laboratory, Forestry Research Institute of Ghana (FORIG) of the Council for Scientific and Industrial Research (CSIR) at Fumesua near Kumasi in the Ashanti Region.

3.3 Wood sample collection

Three (3) trees of *Allanblackia parviflora* were purposefully selected (because of the known age of trees from plantation), and felled from the cocoa farm.

The diameter of trees harvested were 45cm, 48cm and 50cm respectively at breast height (150cm from the ground). And height of the trees were 1,290cm, 1,370cm and 1,340cm with a known age of 44 years from plantation as shown in *Figure 3.2*



208cm
302cm
287cm
75cm
100cm
Tree (1) 958cm
Tree (2) 1052cm
Tree (3) 1037cm
35
This will give two lengths of max sample sizes
150cm Btt. From the ground
=45cm from the breast height
= 48cm
= 50cm

Figure 3.2 **Sample tree height and divisions showing points where test samples were collected.**

Clear boles between where the buttresses terminated and the branches began in each tree were obtained. The bole of each tree was divided into four billets to determine the within and among tree variation. Division of each tree start 75cm from the breast height (150cm from the ground) which represent the buttress part (1), then 100cm intervals before taking 75cm as the middle from butt. Part (2), then another 100cm interval before taking75cm portion as middle from top part (3) and100cm intervals before finally taking 75cm high billet as the top part (4). These divisions were used to reflect the whole length of each tree.

The billet of each selected portion/part was divided into four (i.e. North, South, East and West) and sawn into three planks (1-3) from the pit portion of the billet to the bark portion of the tree to represent heart and sapwood part (sawn-planks division 1, 2, 3) of the tree. Marking and sawing were carefully done to ensure that the heart and sapwood portion of each billet was obtained as shown in *Figure 3.3*. The juvenile wood portion of each billet was rejected as from literature juvenile wood may be lower than normal in density and other strength properties.

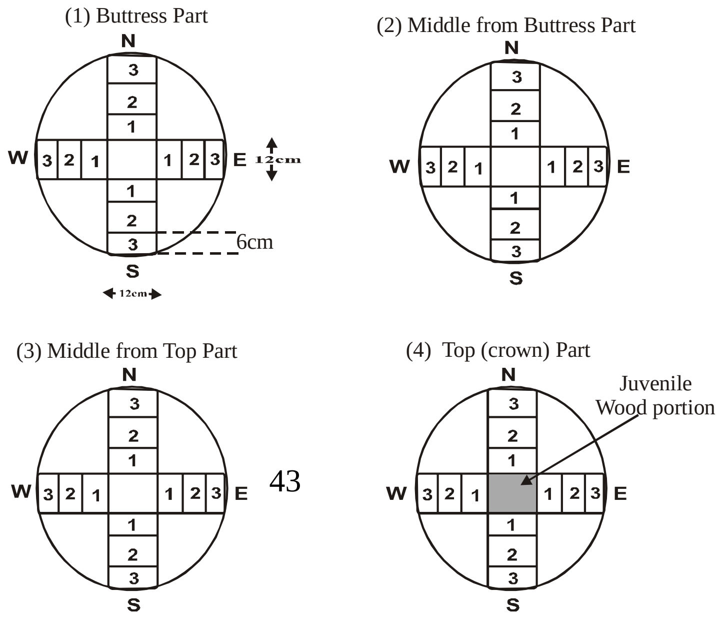
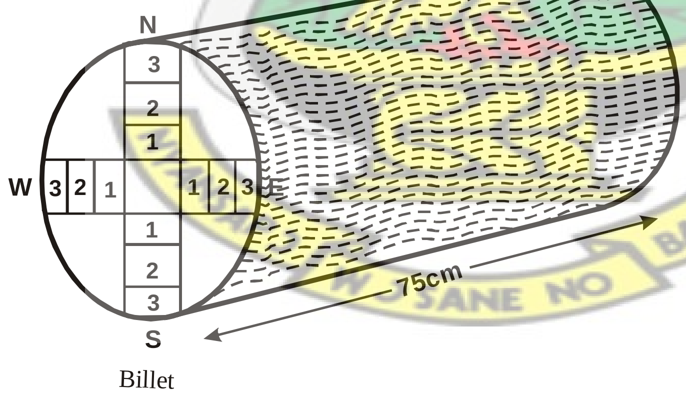
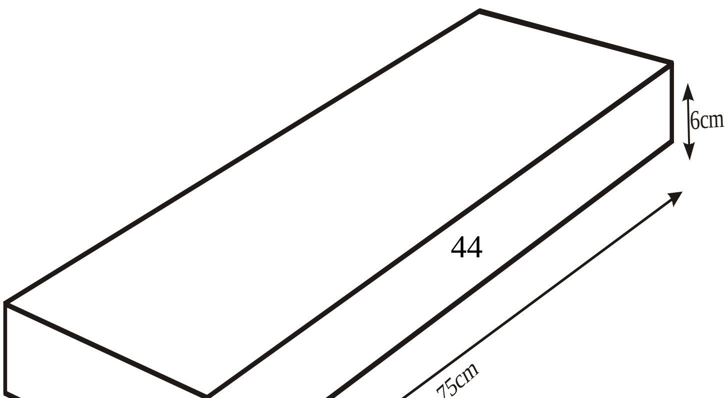


Figure 3.3 **How surfaces of each billet were marked for sawing**

A





B

Figure 3.4 **Pictorial views of billet and sawn planks from *Allanblackia* wood**

In all, twelve (12) billets of 75cm length were selected and for each billet, twelve (12) mini boards (sawn planks) were extracted giving a total, one hundred and forty four (144) sawn planks. Each board was carefully marked for easy identification. And half of the selected boards were kept in polythene bags to prevent changes in moisture content for moisture content, basic density and green mechanical tests.

3.4 Preparation of test specimen for the strength properties.

The samples were prepared based on British Standards BS 373 for modulus of rupture, modulus of elasticity, compression parallel to grain, moisture content, basic density and shear parallel to grain were prepared based on American Society for Testing and Materials (ASTM 1666) methods of testing small clear specimen of timber. It utilizes small, clear, straight-grained pieces of wood, which represent maximum quality that can be obtained.

For each tree extracted from the farm, four (4) portion/parts of the billets were used to determine the strength and the physical properties.

Samples were carefully selected from the prepared stakes of each board (sawn planks) free from defects such as knots, sloping grain and other deterioration caused by insects and fire as from literature these factors reduce some strength properties of wood.

The boards were divided into two; half were immediately prepared for green tests after harvesting. Whiles the other half were sawn into smaller sizes and stacked to air dry. The green boards were first sawn by a surfacer for a smooth surface ready to be ripped by a circular saw and finally, a thicknesser to get the required size for the test at Wood Science Department, wood work laboratory, FRNR – KNUST.

After sawing, the boards were further planned and carefully examined for any visible defect. Each wood sample was further ripped into the various sizes for the test. After the preparation, samples of a given strength test (of each billet) were kept in polythene bags to prevent changes in moisture content. One hundred and eighty (180) samples (made up of heart, sapwood portions and billet divisions) of each tree were prepared for green and one hundred and eighty (180) samples for dry compression parallel to grain, modulus of elasticity (MOE) and modulus of rupture (MOR) tests. And one hundred and eight (108) samples each for green and dry shear parallel to grain test, making a total of three hundred and sixty (360) samples for compression parallel to grain, modulus of rupture (M.O.R), modulus of elasticity (MOE) and two hundred and sixteen (216) samples for shear parallel to grain test making a grand total of one thousand, two hundred and ninety six (1,296) samples for all mechanical tests as depicted in *Table 3.1* Dimensions of the test specimens for the various strength properties are also depicted in *Table 3.2*

Table 3.1 **Samples taken from billets A, B, C and D of each tree for the determination of MOR, MOE, Compression, and Shear parallel to grain.**

A

	Compression		**MOR**		**MOE**		**Shear**	
Buttress Part (1)	Green	Dry	Green	Dry	Green	Dry	Green	Dry
1^1	15	15	15	15	15	15	9	9
1^2	15	15	15	15	15	15	9	9
1^3	15	15	15	15	15	15	9	9
Total	45	45	45	45	45	45	27	27

B

	Compression		**MOR**		**MOE**		**Shear**	
Middle from butt (2)	Green	Dry	Green	Dry	Green	Dry	Green	Dry
2^1	15	15	15	15	15	15	9	9
2^2	15	15	15	15	15	15	9	9
2^3	15	15	15	15	15	15	9	9
Total	45	45	45	45	45	45	27	27

C

	Compression		MOR		MOE		Shear	
Middle from top (3)	Green	Dry	Green	Dry	Green	Dry	Green	Dry
3^1	15	15	15	15	15	15	9	9
3^2	15	15	15	15	15	15	9	9
3^3	15	15	15	15	15	15	9	9
Total	45	45	45	45	45	45	27	27

D

	Compression		MOR		MOE		Shear	
Top (crown) (4)	Green	Dry	Green	Dry	Green	Dry	Green	Dry
4^1	15	15	15	15	15	15	9	9
4^2	15	15	15	15	15	15	9	9
4^3	15	15	15	15	15	15	9	9
Total	45	45	45	45	45	45	27	27

360 360 360 216

Compression parallel to the grain test

Modulus of Rupture test

Modulus of Elasticity

Shear parallel to the grain test

In all**, 1,296 samples** were used.

3.5 Determination of moisture content and basic density of the fresh wood samples

Before the determination of the strength properties, fresh wood samples from twelve billets of *Allanblackia parviflora* were prepared for determining moisture contents and basic density.

Moisture content is expressed as the percentage of the oven dry weight of the wood (Panshin *et al*, 1980). Thus,

$$MC = \frac{[\text{Initial weight - Oven-dry weight}]}{\text{Oven-dry weight}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots 3.1$$

Data:

W_1 = initial weight of sample in grams (g)

W_O = oven-dry weight of samples in grams (g) (BS 373: 1957).

Basic density (kgm^3) is usually expressed as weight per unit volume. Mathematically, it is expressed as

$$\text{Basic density} = \frac{[\text{oven-dry mass (kg)}]}{[\text{Mass of water displaced by swollen specimen or volume of cube } m^3]} \quad \ldots\ldots\ldots 3.2$$

Fresh samples for M.C. and Basic density were cut into dimension of 2cm x 2cm x 2cm. These samples were prepared from each division within the three trees of *Allanblackia parviflora.*

One hundred and twenty (120) samples from four (4) billets of each tree were used for the determination of each physical property (moisture content and basic density). After the preparation of the test, specimen /samples were immediately weighed by an electronic balance and oven-dried. The initial weights (W_1) and the oven-dry weight (W_O) were substituted in M.C. equation for moisture content determination.

The same test specimens of MC were used for the basic density test, where each 2cm x 2cm x 2cm cube was soaked in water for 24 hours. The basic density on swollen volume and oven-dry mass basis was determined by the immersion method. (The weight of a container and the water it contained were determined). The wood specimen was submerged in the water, and the mass of container plus water plus specimen was determined by electronic balance. The increase in mass of water displaced by the specimen in grams is numerically equal to the volume of water displaced in cm^3. The wood blocks were then oven-dried at a temperature of 101^oC - 105^oC to constant mass and oven dry mass determined.

3.6 Determination of strength properties of the wood

Immediately after preparation of test specimens, strength properties were determined. Compression parallel to grain and static bending (MOR) tests were tested on a Universal (multiple) 50 – ton Avery Machine made in Birmingham, England, installed at the laboratory of mechanical engineering department of KNUST Kumasi. And a shear parallel to grain test was carried out at the Timber Mechanics and Engineering laboratory at FORIG by an Instron -4482 machine with load cell capacity of 100kn

In all, four strength properties were determined, namely, compression strength parallel to grain, modulus of rupture (MOR) and modulus of elasticity (MOE) of static bending and shear strength parallel to grain. The straining rate for MOR and MOE was 0.26 in/min while shear and compression were strained at the rate of 0.25in/min each. After loading of each sample test, the load that caused each wood sample to fail was recorded and immediately kept in polythene bag to prevent moisture content changes.

The moisture content of each wood sample was immediately determined after the test of each strength property. Small portions of wood samples (2cm x 2cm x 2cm) near the portion of rupture (of test pieces for MOR) were used to determine moisture content. However, the whole test piece (for each strength test) for compression and shear parallel to grain was used for moisture content (MC) determination. The value of MC of each specimen (of a particular test) so obtained was recorded with the results of the particular test to which it refers. The formulae used in calculating strength values from the test data were those given in the British Standards BS 373: 1957 which was followed in the test programme of this study. The bending strength modulus of rupture and modulus of elasticity was computed using the central loading method (2cm standards test piece). Formulae for the various strength properties are recorded in *Table 3.2*.

Table 3.2 **Test sample dimensions and formulae for the strength Properties determination.**

Strength property	Sample Dimension	Formula

(N/mm^2)		Used
Modulus of Rupture (MOR)	20mmx20mmx300mm	$\frac{3PL}{2bh^2}$
Modulus of Elasticity (MOE)	20mmx20mmx300mm	$\frac{PL^3}{4bd^3\triangle}$
Shear Parallel to grain	50mmx50mmx50mm	$\frac{P}{bh}$
Compression parallel to grain	20mmx20mmx60mm	$\frac{P}{A}$

Source: BS 373: 1957, ASTMD 1666-143.

P= maximum load in Newton's

L=span = distance between the points of support of the test piece

= 280mm

h=breadth of test piece in mm

h=height of test piece in mm

A=area of cross-section of test piece in mm^2

The results were adjusted to12% moisture content as stated by Ishengoma and Nagoda, (1991), by the equations 3.3 to 3.5.

The ultimate strength in static bending (Modulus of Rupture) at moisture content w, was adjusted to strength at 12% moisture according to the formula

$\sigma_{12} = \sigma_{bw}$ (1+a (w-12)……………………………………………………………………3.3

σ_{12} = strength 12% moisture content

σ_{bw} = strength at moisture content w%

α = constant is the correction factor for moisture content, whose value shall be obtained from national standards (if not available a factor of 0.04 can be used for rough estimate)

For compression parallel to grain, the equation for strength at 12% moisture content is given by

$\sigma_{12} = \sigma_w (1+ \alpha (w-12)$ ……………………………………………………..*3.4*

Where $_w$ = strength at moisture w%

$\alpha = 0.05$

The equation *3.5* was also used to estimate shear strength at 12% moisture content;

$t_{12} = t_w = (1 + \alpha (w - 12))$ ………………………………………………………*3.5*

Where

t_{12} = shear strength at 12%

t_w = shear strength at moisture content w

$\alpha = 0.03$

3.7 Methods of statistical analysis

The data was analyzed statistically to assess the significant difference within each division of each tree and the variability between strength properties of three trees of *Allanblackia* *parviflora* using Excel analysis Tool pack (tools for scientific data analysis) in finding the descriptive statistics such as the means, standard deviation, standard error, minimum, maximum, count, confidence level and a single factor analysis of variance (ANOVA) to describe relationships.

3.8 Test recommended indicating the suitability of timber for specific uses

In order to reduce the amount of testing as far as possible the following table adopted from BS 373 : 1957, has been prepared to indicate the principal and auxiliary tests recommended for selecting the appropriate species of timber for the specific uses shown in *Table 3.3*

Table 3.3 **Recommended strength tests for specific uses of wood for flouring furniture, according to BS 373: 1957**

Specific use	Com. parallel to grain	Com. perpendicular to grain	Static Bending MOR MOE	Impact Bending	Inden-tation	Shear	Cleav-age	Tension parallel to grain	Shrinkage
13. Timber finished to size									X
14. Flooring (strip and plank wood block)		O	X		O		X		X
15. Furniture	X		X	O	O	X	O		

X = Principal tests, O = Auxiliary tests.

Source BS 373: 1957.pp 1

CHAPTER FOUR

Results

4.1 Introduction

The research set to determine some strength and physical properties of *Allanblackia parviflora* tree wood and to assess its suitability for furniture production. This chapter outlines results of basic/descriptive statistics and summary of ANOVA mean green moisture content and basic density among trees and within tree (Billet and sawn-planks divisions). And results of descriptive statistics when green and at 12% MC for static bending (MOR, MOE), compression and shear parallel to grain. And other physical and mechanical properties observed, during sample preparation and making a prototype chair from *Allanblackia parviflora* wood.

4.2 Moisture content of the fresh wood samples

One hundred and twenty test samples from each tree were used for moisture content determination. Statistical results indicate the means of tree one, two and three as 79.02, 82.52 and 82.05 percent with a standard deviation as 13.63, 11.20, and 8.29. At 95% confidence level, tree one, recorded 2.46, tree two 2.02 and tree three 1.49. *Table 4.1* and *4.2* depicts summary of the basic statistics and ANOVA of the green moisture content. And *Table 4.3* and *4.4* depicts results of the descriptive statistics of M.C for billet and sawn-planks divisions.

Table 4.1 **Summary of basic statistics of the green moisture content of *Allanblackia parviflora* (Among tree variations)**

STATISTIC	TREE 1	TREE 2	TREE 3	AVERAGE
Mean	79.00	82.52	82.05	81.19
Standard Deviation	13.60	11.20	8.29	11.33

Minimum	43.90	59.80	64.40	43.90
Maximum	100.70	100.70	96.20	100.70
Count	120.00	120.00	120.00	360.00
95% Confidence level (C.L)	2.46	2.02	3.09	1.17

Table 4.2 **Summary of ANOVA of mean Green Moisture content three trees.**

Allanblackia parviflora	Mean (± σ n-1)*	ANOVA between each Tree	
		Degrees of freedom	F
Tree 1	79.0 ± 12.6	F (6,113)	2.912
Tree 2	82.5 ± 10.9	F (6,113)	1.000
Tree 3	82.1 ± 8.3	F (6,113)	0.448

Table 4.3: **Results of the descriptive statistics for moisture content (Billet Divisions)**

		Tree (1)	Tree (2)	Tree (3)
	Mean	72.61	78.40	80.67
Buttress part	Std.Dev.	9.28	8.92	8.51
[1]	Min.	43.90	64.40	66.40
	Max.	83.20	92.40	91.90
	Count	30.00	30.00	30.00
	C.L	3.46	3.33	3.18
	Mean	76.01	82.79	80.96
Middle from buttress	Std.Dev.	11.58	12.79	9.56
Part [2]	Min.	58.20	59.80	64.40

	Max.	88.70	100.60	94.20
	Count	30.00	30.00	30.00
	C.L	4.33	4.77	3.57
	Mean	82.30	83.84	82.98
Middle from top	Std.Dev.	14.97	11.27	7.47
Part [3]	Min.	51.20	66.60	70.00
	Max.	100.60	100.20	96.20
	Count	30.00	30.00	30.00
	C.L	5.59	4.21	2.78
	Mean	85.17	85.03	83.58
Top part [4]	Std.Dev.	14.70	10.90	7.49
	Min.	57.10	61.60	71.70
	Max.	98.00	100.70	92.90
	Count	30.00	30.00	30.00
	C.L	5.49	4.07	2.78

Table 4.4 **Results of the descriptive statistics for moisture content sawn-planks division [Heart to sap, 1, 2, 3 divisions]**

		Tree (1)	Tree (2)	Tree (3)
[1]	Mean	80.85	95.32	88.05
	Std. Dev.	1.65	3.88	4.40
Buttress Part (1)	Min.	77.30	88.40	80.90
	Max.	83.20	100.70	96.20
	Count	10.00	10.00	10.00
	C.L.	1.18	2.78	3.15
[2]	Mean	68.23	86.63	86.40
	Std. Dev.	5.30	2.71	4.86
	Min.	60.40	81.80	80.90
	Max.	78.60	90.60	92.60
	Count	10.00	10.00	10.00
	C.L.	3.79	1.94	3.48
[3]	Mean	68.75	73.15	74.50
	Std. Dev.	11.54	9.11	3.88
	Min.	43.90	61.60	70.00
	Max.	81.00	96.80	80.90
	Count	10.00	10.00	10.00
	C.L.	8.26	6.52	2.78
[1]	Mean	85.84	96.37	90.07
Middle from Buttress part	Std. Dev.	1.97	2.18	2.13
	Min.	81.70	92.20	86.70

86.70

	Max.	88.70	100.20	92.90
	Count	10.00	10.00	10.00
	C.L.	1.41	1.56	1.52
[2]	Mean	81.53	84.70	85.67
	Std. Dev.	3.94	4.83	5.12
	Min.	73.70	76.20	74.30
	Max.	84.50	91.90	91.90
	Count	10.00	10.00	10.00
	C.L.	2.82	3.45	3.66
[3]	Mean	60.67	70.46	75.02
	Std. Dev.	3.21	2.59	4.16
	Min.	58.20	66.60	71.70
	Max.	69.10	74.90	85.00
	Count	10.00	10.00	10.00
	C.L.	2.29	1.86	2.97
[1]	Mean	93.47	95.21	88.51
	Std. Dev.	4.33	4.94	3.03
Middle from Top part	Min.	85.50	83.40	82.90
	Max.	100.60	100.60	91.90
	Count	10.00	10.00	10.00
	C.L.	3.09	3.53	2.17

[2]	Mean	90.88	85.98	83.07
	Std. Dev.	4.43	5.10	5.15
	Min.	83.10	79.60	76.20
	Max.	96.70	92.60	91.90
	Count	10.00	10.00	10.00
	C.L.	3.17	3.66	3.68
[3]	Mean	62.55	67.19	70.42
	Std. Dev.	5.54	4.80	2.54
	Min.	51.20	59.80	66.40
	Max.	71.60	73.40	74.90
	Count	10.00	10.00	10.00
	C.L.	3.96	3.44	1.82
Top part (4) [1]	Mean	94.11	87.46	87.92
	Std. Dev.	2.35	4.59	5.46
	Min.	88.20	97.40	78.40
	Max.	96.80	92.10	94.20
	Count	10.00	10.00	10.00
	C.L.	1.69	3.28	3.93
[2]	Mean	95.81	78.06	85.24
	Std. Dev.	1.67	7.05	6.24
	Min.	92.70	69.20	73.20
	Max.	98.00	87.20	91.90
	Count	10.00	10.00	10.00
	C.L.	1.19	5.04	4.46

[3]	Mean	65.61	69.65	69.70
	Std. Dev.	6.98	2.98	3.19
	Min.	57.10	64.40	64.40
	Max.	76.50	76.20	76.70
	Count	10.00	10.00	10.00
	C.L.	4.99	2.13	2.28

4.3 Basic density of the fresh wood sample

One hundred and twenty test samples from each tree were used for basic density determination. Statistical results indicate the means of tree one, two and three as 447.00, 539.00, and 536.00 kg/m^3 with a standard deviation of 70.15, 51.50 and 50.56,respectfully. At 95% confidence level, tree one recorded 12.68, tree two 9.31 and tree three 9.14. *Table 4.5* and *4.6* depicts the summary of the statistics and ANOVA of the basic density of the fresh wood samples. And *Table 4.7 and 4.8* also depicts results of the descriptive statistics of basic density for billet and sawn-planks divisions.

Table 4.5 **Summary of basic statistics of the green basic density of *Allanblackia parviflora* trees. (Among tree variations)**

STATISTIC	TREE 1	TREE 2	TREE 3	AVERAGE
Mean	446.65	539.03	536.88	507.50
Standard Deviation	66.34	51.65	49.77	52.22
Minimum	285.00	398.00	348.00	285.00

Maximum	587.00	621.00	613.00	621.00
Count	120.00	120.00	120.00	360.00
95% Confidence level	24.77	19.29	17.34	7.48

Table 4.6 **Summary of ANOVA of mean Green Basic Density of three trees.**

Allanblackia parviflora	Mean ($\pm\sigma_{n-1}$)*	ANOVA between each Tree	
		Degrees of freedom	F
Tree 1	446±66.1	$F(6,113)$	1.960
Tree 2	539±51.7	$F(6,113)$	0.216
Tree 3	536±49.8	$F(6,113)$	0.943

Table 4.7 **Results of the Descriptive Statistics for basic density (Billet Divisions)**

	Tree (1)	**Tree (2)**	**Tree (3)**
Mean	419.17	534.10	518.40

Buttress part [1]	Std.Dev.	47.69	56.54	57.55
	Min.	337.00	398.00	348.00
	Max.	479.00	618.00	601.00
	Count	30.00	30.00	30.00
	C.L	17.81	21.11	21.49
	Mean	432.33	542.27	542.23
Middle from buttress part [2]	Std.Dev.	60.78	45.16	46.25
	Min.	335.00	435.00	428.00
	Max.	502.00	619.00	604.00
	Count	30.00	30.00	30.00
	C.L	22.69	16.86	17.26
	Mean	409.53	546.30	539.60
Middle from top Part [3]	Std.Dev.	81.27	48.82	48.72
	Min.	304.00	432.00	460.00
	Max.	587.00	617.00	608.00
	Count	30.00	30.00	30.00
	C.L	30.55	18.22	18.19
	Mean	465.57	533.40	547.17

Top part	Std.Dev.	75.61	56.07	46.56
[4]	Min.	285.00	428.00	477.00
	Max.	533.00	621.00	613.00
	Court	30.00	30.00	30.00
	C.L	28.23	20.94	17.38

Table 4.8 **Results of the descriptive statistics for basic density sawn-planks division [Heart to sap, 1, 2, 3 divisions]**

			Tree (1)	Tree (2)	Tree (3)
Buttress Part (1)	**[1]**	Mean	466.40	549.00	532.60
		Std. Dev.	9.48	35.59	38.78
		Min.	448.00	518.00	489.00
		Max.	479.00	618.00	601.00
		Count	10.00	10.00	10.00
		C.L.	6.79	25.46	27.74
	[2]	Mean	404.20	584.30	548.70
		Std. Dev.	41.86	16.36	73.79
		Min.	337.00	546.00	348.00
		Max.	457.00	607.00	592.00
		Count	10.00	10.00	10.00
		C.L.	29.94	11.70	52.79
	[3]	Mean	386.90	469.00	473.90
		Std. Dev.	40.03	31.81	16.68
		Min.	337.00	398.00	445.00
		Max.	452.00	508.00	506.00
		Count	10.00	10.00	10.00
		C.L.	28.64	22.76	11.93
Middle from Buttress part	**[1]**	Mean	472.60	570.90	581.80
		Std. Dev.	8.15	23.97	18.12
		Min.	458.00	538.00	555.00

	Max.	490.00	619.00	603.00
	Count	10.00	10.00	10.00
	C.L.	5.83	1.56	12.96
[2]	Mean	474.80	563.10	553.30
	Std. Dev.	18.44	29.90	33.38
	Min.	435.00	532.00	518.00
	Max.	502.00	612.00	604.00
	Count	10.00	10.00	10.00
	C.L.	13.19	21.43	2387
[3]	Mean	349.60	492.80	491.60
	Std. Dev.	9.20	31.41	26.92
	Min.	335.00	435.00	428.00
	Max.	362.00	523.00	521.00
	Count	10.00	10.00	10.00
	C.L.	6.58	22.47	19.26
[1]	Mean	515.80	578.00	565.30
Middle from	Std. Dev.	12.62	28.73	33.59
Top part	Min.	494.00	536.00	513.00
	Max.	939.00	617.00	608.00
	Count	10.00	10.00	10.00

	C.L.	9.03	21.27	24.03
[2]	Mean	523.40	572.20	569.70
	Std. Dev.	32.02	23.91	32.74
	Min.	470.00	527.00	509.00
	Max.	587.00	604.00	603.00
	Count	10.00	10.00	10.00
	C.L.	22.93	17.10	23.42
[3]	Mean	369.40	488.70	483.80
	Std. Dev.	57.89	25.99	15.70
	Min.	304.00	432.00	460.00
	Max.	514.00	526.00	504.00
	Count	10.00	10.00	10.00
	C.L.	41.41	18.59	11.23
Top part (4) [1]	Mean	510.50	577.90	581.60
	Std. Dev.	11.32	42.98	26.62
	Min.	482.00	489.00	538.00
	Max.	524.00	621.00	613.00
	Count	10.00	10.00	10.00
	C.L.	8.10	30.75	19.04
[2]	Mean	519.40	543.00	567.30
	Std. Dev.	8.72	40.94	31.86
	Min.	504.00	488.00	513.00
	Max.	533.00	610.00	603.00

	Count	10.00	10.00	10.00
	C.L.	6.24	29.29	22.79
[3]	Mean	366.80	479.30	492.60
	Std. Dev.	43.87	32.43	13.61
	Min.	285.00	428.00	744.00
	Max.	417.00	518.00	520.00
	Count	10.00	10.00	10.00
	C.L.	31.32	23.19	9.74

4.4 Static bending tests [modulus of rupture (MOR) and modulus of elasticity (MOE)]

Sixty test samples were used for both green and dry MOR determination. Statistical results indicate the means of tree one, two and three when green [and at 12% mc] as 50.3 [91.9], 54.3 [84.7], and 55.1[93.9] with a standard deviation as 0.56 [0.49], 0.50 [0.40] and 0.33 [0.54]. *Table 4.9* A&B shows the basic statistics for both green and 12% mc test results for MOR. And *Table 4.10* and *4.11* also depicts results of the descriptive statistics of MOR for billet and sawn-planks divisions

Table 4.9 **Modulus of Rupture of three trees of *Allanblackia parviflora* when 'green' and at 12% moisture content**

A. Statistics of 'Green' Modulus of Rupture N/mm^2

Tree Nº.	Mean	P_05	Std.Dev.	Min	Max	Count.	Mean Test M.C
1	50.31	49.20	0.56	42.00	56.00	60.00	52.60
2	54.70	53.70	0.50	46.70	60.70	60.00	54.30
3	55.10	54.50	0.33	50.90	58.30	60.00	53.40

B. Statistics of Modulus of Rupture at 12% M.C.

Tree Nº.	Mean	P_05	Std.Dev.	Min	Max	Count.
1	91.90	90.90	0.49	84.40	98.10	60.00
2	84.70	83.90	0.40	78.80	93.50	60.00
3	99.90	92.80	0.54	87.10	99.90	60.00

Table 4.10 **Results of the Descriptive Statistics for MOR at 12% M.C (Billet Divisions)**

		Tree (1)	Tree (2)	Tree (3)
	Mean	85.71	94.99	94.76
Buttress part [1]	Std.Dev.	3.85	4.98	4.67
	Min.	80.70	84.40	87.00
	Max.	93.70	98.10	99.90
	Count	15.00	15.00	15.00
	C.L	2.13	2.76	2.59

	Mean	83.92	91.95	93.39
Middle from buttress	Std.Dev.	3.29	2.97	3.54
Part [2]	Min.	78.80	86.60	87.00
	Max.	88.40	95.10	98.30
	Count	15.00	15.00	15.00
	C.L	1.83	1.65	1.96
	Mean	83.92	91.42	93.95
Middle from top	Std.Dev.	3.29	3.95	4.46
Part [3]	Min.	78.80	85.30	87.10
	Max.	88.40	97.20	99.90
	Count	15.00	15.00	15.00
	C.L	1.83	2.19	2.47
	Mean	84.20	91.32	93.37
Top part [4]	Std.Dev.	2.48	3.01	4.19
	Min.	79.30	85.30	87.60
	Max.	87.90	94.50	99.90
	Count	15.00	15.00	15.00
	C.L	1.37	1.67	2.32

Table 4.11 **Results of the descriptive statistics for modulus of rupture sawn-planks division [Heart to sap, 1, 2, 3 divisions]**

		Tree (1)	Tree (2)	Tree (3)
[1]	Mean	89.10	96.86	98.36

		Std. Dev.	3.75	1.25	1.08
Buttress Part (1)		Min.	86.20	95.60	96.90
		Max.	93.50	98.10	99.90
		Count	5.00	5.00	5.00
		C.L.	4.66	1.55	1.34
	[2]	Mean	85.44	95.58	97.12
		Std. Dev.	2.41	1.51	1.64
		Min.	82.80	94.10	94.50
		Max.	87.30	97.50	98.50
		Count	5.00	5.00	5.00
		C.L.	2.99	1.87	2.03
	[3]	Mean	82.58	86.54	88.80
		Std. Dev.	2.27	2.00	2.21
		Min.	80.70	84.40	87.00
		Max.	85.10	88.70	91.50
		Count	5.00	5.00	5.00
		C.L.	2.82	2.49	2.75
	[1]	Mean	87.46	93.78	95.98
		Std. Dev.	1.23	1.41	1.56
Middle from Buttress part		Min.	85.50	92.30	93.90
		Max.	88.40	95.10	98.30
		Count	5.00	5.00	5.00
		C.L.	1.52	1.75	1.94

[2]	Mean	84.08	93.82	94.94
	Std. Dev.	1.44	0.83	0.96
	Min.	82.50	92.90	93.90
	Max.	85.70	95.10	96.00
	Count	5.00	5.00	5.00
	C.L.	1.79	1.03	1.19
[3]	Mean	80.22	88.24	89.20
	Std. Dev.	1.29	1.60	2.64
	Min.	78.80	86.60	87.00
	Max.	81.20	89.80	92.60
	Count	5.00	5.00	5.00
	C.L.	1.61	1.98	3.27
[1]	Mean	86.86	93.60	97.58
	Std. Dev.	2.17	3.29	1.89
Middle from	Min.	84.20	88.40	95.10
Top part	Max.	90.10	97.20	99.90
	Count	5.00	5.00	5.00
	C.L.	2.71	4.09	2.34
[2]	Mean	86.04	93.36	96.10
	Std. Dev.	1.83	3.16	1.37
	Min.	84.20	88.70	94.80
	Max.	88.10	97.20	98.30
	Count	5.00	5.00	5.00

	C.L.	2.28	3.92	1.71
[3]	Mean	82.46	87.30	88.18
	Std. Dev.	2.05	1.35	0.61
	Min.	81.40	85.30	87.10
	Max.	86.10	88.70	88.50
	Count	5.00	5.00	5.00
	C.L.	2.55	1.68	0.75
Top part (4) [1]	Mean	86.32	93.98	95.94
	Std. Dev	1.47	0.50	2.22
	Min.	85.00	93.50	94.80
	Max.	87.90	94.50	99.90
	Count	5.00	5.00	5.00
	C.L.	1.84	0.62	2.75
[2]	Mean	84.58	92.14	96.26
	Std. Dev.	0.89	0.45	0.78
	Min.	83.30	91.80	95.60
	Max.	85.50	92.90	97.50
	Count	5.00	5.00	5.00
	C.L.	1.10	0.52	0.96
[3]	Mean	81.70	87.84	87.92
	Std. Dev.	2.21	2.53	0.44
	Min.	79.30	85.30	87.60

Max.	83.80	91.20	88.40
Count	5.00	5.00	5.00
C.L.	2.75	3.14	0.54

Same sample number used for M.O.R were used for MOE statistical results indicate the means of tree one, two and three when green and [at 12% M.C] as 6,387.00 [8,287.00], 6,951.00 [8,875.00], and 6,556.00 [8,475.00] with a minimum of 5,987.00 and a maximum of 11,084.00 and a standard deviation of 121.00 [127.00], 126.00 [127.00] and 112.00 [116.00] respectively. The mean test moisture content of three trees for green tests ranges from 52.60-64.30. *Table 4.12* shows the basic statistics for both green and dry [12%mc] test results for MOE. And *Table 4.13* and *4.14* also depicts results of the descriptive statistics of MOE for billet and sawn-planks divisions

Table 4.12 **Modulus of Elasticity of Three *Allanblackia parviflora* Tree When 'Green' and at 12% M.C**

A. Statistics of 'green' MOE (N/mm^2)

Tree Nº.	Mean	P_05	Std.Dev.	Min	Max	Count.	Mean Test M.C
1	6,387.00	6,149.00	121.00	3,994.00	8,446.00	60.00	52.60
2	6,951.00	6,704.00	126.00	4,386.00	9,121.00	60.00	54.30
3	6,556.00	6,336.00	112.00	3,994.00	8,650.00	60.00	53.40

B. Statistics of MOE at "12% MC"

Tree Nº.	Mean	P_05	Std.Dev.	Min	Max	Count.

1	8,287.00	8,038.00	127.00	5,987.00	10,381.00	60.00
2	8,875.00	8,626.00	127.00	6,264.00	11,084.00	60.00
3	8,475.00	8,247.00	116.00	5,987.00	10,526.00	60.00

Table 4.13 **Results of the Descriptive Statistics for MOE at 12% M.C (Billet Divisions)**

		Tree (1)	Tree (2)	Tree (3)
Buttress part [1]	Mean	7763.47	8967.60	8777.93
	Std.Dev.	1129.27	610.71	792.23
	Min.	5987.00	8110.00	7218.00
	Max.	9341.00	10019.00	10019.00
	Count	15.00	15.00	15.00
	C.L	625.37	338.19	838.73
Middle from buttress Part [2]	Mean	9139.27	8730.33	8331.20
	Std.Dev.	762.63	791.26	576.91
	Min.	8015.00	7218.00	7391.00
	Max.	10381.00	9673.00	9200.00
	Count	15.00	15.00	15.00
	C.L	422.32	438.09	319.48
Middle from top Part [3]	Mean	8205.05	9568.00	8766.47
	Std.Dev.	768.11	817.67	576.91
	Min.	7100.00	8435.00	7401.00
	Max.	9162.00	11084.00	9661.00
	Count	15.00	15.00	15.00

	C.L	425.37	452.81	372.72
	Mean	8042.20	8967.60	8024.46
Top part [4]	Std.Dev.	706.45	610.70	1266.62
	Min.	6672.00	8110.00	5987.00
	Max.	9200.00	10019.00	10526.00
	Count	15.00	15.00	15.00
	C.L	391.22	338.19	701.43

Table 4.14 **Result of the descriptive statistics for modulus of elasticity sawn-planks division [Heart to sap, 1, 2, 3 divisions]**

		Tree (1)	Tree (2)	Tree (3)
[1]	Mean	6948.60	6848.40	9228.61
	Std. Dev.	611.69	609.41	773.12
Buttress Part (1)	Min.	6249.00	6310.00	8214.00
	Max.	7610.00	7558.00	10381.00
	Count	5.00	5.00	5.00
	C.L.	759.51	759.59	959.92

	[2]	Mean	7680.20	7564.00	8558.20
		Std. Dev.	1246.05	611.69	607.12
		Min.	5987.00	1260.06	8008.00
		Max.	9341.00	5987.10	9151.00
		Count	5.00	5.00	5.00
		C.L.	154.18	1524.16	628.43
	[3]	Mean	8661.60	8447.60	8380.42
		Std. Dev.	830.39	830.12	489.64
		Min.	7331.00	6423.00	7651.00
		Max.	9284.00	9284.00	11900.00
		Count	5.00	5.00	5.00
		C.L.	1031.07	1031.07	607.97
Middle from Buttress part	[1]	Mean	9227.60	6948.60	8568.40
		Std. Dev.	773.12	611.69	506.38
		Min.	8214.00	8214.00	8006.00
		Max.	10381.00	10681	9156.00
		Count	5.00	5.00	5.00
		C.L.	959.95	959.01	628.40
	[2]	Mean	9265.00	9227.60	8214.60
		Std. Dev.	834.47	773.12	870.16
		Min.	8431.00	8214.00	7236.00
		Max.	10126.00	10381.00	14071.00
		Count	5.00	5.00	5.00

	C.L.	1038.13	959.42	1080.32
[3]	Mean	8925.40	7844.06	8661.60
	Std. Dev.	809.23	856.22	830.39
	Min.	8015.00	7200.00	7331.00
	Max.	10121.00	9101.00	9284.00
	Count	5.00	5.00	5.00
	C.L.	1004.79	963.48	1031.07
[1]	Mean	8558.20	9228.40	7564.00
	Std. Dev.	504.86	796.22	611.69
Middle from Top part	Min.	8006.00	8431.00	1260.00
	Max.	9151.00	10126.00	5987.00
	Count	5.00	5.00	5.00
	C.L.	626.87	964.03	1524.16
[2]	Mean	8214.20	9267.80	8380.00
	Std. Dev.	870.45	836.41	489.64
	Min.	7236.00	8431.00	7654.00
	Max.	41071.00	10124.00	10900.00
	Count	5.00	5.00	5.00
	C.L.	1080.81	908.47	608.46

[3]	Mean	7844.00	8925.40	8925.40
	Std. Dev.	856.44	809.20	809.23
	Min.	7100.00	8015.00	8015.00
	Max.	9101.00	10121.00	10121.00
	Count	5.00	5.00	5.00
	C.L.	1063.00	972.00	1004.79
[1]	Mean	8060.80	8264.30	6864.42
	Std. Dev.	871.80	869.70	608.33
Top part	Min.	6892.00	6896.00	9893.00
(4)	Max.	10304.00	10304.00	10371.00
	Count	5.00	5.00	5.00
	C.L.	1082.48	1081.48	966.48
[2]	Mean	8280.00	8463.24	8214.20
	Std. Dev.	489.64	496.31	870.45
	Min.	7651.00	7659.00	7236.00
	Max.	11900.00	12060.00	14107.00
	Count	5.00	5.00	5.00
	C.L.	607.97	609.04	1018.00
[3]	Mean	7685.80	8060.80	8664.92
	Std. Dev.	667.17	871.80	846.01
	Min.	6672.00	6892.00	7432.00
	Max.	8429.00	10304.00	9286.00
	Count	5.00	5.00	5.00
	C.L.	828.41	1063.00	1001.10

4.5 Compression parallel to grain test

For compression parallel to grain, sixty test samples for both green and dry were used for the test. Basic statistical results indicate the means of tree one, two and three when green and [at 12%mc] as 23.60 [12.90], 27.90 [13.00] and 22.80 [14.10] with a standard deviation 1.23 [0.23], 1.04 [0.31] and 1.16 [0.32]. *Table 4.15* show the basic statistics for both green and dry [12%] test results for compression parallel to grain. And *Table 4.16* and *4.17* also depicts results of the descriptive statistics of compression parallel to grain for billet and sawn-planks divisions.

Table 4.15 **Compression parallel to grain of three *Allanblackia parviflora* trees when 'green' and at 12% moisture content.**

A. Statistics of 'green' comp. parallel to grain. N/mm²

Tree Nº.	Mean	P_05	Std.Dev.	Min	Max	Count.	Mean Test M.C
1	23.60	21.20	1.23	38.80	60.00	60.00	55.70
2	27.90	25.10	1.04	40.10	60.00	60.00	57.10
3	22.80	20.90	1.16	38.30	60.00	60.00	56.70

B. Statistics of compression parallel to grain at 12% M.C.

Tree Nº.	Mean	P_05	Std.Dev.	Min	Max	Count.
1	12.90	12.50	0.23	8.70	15.60	60.00
2	13.00	12.40	0.31	8.60	17.60	60.00

3	14.10	13.50	0.32	8.80	21.50	60.00

Table 4.16 **Results of the Descriptive Statistics for Compression parallel to grain at 12% M.C (Billet Divisions)**

Buttress part [1]	Mean	13.35	14.87	15.81
	Std.Dev.	1.85	2.14	2.64
	Min.	11.00	10.80	10.90
	Max.	15.60	17.60	21.50
	Count	15.00	15.00	15.00
	C.L	1.02	1.19	1.69
Middle from buttress Part [2]	Mean	12.62	13.10	13.34
	Std.Dev.	1.94	2.02	1.55
	Min.	8.70	8.60	10.70
	Max.	15.30	15.40	15.60
	Count	15.00	15.00	15.00
	C.L	1.08	1.12	0.86
Middle from top part [3]	Mean	13.17	12.89	13.86
	Std.Dev.	1.56	2.56	2.29
	Min.	10.70	8.70	10.70
	Max.	15.30	15.30	17.60
	Count	15.00	15.00	15.00
	C.L	0.86	1.42	1.27

	Mean	12.42	11.41	13.47
Top part [4]	Std.Dev.	1.43	1.65	2.56
	Min.	10.50	8.80	8.80
	Max.	15.60	15.00	17.60
	Count	15.00	15.00	15.00
	C.L	0.79	0.92	1.42

Table 4.17 **Results of the descriptive statistics for compression parallel to grain sawn-planks division [Heart to sap, 1, 2, 3 divisions]**

			Tree (1)	**Tree (2)**	**Tree (3)**
	[1]	Mean	14.84	16.24	17.90
		Std. Dev.	` 0.43	1.05	2.22
Buttress Part (1)		Min.	14.60	15.10	15.40
		Max.	15.60	17.20	21.50
		Count	5.00	5.00	5.00
		C.L.	0.53	1.30	2.75
	[2]	Mean	14.20	16.04	16.64
		Std. Dev.	1.15	1.34	1.13
		Min.	13.30	15.00	15.40
		Max.	15.60	17.60	17.60
		Count	10.00	10.00	10.00
		C.L.	1.42	1.67	1.41

[3]		Mean	11.02	12.34	12.90
		Std. Dev.	0.04	1.05	1.12
		Min.	11.00	10.80	10.90
		Max.	11.10	13.20	13.50
		Count	5.00	5.00	5.00
		C.L.	0.05	1.30	1.39
[1]		Mean	14.10	14.12	14.18
		Std. Dev.	1.25	1.00	1.31
	Middle from	Min.	12.60	12.90	12.90
	Buttress part	Max.	15.30	15.10	15.60
		Count	5.00	5.00	5.00
		C.L.	1.56	1.05	1.63
[2]		Mean	13.42	13.36	13.98
		Std. Dev.	0.89	1.12	0.96
		Min.	12.90	13.00	12.90
		Max.	15.00	15.40	15.00
		Count	5.00	5.00	5.00
		C.L.	1.10	1.39	1.19
[3]		Mean	10.34	10.74	11.86
		Std. Dev.	0.93	1.52	1.25
		Min.	8.70	8.06	10.70
		Max.	10.90	12.90	13.50
		Count	5.00	5.00	5.00

	C.L.	1.15	1.89	1.55
[1]	Mean	14.10	14.64	15.75
	Std. Dev.	1.25	0.94	0.93
Middle from Top part	Min.	12.60	13.00	15.30
	Max.	15.30	15.30	17.40
	Count	5.00	5.00	5.00
	C.L.	1.56	1.15	1.15
[2]	Mean	13.68	14.34	14.42
	Std. Dev.	1.09	1.18	2.08
	Min.	12.60	13.00	12.90
	Max.	15.00	15.30	17.60
	Count	5.00	5.00	5.00
	C.L.	1.36	1.47	2.59
[3]	Mean	11.74	9.70	11.42
	Std. Dev.	1.33	1.19	0.96
	Min.	10.70	8.70	10.70
	Max.	13.20	11.00	13.10
	Count	5.00	5.00	5.00
	C.L.	1.66	1.48	1.19
[1]	Mean	13.48	12.96	15.24
	Std. Dev.	1.24	1.48	2.23
Top part (4)	Min.	12.60	10.80	12.90
	Max.	15.60	15.00	17.60

	Count	5.00	5.00	5.00
	C.L.	1.53	1.84	2.77
[2]	Mean	12.56	11.18	14.22
	Std. Dev.	1.00	0.91	1.08
	Min.	10.90	10.60	13.30
	Max.	13.40	12.80	15.50
	Count	5.00	5.00	5.00
	C.L.	1.24	1.13	1.34
[3]	Mean	11.22	10.10	10.94
	Std. Dev.	1.17	1.14	2.05
	Min.	10.50	8.80	8.80
	Max.	13.30	11.00	13.00
	Count	5.00	5.00	5.00
	C.L.	1.45	1.42	2.54

4.6 Shear parallel to grain test

For shear parallel to grain, thirty six test samples was used for both green and dry test of each tree statistical results of tree one, two and three, green and [dry] are as follows: 7.74 [9.92], 6.83 [9.62] and 7.08 [10.82] as mean values. The standard deviations are 0.14 [0.19], 0.09 [0.09], and 0.07[0.14] respectively. Mean test moisture content ranges from 89.6-94.8 for green and 16.40-17.00 for dry. *Table 4.18* shows results of the basic statistics for green and dry shear test conducted. And *Table 4.19* and *4.20* also depicts results of the descriptive statistics of shear parallel to grain for billet and sawn-planks divisions

Table 4.18 **Shear parallel to grain of three *Allanblackia parviflora*, trees when green and at 12% moisture Content.**

A. Statistics of 'green' shear parallel to grain N/mm²

Tree Nº.	Mean	P_05	Std.Dev.	Min	Max	Count.	Mean Test M.C
1	7.74	7.14	0.14	5.84	9.61	36.00	89.60
2	6.83	6.65	0.09	5.84	7.80	36.00	94.80
3	7.08	6.94	0.07	6.24	7.85	36.00	93.70

B. Statistics of 'dry' shear parallel to grain

Tree Nº.	Mean	P_05	Std.Dev.	Min	Max	Count.	Mean Test M.C
1	9.92	9.55	0.19	7.97	12.32	36.00	16.4
2	9.62	9.44	0.09	8.68	10.56	36.00	16.9
3	10.82	10.55	0.14	9.24	12.32	36.00	17.0

Table 4.19 **Results of the Descriptive Statistics for Shear parallel to grain (dry) (Billet Divisions)**

		Tree (1)	Tree (2)	Tree (3)
	Mean	10.02	9.97	11.11
Buttress part [1]	Std.Dev.	1.27	0.47	0.83
	Min.	7.97	9.16	9.64
	Max.	12.29	10.50	12.29
	Count	9.00	9.00	9.00
	C.L	0.98	0.36	0.64

		Tree (1)	Tree (2)	Tree (3)
	Mean	9.65	9.92	11.09
Middle from buttress	Std.Dev.	1.04	0.59	0.79
Part [2]	Min.	8.26	9.16	10.12
	Max.	11.57	10.86	12.32
	Count	9.00	9.00	9.00
	C.L	0.80	0.46	0.61
	Mean	9.65	9.34	10.76
Middle from top	Std.Dev.	1.37	0.29	0.29
Part [3]	Min.	8.39	8.86	9.63
	Max.	115.57	9.77	11.89
	Count	9.00	9.00	9.00
	C.L	1.05	0.22	0.61
	Mean	10.06	9.25	10.31
Top part [4]	Std.Dev.	1.16	0.31	0.67
	Min.	8.66	8.68	9.27
	Max.	11.87	9.63	11.36
	Count	9.00	9.00	9.00
	C.L	0.89	0.24	0.52

Table 4.20 **Results of the descriptive statistics for shear parallel to grain sawn-planks division [Heart to sap, 1, 2, 3 divisions]**

		Tree (1)	**Tree (2)**	**Tree (3)**
[1]	Mean	10.99	10.39	11.60
	Std. Dev.	1.13	0.18	0.26

Buttress Part (1)		Min.	10.19	10.19	11.36
		Max.	12.28	10.50	11.87
		Count	3.00	3.00	3.00
		C.L.	2.81	0.44	0.64
	[2]	Mean	9.42	10.06	11.50
		Std. Dev.	1.74	0.27	0.73
		Min.	7.97	9.76	10.86
		Max.	11.36	10.31	12.29
		Count	3.00	3.00	3.00
		C.L.	4.34	0.68	1.80
	[3]	Mean	9.65	9.45	10.23
		Std. Dev.	0.10	0.25	0.61
		Min.	9.56	9.15	9.63
		Max.	9.76	9.63	10.68
		Count	3.00	3.00	3.00
		C.L.	0.27	0.63	1.53
Middle from Buttress part	**[1]**	Mean	10.85	10.61	11.37
		Std. Dev.	0.73	0.21	0.47
		Min.	10.12	10.50	10.86
		Max.	11.57	10.86	11.69
		Count	3.00	3.00	3.00
		C.L.	1.80	0.51	1.12
	[2]	Mean	9.39	9.81	11.57

	Std. Dev.	0.27	0.30	0.95
	Min.	9.08	9.52	10.50
	Max.	9.58	10.12	12.32
	Count	3.00	3.00	3.00
	C.L.	0.67	0.74	2.36
[3]	Mean	8.74	9.33	10.35
	Std. Dev.	0.39	0.18	0.34
	Min.	8.26	9.16	10.12
	Max.	9.01	9.53	10.74
	Count	3.00	3.00	3.00
	C.L.	0.97	0.46	0.85
[1]	Mean	11.17	9.58	11.16
	Std. Dev.	1.62	0.21	0.63
Middle from	Min.	9.31	9.35	10.74
Top part	Max.	12.32	9.77	11.89
	Count	3.00	3.00	3.00
	C.L.	4.04	0.53	1.57
[2]	Mean	9.10	9.41	11.26
	Std. Dev.	0.62	0.15	0.48
	Min.	8.39	9.24	10.74

	Max.	9.52	9.52	11.69
	Count	3.00	3.00	3.00
	C.L.	1.55	0.37	1.95
[3]	Mean	9.61	9.04	9.86
	Std. Dev.	1.00	0.19	0.29
	Min.	8.68	8.86	9.63
	Max.	10.68	9.24	10.19
	Count	3.00	3.00	3.00
	C.L.	2.51	0.47	0.73
[1]	Mean	10.51	9.54	10.85
Top part	Std. Dev.	1.27	0.08	0.45
(4)	Min.	9.35	9.47	10.50
	Max.	11.87	9.63	11.36
	Count	3.00	3.00	3.00
	C.L.	3.16	0.19	1.12
[2]	Mean	10.15	9.32	10.55
	Std. Dev.	1.23	0.08	0.27
	Min.	9.24	9.24	10.31
	Max.	11.69	9.41	10.86
	Count	3.00	3.00	3.00
	C.L.	3.06	0.21	0.69

[3]	Mean	9.12	8.89	9.52
	Std. Dev.	0.44	0.20	0.26
	Min.	8.66	8.68	9.24
	Max.	9.53	9.08	9.77
	Count	3.00	3.00	3.00
	C.L.	1.09	0.50	0.67

4.7 Other physical and mechanical properties observed

Some mechanical properties observed during harvesting, samples preparation of the actual strength and physical tests conducted and making a prototype chair from *Allanblackia parviflora* wood.

4.7.1 General characteristics

Heartwood of the tree is dark brown to purplish brown, moderately heavy and hard, with medium texture and even/straight grain. Sapwood is a light grey brown moderately heavy but not hard with medium texture and straight grain. When green, sapwood is well demarcated but sapwood not well demarcated when dry.

4.7.2 Working properties

It saws and machines well. Good nailing, screwing and gluing characteristics. It takes veneer and polishes to a very good finish.

4.7.3 Seasoning

Allanblackia parviflora tree dries fairly slowly with no checking or twisting.

4.7.4 Comments and possible uses

Precautions need to be taken when cutting to avoid tear out or chipping and is suitable for furniture and joinery production.

CHAPTER FIVE

Discussion

5.1 Introduction

This chapter analysed and discusses the findings and opinions about the results. The analysis covers the moisture content and basic density of fresh wood samples, strength properties of *Allanblackia parviflora* wood at 12% MC for strength tests conducted, assigning grades to *Allanblackia parviflora* wood based on the results and comparing *Allanblackia parviflora* properties with three known species to determine its suitability for furniture production.

5.2 Moisture content of the fresh wood samples

Strength properties of wood samples are related to the moisture content of the wood, (Kollmann and Cote, 1968) and hence it was expedient to determine the moisture content of fresh wood samples.

A summary of the basic statistics for the green moisture content of the three species is represented by the data for three trees of *Allanblackia parviflora* presented in *Table 4.1*. The green moisture content for all 360 specimens ranged from a minimum of 43.90% to a maximum of 100.70%. The overall average was 81.19% with standard Deviation 11.33. The analysis of variances (ANOVA) indicates that, differences between the average green moisture contents of the three trees were not significant (P – value > 0.001) The raw data as well as the statistical analysis of moisture content of the fresh wood samples are presented in Appendices A1 – A3. *Allanblackia parviflora* wood had an average moisture content of 81.19% which is higher than three known species when compared. *Aningeria altissima* had 60.00% m.c., *Terminaria ivorensis* had 74.35% m. c., and *Antiaris toxicaria* had 50.00% m.c.

From literature, these known species had more moisture in the sapwood portion than the heartwood portion .For variations among the trees, the trend did not change, sapwood portion had higher mean moisture content than the heartwood portion. Moisture content of each tree varies but their variations are not significant. These results could be attributed to the fact that, trees were harvested from one location and of the same age. The moisture content variation within tree (billet divisions) also varies, but their variations are not significant. Again the trend did not change; sapwood portion had higher mean moisture content than the heartwood portion. The tree had consistent trend of moisture content in all divisions where the sapwood portion had higher mean moisture content than the heartwood portion.

A summary of the analysis of variance (ANOVA) of the green moisture content of three trees of *Allanblackia parviflora* are shown in *Table 4.2*.

The analysis of variance indicates that differences between the average green moisture contents of three trees were not significant (P – value > 0.001).

5.3 Basic density of the fresh wood sample

A summary of the basic statistics for the basic density of three wood species is represented by the data for the 3- trees of *Allanblackia parviflora* in *Table 4.5*. The basic density ranged from a minimum of 285.00 to a maximum of 621.00 kg/m^3.

The overall average was 507.50kg/m^3 with standard deviation 52.22. The analysis of variance (ANOVA) indicates that differences between the average basic densities of three trees were not significant (P – value > 0.001).

The raw data as well as the statistical analysis of basic density of the fresh wood samples are presented in Appendices B1 – B3.

Allanblackia parviflora wood showed similar trend that, the heartwood portion of each sawn-planks division had a higher density than the corresponding sapwood portion when compared to the three known wood species. The mean basic density of heartwood is 621.00 kg/m^3 as compared to 285.00 kg/m^3 of its respective sapwood. From literature, *Aningeria altissima* had 540.00-590.00 kg/m^3, *Terminaria ivorensis* had 545.00 kg/m^3 and *Antiaris toxicaria* had 433.00 kg/m^3. For variations among trees, basic density of each tree varies but their variations are not significant. Within tree billet divisions also varies, but their variations are not significant as shown in *Table 4.7* .The tree had consistent trend of basic density in all divisions where the heartwood portion recorded higher mean density than the sapwood portion.

A summary of the analysis of variance (ANOVA) of the basic density of each tree is indicated in *Table 4.6*. The differences between the average basic densities of the three trees were not significant (P – value > 0.001).

5.4 Strength properties of trees of *Allanblackia parviflora* at 12% moisture content

It is very essential that only the results for woods with the same moisture content or values reduced to the same moisture content be compared (Kollmann and Cote, 1984).

The data for the various strength properties of the wood samples adjusted to 12% moisture content and results of statistical analysis are presented in Appendices C1 – C3, D1 – D3, E1 – E3, and F1 – F3 respectively.

Wilcox *et al.,* (1991) found that the heartwood of wood sample is slightly stronger than the sapwood. This idea is true in the research conducted. Almost all strength tests conducted show that, the heartwood portion of each division is stronger (in terms of resistance to failure) than the sapwood portion.

According to Hoadley (1990) there is no significant difference in the strength of sapwood and heartwood *per se* within a given species. Although, the heartwood portion of almost all the strength test conducted shows a stronger resistance to failure than the sapwood portion, the difference is significant; but the sapwood portions can be used for some parts of furniture under certain conditions.

5.4.1 Strength Values

Table 4.9, -4.20 gives summaries and results of the descriptive statistics of the Modulus of Rupture, Modulus of Elasticity, Compression and Shear parallel to grain values for three *Allanblackia parviflora* trees in the 'green' and 12% moisture conditions.

5.5 Modulus of rupture (MOR)

The static bending strength values of the trees when 'green' and at 12% moisture content are shown in *Table 4.9*. The range of mean strength values in the 'green' and dry [12% MC] condition for the three species were as follows: - Modulus of Rupture: 50.00 – 56.00 N/mm^2 and dry [85.00 – 94.00 N/mm^2]. At 12% moisture content, it is observed in *Table 4.11* that, the heartwood portion [1] and [2] of *Allanblackia parviflora* recorded the highest mean static bending (MOR) which was 98.36 N/mm^2 while the least mean bending strength (MOR) of 80.22 N/mm^2 was found in sapwood portion [3] of each sawn –planks divisions within the tree. It is therefore realised from the result that the resistance of heartwood to static bending (MOR) was higher than that of the sapwood at the same moisture content.

When compared to the three known wood species, MOR of *Aningeria altissima* had 93.00 -130.00 N/mm^2, *Terminaria ivorensis* had 83.00 N/mm^2 and *Antiaris toxicaria* had 59.00 N/mm^2. These results are closely related to that of *Allanblackia parviflora*. Again, the heartwood portion has a higher resistance to static bending (MOR) than the sapwood portion from literature of these three known species. Among the trees MOR varies but their variations are not significant as shown in *Table 4.9*. Again within tree variation (billet divisions) did not show any significant difference as shown in *Table 4.10*. The overall order of decreasing MOR of the three species was as follows: Tree "Three" > Tree "two" and Tree two > tree "one", when green and at 12% M.C.

5.6 Modulus of elasticity (MOE)

MOE is a measure of resistance to bending. The MOE strength values of the 3 – trees when green and at 12% M.C are shown in *Table 4.12*. The range of mean strength values in the green and dry conditions for the three trees were as follows: MOE green 6,387.00 – 6,951.00 and 12% M.C (dry) 8,287.00 – 8,875.00 N/mm^2. At 12% MC, it is observed in *Table 4.14* that, the modulus of elasticity for each sawn-planks division 1, 2, 3 did not show consistent variations, that is the divisions varies but their variations are not significant. When compared to the three known species ,*Aningeria altissima* 11,100.00 N/mm^2, *Terminaria ivorensis* 9300.00 N/mm^2, *Antiaris toxicaria* 7200.00 N/mm^2, and *Allanblackia parviflora* 8545.98 N/mm^2, from *Table 5.2*. These values are closely related and predict *Allanblackia parviflora* tree wood performance when used for furniture production. Among trees, (MOE) varies but their variations are not significant so as the variations within tree (billet divisions) in *Table 4.13*. The overall order of decreasing MOE of three trees was as follows: Tree "two" > Tree 'three', and tree 'three' > tree 'one'.

5.7 Compression parallel to grain test

The compression parallel to grain strength values of the 3 – trees when green and at 12% moisture content are shown in *Table 4.15*. The range of mean strength values in the 'green' [and dry] conditions for the three trees was as follows: - Compression parallel to grain 23.60 – 27.90 N/mm^2 and dry 12.90 – 14.10 N/mm^2. At 12% moisture content, it is observed in *Table 4.17* that, the heartwood portion [1] and [2] of *Allanblackia parviflora* recorded highest mean compression parallel to grain which was 14.10 N/mm^2 while as compared to 12.90 N/mm^2 of its respective sapwood portion [3] of each sawn-planks divisions within the tree.

When compression results were compared to the three known species, *Allanblackia parviflora* gave lower values. *Aningeria altissima* had 52.00 - 57.00 N/mm^2, *Terminaria ivorensis* had 35.00 N/mm^2 and *Antiaris toxicaria* had 54.00 N/mm^2. There are variations among the three trees of *Allanblackia parviflora* from *Table* 4.15_B but their variations are not significant. Again within tree a variation (billet divisions) also varies but their variations are not significant as depicted in *Table 4.16*. The overall order of decreasing compression parallel to grain of three trees was as follows: - Tree "two" >, Tree "one" ≥ Tree "three". When green and Tree "three" > tree "two" and tree two is ≥ tree "one" when at 12% M.C.

5.8 Shear parallel to grain test

The shear parallel to grain strength values of the 3-tress when green and at 12% M.C. are shown in *Table 4.18*. The range of mean strength values in the green [and dry] Condition for the three trees was as follows; shear parallel to green. 6.80-7.70 N/mm^2 and dry [9.60-10.80 N/mm^2] At its dry state, it is observed in *Table 4.20* that, the heartwood portion [1] and [2] of *Allanblackia parviflora* recorded highest mean shear parallel to grain which was 10.80 N/mm^2 as compared to 9.60 N/mm^2 of its respective sapwood portion of each sawn-planks divisions within each tree. It is realised from the results that, the resistance of heartwood to failure in shear parallel to grain was higher than that of the sapwood at the same moisture content.

When compared shear results to the three known species, *Allanblackia parviflora* had 9.60 N/mm^2 and relates to *Aningeria altissima* (9.50 N/mm$^{2)}$, *Terminaria ivorensis* (12.10 N/mm$^{2)}$ and *Antiaris toxicaria*(7.90 N/mm$^{2)}$. There are variations among the three trees of *Allanblackia parviflora*. In *Table 4.18*, but their variations are not significant. Again within tree variation (billet divisions) also varies, but their variations are not significant as depicted in *Table 4.19*. This means that each billet can used for furniture production.

The overall order of decreasing shear parallel to grain of three trees was as follows:

Tree one > Tree "three"-and Tree three ≥ tree two when green. And Tree 'three' is > tree 'one' and tree 'one' is ≥ tree 'two' when dry.

5.9 Assigning grades to *Allanblackia parviflora*

5.9.1 TEDB (1994) Weight classification, kg/m^3 at 12% moisture content.

Light → 350 or less

Light-Medium ~~350 –~~ → 450

Medium → 450 – 575

Medium-Heavy → 575 – 725

Heavy → 725 – 900

Very Heavy → 900 or higher

The overall average mean of basic density (weight) of *Allanblackia parviflora* wood was 507.50k/gm^3. And from TEDB (1994) Weight classification, [5.9.1], weight is medium in *Allanblackia parviflora* wood. From the classification this tree can exhibit medium level of strength, and toughness and therefore can be used for furniture and other productions.

5.9.2 Ratio of Dry to Green 'Clear' Mechanical Strength Values.

Many of the mechanical strength properties are affected by changes in moisture content below the fibre saturated point. Generally, most of the strength properties increase as wood is dried. Above the fibre saturation point, most of the mechanical properties are not affected by changes in moisture content. *Table 5.1* shows the ratio of the mechanical strength at 12% moisture content (dry) to that when 'green' for the species studied and the comparative range ratios for USA hardwood. (ASTM, 1978) Ratios for the Ghanaian hardwoods were generally highest in Modulus of Rupture (MOR) followed by compression parallel to grain (1.84), shear parallel to grain and Modulus of elasticity. Mean ratios for MOR was (1.68) compression parallel to grain (1.84) shear parallel to grain (1.40) and MOE (1.28).

Table 5.1 **Ratio of dry to green mechanical strength values**.

Allanblackia parviflora Tree Nº.	MOR	MOE	Cll_g	Shear ll_g
1	1.68	1.29	1.83	1.28
2	1.68	1.27	2.08	1.40
3	1.70	1.29	1.62	1.53
Mean	1.68	1.28	1.84	1.40
Ghanaian hardwood (mean)	1.20 – 1.61	1.13 – 1.39	1.4 – 1.75	1.39 – 1.71
USA hardwood (mean)	1.20 – 2.10	1.11- 1.52	1.61 – 260	1.13 – 1.82

Dry means 12% moisture content source: (ASTM, 1978).

From *Table 5.1* the ratio of dry to green mechanical strength values indicates that almost all mechanical test falls at the highest range for both Ghanaian hardwoods and USA hardwood ranges. This predicts the tree(s) suitability for furniture production.

5.9.3 Assigning Grades to the Results Based on Timber Export Development Board – Ghana (1994)

TEDB (1994) have classified strength of species based on the MOE at 12% moisture Content as follows:

'Very High' → [19,000 N/mm^2 and more]

'High' → [14,000 N/mm^2 – 19,000 N/mm^2]

'Medium' → [11,000 N/mm^2 – 14,000 N/mm^2]

'Low' → [below 9,000 N/mm^2]

The above classification indicates the strength of *Allanblackia parviflora* trees studied to be in range of 10,381.00 – 11,084.00 N/mm^2 "medium" and this would be suitable for furniture production.

5.9.4 Based on Bolza and Keating (1972)

S2 ⟶ [MOR of 134 N/mm^2 and more]

S3 ⟶ [MOR of 114 N/mm^2 - 134 N/mm^2]

S4 ⟶ [MOR of 93.7 N/mm^2 -114 N/mm^2]

The above classification also indicates the strength of *Allanblackia parviflora* trees studied to be in a range of 84.70 – 93.90 N/mm^2 "S4" and this also confirmed the trees suitability for furniture.

Table 5.2 Allanblackia parviflora **compared to other known species suitable for furniture production in N/mm^2**

Species	**MC %**	**density**	**MOR**	**MOE**	**Cll_g**	**Shear ll_g**
Allanblackia parviflora (**Sonkyi**)	81	508	85-94	5987-11084	14	9.6
Aningeria altissima ***(Asanfena)***	60	540-590	93-130	11,100	52-57	6.8-9.5
Terminaria ivorensis ***(Emeri)***	12	545	83	9300	35	12.1
Antiaris toxicaria	50	433	59	7200	54	7.9

(Kyenkyen)						
Milicia exelsa (**Odum**)	12	657	90	9400	-	14.1
Piptadeniastrum africanum (**Dahoma**)	-	689	109	11200	23	17.6
Cyclidiscus gabunensis (**Denya**)	-	481-625	54-64	6300	-	11.1
Canarium schweinfurthii (**Bediwonua**)	-	593	41	6200	-	6.4

Source: Lavers (1983)

Allanblackia parviflora tree has similar strength and other physical properties compared to species like *Aningeria altissima* (**Asanfena**), *Terminaria ivorensis* (**Emire**), *Antiaris toxicaria* (**kyenkyen**) and others in *Table 5.2*. These species are well known to be species suitable for furniture. These again predict *Allanblackia parviflora* tree's suitability for furniture production.

5.9.5 The Relationship between Modulus of Elasticity and Modulus of Rupture of *Allanblackia parviflora* tree wood

The precision with which a mechanical grading system can sort small clear samples into strength classes [grades] is dependent upon the degree of correlation between bending strength (MOR) and bending stiffness (MOE) (Green and Rosales 2006). For the three trees tested in this study, the ratio of dry to green values between MOE and MOR correlates in *Table 5.1* and therefore predicts the tree(s) suitability for furniture production.

CHAPTER SIX

Conclusion and Recommendations

6.1 Conclusion

The physical and mechanical tests were conducted to predict the performance of *Allanblackia parviflora* wood for furniture production.

The results from all tests predict the tree(s) suitability for furniture production.

The range of mean strength values in the 'green' [and dry] conditions for three trees were as follows: Modulus of Rupture: 50.00 – 56.00 [85.00 – 94.00] N/mm^2, Modulus of Elasticity: 6,387.00 – 6,951.00 [8,287.00 – 8,875.00] N/mm^2, compression parallel to grain: 24.00 – 28.00 [13.00 – 14.00] N/mm^2 and shear parallel to grain: 6.80-7.70 [9.60-10.80] N/mm^2. Again, moisture content had an average of 81.19% with a standard deviation 11.33 and a basic density also had an average of 507.50kg/m^3 with a standard deviation 52.00. The analysis of variance (ANOVA) for moisture content and basic density indicates that, the difference between the average moisture content and basic density of three trees was not significant (p-value > 0.001).

From the study, there is no significant difference in the strength of sapwood and heartwood *per se* within a given species, therefore both heart and sapwood portions of *Allanblackia parviflora* wood can be used for furniture production.

The mean ratios of dry to 'green' MOR and MOE were 1.68 and 1.28. And this predicts the suitability of *Allanblackia parviflora* wood for furniture production. *Allanblackia parviflora* wood can be used for furniture production. Indeed, it is a good substitute for all species. And will increase the wood resource base.

It should be considered as exploitable raw material base for timber industries by stakeholders in wood industry.

The variation among trees based on four strength and two physical tests conducted indicates that variations among 3- trees are not significant.

For within tree billet divisions, each division varies but their variations are not significant. But for variations within tree sawn- planks [Heart to sap division -1, 2, 3] indicates that, the strength of division one (1) and two (2) are higher than division three (3). Based on the strength tests results, division one and two can be described as the heartwood portion and division three (3) as sapwood portion respectively. Although the heartwood portion of almost all the strength and physical tests conducted shows a higher resistance to failure than the sapwood portion, the differences is significant, but the sapwood portion can also be used for certain furniture parts.

6.2 Recommendations

Strength properties of other lesser-used wood species should be determined to find out whether they can be used as a structural raw material for furniture and other productions.

Allanblackia parviflora wood should be used by the local furniture makers and carpenters to produce furniture and other artifacts made of wood to know its practical strength and how this lesser-used wood species will perform.

Diversification of market species should be encouraged to accommodate lesser used wood species such as *Allanblackia parviflora* to serve as a means for sustainable management of the tropical forest of Ghana.

Again, the timber species were extracted from one location (Moist semi-deciduous forest) for the study. It is therefore suggested that some physical and mechanical properties of the same wood species be studied at different geographical areas in order to get more information on the trees characteristics.

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