BASIC DENSITY AND SOME STRENGTH PROPERTIES OF *MELIA AZEDARACH* L. AND *MARKHAMIA LUTEA* (BENTH.) K. SCHUM. GROWN IN AGROFORESTRY IN BUNDA, MARA, TANZANIA.

BY

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ABSTRACT

Basic density and some strength properties of *Melia azedarach* L. and *Markhamia lutea* (Benth.) K. Schum. grown in agroforestry in Bunda district were studied. The overall objective of this study was to assess the quality of wood of these species in order to improve their utilization.

A survey of end uses of both species was conducted by using structured questionnaires. Tree form was determined by observation on standing trees. Five mature trees aged between 25 to 30 years with good form and free from defects were selected. Basic density was determined by using maximum moisture content method. Strength properties were measured on a Monsanto Tensiometer machine.

The main findings were as follows:

- Wood of *Melia azedarach* and *Markhamia lutea* is already being utilized in Bunda for furniture making and construction work.

- Trees of *Melia azedarach* were straight up to about 7 m with sparse crown cover while those of *Markhamia lutea* were straight up to about 5 m from the base.

- Mean basic density were found to be 436 kg/m^3 and 430 kg/m^3 for *Melia azedarach* and *Markhamia lutea* respectively.

- There was no significant difference in mean basic density between the two species ($P>0.05$).

- There were significant differences in all studied strength properties except work to maximum load for the two species ($P<0.05$).

- All studied strength properties of *Markhamia lutea* were significantly higher by an average of about 37% compared with those of *Melia azedarach* except work to maximum load and cleavage strength .

- Variations in basic density and studied strength properties were found between trees and within trees of the same species. Within trees of the same species variation was found in radial and axial directions.

- These results suggest that it is possible to improve the wood quality of these species through among other methods selection of trees with the desired properties for further planting.

- There were significant relationships between basic density and the studied strength properties which indicate that it is possible to predict one strength property from basic density hence reduction of cost and time required for testing.

- There were positive significant relationships between both basic density and studied strength properties with rate of growth measured by dbh and total tree height for both species. The relationships were all significant with dbh for *Melia azedarach* and not significant for *Markhamia lutea.*

DECLARATION

I James Peter Matekere, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work, and has not been submitted for a degree award in any other University.

Signature .....

Date 19th November 1999.

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DEDICATION

This work is dedicated to my father Matekere Peter, my lovely late mother Nyafuru Matekere, my aunt Susan Peter, my young brothers Sebastian and Peter, my wife Meryciana and my beloved sons Peter, Innocent and Frank.

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ABBREVIATIONS AND SYMBOLS

a.s.l.	above sea level
Bd[1]	Basic density
CLV[1]	Cleavage strength
Dbh	Diameter at breast height (1.3m of tree height)
et al.	and others
Gv	Green volume
Ht	Total tree height
Max	Maximum value
M.C.	Moisture content
MCS[1]	Maximum crushing stress parallel to grain in compression
Min	Minimum value
MOE	Modulus of Elasticity
MOR	Modulus of rupture
Odw	Oven dry weight
P	probability level
Rposi[1]	radial position
sd	standard deviation
SPG[1]	Shear strength parallel to grain
TWF[1]	Total work fracture in standing bending
Vposi[1]	vertical position
Wmax[1]	Work done to maximum load in static bending

Note: Abbreviation or Symbol[1] is not standard

CHAPTER ONE

1 INTRODUCTION

1.1 Background

Tanzania has a total area of 88.6 million hectares (MLNRT, 1989). In 1989 about 50% of her land was covered by forests of which 13.8% were nationally protected. Land suitable for cultivation and grazing but with varying soil types and degree of fertility covered about 45% of the total land area (Kilahama, 1988). Apparently there has been over exploitation of natural forests in Tanzania (Ewusie, 1980; Ahlback, 1988 in O'kting'ati and Monela, 1996). FAO (1981) indicated that Tanzania is losing about 2% of her forest cover annually. Deforestation ranges between 300 000 and 400 000 ha per annum (MLNRT, 1984). In densely populated coastal areas, islands and highlands most of the land is under cultivation (Ewusie, 1980, Hofstad, 1988; Stone *et al.*, 1993). Therefore there is a high demand for forest products from the remaining natural forests (FAO, 1974; FAO, 1985; Rocheleau *et al.*, 1988; Tibaijuka, 1985; FAO, 1993). Practically all parts of Tanzania are experiencing problems of deforestation and land degradation (Olsson, 1985; Tibaijuka, 1985; Stone *et al.*, 1993; Ishengoma, 1995). While in the Usambara, Kilimanjaro, Meru and Mbulu the causes are clearing for agriculture and settlement, harvesting for industrial and construction due to high population density (Makombe, 1995), in Mara, Mwanza and Shinyanga regions the causes are rapid increase in population, extensive cotton farming, overgrazing, high demand for construction materials and woodfuel (ICRAF, 1988; Anon, 1989; Otsyina

and Asenga, 1993; Makombe, 1995; Budelman, 1996). Todate only 32.51 million hectares are covered by forests which is about 36.8% of the total land area (FAO, 1997).

Deforestation in turn caused land degradation, soil erosion and high pressure on the remaining natural forests. In order to relieve pressure on plantations and natural forests, to rehabilitate degraded land, to improve the environment and the supply of forest products, the government started a national tree planting campaign in 1967/68 (Mnzava, 1979). Trees were also planted in croplands i.e. agroforestry.

Agroforestry is a technology in which woody perennial (tree and shrubs) are combined on the same land management unit with herbaceous crops and/or animals either in form of spatial arrangement or temporal sequence (Barrow *et al.*, 1988; Chidumayo, 1988; ICRAF, 1988). In reality agroforestry is not a new concept in Tanzania as it has been practised successfully for many decades in some parts of the country including Kagera, Kilimanjaro and Tanga regions (MLNRT, 1984).

2.1 Problem statement

Utilization of wood for timber still concentrates on few well-known species. This is due to among other reasons lack of knowledge on wood physical and mechanical properties of most species in the country. This situation has led to depression of the few well-known timber species and high rate of deforestation and land degradation on the

respective areas. In order to reduce pressure on these species there is a need to diversify the source of timber. One source is trees grown in agroforestry.

Silvicultural and biological factors such as soil nutrient improvement, light shade, less competition for mineral and water uptake, and fast growth were considered more when selecting agroforestry tree species. Little or no emphasis was put on wood properties required for end uses.

Although *Melia azedarach* and *Markhamia lutea* have been grown in agroforestry since early times in the tropics and sub-tropics (Mbuya *et al.*, 1994), it is only during the tree planting campaign which started in 1967 that a large number of these tree species were planted. Some of these trees have reached merchantable sizes and have been harvested for certain uses.

Timber from *Markhamia lutea* and *Melia azedarach* grown in agroforestry systems are already in the market for utilization. The wood is less utilized for poles, furniture making and construction in Mara region and Ukerewe islands in the Lake Victoria basin (Mbuya *et al.*, 1994). Their low utilization level may be caused by among other reasons lack of information on their physical and mechanical properties, prejudice and heavy traditional reliance on well known timber species (Bryce, 1967; Smith *et al.*, 1994). Wood from these two species is used without knowledge of their physical and mechanical properties. This may result in inefficient utilization of the wood of both species and safety hazards especially when used in construction.

Literature indicates that only few studies on the properties of these species have been conducted. Chudnoff (1984) reported wood basic density of 470 kg/m^3 for naturally occuring *Melia azedarach*. However, studies have shown that environmental and silvicultural factors do affect the properties of wood (Zobel and van Buijtenen, 1989). This means that trees on different growing conditions would produce wood of different properties. Todate, no studies have been conducted on wood properties of these two tree species grown in agroforestry. Therefore there is a need of conducting studies on wood properties of these species. For this study basic density and strength properties were studied. These properties were selected because of the following reasons:

- basic density is related to most strength properties and is an indicator of quality of wood,
- strength properties are more important in general construction and furniture making.

1.3 Justification and Significance of the Study

The existing large volume of wood from these two species grown in agroforestry and the inefficient utilization of this wood due to lack of knowledge on their properties justify the study. Results from this study will form a basis for recommendation on their consideration for future planting in agroforestry systems and increased efficient utilization of the wood from these species. This will thereby reduce pressure on the

well known timber species and also improve income generation of the rural poor.

1.4 Objectives

The overall objective of this study was to assess the quality of wood of *Melia azedarach* L. and *Markhamia lutea* (Benth.) K. Schum. grown in agroforestry in Bunda.

The specific objectives were:

- to conduct a survey of the end uses of the wood of *Melia azedarach* and *Markhamia lutea,*
- to determine tree characteristics such as branching habit, tree form and crown size,
- to determine and compare basic densities of the two species,
- to determine and compare strength properties of these species,
- to investigate the variation in basic density and strength properties between and within trees for each species,
- to determine the relationship between basic density and strength properties for each species,
- to determine the relationship between different strength properties, and
- to determine the effect of rate of growth on basic density and strength properties for each species.

1.5 Delimitations

Due to time and cost factors, this study was confined to the determination of basic density and some strength properties of *Melia azedarach* and *Markhamia lutea*. The studied strength properties included:

- maximum crushing stress parallel to grain in compression (MCS),
- static bending:
  - modulus of elasticity (MOE),
  - modulus of rupture (MOR),
  - work to maximum load (Wmax),
  - total work to fracture (TWF),
- shear parallel to grain (SPG), and
- cleavage strength (CLV).

Results from this study can be applied for the same tree species grown on similar climatic conditions.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Nomenclature and distribution of the studied species

Melia azedarach and *Markhamia lutea* are both hardwood species. They are fairly fast growing, pollarding and coppicing (Rocheleau *et al.*, 1988; Mbuya *et al.*, 1994).

2.1.1 *Melia azedarach* L.

Melia azedarach L. of the family *Meliaceae* is an exotic tree species from western Asia and Himalayas commonly known as bead tree or China berry. It is a small tree up to 10-12 m high (Chudnoff, 1984). It is usually deciduous with a smooth grey bark, later turning rough and brown. The tree grows on most soils, both acid and saline from the coast to 2000 m a.s.l. (Kielland-Lund, 1992; Mbuya *et al.*, 1994). It is generally well suited to shallow soil sites, infertile soils, light or sandy soils but not periodically waterlogged (Evans and Rombold, 1987; Rocheleau *et al.*, 1988; ICRAF, 1997). The total length of its main root plus the primary or first order lateral roots exceeds 30 m (Longman and Jenik, 1987). Trees of *Melia azedarach* have been planted for protection and stabilization of waterways, gullies and flood plains. In India this tree species has long been planted along canal banks usually six metres from the inner edge. Also many trees of this species are commonly planted on urban and sub-urban roadside for shade

and decoration (Rocheleau *et al.*, 1988). Furthermore many trees of this species are present in public and home compound sites, often they were not planted but have been carefully protected and maintained. In some cases, the presence of such trees determines the location of homes, markets or place of worship (Rocheleau *et al.*, 1988). According to Mbuya *et al.* (1994) in Tanzania *Melia azedarach* is used for firewood, poles, timber (furniture), posts, tool handles, bee forage, shade, ornamental, beads (seeds), insecticides, dye (leaves) and its boiled leaves is medicine for stomach complaints. Its timber (heartwood) is reported to be resistant to attack by decay fungi and termites (Chudnoff, 1984). In Bunda district this tree is commonly known as mbulumatare.

2.1.2 *Markhamia lutea* (Benth.) K. Schum.

Markhamia lutea (Benth.) K. Schum. of the family *Bignoniaceae* is an indigenous tree species common in high rainfall areas on forest edges and river valleys of east Africa. It is an upright evergreen tree usually 10-15 m high with a narrow irregular crown and a green bark finely cracked. It has deep roots, preferring red loam soils, it can also stand acid heavy soils but not waterlogging (Kielland-Lund, 1992). In Tanzania it is mainly found in the lake Victoria basin (Schultz, 1973; Mbuya *et al.*, 1994).

In the Sahel zone, *Markhamia lutea* is commonly grown with other trees on farmer fields as dispersed trees on cropland and windbreaks. Farmers in Kenya's Nyanza Province plant *Markhamia lutea* in blocks near the home compounds. The trees mature

in about 15 years and are harvested for building poles (ICRAF, 1997). Crops are then planted between the coppicing trees which produce small poles, wood and fodder. Where natural regeneration occurs it may not be necessary to plant seedlings (Rocheleau *et al.*, 1988).

Due to its economic value *Markhamia lutea* is planted in improved fallow of which its main function is to maintain or to restore soil fertility and reduce erosion (ICRAF, 1994; Rocheleau *et al.*, 1988). It is mainly used for charcoal, tool handles, medicine (leaves), bee forage, shade, ornamental, mulch, soil conservation, tobacco curing and banana props (Mbuya *et al.*, 1994). It also provides wood for construction and furniture as well as a limited quantity of fuelwood as a waste product. Leaves are used as fodder in times of drought (Rocheleau *et al.*, 1988). This species is locally known as msambya in Bunda district.

2.2 Wood density

2.2.1 Definition

Density of wood which is usually measured in kg/m^3 or g/cm^3 refers to its weight per unit volume (Desch, 1973; Ostal *et al.*, 1981; Hygreen, 1980). Wood density can be determined based on oven dry weight and oven dry volume, oven dry weight and volume at 12% moisture content or oven dry weight and green volume i.e. volume when moisture content is above fibre saturation point (Ishengoma and Nagoda, 1991).

The density of wood based on oven dry weight and green volume is called basic density. It is commonly used since the oven dry weight and green volume conditions can be reproduced easily (Sardinha, 1977; Zobel, 1984; Ishengoma and Nagoda, 1991).

Wood with a density 360 kg/m^3 or less are considered to be light, the one with 360-500 kg/m^3 is medium and above 500 kg/m^3 is considered to be heavy (Panshin and de Zeeuw, 1970). Table 1 shows the basic densities of timber species well known within the study area.

Table 1: Basic densities for timber species more preferred in Bunda district

Species	Basic density (kg/m^3)	source
Pterocarpus angolensis (Mninga)	657[1]	Tanzania
Maesopsis eminii (Misizi/Msila)	481[1]	Uganda
Milicia excelsa (Mvule)	617[1]	West Africa
Afzelia quazensis (Mkora/Mkongo)	865[1]	Tanzania
Pinus caribaea (Pine)	406[2]	Masawi - Tanzania
Pinus Patula (Pine)	424[3]	Meru - Tanzania

Source: [1] Lavers (1969), [2] Silinge and Iddi (1990), [3] Ringo and Klem (1980).
Local names in brackets

2.2.2 Importance of wood density

Density is the major determinant of wood strength or mechanical properties out of all the physical properties of wood (Kollmann *et al.*, 1975; Schniewind, 1980; Harris, 1993; Walker, 1993). It is generally known that the quality of wood as a building material depend mainly on its density (Kellogg, 1981). There is a close relationship between density and mechanical properties, hardness, abrasion resistance, dimensional changes with change in moisture content below fibre saturation point, and the heat value of wood. By influencing basic properties, density influences the utility of wood, including its working and finishing characteristics (Schniewind, 1980; Kellogg, 1981; Ishengoma and Nagoda, 1991). All the strength properties of wood are closely correlated to density (Kollmann *et al.*, 1975; Hygreen, 1980; Harris, 1993). Density is a useful index for predicting the properties of clearwood, because it is a direct measure of the amount of cellwall materials in a given volume (Siau, 1984; Ishengoma and Nagoda, 1991; Walker, 1993). Density is a key in forest product manufacture because it affects both yield and quality of fibrous and solid wood products (Davis, 1961; Brown, 1982).

The grading of lumber products in some developed countries is done on the basis of density rather than their end uses (Hygreen, 1980). However the selection of wood for a given use considers also other properties (Iddi and Nagoda, 1992).

2.2.3 Factors affecting wood density

Factors affecting wood density include genetical factors for example anatomical characteristics and position in the tree trunk (Dadswell, 1960; Wangaard, 1979; Dinwoodie, 1981; Schniewind, 1989), age of the tree (Ladrack, 1986), silvicultural treatment such as spacing (Brazier, 1977; Malimbwi *et al.*, 1992a,b; Sibomana *et al.*, 1994 in Iddi *et al.*, 1996), and moisture content. Others are environmental factors such as heat, precipitation and wind (Polge, 1965; USDA, 1974; Dietz *et al.*, 1980; Erickson and Lambert, 1980) and chemicals deposits (Zobel and Talbert, 1984).

2.2.3.1 Genetical factors

Hereditary materials in different trees results in wood of different densities (Zobel and Talbert, 1984). For example anatomical characteristics and position in the tree trunk (Kellogg, 1981).

Anatomical characteristics

The density of wood is affected by average cell dimensions, amount of resins and extractives, cell wall structure, lumen size and the amount of non fibrous elements (Willon and White, 1986; Ishengoma and Nagoda, 1991). This means that dry wood consists of cell walls, and air filled cavities (Panshin *et al.*, 1964; Wangaard, 1979; Kubler, 1980). The thicker the cellwall the greater the density and vice versa

(Purkayastha *et al.*, 1972). In hardwood, fibres are the most important elements affecting wood density followed by vessels. Wood density is rather growth measurement giving average figures, which do not reveal the distribution on the different kinds of cells (Zobel and van Buijtenen, 1989).

Position in the tree trunk

Density of wood varies within the tree trunk mainly in the axial and radial direction (Dadswell, 1960; Ladrack, 1986). According to Panshin and de Zeeuw (1970), in hardwoods the heaviest wood is formed at the base of the tree and near the pith for axial and radial direction respectively. However there also other patterns of variation.

2.2.3.2 Age of the tree

The wood produced in early life of the tree which is referred to as juvenile wood often exhibits properties which vary from those generally associated with normal wood (Hygreen, 1980; Hamza and Iddi, 1996). Juvenile wood is found in the central portion of the stem of a tree. This is the wood, which is produced during the first four to ten years. Juvenile wood presents problems in utilization. It has the density which is less than normal (Hygreen, 1980). In general mature trees may have higher density than young ones (Ladrack, 1986).

2.2.3.3 Silvicultural treatment

Silvicultural treatment and environmental factors may promote or hinder high growth rate resulting in increased or decreased wood density (Paul, 1966; Erickson and Lambert, 1980). In plantations, spacing has significant effect on wood properties. Sibomana *et al.* (1994) in Iddi *et al.* (1996) reported an increase in density of 14 years old *Tectona grandis* grown at Longuza with increase in spacing.

2.2.3.4 Moisture content

Wood is a porus and highly hygroscopic material. The amount of moisture present in a piece of wood may vary significantly in different circumstances and therefore its weight (Siau, 1984). Also below fibre saturation point, the volume of wood changes with change in moisture content. Excessive moisture renders wood porosity and spongy, also moisture content is negatively related to density (Panshin and de Zeeuw, 1970; Zobel and van, Buijtenen, 1989). It is therefore necessary to specify the moisture content of wood at which weight and volume were determined when reporting density of wood and that comparison of wood density can only be made at the same moisture content (Ishengoma and Nagoda, 1991).

2.2.3.5 Chemical deposits

Chemical deposits mainly occur in tropical hardwoods. Where such deposits are present, the density of dry matter increases as a result it affects the estimation of density on the final product (Erickson and Lambert, 1980).

2.2.4 Wood density determination

Wood density can be determined by three major methods. These include densitometry, radiation and gravimetric (Polge, 1965; Kollmann and Côté, 1968; Panshin and de Zeeuw, 1970). Other methods include immersion in mercury and use of helium gas at 30°C as a displacement medium (Kollmann and Côté, 1968).

Among these methods wood density can be measured quickly by gravimetric technique if the samples are considerably large and accurately prepared (Hughes and Plumptre, 1976). Radiation methods are known to provide accurate and non destructive measurements (Ishengoma and Nagoda, 1991).

But the simplest method is to weigh a piece of wood and then find its volume. If the sample has regular dimensions and no cracks its volume can be obtained by calculation from the measurements of length, width and thickness while for smaller specimens and those of irregular shapes liquid displacement is more suitable (Ishengoma and Nagoda, 1991). The value obtained for the volume are on the average,

only 1.79% greater than the measured one (Kollmann and Côté, 1968). The most preferable method to be used would be the one producing accurate results at a low cost (Elliott, 1970). According to Olesen (1971), the maximum moisture content displacement method is preferred because of the following reasons:

- it is cheaper,
- it is fast and accurate,
- the green volume can easily be reproduced, and
- it can measure volume of smaller and irregular shaped specimens.

2.2.5 Wood density variations

According to Bryce (1967), Plumptre (1977), Klem and Ishengoma (1984), Hamza and Ringo (1991), Lema (1996) and Hamza *et al.* (1998) variation in wood density is known to occur in:

- different tree species.
- within a species, and
- within a tree (radial and axial direction).

2.2.5.1 Variation between different tree species

Different tree species have different densities (Gashumba, 1989; Hamza *et al.*, 1998). For example *Khaya nyasica* and *Afzelia quazensis* both from Tanzania have density of 545 kg/m^3 and 865 kg/m^3 respectively. Variation in density is due to differences in

amount of cell substances (Hamza, 1987; Ishengoma and Nagoda, 1991) and chemical deposits within and between cells (Zobel and van Buijtenen, 1989).

2.2.5.2 Variation between trees of the same species

There is a considerable variation in density of timber from the same species. Within the species, variations occur between wood of different trees (Gashumba, 1989; Ishengoma and Nagoda, 1991). This variation is influenced by environmental factors (Zobel and van Buijtenen, 1989). In this case therefore variation is a product of interacting factors which modify the physiological processes involved in the formation of wood (Ishengoma and Nagoda, 1991). Bryce (1967) and Plumptre (1977) reported that there is a large variation between trees of the same species taken from different localities.

2.2.5.3 Variation within a tree

Within the same tree variation exists within growth rings, in radial and axial directions (Panshin and de Zeeuw, 1970; Bendtsen, 1978; Dinwoodie, 1981; Willon and White, 1986; Ishengoma and Nagoda, 1991).

Radial variation

Growth rings are apparent because the wood produced at the beginning of the growth season is different in character from that formed later in the season. Cells having relatively large cavities and thin walls characterize earlywood (springwood). Latewood (summerwood) cells have smaller cavities and thicker walls (Ishengoma and Nagoda, 1991). In some species latewood is three times denser that earlywood (Kollmann and Côté, 1968; Hamza and Ringo, 1991). The difference in density between earlywood and latewood is more pronounced in conifers and ring porus hardwood than in defuse porus hardwood as shown in Table 2.

Table 2: Mean values of density (kg/m^3) of earlywood, latewood and the density ratio for some tree species

Species	Early wood	Late wood	Ratio
CONIFERS			
Pinus sylvestris	300	920	3.1
Pinus caribaea	300	680	2.3
Pinus taeda	300	850	2.7
RING PORUS HARDWOODS			
Fracsinus excelsior	385-506	721-751	1.6-2.0
Quercus sp	317-454	888-930	2.0-2.8
DIFFUSE PORUS HARDWOODS			
Acer sp	500-530	668-751	1.3-1.4
Fagus sylvatica	502-536	747-883	1.3-1.8

Source: Kollmann and Côté (1968)

The density variation from pith towards bark follows different patterns in different tree species. Panshin and de Zeeuw (1970) reported four general patterns:

- density increasing from pith to bark,
- high density near the pith followed by a decrease for the first few years and then increase to maximum at the bark,
- moderate increase of density for the first five years followed by a more or less constant plateau or sometimes a decrease in the last formed increment near the bark, and
- a gradual decrease of density from pith to bark.

In ring porous woods the density at any given height in the trunk usually decreases from pith towards bark. In diffuse porous woods density often increase in growth rings near the pith then remains more or less constant, or sometimes decreases in the last formed growth rings near the bark (Ishengoma and Nagoda, 1991).

Axial variation

As a rule the heaviest wood is found at the base of the tree and there is a gradual decrease in density with increasing height from the base (Sekhar and Negi, 1966; Brown, 1971; Koch, 1972a,b). This rule however, does not apply to all species, and other patterns of density variation are known (Quelch, 1982; Ishengoma and Nagoda, 1991).

Panshin and de Zeeuw (1970) reported three general pattern of density variation along the axis of the trunk from base to top of the tree as follows:

- decreasing uniformly from base to top of the tree,
- decreasing in the lower trunk and increasing in the upper trunk, or
- increasing in the stem from base to top.

Broad-leaved trees produce the heaviest wood at base of the tree within the buttresses. Above the buttresses the density usually decreases in the lower portion of the trunk and then increase in the upper portion of the trunk (Dick, 1972; Ishengoma and Nagoda, 1991).

2.3 Strength properties

2.3.1 Definition

The term strength when applied to a material such as wood refers to its ability to resist external forces or loads tending to change its size or alter its shape (Desch, 1973). The effect of applying external loads to a body is to induce internal forces called stress within the body that resist changes in size and shape. Stress is a force expressed on the basis of unit area as Newton per Square millimetre in International System (Ishengoma and Nagoda, 1991).

There are three kinds of stress which can act on wood when subjected to forces. These are:

- tensile stress in which the force cause elongation of the body,
- compressive strength in which the force tend to shorten or crush the timber, and
- shear stress which results from forces which tend to cause one portion of the body to slide over the remainder.

Table 3 shows some strength properties for the common timber species in Tanzania.

Table 3: Strength properties for common timber species in Tanzania

Species	strength properties						
	MCS	MOE	MOR	Wmax	TWF	SPG	CLV
Pterocarpus angolensis	40.6	7600	85	0.10	0.31	12.2	16.6
Maesopsis eminii	28.5	8100	55	0.06	0.12	7.4	13.3
Khaya nyasica	33.2	7300	63	0.07	0.21	10.4	11.9
Afzelia quazensis	47.0	8700	89	0.10	0.36	18.7	21.4
Tectona grandis	41.2	8900	90	0.17	0.36	11.5	16.5

Source: Lavers (1969)

Where:-

MCS = maximum crushing stress parallel to grain in compression (N/mm^2),
MOE = modulus of elasticity (N/mm^2),
MOR = modulus of rupture (N/mm^2),
Wmax= work to maximum load (N/mm^2),
TWF = total work to fracture (N/mm^2),
SPG = shear strength parallel to grain (N/mm^2),
CLV = cleavage strength (N/mm).

2.3.2 Importance of strength properties

Although experience and availability have some times being used to dictate which species of timber for a particular purpose, knowledge of its strength properties is required for efficient utilization, and choice for afforestation (Lavers, 1969). Strength properties of wood define the performance of wood under load (USDA, 1974). The use of wood without knowledge of its strength properties may result in safety hazards especially in construction. For example wood of low strength may be subjected to structural uses which require high strength. It was reported by Hygreen (1980) that a timber strong in one way may be completely weak in another. Therefore the knowledge of strength properties of wood is a key for determining the suitability of wood as a construction material (Walker, 1993). This is generally important because strength properties correlate with density of wood.

2.3.2.1 Maximum crushing stress parallel to grain in compression

Compression strength is the load per unit area sustained by a timber on its ends (Lavers, 1969). High crushing stress parallel to grain in compression is therefore required for timber used as columns, props and chair legs in order to sustain loads applied on them (Hygreen, 1980).

2.3.2.2 Static bending

Static bending is a measure of the strength of a material as a beam. Static bending is one of the most widely used tests because of the general utility of the results (Ishengoma and Nagoda, 1991). In static bending modulus of elasticity, modulus of rupture, work done to maximum load and total work to fracture in bending can be determined.

Modulus of elasticity

Modulus of elasticity (MOE) provides a convenient figure for expressing the stiffness or flexibility of timber. The greater the MOE the stiffer the timber and the lower the modulus of elasticity the flexible the timber is (Ishengoma and Nagoda, 1991).

Modulus of rupture

Modulus of Rupture (MOR) is the measure of ability of a piece of wood to withstand loads up to the point of failure in static bending (Ishengoma and Nagoda, 1991).

Work to maximum load

Work to maximum load is a measure of capacity of substance to store a considerable amount of energy before failure (Hygreen, 1980).

Total work to fracture

Total work to fracture in bending, provides an estimate of ability of substance to sustain a considerable load after the maximum load has been reached (Ishengoma and Nagoda, 1991).

2.3.2.3 Shear parallel to grain

Is a condition of stress and resulting strain acting on a piece of wood causing portions of a sample to slide in parallel but opposite directions to each other (Lavers, 1969). Shear parallel to grain is an important property in the structural use of timber especially in the region of joints (Shukla and Sangal, 1986).

2.3.2.4 Cleavage strength

Cleavage strength gives an indication of how easily a timber will split (Desch, 1973; Shukla and Sangal, 1986). The resistance against cleavage is important in structural work in respect to type of nails used and their holding power in different species of timber since a wedge action is produced when driving nails into wood (Lavers, 1969). Low cleavage property is desirable in woodfuel and for other uses where splitting is necessary. For manufacture of packing cases and other uses where nail and screw holding is required a high cleavage strength is essential.

2.3.3 Factors affecting strength properties

According to Davis (1961), Dinwoodie (1981), Zobel and van Buijtenen (1989) the factors affecting wood strength properties include density, defects especially knots and grain angle, moisture content, temperature, wood biodegradation, time of loading and chemicals in wood. Other factors include ring width, ratio of earlywood and latewood, cell length, microfibrillar angle, anisotropy and site (Chudnoff, 1961; Purkayastha *et al.*, 1972; Skaar, 1972; Scheffer, 1973; Ishengoma and Nagoda, 1991).

2.3.3.1 Density

Density is related to the strength of wood since it is an index of the amount of cell wall substance contained in a piece of wood (Ishengoma and Nagoda, 1991). The relationship between density of wood and various strength properties of wood is known to conform to the equation developed by Armstrong (1960):

$$S = kd^b$$

Where:

S = strength value,

d = density, and

k = proportionality constant differing for each strength property,

b = exponent that defines the shape of the curve representing the relationship.

2.3.3.2 Defects

Defects which affect strength properties include among others cross grain and knots.

Cross grain

Grain is defined as the general direction or arrangement of the longitudinally oriented cells relative to the main axis of the tree or a piece of sawnwood. The term cross grain is used when fibres run at an angle to the main axis (Hygreen, 1980; Klem and Iddi, 1996). Due to cross grain, the greatest stress may be acting at an angle to the grain where strength is less than maximum (Kollmann and Côté, 1968; Ishengoma and Nagoda, 1991). Such strength is estimated by the empirical Hankinson's formula:

$$N = PQ/(P\sin^2\beta + Q\cos^2\beta)$$

Where:-

N = strength at an angle β

P and Q = strengths parallel and perpendicular to grain.

Knots

A knot is a portion of a branch that become incorporated into the tree trunk during growth. The knot may be an integral part of the wood if the branch was alive at the time the wood around it was formed (inter-grown knot), it may be loose (encased knot) or even missing knot (hole knot) if the branch had been dead at the time of wood formation (Hygreen, 1980). Knots have been recognized as major strength reduction defect in timber. Ishengoma and Nagoda (1991) advanced the following reasons as to why knots decrease strength properties of wood:

- clear wood is displaced by a knot,
- fibres around the knots are distorted causing cross grain,
- discontinuity of wood fibres lead to stress concentration,

checking often occur around knots in drying.

2.3.3.3 Moisture content

Below fibre saturation point, which is a moisture content of 28%, most of the strength properties of wood vary inversely with moisture content except work to maximum load in static bending and hardness (Wmax) or impact bending. Therefore it is necessary to adjust strength values before any comparison is made (Ishengoma and Nagoda, 1991).

2.3.3.4 Temperature

The effect of temperature on strength and elastic properties of wood is classified either temporary i.e. reversible or permanent i.e. irreversible (Dietz *et al.*, 1980). Temporary effects are those which are independent of the period of exposure to high or low temperatures. Most strength properties except toughness and shock resistance increase as the temperature increases. Compressive strength and modulus of rupture are the most sensitive (Ishengoma and Nagoda, 1991).

2.3.3.5 Wood biodegradation

The main agents of wood biodegradation are decay fungi and insects. The removal of wood substance from a piece of wood by these agents cause a considerable decrease in strength of the wood (Scheffer, 1973; Iddi and Nagoda, 1992).

2.3.3.6 Time of loading

Rate of loading

Higher strength values are obtained for wood loaded at rapid rates and lower values are obtained for slower rates. For example load required to produce failure in a pieces of wood in one second is approximately 10% higher than that required in a standard test (Panshin and de Zeeuw, 1970; Ishengoma and Nagoda, 1991).

Duration of stress

The duration of stress or the time during which the force acts on a piece of wood has an important effect on the magnitude of the load which can be sustained by that piece. Strength is a function of duration of stress, with strength decreasing about 8% for each ten-fold increase in duration. Strength is approximately linearly related to the logarithm of time (Panshin and de Zeeuw, 1970).

Creep

Creep is defined as time dependent deformation exhibited by material under constant load. Creep is proportional to logarithm of time for the first 30 to 40 minutes of sustained load period. At longer periods, creep tends to increase more than proportionality with the logarithm of time (Kollmann and Côté, 1968). Changes in climatic conditions increase the rate of creep and shorten the duration which the test sample can support a given load (Ishengoma and Nagoda, 1991).

Fatigue

Fatigue refers to the progressive damage that occurs to a material subjected to cyclic loading. It is the ability of wood to sustain repeated, reversed or vibrational loads without failure. Like other strength properties fatigue also increases with density (Panshin and de Zeeuw, 1970).

2.3.3.7 Chemicals in wood

Strong acids and alkalis cause chemical changes and degradation in the cellulose and lignin therefore reducing the strength of wood (Iddi and Nagoda, 1992).

2.3.4 Determination of strength properties

Because of anisotropical behaviour of wood, determinations of strength properties require tests on the three directions of wood that is radial, tangential and longitudinal (Ishengoma and Nagoda, 1991). Strength properties of wood include maximum crushing stress parallel to grain in compression, compression perpendicular to grain, static bending which includes modulus of elasticity (MOE), modulus of rupture (MOR), work to maximum load (Wmax) and total work to fracture (TWF), shear parallel to grain (SPG), shear perpendicular to grain, cleavage (CLV), hardness and impact bending (Desch, 1973; Criswell and Vanderbilt, 1980). Normally, strength properties calculations are based on dry weight and green volume (Criswell and Vanderbilt, 1980). Ishengoma and Nagoda (1991) reported that strength properties of wood are measured by standard methods either by service test when wood is subjected to actual conditions in practice or by laboratory tests.

Two standard procedures have been used internationally for testing strength properties of clear timber specimens (Lavers, 1969). These are the American Society for Testing

Material (ASTM) D143-52 (1965) and the British Standard No. 373: (1957). The latter is the one also used in this study because the small section makes it possible to obtain adequate test specimens of 20*20 mm for special investigation and the results of the strength properties obtained by this standard are directly expressed in SI units.

2.3.5 Variations in strength properties

There are variations in strength properties between species, between trees of the same species and within a tree (Tsoumis, 1968; Scheffer, 1973; Sanwo, 1986). Lavers (1969) reported that the magnitude of variation differs from one property to another. Compression strength changes relatively more than modulus of elasticity with decrease in moisture content.

2.3.5.1 Variation between different tree species

Since the amount of wood substance per unit volume varies from one species to another it is therefore expected that strength properties also vary from one species to another. This variation is due to differences in anatomical structures in various wood species (Koch, 1972b).

2.3.5.2 Variation between trees of the same species

According to Panshin and de Zeeuw (1970), the existing variation within the same species is a product of interacting factors that modify the physiological processes involved in formation of wood. Difference in environmental conditions, climate and genetical difference are probably the main cause for large variation between trees of the same species (Bryce, 1967).

2.3.5.3 Variation within a tree

Strength properties variation with a single tree is known to occur considerably in axial direction (base to top), and radially (pith to bark) of the tree (Sekhar and Negi, 1961; Sekhar and Negi, 1966; Dinwoodie, 1981; Brown, 1982).

2.3.6 Relationship between different wood properties

There is a relationship between density and strength properties of the wood and also some relationship exists among some strength properties. This relationship can be examined by regression or correlation of the variables (Dadswell, 1960; Dinwoodie, 1981). The higher the correlation coefficient between the variables the stronger the relationship between wood properties (Kollmann and Côté, 1968; Dinwoodie, 1981; Ishengoma and Nagoda, 1991).

2.3.6.1 Relationship between density and strength properties

The relationship between density and various strength properties of wood based on the results of tests on small clear specimens is known to conform to the curvilinearly equation developed by Armstrong (1960) as indicated in part (2.2.3). This relationship is especially found in conifers (Kollmann, and Côté, 1968). But according to Dinwoodie (1981) the relationship between density and strength properties is assumed to be linear for most timber species.

2.3.6.2 Relationship between different strength properties

There is a high correlation between modulus of elasticity (MOE) and modulus of rupture (MOR), also there is a strong correlation between impact bending and total work, hardness and compression perpendicular to grain. (Dinwoodie, 1981).

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

Bunda District is situated south of Mara region in the north-western side of Tanzania. It covers an area of about 3088 km^2 between latitude 2°3'-2°20'S and longitude 33°15'-34°30'E. The south-eastern part of the district bordering Mwanza region forms part of the Serengeti National Park. To the west the district borders Lake Victoria. In 1997 its population was about 200 870.

3.1.2 Climate

Usually this area receives a bimodal pattern of rainfall. Short rains from September to December and long rains from February to June with an average of 1000 mm annually. Temperature varies between 26-28°C.

3.1.3 Topography and soils

The area is flat to hilly. The soils are vertisol clay with imperfect drainage (Enserink and Kaitaba, 1996).

3.1.4 Natural Vegetation

The area was originally covered by savannah grassland and tropical vegetation of which some have been cleared for cultivation and settlement. The remaining vegetation is composed of a diversity of species of both economic and ecological values. The tree species include among others *Combretum molle*, *Grewia bicolor*, *Parinari curatellifolia*, *Acacia senegal*, *Acacia nilotica*, *Acacia polyacantha*, *Combretum zeyherii* and *Markhamia lutea*.

3.1.5 Human activities

In Bunda District people mainly engage in agriculture, livestock grazing and fisheries. The agricultural crops include cotton, cassava, maize, potato, fingermillet, sorghum, beans and paddy. In another hand people also engage in forestry activities. These are management of watershed and tree planting initiated in 1994 by the Vi Tree Planting (Agroforestry) Project for villages around lake Victoria. The planted tree species include among others *Melia azedarach*, *Markhamia lutea*, *Acacia nilotica*, *A. polyacantha*, *A. senegal*, *Maesopsis eminii*, *Tamarindus indica*, *Sesbania sesban*, *Balanite aegyptiaca*,

Azadirachta indica, Tectona grandis, Terminalia catappa, T. brownii, Milcia excelsa, Grevilea robusta, Cedrela ordorata, Khaya nyasica, Moringa stenopetala, M. oleifera, Dalbergia melanoxylon, Croton megalocarpus, Casuarina equisetifolia, Albizia lebbeck, Faidherbia albida, Afzelia quazensis, Calliandra calothyrsus, Syzgium cuminii, Persia americana, Pithecellobium dulce, Citrus sinensis, C.limon, C. reticulata, Psidium guajava, Annona muricata, A. squamosa and *Carica papaya.*

3.2 Data collection

3.2.1 Survey of the current end uses

A survey was conducted in the area to determine the current end uses of wood of *Melia azedarach* and *Markhamia lutea.* The surveyed places were Bunda town and other six villages namely Igundu, Kisorya, Mwitende and Nambaza in Nansimo Division, Kasahunga and Sikiro in Kenkombyo Division. This was done through interviews and structured questionnaires distributed to pitsawyers, timber dealers, constructors, wood users and tree owners (Appendix 1).

3.2.1.1 Sampling unit

The sampling unit was a crew for pitsawyers, timber dealers and constructors. For wood users and tree owners the sampling unit was an individual concerned. The sample

of interviewed respondents constituted only by men of age between 20 to 50 years for pitsawyers, timber dealers and constructors. 28% and 7% of women constituted a sample of respondents for wood users and tree owners respectively while the rest of the respondents were men. It was noted that women owning trees were those divorced or widowed, that is they are the heads of their households.

3.2.1.2 Sampling design

A random sampling method was used in selecting the respondents from each group for interview. This aimed at minimizing sampling error for best representation of the population.

3.2.1.3 Sampling intensity

Sample sizes depended on the number and availability of members in a targeted group. For example there were only two or three pitsawyer crews in each village, therefore each was interviewed. But for the rest of the groups i.e. timber dealers, constructors, wood users and tree owners the sampling intensity was 5%.

Boyd *et al.* (1981), cited by Kajembe and Luoga (1996) suggested that a random sample should at least constitute 5% of the total population in order to represent a population. The larger the sample sizes the smaller the sampling error.

3.2.2 Tree characteristics

Tree characteristics determined in the field were diameter at breast height, tree height, crown size, branching habit and tree form. The first three parameters were measured by using a tape measure while the number of branches at high levels of tree height for both species were obtained by counting the branches. Tree form was determined by observation on standing trees.

A random sampling method was used for selecting trees for determination of these characters with exception of tree heights which only sample trees were measured after being felled. The sample size consisted of ten trees of each species in each of the selected villages.

3.2.3 Wood samples

Sampling methods and procedures and general requirement for basic density and strength properties followed ISO 3129 standards of 1975 (ISO, 1975). Five trees of age between 25 to 30 years for each tree species (*Melia azedarach* and *Markhamia lutea*) grown in agroforestry were selected. According to Burley and Wood (1976), sample trees of good form and free from remarkable defects were randomly selected from agroforestry systems preferably scattered trees in croplands. The sample trees were taken from five different villages in Bunda district namely; Igundu, Kisorya, Mwitende, Nambaza and Kasahunga. Standard methods for collecting samples and recording data

(Hughes and Plumptre, 1976) were used (Appendices 2 and 3). Before felling diameter at breast heiht (dbh) for each sample tree was recorded. The sample trees were felled by using two man cross-cut saws. After felling total tree height was measured. From each sample tree three disks measuring 5 cm thick were cut at breast height (1.3 m), 45% and 75% of the total tree height. The disks were marked to indicate species, tree number and their vertical position. The disks were dried under shade then put in polythene bags for transportation. A sample log 1 m long was cut above 1.3 m. The log was also marked. The diameters at breast height (dbh) and heights of the sample trees are shown in Table 4. A centre plank of 65 mm was sawn from each log. The planks were labelled using paint with codes indicating the species and tree number. The planks were air dried. Laboratory tests were done at Sokoine University of Agriculture, Morogoro.

Table 4: Species diameter at breast height, (dbh) and total heights of sample trees

Species	Tree No	Dbh (cm)	Height (m)
Melia azedarach	1	20.7	9.0
	2	17.5	7.7
	3	19.4	7.0
	4	20.7	8.0
	5	38.2	8.0
Markhamia lutea	1	35.7	14.0
	2	17.8	8.1
	3	25.5	13.1
	4	22.3	10.0
	5	21.3	8.0

3.3 Laboratory procedures

3.3.1 Sample preparation for basic density

The three disks from each tree sample were for determination of basic density. The data obtained from these disks were used to determine radial and axial variation in basic density between and within the studied species. Basic density for correlation with strength properties was determined from the log centre planks.

- from the disks radial strips from pith to bark were cut. Then each strip was divided into 10 subsamples and systematically numbered from pith to bark.

- from the resawn scantlings, labelled from pith to bark, specimens measuring 20*20*10 mm were cut for determination of basic density for correlation with strength properties.

3.3.2 Sample preparation for strength properties

The log centre planks were for determination of strength properties and basic density for correlation with strength properties. In the laboratory the 10 planks were air dried. Scantlings measuring 300*65*1000 mm were radially resawn from the 1 m planks and labelled from pith to bark representing the two sides east and west from the pith following B.S. 373 MTSCT in accordance to Lavers (1969). The scantlings were again

dried and further planed to 20*20 mm square section and labelled serially from pith to bark. The number of samples obtained from pith to bark depends on the width of scantling for each sample plank. Each scantling provided specimens for all tests. The dimensions of each specimen depended on the relevant test as follows:

- 20*20*60 mm for maximum crushing stress parallel to grain in compression,
- 20*20*300 mm for static bending,
- 20*20*20 mm for shear parallel to grain, and
- 20*20*45 mm for cleavage perpendicular to grain.

3.3.3 Determination of basic density

Basic density was determined using the maximum moisture content method (Olesen, 1971).

3.3.3.1 Green volume determination

All specimens were soaked in distilled water until they attained green volume. The green volume in cubic centimetre for each specimen was obtained by water displacement. A beaker of water was placed on a balance then the specimen was suspended by needle clamped on a stand, then each specimen was lowered into the beaker while being in no contact with the sides or bottom of the beaker. The weight in grams equals to the weight of the volume of water displaced of each specimen was recorded.

3.3.3.2 Oven dry weight determination

After measuring the green volume specimens were then oven dried to constant weight in the oven at temperature of 102±3°C and then cooled in a descator. The specimens were reweighed and the weight of each in grams was recorded.

Basic density was calculated by using the following formula:

$$Bd = Odw/Gv$$

Where:-

Bd = basic density (g/cm^3),

Odw = oven dry weight (g),

Gv = green volume (cm^3).

3.3.4 Strength properties determination

The strength tests were done following procedures by Lavers (1969). All the tests were carried out at room temperature and relative humidity in accordance with B.S 373 (1957). Before testing for strength properties all specimens were weighed and the weight at test (g) of each specimen was recorded. After weighing the specimens were subjected to stress on a Monsato Tensiometer. The measurement was needed for

moisture content adjustment. Strength values for each specimen at moisture content μ were obtained as follows:

3.3.4.1 Maximum crushing stress parallel to grain in compression

Maximum crushing stress parallel to grain in compression (MCS) in N/mm^2 was calculated by using the following formula:

$$MCS = Pmax/a*b$$

Where:-

Pmax = maximum load (N)

a and b = cross-sectional dimensions (mm)

3.3.4.2 Static bending

Load deflection diagrams were drawn until the specimen failed to support 0.1 of the maximum load. The area under the stress/strain curve was measured by using a planimeter. Properties including MOR, MOE, work to maximum load and total work to fracture were determined from this test.

Modulus of elasticity (MOE) in N/mm^2 of each test specimen was obtained by using the following formula:

$$MOE = Pmax*L^3/2*S*h^2$$

Where:-

Pmax = maximum load (N),

L = span length equal to 280 mm,

S = actual deflection to the elastic limit (mm),

h = thickness of the specimen equal to 20 mm.

The multiplying factor used was as follows:

$$MOE = Pmax * 34.3$$

Modulus of Rupture (MOR) in N/mm^2 for each specimen was calculated by using the following formula:

$$MOR = 3*Fmax*L/2*W*h$$

Where:-

Fmax = maximum load (N),

L = span length equal to 280 mm,

W = width of the specimen equal to 20 mm,

h = thickness of the specimen equal to 20 mm.

The multiplying factor used was as follows:

$$MOR = Fmax*0.0525\ N/mm^2$$

Work to maximum load (Wmax) in for each specimen was calculated by using the following formula:

$$Wmax = A_1*Q/V$$

Where:-

A_1 = area under the curve to maximum load (mm^2),

Q = work equivalent to 1mm on the load deflection curve,

V = volume of the specimen equal to 280*20*20 mm = (112000 mm^3).

Total work to fracture (TWF) in N/mm^2 for each specimen was calculated by using the following formula:

$$TWF = A_2*Q/V$$

Where:-

A_2 = area under the curve to total fracture (mm^2),

Q = work equivalent to 1mm on the load, deflection curve,

V = volume of the specimen equal to 280*20*20 mm = (112000 mm^3).

3.3.4.3 Shear strength parallel to grain

Shear strength parallel to grain (SPG) in N/mm^2 was calculated by using the following formula:

$$SPG = Pmax/b*l$$

Where:-

Pmax = breaking load (N)

b = specimen thickness (mm),

l = length of shearing surface (mm).

3.3.4.4 Cleavage strength

The splitting force was applied to each specimen then the maximum load (N/mm) which split a specimen into two section at the point of application of load (CLV) was calculated by using the following formula:

$$CLV = Pmax/b$$

Where:-

Pmax = maximum load (N),

b = specimen width (mm).

3.3.5 Adjustment of strength properties to 12% moisture content

After testing strength properties on a Monsato Tensiometer the specimens were allowed to dry in oven at a temperature of 102±3°C until constant weight was attained, then cooled in a descator and re-weighed. The oven dry weight (g) for each specimen was recorded.

The percentage moisture content (M.C) of each specimen at test was calculated as follows:

$$M.C = 100*(W_1 - W_2)/W_2$$

Where:-

W_1 = weight of a specimen at test (g),

W_2 = oven dry weight (g).

The difference in moisture content (n) at test from 12% for each specimen was calculated and recorded .

All strength property values of the specimens for all tests were adjusted to 12% moisture content by the formula:

$$Y_{12} = Y_w(1+Z)^n$$

Where:-

Y_{12} = strength value at 12% moisture content,

Y_w = strength value at test,

Z = correlation factor.

Where: Z = 0.04 for maximum crushing stress parallel to grain in compression, shear parallel to grain and MOR,

Z = 0.02 for cleavage and MOE,

Z = -0.01 for Work to maximum load and total work to fracture, (Desch, 1973).

n = difference in moisture content at test from 12%.

3.4 Data analysis

3.4.1 Survey of the current end uses of wood

Data collected by interviews and questionnaires were analysed by using qualitative and quantitative methods. Quantitative data were analysed by using statistical package for social sciences (SPSS).

Questionnaires were first coded so that they could be in a form which can address the research questions suitably. Then data were explored for descriptive statistics. Chi-square was used to determine if there were variations between ideas collected from different studied villages.

3.4.2 Tree characteristics

Simple statistics were used to obtain average values for diameter at breast height, tree height, crown diameter and number of branches. The average form for each species was based on the form of most trees for each species.

3.4.3 Variation in basic density and strength properties

Data analysis was done by using statistical analysis system programme (SAS). To determine variations in basic densities and strength properties between species, between trees of the same species and within a tree, t- test, analysis of Variance (ANOVA) and Duncan multiple range test was done.

The following statistical model for ANOVA was used:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

Where:-

Y_{ij} = basic density or strength property at a given tree height or position from pith to bark Y_{ij}'s are random variables

τ_i = height or position at which basic density or strength property was determined. τ_i's are fixed.

μ = general effect.

ε_{ij} = error term, normally distributed with mean 0, and variance δ^2.

3.4.4 Relationship between basic density and strength properties

To determine the relationship between basic density and strength properties regression and correlation coefficient analyses were used.

The statistical model used for Regression was as follows:

$$Y_i = \alpha + \beta X_i + \varepsilon_i$$

Where: Y_i = dependent variable, i.e. strength properties at a given tree height or position from pith to bark. Y_i are random variables.

X_i = independent variable, i.e. basic density at given tree height or position from pith to bark, X_i's are fixed.

ε_i = error term, normally distributed with mean 0 and variance δ^2.

α = general effect.

3.4.5 Relationship between different strength properties

To determine the relationship between different strength properties regression and correlation analysis between the studied strength properties were done. The model for

regression was as shown in (3.4.4).

3.4.6 Effect of rate of growth on basic density and strength properties

To determine if the dbh and total tree heights had any effect on basic density and strength properties of wood of each species, regression and correlation analysis were used. The statistical model was as shown in (3.4.4). In these cases the independent variables were diameters at breast height and tree heights. The dependent variables were basic density and strength properties.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Survey of the current end uses

Table 5 summarises the results of the survey of the current end uses of *Melia azedarach* and *Markhamia lutea* in Bunda district.

Table 5: Percentage of respondents for different end uses of wood of *Melia azedarach* and *Markhamia lutea* in Bunda district

Uses	percentage of respondents	
	Melia azedarach	*Markhamia lutea*
Construction (timber)	35.7	31.6
Furniture	23.7	27.5
Poles	21.4	24.4
Firewood	7.9	11.3
Medicine	7.2	0
Others	4.1	5.2
Total	100	100

It can be observed in Table 5 that wood from the two studied species *Melia azedarach* and *Markhamia lutea* was mainly used for construction i.e. for roofing and production

of door and window frames. This was followed by furniture production i.e. chairs, beds and tables. Uses as poles and firewood take the third and fourth positions respectively.

It is also important to note that *Melia azedarach* has medicinal values. Boiled leaves of *Melia azedarach* were used as a medicine to cure stomach ache.

It is also evident from the table that, wood of *Melia azedarach* is used more in construction than *Markhamia lutea.* This might be caused by among other reasons its longer straight bole as compared to the other species. The wood of *Markhamia lutea* in the other hand was used more for furniture making as compared to *Melia azedarach.* This might be attributed to its wood quality and tree characters (See Table 6).

In addition to the famous uses, wood of *Markamia lutea* was also utilized for making tool handles for axes and hoes. The wood was further used for making boat paddles.

Considering the knowledge on the quality of wood of both *Melia azedarach* and *Markhamia lutea* for construction, furniture and as firewood the study revealed that very little was known (Appendix 4). Furthermore, the results indicated that tree owners sold a large amount and utilised small quantities of wood from these species.

The results of chi-square showed that at 5% probability level there were significant differences between ideas collected from respondents in different villages. This means that the quantity of wood of both species used for a particular purpose differs from one

village to another.

Also there were no significant differences in response between members of the same respondent group i.e. pitsawyers, wood users and tree owners. This implied that members of the same respondent group had similar views on end uses of both *Melia azedarach* and *Markhamia lutea*.

4.2 Tree characteristics and some physical properties

Results of tree characteristics and some physical properties of wood of both species are presented in Table 6. The stems of *Melia azedarach* were straight from the base up to about 7 m. The stem had a number of branches originating from it making an angle less than 90°. The trees had open or light crown covers that do not hinder penetration of sun rays to the soil underneath. But in some home compounds and market centres trees of *Melia azedarach* are used to provide shade despite of their light crowns.

Markhamia lutea had straight bole up to 5 m above the ground. Above 5 m the bole was crocked. Branches were found at angles less than 90° to the main stems at about 5 m above the ground. Its crown was narrow and irregular. The results in Table 6 shown that *Markhamia lutea* had narrow crown size and fewer number of branches as compared to *Melia azedarach.* Inspite of its narrow crown size this tree was also used as a shade tree in some homes.

Table 6: Average tree characteristics and some physical properties for *Melia azedarach* and *Markhamia lutea*

Tree character	*Melia azedarach*	*Markhamia lutea*	differences (percentage)
Dbh (cm)	33	31	6.3
Tree height (m)	10	12	9.5
Crown diameter (m)	6.4	4.8	28.6
Number of branches	8	6	28.6
Merchantable bole form (m)	7	5	33.3
Wood colour			
- Heartwood	Reddish brown	light yellow	-
- Sapwood	Light yellow	light yellow	-
Heartwood percentage	71.4	No colour difference between sapwood and heartwood	-
Bark thickness (cm)	0.5	0.4	22

4.3 Basic density

4.3.1 Mean basic density

Mean basic density, minimum and maximum values and standard deviation for the two species are presented in Table 7. The value for *Melia azedarach* obtained from this investigation was slightly lower as compared to that of 470 kg/m^3 reported by Chudnoff (1984).

Table 7: Mean basic density, minimum and maximum values and standard deviation for *Melia azedarach* and *Markhamia lutea*

Species	Mean	Min	Max	sd
Melia azedarach	436	273	547	40
Markhamia lutea	430	340	577	30

Where:-

Min = minimum value,

Max = maximum value,

sd = standard deviation,

Basic densities obtained in this study for *Melia azedarach* and *Markhamia lutea* are lower than that of common hardwood species in Tanzania presented in Table 1. However, the two species are denser than softwoods such as *Pinus caribaea* and *Pinus patula*. It is obvious that these differences were caused by genetical differences (Zobel and Talbert, 1984). Silvicultural treatment and environmental factors as reported by Erickson and Lambert (1980) may also be the course, since these factors may promote or hinder high growth rate, resulting into increased or decreased wood density.

4.3.2 Variation in basic density

4.3.2.1 Variation between *Melia azedarach* and *Markhamia lutea*

The results of analysis of variance indicated no significant difference ($P>0.05$) in basic density between *Melia azedarach* and *Markhamia lutea* (Appendix 5). The similarity in basic density indicates similarity in cell size and proportions in the wood of the two species.

As it is generally known that the quality of wood especially strength properties depends mainly on its density (Kellogg, 1981; Harris, 1993), the observed similarity in mean basic density for the two species implies that wood of these species can be used interchangeably.

4.3.2.2 Variation between trees of the same species

Analysis of variance showed that there were significant differences between trees of *Melia azedarach* ($P<0.001$) and *Markhamia lutea* ($P<0.05$). Variation in basic density between trees of the same species taken from the same location was also reported by Rajput *et al.* (1991) for *Tectona grandis* from Mizoran.

The significant difference between trees of these species may be caused by among other factors differences in silvicultural treatments (Erickson and Lambert, 1980; Klem and Iddi, 1996) and environmental or growth conditions (Rajput *et al.*, 1991). According to Zobel and van Buijtenen (1989) micro environment of the individual trees due to competition for nutrient uptake with other plants growing on the same locality and site factors may to some extent also contribute to variation of wood density between trees of the same species.

The influence of the growth conditions in many cases affects density of wood. For instance trees growing slowly because of insufficient water produce narrow growth increments consisting of thin-walled cells. Also due to fertilization response trees can grow fast hence produce wood of low density due to wide growth increments and large cell lumen diameters especially in diffuse porous hardwoods.

When growth factors are available at their optimum levels for a particular organism, its development will be the best possible. Therefore the variation between trees of the

same species might be contributed by differences in the levels at which the growth factors were available (Klem and Iddi, 1996).

Moreover the genetical differences plays a major role in variation between trees of same age growing on similar sites. But in this case the seed sources for the studied species were not known.

The differences in basic density for trees of these species suggest that, for both *Melia azedarach* and *Markhamia lutea* there is a possibility of improving basic density and hence quality of wood by selection. If for example higher density is desired, seeds from trees with higher density can be selected for further planting.

4.3.2.3 Variation within a tree

Radial variation

At different tree height levels

Fig. 1 and Fig. 2 present radial variation patterns within a tree at three tree height levels for *Melia azedarach* and *Markhamia lutea* respectively. The patterns are similar at all levels for both species. High basic density was found near the bark and near the pith and lower basic density in between.

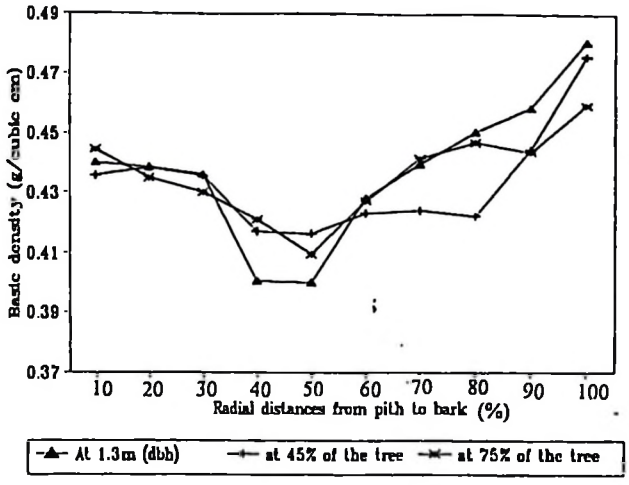


Figure 1: Basic density variation in radial direction at different tree height levels for *Melia azedarach.*

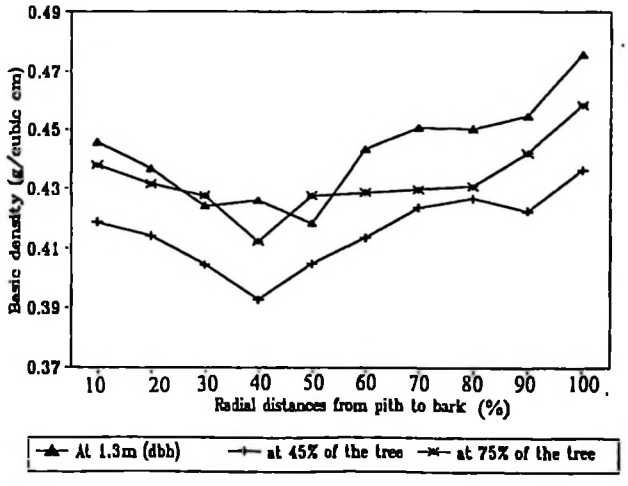


Figure 2: Basic density variation in radial direction at different tree height levels for *Markhamia lutea.*

Results of analysis of variance revealed that there was a significant variation ($P<0.05$) in basic density in radial direction at 45% tree height level for *Melia azedarach* (Appendix 7a). For the other height levels for this species and for all tree height levels for *Markhamia lutea*, there was no significant difference ($P>0.05$) in basic density (Appendix 7b).

The significant difference in basic density in radial direction for wood of *Melia azedarach* at 45% tree height suggest that there were differences in cell size and cell proportion between this level and the two levels.

These results therefore imply that wood of almost the same quality can be produced at different radial positions for *Markhamia lutea* while for *Melia azedarach* at 45% tree height level wood of different quality is produced radially.

Average for the three tree height levels

The results for radial variation in the mean basic density for *Melia azedarach* and *Markhamia lutea* considering all three height levels are illustrated in Fig. 3. It is noted that *Melia azedarach* and *Markhamia lutea* generally form wood of high density near the pith and then wood density decreases for the first few years of growth and finally increase to maximum near the bark (Fig. 3). This pattern of variation found in these species is one of the general patterns of radial variation in density in hardwoods

reported by Panshin and de Zeeuw (1970).

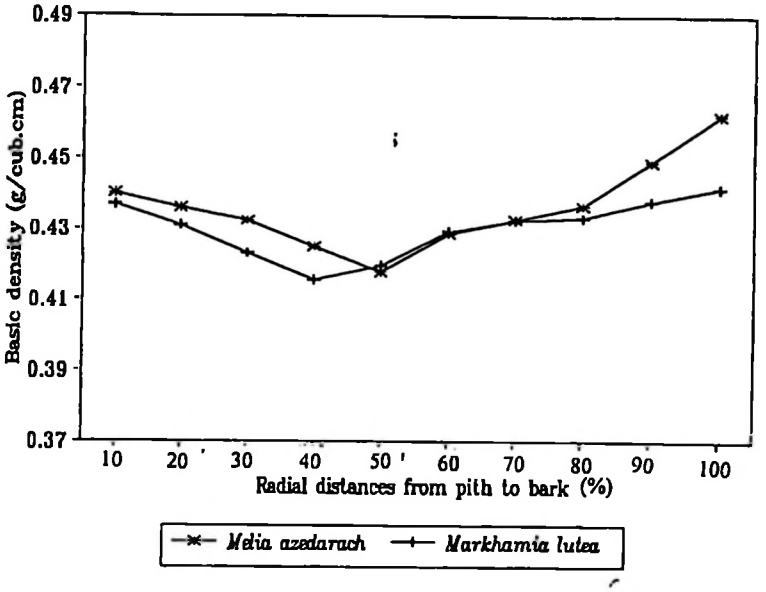


Figure 3: Basic density variation in radial direction for *Melia azedarach* and *Markhamia lutea.*

The results indicated that there was no significant difference in basic density in radial direction for both species.

This means that small boards of similar quality can be made from wood of these species, since density is an index of measure of quality of wood (Harris, 1993).

Axial variation

Fig. 4 illustrates basic density variation in axial direction for *Melia azedarach* and *Markhamia lutea*. The heaviest wood was found at the base of the trunk followed by that near the top and the lowest wood was formed in the middle of the stem for both *Melia azedarach* and *Markhamia lutea*. While there was significant difference in basic density between height levels ($P<0.001$) for *Markhamia lutea* there was no significant difference for *Melia azedarach*.

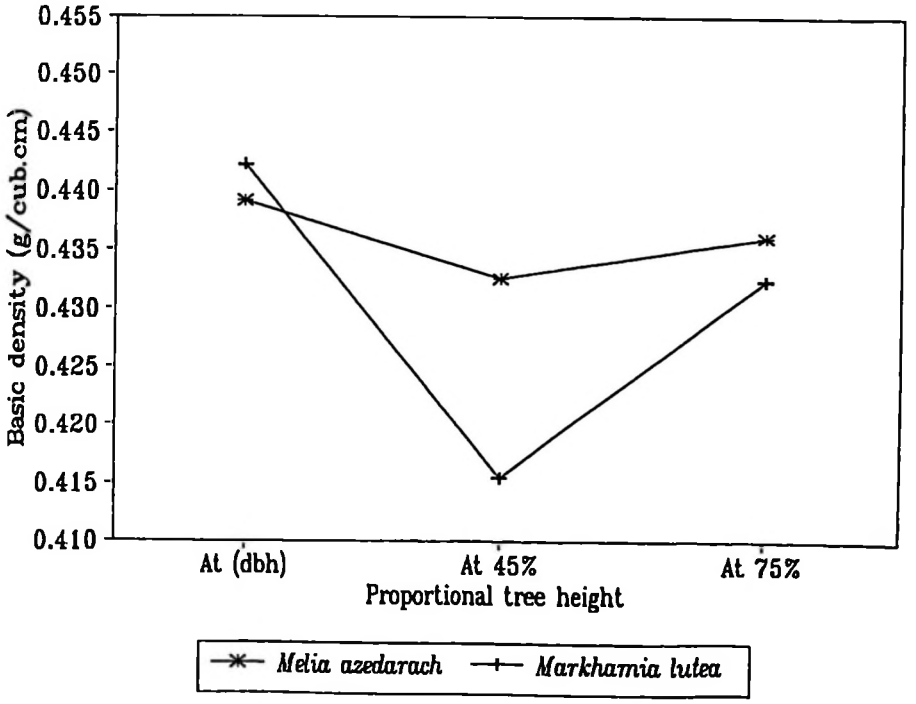


Figure 4: Basic density variation in axial direction for *Melia azedarach* and *Markhamia lutea*

This observation indicates that wood taken for *Melia azedarach* from different tree height levels can be used alternatively. For *Markhamia lutea* however, if higher density is of interest, butt end log and top merchantable log should be used together since they have similar basic density.

Interaction between vertical and radial positions

The results of analysis of variance within trees for the species indicated no significant difference ($P>0.05$) in basic density for the interaction between vertical and radial positions for both *Melia azedarach* and *Markhamia lutea* (Appendices 6a and 6b). This implies that for both species basic density of wood at any two or more positions at a given tree height is almost the same provided that they occupy same radial position.

4.3.2.4 Sources of variation

Basic density variation between trees of *Melia azedarach* and *Markhamia lutea* was a result of variations obtained from different sources including trees, vertical position, radial position and the interaction between vertical and radial position (Table 8).

Table 8: Percentage variation in basic densities between trees of *Melia azedarach* and *Markhamia lutea* as contributed by different sources of variation

Source of variation	Species	
	Melia azedarach	*Markhamia lutea*
Trees	12.5 (35.90)	6.5 (10.74)
Vposi	0.4 (1.13)	10.9 (18.27)
Rposi	7.0 (21.03)	5.6 (9.35)
VposixRposi	15.9 (45.73)	11.9 (19.89)
Error	63.8 (183.08)	65.1 (108.61)
Total	100 (286.90)	100 (166.87)

Where:-

Vposi = vertical position,
Rposi = radial position.

NB. Sum of squares are shown in brackets

The percentage contribution in total variation between trees of the same species are reported in Table 8. A largest variation is contributed by error term for both species followed by the interaction between vertical position and radial position. The smallest variation was contributed by vertical position for *Melia azedarach* and radial position for *Markhamia lutea.* This means that for *Melia azedarach* wood used in round form varies more in basic density as compared to when sawn.

4.3.3 Effect of rate of growth on basic density

Regression equations and correlation coefficients for the relationship between basic density and dbh and between basic density and total tree height (Ht) for *Melia azedarach* and *Markhamia lutea* are shown in Table 9.

Table 9: Regression equations and correlation coefficients for the relationship between basic density and diameter at breast height and between basic density and total tree height for *Melia azedarach* and *Markhamia lutea*

Species	Regression equation	Correlation coefficient "r"
Melia azedarach	Bd = 1.002(Dbh) + 413.6	0.66**
	Bd = 4.39 (Ht) + 401.3	0.73**
Markhamia lutea	Bd = 0.27(Dbh) + 423.2	0.11NS
	Bd = 2.54 (Ht) + 404.3	0.55*

Where:-

**	=	significant at 1% probability level,
*	=	significant at 5% probability level,
NS	=	not significant at 5% probability level,
Bd	=	basic density (kg/m^3),
Dbh	=	diameter at breast height (cm),
Ht	=	total tree height (m),

It can be noted from Table 9 that basic density of both *Melia azedarach* and *Markhamia lutea* was found to have positive correlation with dbh and total tree height. This means that for both species, the increase in dbh and total tree height result into increase in basic density. The relationships with basic density were significant for *Melia azedarach* for

both dbh and total tree height ($P<0.01$). For *Markhamia lutea* the relationships was significant for total tree height ($P<0.05$). However, basic density had no significant relationship with dbh for *Markhamia lutea* ($P>0.05$).

Therefore large diameter and tall trees of *Melia azedarach* produce wood which is denser than shorter trees with small diameters. While for *Markhamia lutea* wood of high basic density is produced from tall trees. This means factors which favour fast rate of growth should be encouraged to get denser wood.

Positive significant relationship between dbh and basic density was also reported by Aldridge and Hudson (1955a,b) for teak grown in plantation. The authors suggested that rate of growth is an indicator of mechanical and physical properties. The results of this study support this idea.

These results suggest that basic density of *Melia azedarach* can be estimated from both diameter at breast height and total tree height by using the developed regression equations. While for *Markhamia lutea* it can only be predicted from total tree height.

4.4 Strength properties

4.4.1 Mean strength properties

Table 10 summarises the mean values for the studied strength properties of *Melia azedarach* and *Markhamia lutea*. These results are different to those reported for other hardwood species found in Tanzania. Both *Melia azedarach* and *Markhamia lutea* had lower modulus of elasticity, modulus of rupture, work to maximum load and total work to fracture as compared to the reported values for *Tectona grandis*, *Afzelia quazensis, Pterocarpus angolensis Maesopsis eminii* and *Khaya nyasica* (see Table 3).

Melia azedarach had lower maximum crushing stress compared to those of *Pterocarpus angolensis, Afzelia quazensis* and *Tectona grandis* which had 40.6, 47 and 41.2 N/mm^2 respectively. MCS values for *Markhamia lutea* were similar to that of *Pterocarpus angolensis* and *Tectona grandis.*

Shear strength parallel to grain for *Melia azedarach* was lower than that of *Tectona grandis*, *Khaya Nyasica, Afzelia quazensis* and *Pterocarpus angolensis* (see Table 3). But it was higher than that of *Maesopsis eminii.* While that of *Markhamia lutea* was the same as that of *Tectona grandis.*

Table 10: Mean values for the studied strength properties for *Melia azedarach* and *Markhamia lutea*

	Melia azedarach			*Markhamia lutea*		
Str.	Mean	Min	Max	Mean	min	Max
MCS (N/mm^3)	35.13 (1.84)	30.97	36.9	40.7 (3.2)	35.5	48.3
MOE (N/mm^2)	3119 (648)	2795	4648	4990 (1115)	3667	8260
MOR (N/mm^2)	29.45 (3.29)	24.3	35.95	41.83 (8.6)	32.3	61.0
Wmax (N/mm^2)	0.045 (0.02)	0.023	0.08	0.053 (0.02)	0.03	0.09
TWF (N/mm^2)	0.054 (0.02)	0.023	0.09	0.082 (0.03)	0.03	0.15
SPG (N/mm^2)	9.75 (0.78)	7.63	10.6	11.26 (0.95)	9.64	13.2
CLV (N/mm)	22.00 (4.18)	16.58	31.7	16.28 (1.76)	13.5	18.9

Where:-

MCS = maximum crushing stress parallel to grain in compression,
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax= work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
Min = minimum value,
Max = maximum value,
CLV = cleavage strength.

NB. Standard deviations are shown in brackets

It is noted that cleavage strength for *Melia azedarach* was higher than that of any of the five species mentioned in Table 3. While that of *Markhamia lutea* was similar to that of *Tectona grandis* and *Pterocarpus angolensis.* Unfortunately in the literature there are no comparable strength values for the studied species.

4.4.2 Variation in strength properties

4.4.2.1 Variation between species

The results of analysis of variance showed significant difference in all the strength properties between the two species (Appendix 8). The differences were highly significant ($P<0.001$) for maximum crushing stress parallel to grain (MCS), modulus of elasticity (MOE), modulus of rupture (MOR), shear strength parallel to grain (SPG) and cleavage strength (CLV). The differences were also significant for total work to fracture (TWF) ($P<0.05$). There was no significant difference between *Melia azedarach* and *Markhamia lutea* considering work to maximum load (Wmax) at 5% probability level.

Wood of *Markhamia lutea* is generally stronger than that of *Melia azedarach.* This can be observed in Table 10 where, except for work to maximum load and cleavage strength all studied strength properties of *Markhamia lutea* were significantly higher than those of *Melia azedarach* by an average of about 37%.

High cleavage strength value of wood of *Melia azedarach* suggest more cross or spiral grain in wood of *Melia azedarach* than that of *Markhamia lutea*. Therefore high nail holding capacity is expected in wood of *Melia azedarach* as compared to that of *Markhamia lutea*.

4.4.2.2 Variation between trees of the same species

The results of the Duncan multiple range test for *Melia azedarach* and *Markhamia lutea* are presented in Tables 11a and 11b respectively. The results revealed that there were significant variations in all strength properties between trees for both *Melia azedarach* and *Markhmia lutea* ($P<0.05$).

The observed significant variation between trees of the same species in this study is in agreement with the reports by Bryce (1967) and Plumptre (1977) that there is a large variation between trees of the same species taken from different localities. Similar results were found between trees of *Tectona grandis* growm in plantation in Mizoran (Rajput *et al.*, 1991). These variations may be caused by different environmental conditions (Zobel and van Buijtenen, 1989).

The observed variations in strength properties between trees of *Melia azedarach* and *Markhamia lutea* indicate a possibility of improving these properties through selection of trees with the desired properties.

Table 11a: Mean values of strength properties for trees of *Melia azedarach*

Strength property	Trees				
	1	2	3	4	5
MCS (N/mm^2)	34.20BA	33.64 B	35.9 BA	35.47BA	36.24 A
MOE (N/mm^2)	3494 CB	3061.7C	3881.9B	3694.1B	4454.1A
MOR (N/mm^2)	27.87 B	26.49 B	30.73BA	29.70BA	32.36 A
Wmax (N/mm^2)	0.036 B	0.034 B	0.051BA	0.046BA	0.059 A
TWF (N/mm^2)	0.044CB	0.035 C	0.059 B	0.054 B	0.079 A
SPG (N/mm^2)	9.49 CB	8.810 C	10.37 A	9.70B A	10.38 A
CLV (N/mm)	19.06 C	19.05 C	22.02 B	20.86 B	29.01 A

For each strength property, means with the same letter are not significantly different at 5% probability level.

Where:-

MCS = maximum crushing stress parallel to grain in compression,
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax= work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
CLV = cleavage strength.

Table 11b: Mean values of strength properties for trees of *Markhamia lutea*

Strength property	Trees				
	1	2	3	4	5
MCS (N/mm^2)	39.56CB	39.04CB	41.54 B	44.87 A	37.46 C
MOE (N/mm^2)	4608.6B	4585.4B	5076.3B	6458.1A	4223.3C
MOR (N/mm^2)	39.13CB	38.26CB	45.26 B	52.78 A	33.74 C
Wmax (N/mm^2)	0.054BA	0.042CB	0.061 B	0.077 A	0.031 C
TWF (N/mm^2)	0.08CBA	0.075CB	0.088BA	0.117 A	0.046 C
SPG (N/mm^2)	11.32BA	10.83BA	11.78 A	12.13 A	10.25CB
CLV (N/mm)	15.69 B	15.44 B	17.58 A	18.10 A	14.60 B

For each strength property, means with the same letter are not significantly different at 5% probability level.

Where:-

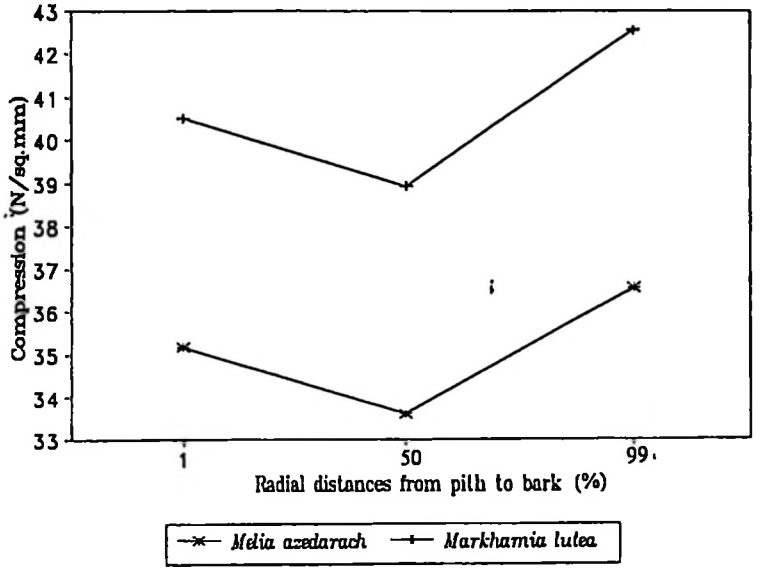
MCS = maximum crushing stress parallel to grain in compression,
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax= work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
CLV = cleavage strength

4.4.2.3 Variation within a tree

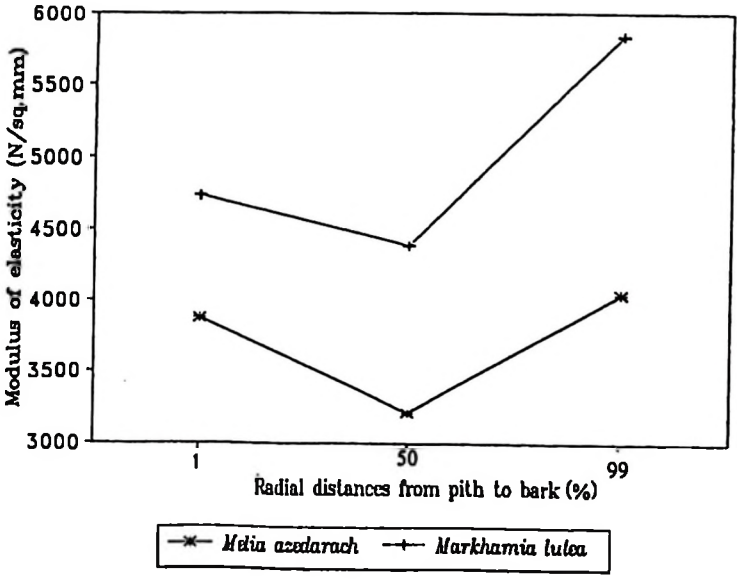
Radial variation

In this study the variation in strength properties within a tree was considered only in the radial direction (pith to bark) since a sample log for strength property determination was

only taken at 1.3 m tree height level. The variations in strength properties in the radial direction are illustrated in Fig. 5a, b, c and d.

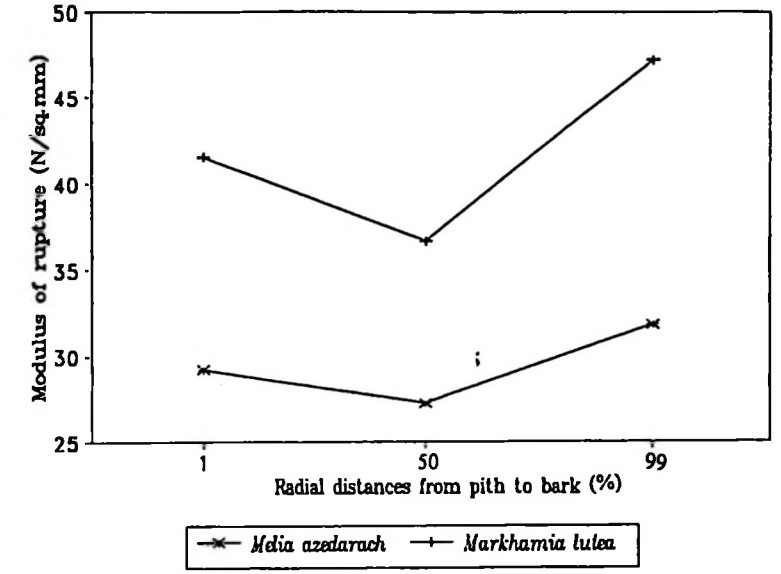


(i) MCS

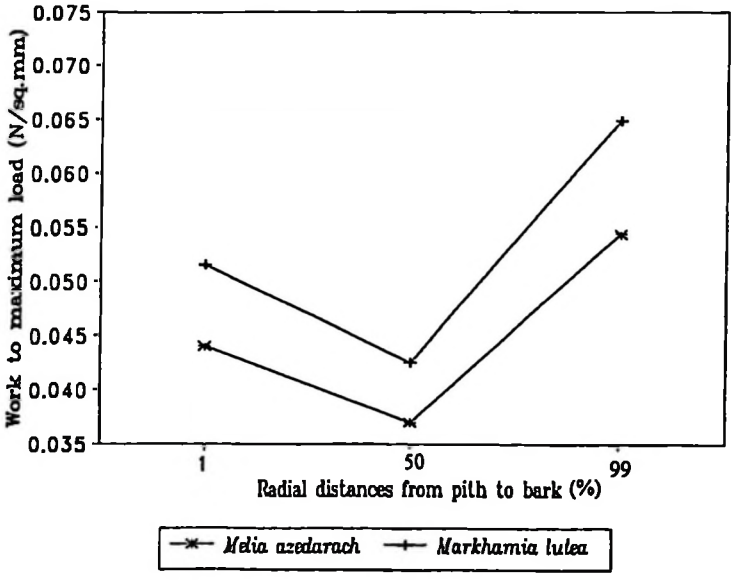


(ii) MOE

Figure 5a: Radial variation in MCS and MOE for *Melia azedarach* and *Markhamia lutea*

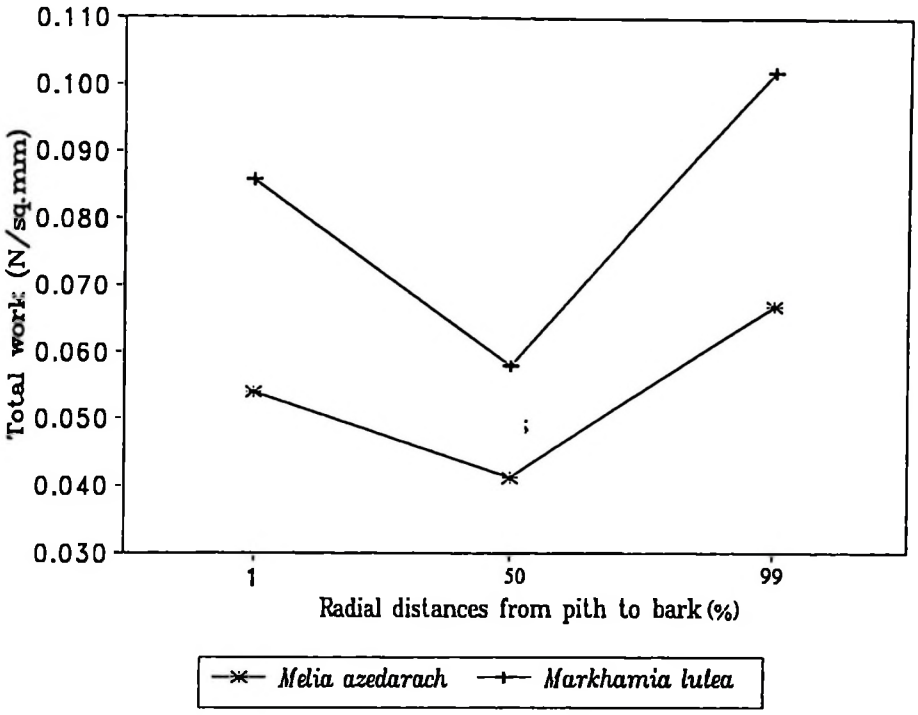


(i) MOR

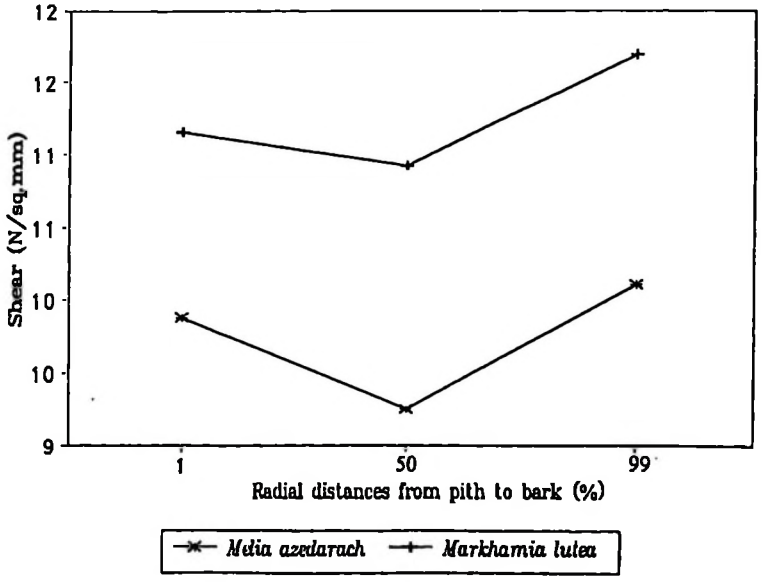


(ii) Wmax

Figure 5b: Radial variation in MOR and Wmax for *Melia azedarach* and *Markhamia lutea*



(i) TWF



(ii) SPG

Figure 5c: Radial variation in TWF and SPG for *Melia azedarach* and *Markhamia lutea*

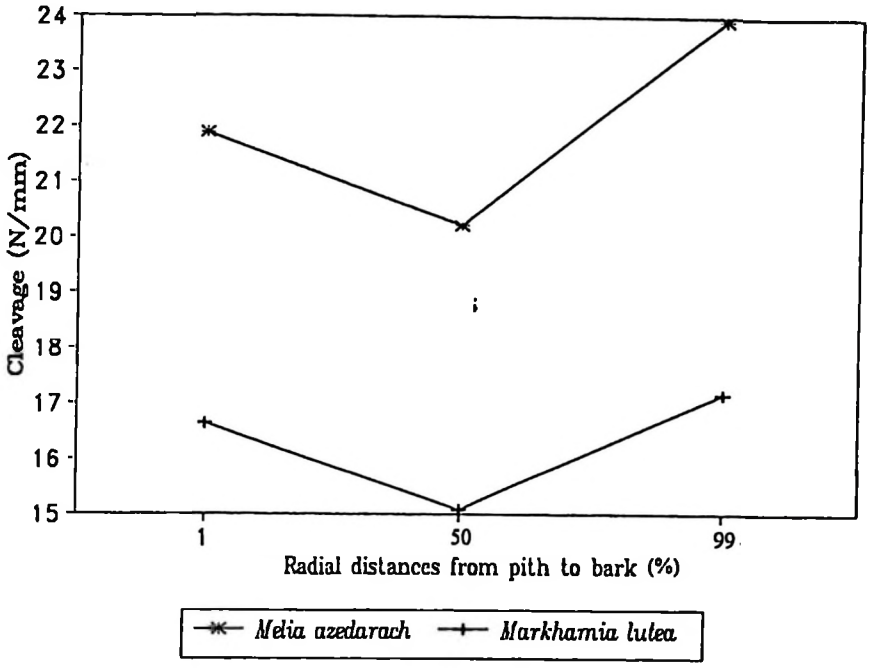


Figure 5d: Radial variation in CLV for *Melia azedarach* and *Markhamia lutea*

In Figures 5a and 5b there was similarity in the pattern of variation for the studied strength properties for both *Melia azedarach* and *Markhamia lutea*. Stronger wood was produced near the bark and near the pith and that wood of low strength was formed in the middle.

This pattern of variation for both species is similar to that for basic density observed in this study. This is one of the general trends of variation in radial direction reported by Panshin and de Zeeuw (1970).

The results of analysis of variance in Appendices 9a and 9b indicated that significant differences existed in all strength properties between the radial position for both species ($P<0.05$) with exception of Work to maximum load (Wmax) for *Melia azedarach* and shear strength parallel to grain (SPG) for *Markhamia lutea* which are not significant ($P>0.05$). This means that wood of different strength property is produced at different radial positions for both species. These results suggest selection in radial direction for both these species. If for example wood of high strength values is of interest it should be taken near to the bark.

4.4.2.4 Sources of variation

The total variation between trees was a result of variation in radial positions and also variation in individual trees. The percentage contribution from these sources of variation were deduced from the sum of squares and reported in Table 12, for both *Melia azedarach* and *Markhamia lutea.*

The results in Table 12 showed that for both species the highest variation was contributed by trees followed by radial positions. The lowest variation was contributed by error in all strength properties of the two species with exception of maximum crushing stress parallel to grain in compression (MCS) for *Markhamia lutea.*

Table 12: Percentage variation in strength properties between trees of *Melia azedarach* and *Markhamia lutea*

Species Sources	Strength properties						
	MCS N/mm^2	MOE N/mm^2	MOR N/mm^2	Wmax N/mm^2	TWF N/mm^2	SPG N/mm^2	CLV N/mm^2
Melia azedarach							
Trees	45.2	53.0	42.3	45.0	56.7	62.2	83.4
Radial	33.0	34.5	33.3	25.4	28.5	22.8	14.1
Error	21.8	21.5	24.4	30.6	14.8	15.0	2.5
Total	100	100	100	100	100	100	100
Markhamia lutea							
Trees	53.3	52.8	62.9	63.8	49.4	61.4	73.7
Radial	11.9	32.7	26.4	22.4	31.0	27.1	16.6
Error	35.8	14.5	10.7	13.8	19.6	11.5	9.7
Total	100	100	100	100	100	100	100

Where:-

MCS = maximum crushing stress parallel to grain in compression,
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax= work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
CLV = cleavage strength.

4.4.3 Relationship between basic density and strength properties

4.4.3.1 Relationship between basic density and strength properties for *Melia azedarach*

Table 13a presents the regression equations and correlation coefficients for the relationship between basic density and all studied strength properties for *Melia azedarach.* The relationships were significant at 0.1% probabilty level for maximum

crushing stress parallel to grain in compressiom (MCS), shear strength parallel to grain (SPG) and cleavage strength (CLV). They were also significant at 1% probability level for modulus of elasticity (MOE) and total work to fracture (TWF). Further, the relationships were significant at 5% probability level for modulus of rupture (MOR) and work to maximum load (Wmax). These results are similar to those reported by Davis (1961) for *Tectona grandis*. These results support the report by Dinwoodie (1981) that there exist relationships between density and strength properties of wood for most timber species.

Table 13a: Regression equations and correlation coefficients for the relationship between basic density and strength properties of wood of *Melia azedarach*

Regression equation	Correlation coefficient "r"
MCS = 62.60 (Bd) + 7.659	0.83***
MOE = 19398 (Bd) - 4792.9	0.73**
MOR = 73.99 (Bd) - 3.033	0.53*
Wmax = 0.374 (Bd) - 0.1188	0.62*
TWF = 0.623 (Bd) - 0.219	0.75**
SPG = 25.72 (Bd) - 1.537	0.81***
CLV = 155.39(Bd) - 46.150	0.91***

Where:-

*** = significant at 0.1% probability level,
** = significant at 1% probability level,
* = significant at 5% probability level,
MCS = maximum crushing stress parallel to grain in compression
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax= work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
CLV = cleavage strength,
Bd = basic density (kg/m^3).

4.4.3.2 Relationship between basic density and strength properties for *Markhamia lutea*

Table 13b shows regression equations and correlation coefficients for the relationship between basic density and strength properties of wood of *Markhamia lutea*.

Table 13b: Regression equations and correlation coefficients for the relationship between basic density and strength properties of wood of *Markhamia lutea*

Regression equation	Correlation coefficient"r"
MCS = 108.14(Bd) - 6.973	0.77***
MOE = 33940 (Bd) - 9969	0.70**
MOR = 290.11(Bd) - 86.03	0.77***
Wmax = 0.637 (Bd) - 0.228	0.72**
TWF = 1.168 (Bd) - 0.433	0.80***
SPG = 22.91 (Bd) + 1.163	0.55*
CLV = 46.87 (Bd) - 4.377	0.62*

Where:-

*** = significant at 0.1% probability level,
** = significant at 1% probability level,
* = significant at 5% probability level,
MCS = maximum crushing stress parallel to grain in compression,
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax= work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
CLV = cleavage strength,
Bd = basic density (kg/m^3).

The relationships in Table 13b are significant at 0.1% probability level for maximum crushing stress parallel to grain in compression (MCS), modulus of rupture (MOR) and total work to fracture (TWF), at 1% probability level for modulus of elasticity (MOE) and work to maximum load (Wmax) and at 5% probability level for shear strength parallel to grain (SPG) and cleavage strength (CLV). The results are similar to those reported by Davis (1961).

Basic density was found to correlate positively with the studied strength properties. This means that when basic density increases from pith to bark, strength properties also increase. These results support the earlier observation that density is a measure of strength properties as reported by Lavers (1969) and Dinwoodie (1981).

High coefficients of correlation indicate strong relationships between basic density and strength properties of wood of these species. These results imply that there is a possibility of reducing cost and time by estimating strength properties from basic density for both species.

4.4.4 Relationships between strength properties

The results of correlation analysis showed significant relationships ($P<0.05$) between most of the strength properties of wood of *Melia azedarach* and *Markhamia lutea* respectively (Tables 14a and 14b).

Table 14a: Correlation coefficients for the relationships between different strength properties of *Melia azedarach*

	Correlation coefficient "r"						
Spr.	MCS	MOE	MOR	Wmax	TWF	SPG	CLV
MCS	1.00	0.60*	0.46NS	0.60*	0.64*	0.82***	0.63*
MOE	0.60*	1.00	0.81***	0.53*	0.61*	0.47NS	0.61*
MOR	0.46NS	0.81***	1.00	0.71**	0.69**	0.63*	0.42NS
Wmax	0.60*	0.53*	0.71**	1.00	0.95***	0.48NS	0.57*
TWF	0.64*	0.61*	0.69**	0.95***	1.00	0.54*	0.71**
SPG	0.82***	0.47NS	0.63*	0.48NS	0.54*	1.00	0.63*
CLV	0.63*	0.61*	0.42NS	0.57*	0.71**	0.63*	1.00

Where:-

*** = significant at 0.1% probability level,
** = significant at 1% probability level,
* = significant at 5% probability level,
NS = not significant 5% probability level,
Spr. = strength properties at 12% m.c,
MCS = maximum crushing stress parallel to grain in compression,
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax = work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
CLV = cleavage strength.

Table 14b: Correlation coefficients for the relationships between different strength properties of *Markhamia lutea*

	Correlation coefficient "r"						
Spr.	MCS	MOE	MOR	Wmax	TWF	SPG	CLV
MCS	1.00	0.87***	0.89***	0.78***	0.72**	0.72**	0.41 NS
MOE	0.87***	1.00	0.83***	0.75**	0.68**	0.66**	0.51*
MOR	0.89***	0.83***	1.00	0.97***	0.86**	0.66**	0.68**
Wmax	0.78***	0.75**	0.97***	1.00	0.88***	0.56*	0.72**
TWF	0.72**	0.68**	0.86***	0.88***	1.00	0.97***	0.86***
SPG	0.72**	0.66**	0.66**	0.56*	0.46 NS	1.00	0.19 NS
CLV	0.41 NS	0.51*	0.68**	0.72**	0.72**	0.19 NS	1.00

Where:-

*** = significant at 0.1% probability level,

** = significant at 1% probability level,

* = significant at 5% probability level,

NS = not significant at 5% probability level,

Spr. = strength properties at 12% m.c,

MCS = maximum crushing stress parallel to grain in compression,

MOE = modulus of elasticity,

MOR = modulus of rupture,

Wmax = work to maximum load,

TWF = total work to fracture,

SPG = shear strength parallel to grain,

CLV = cleavage strength.

Highly significant relationships ($P<0.001$) were found to exist between work to maximum load and total work to fracture, between maximum crushing stress parallel to grain in compression and shear strength parallel to grain.

Also there was higher significant relationships between modulus of elasticity and modulus of rupture for wood of *Melia azedarach*. Modulus of rupture and work to maximum load, maximum crushing stress parallel to grain in compression and modulus of elasticity also correlated significantly between one another for wood of *Markhamia lutea* .

There was no significant correlation ($P>0.05$) between modulus of rupture and shear strength parallel to grain, between maximum crushing stress parallel to grain in compression and modulus rupture, and between modulus of rupture and cleavage strength for *Melia azedarach.*

Similarly, for *Markhamia lutea* there was no significant relationship between maximum crushing stress parallel to grain in compression and total work to fracture, between maximum crushing stress parallel to grain in compression and cleavage strength. Similarly there was no significant relationship between maximum crushing stress parallel to grain in compression and cleavage strength.

The results for the strong relationship between modulus of elasticity and modulus of rupture support the earlier findings by Dinwoodie (1981).

It is therefore possible to reduce cost and time by estimating one strength property from another for those showing significant relationships for both species.

4.4.5 Effect of rate of growth on strengthproperties

4.4.5.1 Diameter at breast height (dbh)

Regression equations relating (dbh) and strength properties and their corresponding correlation coefficients for both *Melia azedarach* and *Markhamia lutea* are shown in Table 15.

It can be noted in Table 15 that all the studied strength properties for both species increased with increase in dbh. For *Melia azedarach* the relatioships were highly significant for cleavage strength, for total work to fracture, for work to maximum load and for modulus of rupture ($P<0.001$). It was also significant for maximum crushing stress parallel to grain in compression ($P<0.01$). Furthermore the relationships were also significant for modulus of elasticity and for shear strength parallel to grain ($P<0.05$).

Like for basic density however, dbh had no significant relationship with all studied strength properties for *Markhamia lutea* ($P>0.05$).

Table 15: Regression equations and correlation coefficients for the relationship between diameter at breast height and strength properties for *Melia azedarach* and *Markhamia lutea*

Species	Regression equation	correlation coefficient "r"
Melia azedarach	MCS = 0.0659(Dbh) + 33.78	0.65**
	MOE = 38.48 (Dbh) + 3026	0.56*
	MOR = 0.179 (Dbh) + 25.62	0.80***
	Wmax = 0.0008(Dbh) + 0.027	0.82***
	TWF = 0.0016(Dbh) + 0.019	0.96***
	SPG = 0.0388(Dbh) + 8.920	0.62*
	CLV = 0.449 (Dbh) + 11.84	0.97***
Markhamia lutea	MCS = 0.0953(Dbh) + 38.42	0.11NS
	MOE = 9.225 (Dbh) + 4852	0.04NS
	MOR = 0.261 (Dbh) + 36.12	0.14NS
	Wmax = 0.0012(Dbh) + 0.025	0.26NS
	TWF = 0.0013(Dbh) + 0.051	0.19NS
	SPG = 0.060 (Dbh) + 9.829	0.31NS
	CLV = 0.079 (Dbh) + 14.50	0.21NS

Where:-
*** = significant at 0.1% probability level,
** = significant at 1% probability level,
* = significant at 5% probability level,
NS = not sgnificant at 5% probability level,
MCS = maximum crushing stress parallel to grain in compression,
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax = work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
CLV = cleavage strength,
Dbh = diameter at breast height.

Positive relationships implied that trees with larger diameters had higher strength values as compared to trees with smaller diameters especially for *Melia azedarach.* These differences might be caused by differences in silvicultural and environmental conditions (Erickson and Lambert, 1980), trees with large diameters might have grown on good site and good silvicultural management practice, as a result they grew fast and produce wood of high strength properties. These results are similar to those reported by Aldridge and Hudson (1955a,b) which pointed out that fast rate of growth resulted in increase in mechanical and physical properties for *Tectona grandis* grown in plantation in Mizoran.

These results therefore suggest that all the studied strength properties for *Melia azedarach* can be estimated from dbh by using the developed regression equations. The results also imply that factors which favour fast rate of growth should be employed if wood with high strength properties is required.

4.4.5.2 Total tree height

The regression equations and their correlation coefficients for the effect of tree heights on all studied strength properties are shown in Table 16.

Like for dbh, it is indicated in Table 16 that there were positive correlation between total tree height and all the studied strength properties for both species.

Table 16: Regression equations and correlation coefficients for the relationship between total tree height and strength properties for *Melia azedarach* and *Markhamia lutea*

Species	Regression equation	Correlation coefficient "r"
Melia azedarach	MCS = 0.273 (Ht) + 33.11	0.44NS
	MOE = 263.4 (Ht) + 1731	0.62*
	MOR = 0.843 (Ht) + 22.91	0.61*
	Wmax = 0.039 (Ht) + 0.015	0.63*
	TWF = 0.008 (Ht) + 0.098	0.76**
	SPG = 0.155 (Ht) + 8.58	0.41NS
	CLV = 2.433 (Ht) + 2.30	0.86***
Markhamia lutea	MCS = 0.592 (Ht) + 34.71	0.43NS
	MOE = 121.33(Ht) + 3856	0.29NS
	MOR = 1.635 (Ht) + 25.82	0.46NS
	Wmax = 0.0048(Ht) + 0.005	0.56*
	TWF = 0.0063(Ht) + 0.017	0.49NS
	SPG = 0.237 (Ht) + 8.85	0.65**
	CLV = 0.418 (Ht) + 12.15	0.60*

Where:-

*** = significant at 0.1% probability level,
** = significant at 1% probability level,
* = signifficant at 5% probabilty level,
NS = not significant at 5% probability level,
MCS = maximum crushing stress parallel to grain in compression,
MOE = modulus of elasticity,
MOR = modulus of rupture,
Wmax = work to maximum load,
TWF = total work to fracture,
SPG = shear strength parallel to grain,
CLV = cleavage strength,
Ht = total tree height.

For *Melia azedarach* the relationships was highly significant for cleavage strength ($P<0.001$). It was significant for total work to fracture ($P<0.01$). Further, relationships were also significant for modulus of elasticity, for modulus of rupture and for total work to fracture ($P<0.05$). There were no significant correlations between total tree height and both maximum crushing stress parallel to grain in compression and shear strength parallel to grain for this species ($P>0.05$).

Total tree height for *Markhamia lutea* had significant relationship with shear strength parallel to grain ($P<0.01$). The relationships were also significant for work to maximum load and cleavage strength ($P<0.05$). For this species total tree height was found to have no significant relationship with maximum crushing stress parallel to grain in compression, modulus of elasticity, modulus of rupture and total work to fracture ($P>0.05$).

This means that except for maximum crushing stress parallel to grain in compression and shear strength parallel to grain, tall trees had significantly higher values of strength properties for *Melia azedarach.* Also tall trees had higher values for shear strength parallel to grain, for modulus of elasticity and for work to maximum load for *Markhamia lutea* as compared to short trees of the same species.

Since there were positive relationships between total tree height and all the studied strength properties, thus the results of this study for both species support the suggestion by Aldridge and Hudson (1955a,b) for teak grown in plantation that rate of growth is an

indicator of mechanical and physical properties probably due to silvicultural and environmental factors. According to Erickson and Lambert (1980), silvicultural and environmental factors may promote or hinder high growth rate resulting in increased or decreased wood density and strength properties.

These results suggest that for *Melia azedarach* with exception of maximum crushing stress parallel to grain in compression and shear parallel to grain, the other strength properties can be estimated from total tree height. For *Markhamia lutea* the developed regression equations can give estimates for shear parallel to grain, for work to maximum load and for cleavage strength.

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In Bunda district the wood of *Melia azedarach* and *markhamia lutea* is still under-utilized. Most of the wood is used for construction and furniture making.

At the age between 25 to 30 years the trees of *Melia azedarach* grow up to about 12 m high with a diameter at breast height up to 39 cm. They had straight boles with an average of 8 branches originating at about 7 m. On the other hand *Markhamia lutea* grow up to about 14 m high, with a diameter at breast height up to 36 cm, with a narrow and irregular crown. The boles were straight to about 5 m of the tree height. Trees of both *Melia azedarach* and *Markhamia lutea* were used for shade.

Mean basic densities were 436 kg/m^3 and 430 kg/m^3 for *Melia azedarach* and *Markhamia lutea* respectively. No significant difference in basic densities was observed between the two species.

The mean values of all studied strength properties except cleavage strength were higher for *Markhamia lutea* than for *Melia azedarach*.

Generally high density and high strength values were found in the wood near the bark, followed by wood near the pith. Less denser wood was found in the middle of the stem for both species.

In axial direction, denser wood was found at the butt end, decreasing in the middle of the stem and finally increasing in the upper part of the stem.

There were positive significant relationships between basic density and all the studied strength properties. Also there were significant relationship between most of the strength properties for both species.

Rate of growth measured by diameter at breast height and total tree height had positive correlation with basic density and all studied strength properties. The relationship between dbh and both basic density and all studied strength were significant for *Melia azedarach*. The relationships were not significant for *Markhamia lutea*.

Total tree height had significant correlation with basic density for both *Melia azedarach* and *Markhamia lutea*. Also with exception of maximum crushing stress parallel to grain in compression and shear strength parallel to grain, it had significant relationship with all other studied strength properties for *Melia azedarach*.

For *Markhamia lutea* total tree height had significant relationship with shear strength parallel to grain, work to maximum load and cleavage strength.

5.2 Recommendations

It is recommended that:-

- The wood of *Melia azedarach* and *Markhamia lutea* can be used alternatively.

- Since wood properties of *Melia azedarach* and *Markhamia lutea* are similar to some preferred hardwoods, wood of these species can be used as an alternative for these hardwoods and thereby reduce pressure on the most preferred timber species.

- Being agroforestry species, the two species are recommended for further planting in agroforestry farming systems to raise farmer's income through selling of grown trees.

- The presence of significant difference in basic densities between trees of the same species gives a possibility of improving wood quality by planting seeds from trees with high density. Wood quality of both species can be improved through selection.

- Since at all tree height levels high basic density and strength properties were found near the bark and near the pith it is recommended that if wood of high strenght is needed, this should be taken near the bark or near the pith for both species.

- A non significant variation in wood basic density for *Melia azedarach* in axial

direction implies that wood of almost the same quality is formed within trees of *Melia azedarach* at all the three levels of the tree height. Therefore assortment of logs for timber can be done at any of the three height levels.

- Regression equation should be used to predict strength properties from basic density for both species.

- Large trees of *Melia azedarach* should be selected if wood of high basic density and high strength values is of interest. While for *Markhamia lutea* tall trees may be chosen for the sake of wood of high basic density.

- Both basic density and strength properties for *Melia azedarach* can be estimated from dbh by using the developed regression equations. Also for both species basic density can be predicted from total tree height.

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APPENDICES

Appendix 1: Questionnaires

Village:

Date:

A: General questionnaires

1.1. What kinds of building materials are currently used for buildings and other structures in the area.

1.2. What species and quality preferred

a) for building poles

b) timber for construction and furniture

1.3. What is the source/supply of wood in the village.

1. Natural forests
2. Individual trees on farmland
3. Village woodlot

Appendix 1 *(continued)*

1.4. Are there any other timber species from outside the area? If yes, what are they

1.....

2.....

3.....

1.5. What are the reasons for preferring timber species from outside the area.

1.6. What are the uses of wood of *Melia azedarach* and *Markhamia lutea.*

1.7. What are other known uses of the species.

1.....

2.....

3.....

B: Tree owners questionnaires

2. General information

2.1. Name of the tree owners .....

2.2. Gender

1. Male

2. Female

2.3. Age ..... years

Appendix 1 (*continued*)

2.4. Marital Status

1. Single
2. Married
3. Divorced
4. Widowed

2.5. Education

1. No formal education years.....
2. Adult education years.....
3. Primary education years.....
4. Secondary education years.....

2.6. Household composition

Male (Age)	Female (Age)
1.	1.
2.	2.
3.	3.
4.	4.
5.	5.
6.	6.

Appendix 1 (*continued*)

2.7. How do you demarcate your land

1. By planting trees
2. By planting sisal
3. No demarcation
4. Others

2.8. Which trees are present in your farm? (both exotic and indigenous).

Species	E/I	Number	Location/ spacial arrangement	Uses	P/R

Key: E = Exotic

I = Indigenous

P = planted trees

R = retained trees

Appendix 1 (*continued*)

3. Building materials information

3.1. What type of building materials do you use in your household?

1. Poles
2. Timber
3. Others Specify.....

3.2. What is the main supply of wood for building in your household?

1. Natural forests
2. Farm trees
3. Forest Reserves
4. Plantations
5. Village woodlots

3.3. If farm trees in (3.2) above which tree species do you prefer. Give reasons for preference.

3.5. Of the available sources of building materials, estimate the contribution of each source in your household

Percentage

1. Natural forest.....
2. Agroforestry.....

Appendix 1 (*continued*)

3. Forest reserves.....

4. Forest plantations.....

5. Village woodlot.....

3.6. Who in the household has control over trees in your farm

1. Male

2. Female

3.7. For planted trees of *Melia azedarach* and *Markhamia lutea* what are their specific uses in your household.

1.....

2.....

3.....

3.8. Do you sell any of the products of wood of *Melia azedarach* and *Markhamia lutea*?

How much do you earn per year?

3.9. Who makes decision in the household with regard to tree harvesting and why

3.10. Do you need licence/permission to harvest/cut trees planted/retained in your farm?

Appendix 1 (*continued*)

3.11. What do you consider to be the main constraints pertaining tree planting and harvesting in your farm?

1. Problems of labour
2. Lack of capital
3. Less land
4. Insecurity of land/tree tenure
5. Taxes
6. Unavailability of planting stock.

C: Questionnaires for pitsawyers

4. General information

4.1. Which species do you often saw?

1.....

2.....

3.....

4.2. What are the uses of wood of *Melia azedarach* and *markhamia lutea?*

4.3. What other uses of these species do you know?

Appendix 1 (*continued*)

D: Questionnaires for wood users

5.1. Which timber species do you sell?

5.2. Where are the main sources of your timber?

5.3. What is the price of each timber species per piece?

5.4. Are there timbers from the species *Melia azedarach* and *Markhamia lutea*? Yes or No

If yes, what is the quantity and quality of wood of these species?

If no, what are the reasons for their absence?

E: Questionnaires for forest workers and Agroforestry project (Forest officers and Vi Agroforestry project)

6. General information

6.1. Do you think the project should involve people in its activities? Yes or No

Appendix 1 (*continued*)

6.2. If yes in (6.1) above in which activities.

1.....

2.....

6.3. What is the response of the villagers on planting trees of *Melia azedarach* and *Markhamia lutea*?

Appendix 2: Pilot test

Species: Local Name:

Location : Altitude:

Description of samples collected:

Climate:

Topography and Relief:

Soils:

Forest vegetation:

History of the Crop:

Appendix 3: General utilization tests - tree

Species: Local Name:

Locatoin: Altitude:

Tree No:

Diameter (dbh cm):

Height (m):

Tree form:

Branching habit:

Crown Size (diameter m) and shape:

Bark:

Log:

No:	Length	Mid-diameter	Distance from base to mid-girth	Shape (Bends,fluting,eccentricity:) Defects (knots,shakes,splits): Condition (borers,rots,stain):

Appendix 4: Different wood consumers response in percentage on use of *Melia azedarach* and *Markhamia lutea* in Bunda district

Respondent	Spp	Wood uses		Fur.	other uses	
		Poles	Timber		Firw.	medi.
Pitsawyers	*Ma*	44	74	66	2	8
	Ml	31	51	48	5	0
Timber dealers	*Ma*	0	0	0	0	0
	Ml	0	0	0	0	0
Constructors	*Ma*	14	12	0	0	0
	Ml	9	10	0	0	0
Wood users	*Ma*	49	59	44	28	22
	Ml	41	43	33	39	0
Tree owners	*Ma*	16	33	28	16	36
	Ml	18	24	31	9	0

Where:-

Spp = species

Ma = *Melia azedarach*

Ml = *Markhamia lutea*

Fur. = furniture

Fir. = firewood

Medi.= medicine

Appendix 5: Analysis of variance for basic density variation between species

Source	DF	Sum of squares	Mean square	F value	Pr>F
Species	1	2.59	2.59	1.70	0.193NS
Error	298	453.76	1.52		
Total	299	389.51			

Where:-

NS = not significant at 5% probability level.

Appendix 6a: Analysis of variance for basic density variation between and within trees of *Melia azedarach*

Source	DF	Sum of squares	Mean square		Fvalue	Pr>F
Trees	4	35.92	8.98		5.69	0.0003***
Vposi	2	1.13	0.56		0.36	0.7007NS
Rposi	9	21.03	2.34		1.48	0.1632NS
Vposi*Rposi	18	45.73	2.54	1.58	1.61	0.0686NS
Error	116	183.08				
Total	149	286.90				

Where:-

Vposi*Rposi= interaction between vertical position and radial position,

*** = significant at 0.1% probability level,

NS = not significant at 5% probability level.

Appendix 6b: Analysis of variance for basic density variation between and within trees of *Markhamia lutea*

Source	DF	Sum of squares	Mean square	F value	Pr>F
Trees	4	10.74	2.69	2.87	0.0262*
Vposi	2	18.27	9.14	9.76	0.0001***
Rposi	9	9.35	1.04	1.11	0.3614NS
Vposi*Rposi	18	19.89	1.11	1.18	0.2887NS
Error	116	108.61	0.94		
Total	149	166.87			

Where:-

Vposi*Rposi	=	interaction between vertical position and radial position,
***	=	significant at 0.1% probability level,
*	=	significant at 5% probability level,
NS	=	not significant at 5% probability level.

Appendix 7a: Analysis of variance for radial basic density variation at the three tree height levels within trees of *Melia azedarach*

- **At 1.3m (Dbh)**

Source	DF	Sum of squares	Mean square	F value	Pr>F
Rposi	9	0.0418	0.0046	2.08	0.0546NS
Error	40	0.0892	0.0022		
Total	49	0.1309			

At 45%

Source	DF	Sum of squares	Mean square	F value	Pr>F
Rposi	9	0.0156	0.0017	2.66	0.0163*
Error	40	0.0262	0.0007		
Total	49	0.0418			

- **At 75%**

Source	DF	Sum of squares	Mean square	F value	Pr>F
Rposi	9	0.0094	0.0010	0.40	0.9269NS
Error	40	0.1037	0.0026		
Total	49	0.1131			

Where:-

* = significant at 5% probability level,

NS = not significant at 5% probability level.

Appendix 7b: Analysis of variance for radial basic density variation at the three tree height levels within trees of *Markhamia lutea*

Source	DF	Sum of squares	Mean square	F value	Pr>F
Rposi	9	0.0129	0.0014	1.42	0.215NS
Error	40	0.0404	0.0010		
Total	49	0.0533			

At 45%

Source	DF	Sum of squares	Mean square	F value	Pr>F
Rposi	9	0.0100	0.0011	1.63	0.1387NS
Error	40	0.0273	0.0007		
Total	49	0.0373			

- **At 75%**

Source	DF	Sum of squares	Mean square	F value	Pr>F
Rposi	9	0.0063	0.0007	0.54	0.8361NS
Error	40	0.0517	0.0013		
Total	49	0.0580			

Where:-

NS = not significant at 5% probability level.

Appendix 8: Analysis of variance for strength properties between species

- Dependent Variable: MCS

-

Source	DF	Sum of squares	Mean square	F value	Pr>F
Species	1	232.13	232.13	33.58	0.0001***
Error	28	193.55	6.92		
Total	29	425.68			

- Dependent Variable: MOE

-

Source	DF	Sum of squares	Mean square	F value	Pr>F
Species	1	12122799	12122799	14.58	0.0007***
Error	28	23285718	831632		
Total	29	35408517			

- Dependent Variable: MOR

-

Source	DF	Sum of squares	Mean square	F value	Pr>F
Species	1	1153.2	1153.2	27.18	0.0001***
Error	28	1187.7	42.42		
Total	29	2340.9			

- Dependent Variable: Wmax

Source	DF	Sum of squares	Mean square	F value	Pr>F
Species	1	0.0005	0.0005	1.46	0.2368NS
Error	28	0.0087	0.0003		
Total	29	0.0092			

Where:-

*** = significant at 0.1% probability level,

NS = not significant at 5% probability level.

Appendix 8 *(continues)*

- Dependent Variable: TWF

Source	DF	Sum of squares	Mean square	F value	Pr>F
Species	1	0.0056	0.0056	7.50	0.016*
Error	28	0.0215	0.0007		
Total	29	0.0273			

- Dependent Variable: SPG

Source	DF	Sum of squares	Mean square	F value	Pr>F
Species	1	17.146	17.146	22.86	0.0001***
Error	28	21.000	0.750		
Total	29	38.146			

- Dependent Variable: CLV

Source	DF	Sum of squares	Mean square	F value	Pr>F
Species	1	245.15	245.15	23.90	0.0001***
Error	28	287.29	10.25		
Total	29	532.42			

Where:-

*** = significant at 0.1% probability level,

* = significant at 5% probability level.