SELECTED WOOD PROPERTIES OF TWO LESSER KNOWN AND LESSER UTILIZED INDIGENOUS AGROFORESTRY SPECIES FROM KILOSA DISTRICT, TANZANIA

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ABSTRACT

This study was conducted to determine basic density, fibre length and some strength properties of *Lonchocarpus capassa* and *Combretum zeyheri* suitable for growing under agroforestry systems in Kilosa district. A total of three 13 year old trees from each species were sampled in Rudewa Gongoni village for the study. Diameter at Breast Height (DBH) and height of each tree were measured. The trees were then felled and cut into logs. Each log was cross cut into three 1.5 m billets representing the butt, middle and the top. The billets were sawn into small scantlings from which small specimens for determination of selected properties were taken. Standard methods were employed in determining the selected properties of the two species. Basic density was determined using water displacement method while fibre length was measured using a microprojector. Strength properties were determined using a Monsanto Tensiometer wood-testing machine. Results showed that basic density of *L. capassa* and *C. zeyheri* was 569.3 and 580 kgm^{-3} respectively. The basic density of the two species did not differ significantly ($p<0.05$). The mean fibre length of *L. capassa* was 1.38 mm and was significantly ($p<0.0001$) longer than that of *C. zeyheri* which was 1.2 mm. Results further showed that there was highly significant ($p<0.0001$) difference in modulus of elasticity (MOE), modulus rupture (MOR), shear, compressive and cleavage strength between the two species. MOE, MOR, compression and cleavage strength values of *L. capassa* are similar to those of *Pterocarpus angolensis* and *Juniperus procera*. Hence, *L. capassa* can be used in furniture especially in the place of the well known species whereas basing on its density, MOE and MOR, *C. zeyheri* can be used for construction purposes. Further research on hardness, impact bending strength, natural durability and treatability with preservatives, finishing and working properties of these two species is recommended.

DECLARATION

I, Isaac Kayumba, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor concurrently being submitted for the award of a degree in any other institution.

Isaac Kayumba (MSc. Candidate)	Date

The above declaration is confirmed by

Prof. S. Iddi (Supervisor)	Date
Dr. S. Augustino (Co - Supervisor)	Date

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DEDICATION

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ABBREVIATIONS AND ACRONYMS

ANOVA -	Analysis of Variance
BSI -	British Standards Institution
FAO -	Food and Agricultural Organization of the United Nations
Fig. -	Figure
FPL -	Forest Products Laboratory
g -	Gram
IAGTS -	Indigenous Agroforestry Tree Species
ICRAF -	International Center for Research in Agroforestry/World Agroforestry Centre
ISO -	International Standards Organization
Kg -	Kilogram
LKTS -	Lesser Known Timber Species
m -	Metre
mm -	Milimetre
MNRT -	Ministry of Natural Resources and Tourism
MOE -	Modulus of Elasticity
MOR -	Modulus of Rupture
N -	Newton
N/mm -	Newtons per milimetre
NAFORMA -	National Forest Resources Monitoring and Assessment
R^2 -	Coefficient of determination
SUA -	Sokoine University of Agriculture
TFS -	Tanzania Forest Services Agency
TZS -	Tanzania shilling

USDA - United States Department of Agriculture

Vol. - Volume

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Tanzania mainland has 48 million hectares of forests and woodlands representing 55% of total land area (TFS, 2013). These resources face many challenges including deforestation and forest degradation which is estimated to be 400,000 (ha) and equivalent to 1.0 % of the country's total forest area (TFS, 2013).

Intervention is needed to limit the rampant destruction of the forests and one option is to increase the utilization and market promotion of lesser known and lesser utilized timber species (LKTS). Findings from an in-depth study conducted by Hines and Eckman (2008) showed that in Tanzania, local people often prefer indigenous species for a variety of uses such as charcoal, furniture, house construction material and medicine. Mahonge (2001) reported that in using these LKTS, little or no emphasis is put on wood properties required for their end uses and the use of wood from the species without good knowledge of their properties may result in safety hazards and inefficient utilization.

The Tanzanian timber market is dominated by a small number of commercially well-known timber species. The country has more than 700 indigenous wood species ranging from low to high density and out of these species, only a handful (about 20 species) of well known tree species are utilized commercially, and often for purposes which unknown but equally suitable and cheaper timber species could be used (Gillah *et al.*, 2009). The well known species include *Khaya anthotheca*, *Olea welwitschii*, *Afzelia quanzensis*, *Dalbergia melanoxylon*, *Pterocarpus angolensis*, *Ocotea usambarensis*, *Milicia excelsa*, *Belschmedia kweo*, *Adina microcephala*, *Afromorsia angolensis*, *Podocarpus* *usambarensis, Cephalosphaera usambarensis, Juniperus procera*, *Milletia stuhlmanii* and *Brachylaena huillensis.* The rest of the timber species in the country are lesser known to users and therefore lesser utilized. Since properties of these lesser known and lesser utilized timber species are not known, it is difficult to promote them in national and international markets (Ishengoma *et al*., 1998). A research conducted by Makonda and Kitojo (2011) in Rufiji and Kilwa village land forest reserves showed that some lesser-known timber species (*Bobgunnia madagascariensis* and *Amblygonocarpus andongensis)* can be used as substitutes of the well known timbers of Tanzania namely *P. angolensis*, *Dalbergia melanoxylon* and *M. excelsa* which are already scarce due to their over-harvesting.

1.2 Problem Statement and Justification

In Tanzania, the main causes of deforestation are clearing for agriculture, overgrazing, wildfires, charcoal making, persistent reliance on wood fuel for energy and lack of land use plans and/or non adherence to the existing ones (TFS, 2013; MNRT, 2009). MNRT (2009) reported that the underlying causes of deforestation are rapid population growth, poverty, policy and market failures. Population growth, expanding need for industrial and residential sites, unemployment, search for farmland and general social economic needs of forest products lead to increased deforestation and degradation. Policy failures include lack of financial incentives and government inability to institute effective management. Market failures include open access exploitation of forests, incomplete information and imperfect competition. Markets are also unable to ensure equitable resource distribution.

The increased deforestation rate has exacerbated the demand-supply situation to the extent that the well known and marketable timber species have become scarce but the demand is so high to the extent that even immature trees are being harvested (MNRT, 2011).

Ishengoma *et al.* (1998) reported that immature timber is not only non-durable but is also mechanically weak. There is therefore, a need to look for alternative timber resources. An alternative which could have a big impact on increasing timber resources are Indigenous Agroforestry Tree Species (IAGTS). A research conducted by Mvanda (2013) on the economic potential of five IAGTs namely *Sclerocarya birrea, L. capassa, Vitex doniana, C. zeyheri* and *Pseudolachnosytlis maprouneifolia* in four villages in Kilosa District showed that the total income for both timber and charcoal per household which comes from these IAGTS is TZS 657 879, yet only three of them (*P. maprouneifolia, S. birrea* and *V. doniana*) whose physical and mechanical properties have been studied (Bryce, 1967; Makonda and Kitojo, 2011; Ali, 2011;) whereas the remaining two have not been studied.

In Tanzania, *L. capassa* (Rolfe) and *C. zeyheri* (Sond) are lesser known and lesser utilized species for commercial purpose. These trees species are found outside farms in miombo woodlands in among other areas, Morogoro and Dodoma regions (Rulangaranga, 1989) but have potentials to grow in agroforestry systems and provide multiple benefits to communities including timber for various uses.

Therefore, there is a need of determining the basic density, fiber length and strength properties of these two lesser known tree species in order to provide technical information to users and hence reduce the pressure on well known timber tree species. The findings from this study could help decision makers to recommend to the government of Tanzania and other parties to promote the use of these lesser known and lesser utilized IAGTs for reducing pressure on well known timber species. The findings from this study could also assist in promoting the IAGTs at national and international markets.

1.3 Objectives

1.3.1 Main objective

To assess selected wood properties of potential indigenous agroforestry tree species *L. capassa* (Rolfe) and *C. zeyheri* (Sond) growing in Kilosa District, Tanzania.

1.3.2 Specific objectives

- i. To determine the basic density of *L. capassa* (Rolfe) and *C. zeyheri* (Sond) from the study area.
- ii. To determine fiber length of *L. capassa* (Rolfe) and *C. zeyheri* (Sond) from the study area.
- iii. To determine some strength properties of *L. capassa* (Rolfe) and *C. zeyheri* (Sond).

1.3.3 Research questions

This study was conducted with the following research questions:

- i. What are the basic density and fiber lengths of *L. capassa* and *C. Zeyheri* ?
- ii. What are the strength properties of these two species?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Lesser Known and Lesser Utilized Timber Species

2.1.1 General information on lesser known and lesser utilized species

The terms lesser known species (LKS), secondary species, unpopular species and weed species as defined by various researchers refer to a mixture of a large number of timber species that are not widely known and fully utilized commercially. In most cases, these species remain in the forests as waste after creaming operations, due to some undesirable properties such as wood colour, stem size and form, wood strength and many others (Bethel, 1984; Yeom, 1994; Smith *et al*., 1994). Yeom (1994) reported that LKS encounter the problem of acceptance both by the national and international markets, hence resulting into their low utilization.

Studies on lesser known and lesser utilized timber species in Tanzania were initiated by TAFORI in 1955 and these led to the production of the text book of the commercial timbers of Tanzania (Bryce, 1967). In 1997 Sokoine University of Agriculture through its Department of Wood Utilization introduced the research on LKS. Research results have shown that a total of 25 LKS have comparable properties to the commercially well known timber species. In terms of uses, some of LKS were recommended to replace the well known species. Such LKS include *Trichilia emetica* and *Pterocarpus stolzii (*Ishengoma *et al*., 1997), *Milletia oblata* sub spp *stolzii* (Ishengoma *et al*., 1998), *Brachystegia bussei* and *Berchemia discolor* (Bangura *et al*., 2001).

Based on research results, Chihongo (1999) revised the book on commercial timbers of Tanzania by Bryce (1967), documenting a bigger number of over 200 timber species.

There are still about 500 timber species which have potential uses but are un-researched and therefore undocumented, indicating need for further research.

Gillah *et al.* (2009) studied two lesser known and lesser utilized species, *Manilkara discolor* and *Uapaca kirkiana.* The results from this study indicated that *M. discolor* has a basic density of 765 kg m^{-3} whereas *U. kirkiana* has a basic density of 518.14 kg m^{-3}. The authors recommended the wood of *M. Discolor* to be used to substitute *Milicia excelsa*, *P. angolensis* and *K. anthotheca* both by structurally and by appearance whereas *U. kirkiana* be used to substitute *K. anthotheca* in wood works like in decoration, in cabinet, panel and furniture making.

Makonda and Kitojo (2011) carried out a study in Rufiji and Kilwa village land forest reserves aimed at determining the potential utilization of twelve lesser known timber species namely *Amblygonocarpus andongensis*, *Bobgunnia madagascariensis*, *Brachylaena hutschii*, *B. spiciformis*, *Hymenaea verrucosa*, *Julbernardia globiflora*, *Milletia stuhlmanii*, *Mimusopsis kummel*, *P. maprouneifolia*, *Spirostachys africana*, *Terminalia sambesiaca* and *Warbugia stuhlmanii*. Results from this study showed that most of properties studied of lesser known timber species are comparable or even superior to those of the better-known and over-harvested commercial timbers of Tanzania. Hence, these timbers can be used as substitutes of the already scarcely stock.

Ali (2011) conducted a study on physical and mechanical properties of 5 lesser known timber species namely *Icuria dunensis, P. maprouneifolia, Sterculia appendiculata*, *Acacia nigrescens* and *Pericopsis angolensis* from Mozambique. Results revealed that *I. dunensis* and *P. maprouneifolia* are heavy timbers with a density in the range of 850-1100 kg/m^3 and have very low dimensional changes (0.2 and 0.3 percent respectively). *S.*

appendiculata is a medium light wood with an average density of 550 kg/m^3. End use assessments suggested that the timbers of these species could be used in similar applications as the well known timbers, like in internal joineries, tool handles and furniture. *S. appendiculata* timber seems to be suitable for packaging boxes and plywood production.

Zziwa *et al.* (2006) conducted a study on physical and mechanical properties of *Antiaris toxicaria*, *Celtis mildbraedii*, *Maesopsis eminii* and *Alstonia boonei* growing in Uganda which are less utilized. Findings revealed that the strength properties of *C. mildbraedii* were comparable with those of *M. excelsa* and *K. anthotheca* that are well known and commercially utilised species. The authors concluded that some lesser utilised species have equivalent or superior strength properties compared to commercially valued tree species. Lesser utilised species should therefore be promoted as substitutes for the well known timber species, thereby reducing pressure on the over harvested species.

Korkut (2011) studied physical and mechanical properties and the use of lesser known native Silver Lime (*Tilia argentea* Desf.) wood from Western Turkey by comparing its physical and mechanical properties with some of the world's most recognized hardwood species. Results showed that the wood of Silver Lime (*Tilia argentea* Desf.) is hard, very tough and heavy, similar to the wood of European Hophornbeam (*Ostrya carpinifolia*). *Tilia argentea* (Desf) is preferable for use as flooring raw material. It is also suitable raw material for walking sticks, turnery, carving, firewood, bow, tool handles, novelties, levers, mallet heads, bawl, platter, carpentry and wooden wares.

2.1.2 Indigenous agroforestry species

Agroforestry has been defined as a dynamic, ecologically-based natural resources management system that, through the integration of trees in agricultural landscapes, diversifies and sustains production for increased social, economic and environmental benefits (Leakey, 1996; ICRAF, 2009). The system is increasingly considered as a solution for limited available resources and is rapidly emerging as a response to global sustainable development goals due to the key role it plays in transforming livelihoods and landscapes (ICRAF, 2009). It provides diverse benefits including inter alia, enhancing biodiversity, climate change adaptation and mitigation, food security, and reducing rural poverty by increasing soil fertility and crop yields.

In Tanzania, agroforestry is contributing to the improvement of the livelihoods of the majority of people, particularly rural communities, through enhanced food security, primary health care (medicinal plants) and is the leading source of energy (Boeckmann and Iolster, 2010). The system has increasingly become a focal entry point for rural development, environmental stewardship including climate change adaptation and mitigation, and ecosystem sustainability through transformation of livelihoods and landscapes (ICRAF, 2008; Boeckmann and Iolster, 2010; Pye-Smith, 2010). Over time, agroforestry research has developed a wide range of practical and robust technologies for different agro ecological zones, which have yielded positive and encouraging results in improving food security, livelihoods and environmental resilience (Mbwambo, 2004; Boeckmann and Iolster 2010; Pye-Smith 2010).

Agroforestry is widely practiced in Tanzania, mixing agricultural crops with trees. However, in most cases, exotic tree species are used in the agroforestry establishment. Vi Agroforestry Programme (2009) reported that there is a serious problem of species selection and tree management which contributes to poor benefits. It is evident that a great number of indigenous timber species of Tanzania have potential contribution as agroforestry trees with multiple benefits (Hines and Eckman, 2008), yet they are not studied and promoted to serve the purpose. The only indigenous agroforestry timber species studied are *Albizia schimperiana* (Makonda *et al.*, 2008), *P. maprouneifolia* (Makonda and Kitojo, 2011) and *V. doniana* (Bryce, 1967) implying the need for more research in that direction.

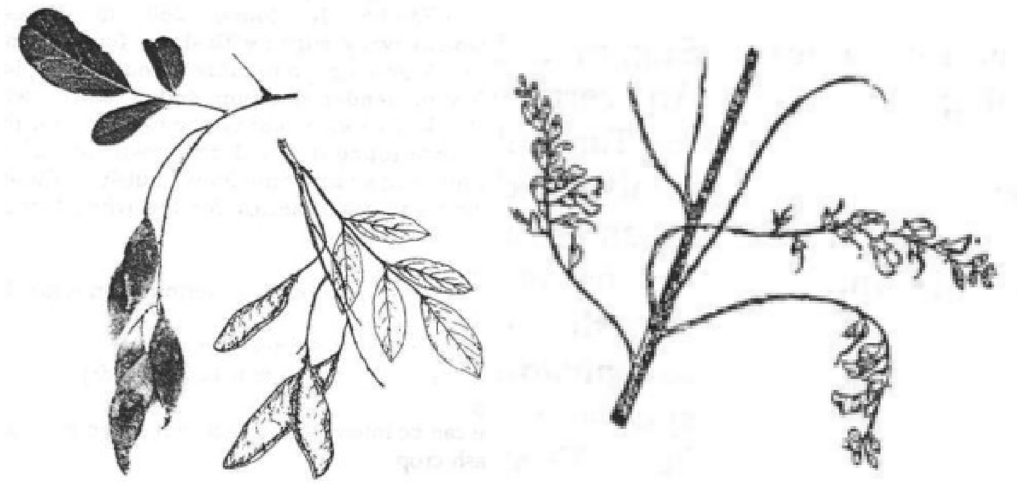
L. capassa and *C. zeyheri* are among indigenous agroforestry species that are found outside farms and in miombo woodlands (Rurangalanga, 1989). Miombo woodlands occur in the sub humid tropical vegetation zone and represent a biotope in the spectrum of different savannas. In Africa, the miombo woodlands cover 2.7 million km^2 and extend over seven different countries namely Angola, Democratic Republic of Congo, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. Miombo woodlands in general occur on old and nutrient poor soil and also it occurs at elevation ranging from sea level to 2000 m above sea level (Fyhrquist, 2007). NAFORMA estimates that there are 13,125,436.49 m^3 of *L. capassa* and 49,554,400.87 m^3 of *C. zeyheri* (MNRT, 2014).

2.1.2.1 *L. capassa*

In Tanzania *L. capassa* is commonly called “Mfumbili” by the Waluguru and “Mvale” by the Waswahiri (Mbuya *et al.*, 1994). The same authors reported that *L. capassa* belongs to the sub-family of Papilionoideae. *L. capassa* is a semi-evergreen tree with a rounded open crown and drooping branches. The tree grows usually to between 4 and 10 m high (Fig. 1a). The bark is grey, smooth when young, becoming rough, fissured and flaking with age. The leaves are compound, 1-3 pairs of grey-green leaflets plus a central larger leaflet to 15 cm, tip rounded (Fig. 1b). Leaflets are hairy at first. Flowers are small pink-blueviolet, pea shaped, sweet scented in sprays to 30 cm long (Fig. 1c). Fruits are flat cream-grey pods, to 15 cm one sided, wing like, 1-5 kidney shaped seeds are set free when the pod rots on the ground (Fig. 1b).

L. capassa tree is found in deciduous woodland and wooded grassland, usually along water courses, from 150 to 1,650 m above sea level. It is found in Democratic Republic of Congo, Angola, Zambia, Malawi, Mozambique, Zimbabwe and South Africa (Mbuya *et al.,* 1994). In Tanzania, it is common in Tabora, Dodoma, Kondoa, Morogoro and Iringa. The tree has various uses namely firewood, timber, utensils (grain mortars), tool handles, food (seed), medicine (roots), fodder (leaves) and bee forage (Mbuya et *al.*, 1994).

Tree (1a)



Leaves and fruits (1b) Flowers (1c)

Figure 1: ***L. capassa*** **tree, leaves, fruits and flowers**

Source: Mbuya ***et al.*** **(1994)**

2.1.2.2 *C. zeyheri*

C. zeyheri belongs to the Combretaceae family. The Waluguru and Waswahili call this species "Mlama mweupe" (Mbuya *et al.,* 1994). It is a deciduous tree that normally grows up to between 3 and 20 m high. Its leaves are often whorled in pairs of three to four, obovate to elliptic, large, somewhat leathery; dark green above; pale grey-green below with domatia in the axils of veins. The flowers are yellow with orange stamens, appearing before the leaves (Fig. 2b). The fruits are four- winged, large and brown to golden in colour; wings are undulate, equally wide all the way down (Fig. 2a).

2a) Fruits and leaves 2 b) Flowers and fruit

Figure 2: Fruits, leaves and flowers of *C. zeyheri*

Source: Curtis and Maheimer (2005)

2.2 Wood Properties

Ishengoma *et al.* (2004) highlight the importance of knowledge of wood properties of LKS prior to their market promotion. The authors showed that for a timber to penetrate the domestic market, a suitable marketing strategy involving market promotion needs to be developed. Successful market promotion, among other things, is backed by full information of the timber species in question. Therefore, information on physical, mechanical and other timber processing properties and potential uses need to be known.

2.2.1 Wood density

Wood density is a reliable indicator of its strength properties (Siau, 1984; Harris, 1993). Walker (1993) stated that basic density of any wood provides an index of wood quality to which all end uses can relate. To saw millers, high density indicates that the timber will be hard and stiff to saw while to the pulp mill, it indicates high pulp yield, but also problems in chipping and in paper formation (Walker, 1993). The same author reported that wood density is a most useful indicator of potential paper properties, principally because it is related to cell wall thickness and indirectly to fibre length.

The main reason why density is an index for predicting strength properties is that it is highly affected by cell wall thickness, cell diameter and the ratio of earlywood to latewood. Dinwoodie (1981) reported that the thicker the cell wall, the higher the density and hence, the stronger the wood. Wood density is an important property for wood utilization and conversion (Zobel and van Buijtenan, 1989). Haygreen and Bowyer (1996) reported that the strength of wood is usually closely correlated to density and it is possible to estimate wood strength based on density without detailed knowledge of the species. Ishengoma *et al.* (1997) noted that density was the main criterion for prediction of clear wood strength properties.

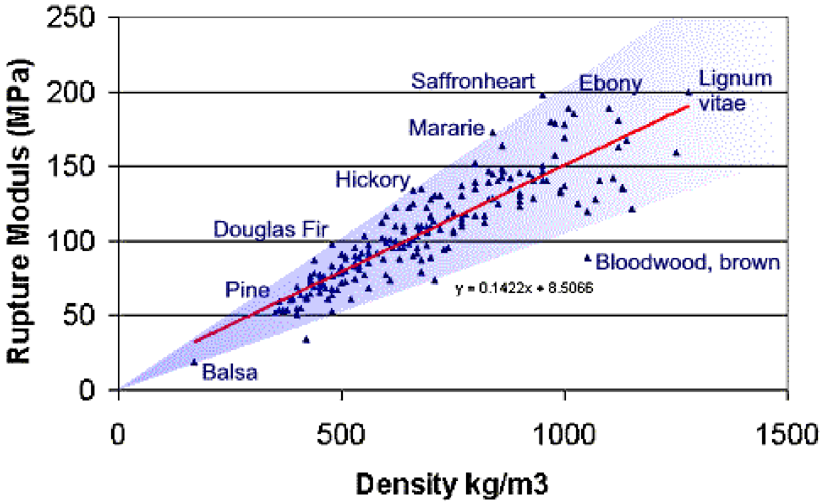


Figure 3: Relationship between wood density and modulus of rupture

Source: Bunny (1993)

2.2.2 Fibre length

Fibre length affects the strength of wood just like density does and there is a relationship between fibre length and some strength properties. For instance, the density of wood is largely determined by the proportion of fibres to other cell types present (Walker, 1993). Fibre length influences strength properties and paper making. Walker (1993) reported that the minimum fibre length of 2 mm is necessary to produce acceptable kraft pulp.

Fibre length is an important index for pulp and paper production. This index has a positive influence on the quality of pulp and paper (Wangaard and Woodson, 1973; Panshin and De Zeeuw, 1980) and wood mechanical strength properties (Bisset *et al*., 1951).

The fibre length has an important effect on the physical and mechanical properties of wood-based products such as paper, paper board, insulation board, medium-density fiberboard (MDF), particleboard, hardboard, and wood fibre polymer composites (Takahashi *et al.*, 1979; Mark and Gillis, 1983; Eckert *et al.*, 1997; Lee et *al.,* 2001; Huber *et al.,* 2003). Significant variability in fibre length exists for wood fibres from the same tree and from different tree species. For example, fibres from softwoods are normally longer than those from hardwoods. In the same tree, the length of individual fibres may vary, depending on many factors, such as distance from the ground, distance from the pith, early wood or late wood, heartwood or sapwood, etc. (Mark and Gillis, 1983).

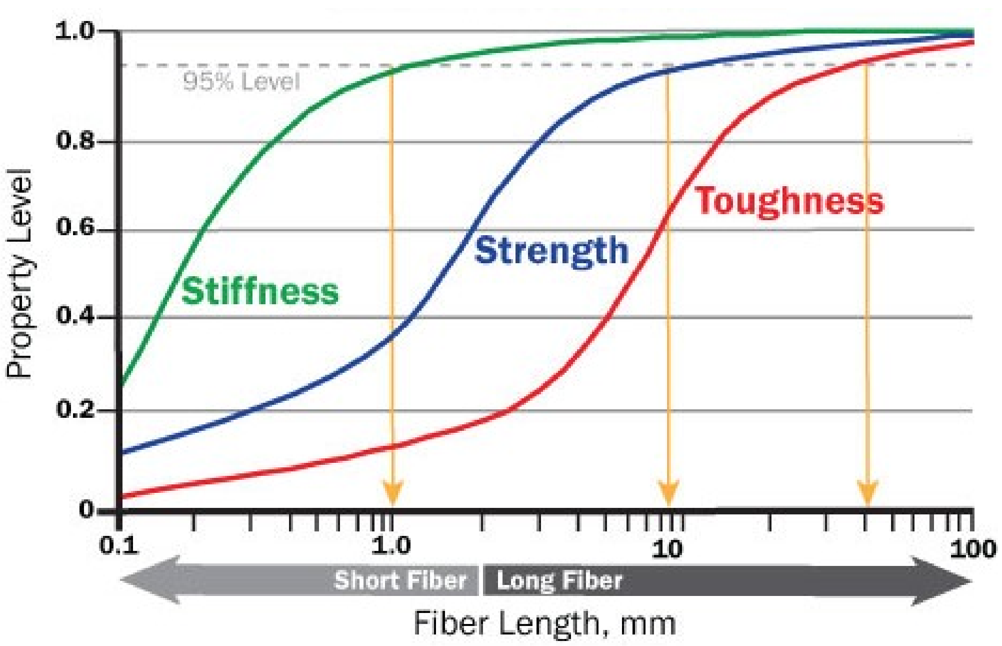


Figure 4: Effect of wood fibre length on wood plastic composite properties

Source: Mathur (2014)

2.2.3 Strength properties

Strength properties or mechanical properties of wood are an expression of its behaviour under applied forces. They reflect the fitness of the wood and the ability to resist applied external forces which tend to alter its size, shape or even deform it (FPL, 2010). The many uses to which wood is put require the ability to resist loads and thus it is appropriate to examine the behaviour of wood when subjected to various forces. Although, experience and availability have often dictated which species of timber should be used for a particular purpose, a detailed knowledge of the properties of timber is required for efficient utilization of lesser known species and to aid in selection of species for afforestation (Ishengoma *et al.*, 2004). These strength properties include static bending, compression parallel to the grain; shear parallel to the grain and cleavage (Desch, 1981).

2.2.3.1 Static bending

Static bending is known as a test that subjects clear wood specimens to a stress-strain machine until failure occurs (BSI, 1975). This test is considered as the first and most important property in timber testing (Dinwoodie, 1981). Ishengoma and Nagoda (1991) reported that static bending test is one of the most widely used tests because of the general utility of the result and the ease with which the test can be conducted. The strength properties determined from this test are MOE and MOR.

a) MOE expresses the relationship between stress and strain of wood. It is important in determining the deflection of a beam under load (Fig. 5). It is also considered as a measure of stiffness of a timber which controls the load bearing capacity of long columns. Hence, the greater the MOE the stiffer the wood (Ishengoma and Nagoda, 1991).

b) MOR it is considered as the equivalent stress in the extreme fibres of the specimen at the point of failure and a measure of the ultimate bending strength of timber that is toughness and shock resistance in wood. FPL (2010) reported that MOR reflects the maximum load-carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen. MOR is an accepted criterion of strength which is important for wood used in tool handles and sport goods (Dick, 1972; FPL, 2010).

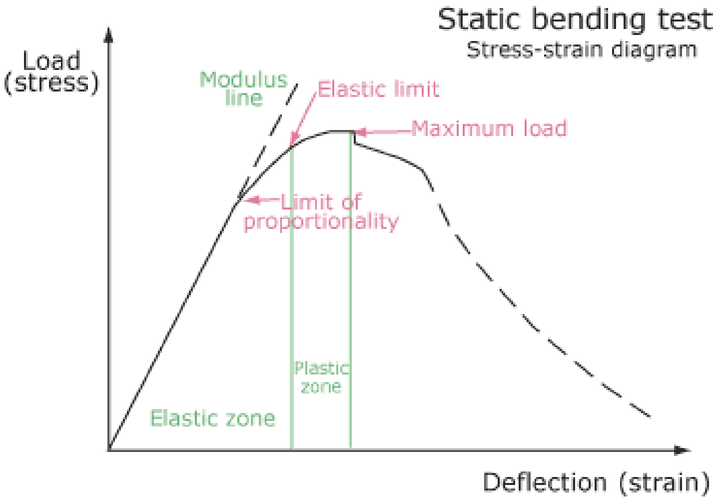


Figure 5: Stress- strain diagram for static loading of wood to failure.

Source: Panshin and de Zeeuw (1980)

2.2.3.2 Compression parallel to the grain

According to Ishengoma and Nagoda (1991), this is another important strength test done on a small clear specimen of wood in order to determine the wood ultimate stress in compression along the grain at a gradually increasing compressive load. The results from this test are important for predicting wood used in columns and structural materials.

2.2.3.3 Shear parallel to the grain

As reported by FPL (2010) shear is the ability to resist internal slipping of one part upon another along the grain. It is the measure of the resistance of the timber to break apart when subjected to sliding forces (Ishengoma and Nagoda, 1991). The results from shear tests are important for predicting the behaviour of wood when subjected to joining; hence, the lower shear strength presents design of joints problems (Walker, 1993).

2.2.3.4 Cleavage

Cleavage strength in wood is the measure of resistance of wood against splitting (Ishengoma and Nagoda, 1991). Wood which has low cleavage strength property is suitable in end use like packaging cases and other uses where nail and screw holding is required but undesirable in fuelwood and other uses where splitting is necessary. This test is normally carried out on both radial and tangential surfaces to give an average cleavage strength value (Ishengoma and Nagoda, 1991).

2.2.4 Relationship between basic density and strength properties

Different authors (Dinwoodie, 1981; Zobel and van Buijtenen, 1989) reported that there is a relationship between wood basic density and strength properties. FPL (2010) reported that density is the main criterion for clear wood strength. Kollman and Côté (1968) reported that basic density is a measure of the amount wood substance in a piece of wood and is a reliable indicator of its strength properties. Ishengoma and Nagoda (1991) reported that basic density influences the strength properties of wood, thus an important attribute in determining its utilization.

2.2.5 Factors affecting strength properties

2.2.5.1 Natural characteristics related to wood structure

FPL (2010) reported that natural characteristics that affect strength properties are specific gravity, cross grain and knots. Specific gravity affects these properties because the substance of which wood is composed is actually heavier than water; its specific gravity is about 1.5 regardless of wood species. In spite of this, the dry wood of most species floats in water, and it is thus evident that part of the volume of a piece of wood is occupied by cell cavities and pores. Variations in the size of these openings and in the thickness of the cell walls cause some species to have more wood substance per unit volume than other species and therefore higher specific gravity. Thus, specific gravity is an excellent index of the amount of wood substance contained in a piece of wood; it is a good predictor of mechanical properties as long as the wood is clear, straight grained, and free from defects (FPL, 2010).

A knot is that portion of a branch that has become incorporated in the bole of a tree. The influence of a knot on the mechanical properties of a wood member is due to the interruption of continuity and change in the direction of wood fibers associated with the knot. The influence of a knot on the performance of lumber depends upon the size, location and shape of the knot as well as attendant grain deviation around the knot and the type of stress to which the wooden member is subjected. Knots have a much greater effect on strength in axial tension than in axial compression. The effect on bending is somewhat less than that in axial tension (FPL, 2010).

Cross grain can also have a major effect on mechanical properties because in some wood products the direction of critical stresses may not coincide with the orthotropic axes of the material. This may occur by choice in design, or it may be a result of the way the wood was removed from the log (FPL, 2010).

2.2.5.2 Effects of manufacturing and use environments

Many mechanical properties are affected by changes in moisture content below the fiber saturation point (Fig. 6). Generally, most mechanical properties increase as wood is dried. Above the fiber saturation point, most mechanical properties are not affected by change in moisture content.

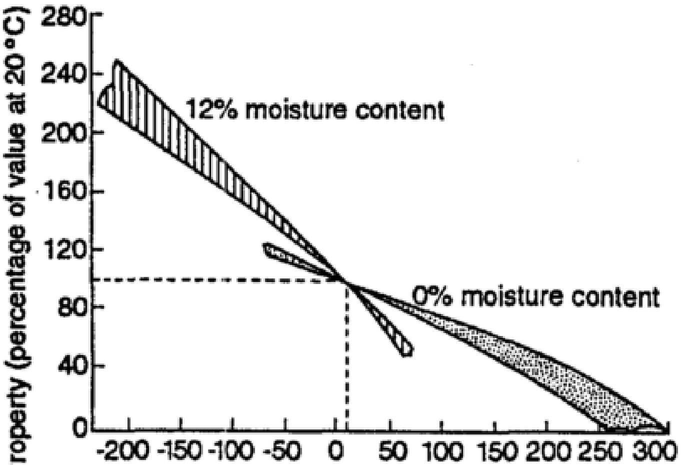


Figure 6: Immediate effect of temperature on bending strength, tensile strength perpendicular to grain, and compression strength parallel to grain. Variability is indicated by the width of bands.

Source: FPL (2010)

Temperature can have both immediate (reversible) and permanent (irreversible) effects on wood properties. In general, one immediate effect is that mechanical properties tend to decrease as the temperature increases. There is an interaction with moisture content because dry wood is less sensitive to temperature change than is green wood. However, increases in temperature are usually accompanied by a reduction in moisture content. Permanent loss in mechanical properties can occur if wood is subjected to high temperatures over long periods. The magnitude of this effect depends upon temperature, duration of exposure, wood moisture content and wood property (FPL, 2010).

2.2.5.3 Other factors

Other factors affecting strength properties include fibre length, extractives, reaction wood and strain rate. Dinwoodie (1981) reported that there is a strong positive correlation between fibre length and the strength of the cell wall material. Thus the longer and thicker the fibre, the stronger the wood.

Heartwood of most tree species has extractives deposited in them. These extractives have an effect on basic density of wood. Walker (1993) found that heartwood with extractives content has a higher density than the sapwood which makes difference in strength properties. A small decrease in modulus of rupture and strength in compression parallel to grain has been measured for some species after the extractives have been removed. The extent to which extractives influence strength is apparently a function of the amount of extractives, the moisture content of the piece and the mechanical property under consideration.

Reaction wood refers to abnormal woody tissue which is frequently associated with leaning boles and crooked limbs of both conifers and hardwoods. It is generally believed that such wood is formed as a natural response of the tree to return its limbs or bole to a more normal position, hence the term reaction wood. In softwoods, the abnormal tissue is called compression wood; it is common to all softwood species and is found on the lower side of the limb or inclined bole. In hardwoods, the abnormal tissue is known as tension wood; it is located on the upper side of the inclined member, although in some instances it is distributed irregularly around the cross section (Green and Shelley, 2006).

Many of the anatomical, chemical, physical, and mechanical properties of reaction wood differ distinctly from those of normal wood. The most evident is the increase in density compared with that of normal wood. The specific gravity of compression wood is commonly 30% to 40% greater than that of normal wood; the specific gravity of tension wood commonly ranges between 5% and 10% greater than that of normal wood, but it may be as much as 30% greater (Green and Shelley, 2006; FPL, 2010).

Strain rate is another factor which affects strength properties. Ishengoma (1986) reported that compression parallel to the grain and bending strength increased by 8 percent for every 10 fold increase in strain rate. Green and Shelley (2006) reviewed that there is a 31 percent increase in MOR for any increase in strain rate of 10^4 x 2.54 cm per minute increase.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area Description

Kilosa District is one of the six districts of Morogoro region. It lies between latitude 6° 00'S and 8° 00' S and longitudes 36° 30' E and 37° 30' E. The District has total land area of 14918 km^2 and the population is 438,175 people (URT, 2012). The average annual rainfall is 600 mm to 1200 mm whereas the mean temperature is 22°C (KDC, 1997). The soils in hilly areas of Kilosa District are sandy or sand loam and poor in nutrients whereas vertisols are found in the valley and these are rich in nutrient and suitable for agriculture. The average altitude of the district is 572 m above sea level (Shishira *et al.*, 1997).

Kilosa District is characterised by a variety of vegetation types. However, the district is mainly dominated by miombo woodland and the dominant tree species are *Brachystegia boehmii*, *B. bussei*, *Brachystegia spiciformis* and *Julbernardia globiflora* (Backéus *et al.*, 2006). The major economic activities in Kilosa District include subsistence farming for both food and cash crops and livestock keeping. Crops that are grown in the District are maize, beans, sunflower, cassava, paddy and sisal. Livestock in the District includes cattle, sheep, goats, pigs and poultry (KDC, 1997). Since 1997, Enhancing Pro-poor Innovation in Natural Resources and Agricultural Value Chains (EPINAV) project initiated a project in Kilosa District which aimed at identifying lesser known IAGTS which are prefered by farmers and the project came up with 5 species namely *Sclerocarya birrea, L. capassa*, *Vitex doniana, C. zeyheri* and *Pseudolachnosytlis maprouneifolia.* Since, then those species are being produced in nurseries and given to farmers.

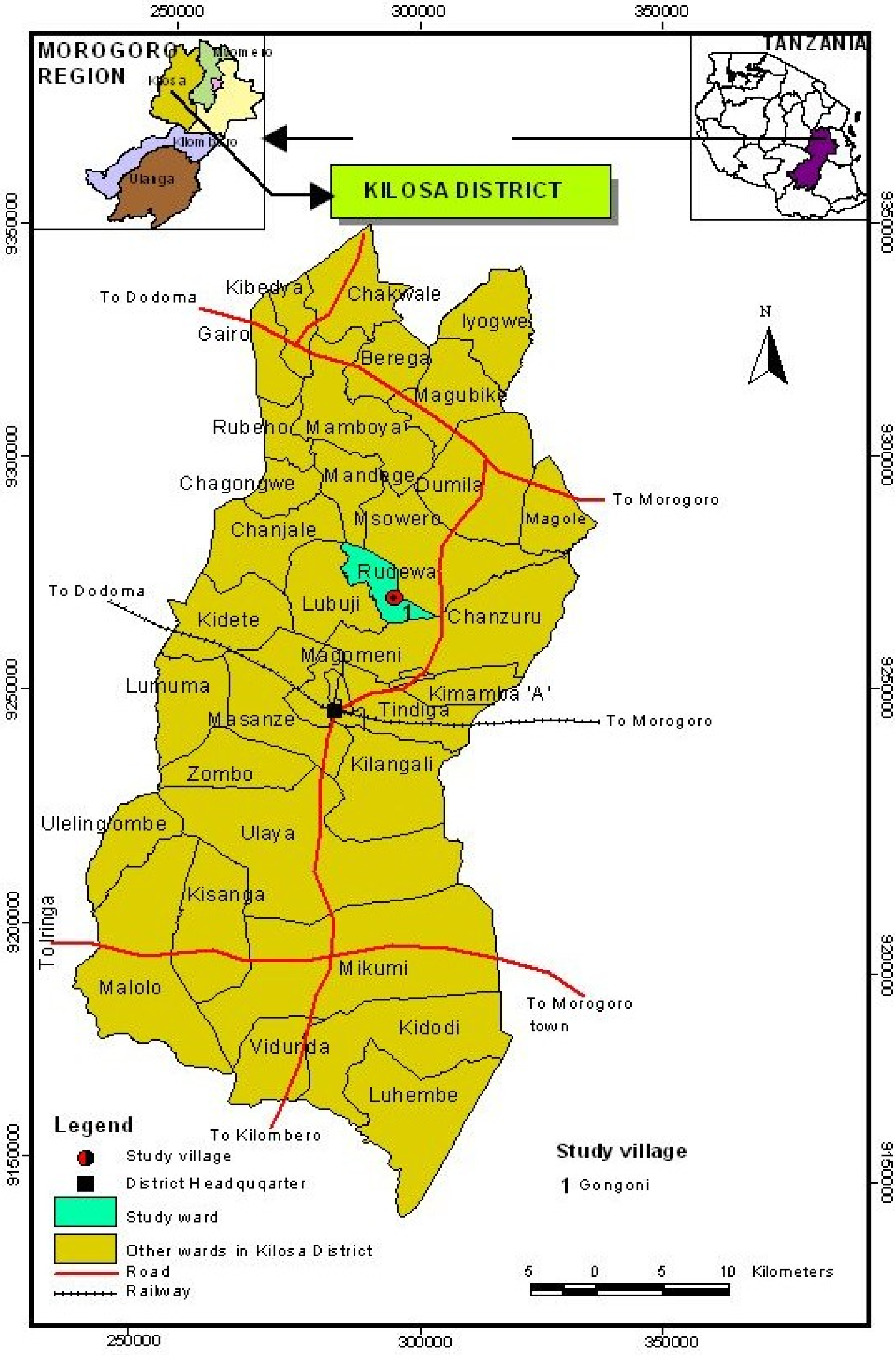


Figure 7: Location of the study area

3.2 Methods

3.2.1 Sampling

Three 13 years old trees representing small, medium and large tree sizes were selected purposively for each tree species. This was done because most of the research conducted in this area used a sample of 3 to 5 trees (Gillah *et al.*, 2009; Makonda *et al*., 2008; Ali *et al.*, 2011; Josué, 2004). Hence; due to time constraint and the destructive method used in this study, only 3 trees were sampled for each tree species. Samples were collected from Rudewa Gongoni village in Kilosa District. The criteria for selection were tree of good form and free from visible defects. Each tree was cut into logs and then logs were cross cut into three 1.5 m long billets (Fig. 8) each representing the butt, middle and the top of the tree and each billet was numbered 1.1, 1.2 and 1.3 i.e 1.1 represented billet number 1 (butt), 1.2 billet number two (middle) and 1.3 billet number three (tip) for tree number one whereas 2.1, 2.2, 2.3, and 3.1, 3.2, 3.3 represented tree number 2 and 3 respectively (Gillah *et al.*, 2009). After selecting trees, the diameter at breast height was measured using a caliper, trees were felled using a chain saw and the length of the log was measured using a tape. The measurements taken on sampled trees are shown in Table 1.

Figure 8: Sample preparation in the field

Table 1: Measurements taken on sampled trees of *C. zeyheri* and *L. capassa*

Tree species	Tree No	DBH (cm)	Total length (m)	Altitude (m)
Combretum zeyheri (Cz)	1	20	15	503
	2	25	14.3	500
	3	30	20.5	506
Lonchocarpus capassa (Lc)	1	20	16	519
	2	24	15	498
	3	28	17	506

3.2.2 Sawing and preparation of test specimens

The billets were transported to Kiwanja cha Ndege sawmill in Morogoro municipality and sawn into 60 mm thick cants (Fig. 9) before being transported to the wood utilization laboratory of Soikoine University of Agriculture, Morogoro for further processing. Thus, the following procedures were pursued:

- The cants were re- sawn radially into 30 mm x 60 mm x 1500 mm planks and labelled from the pith outward showing the position of extraction (Fig.10 a, b).

- Planks were air dried to about 12% moisture content and re- sawn into scantlings measuring 20 x 30 x 1500 mm (Fig. 10 c) and these were planed down to 20 mm x 20 mm x 1500 mm.
- The total number of scantlings was 94 and it is from these scantlings that test specimens for each test were extracted (Fig. 10 d) (ISO 3129, 1975). The number of samples for each test was therefore 94 except for cleavage (188) because it is done radially and tangentially as per standard procedures stipulated in ISO 3129 (1975).

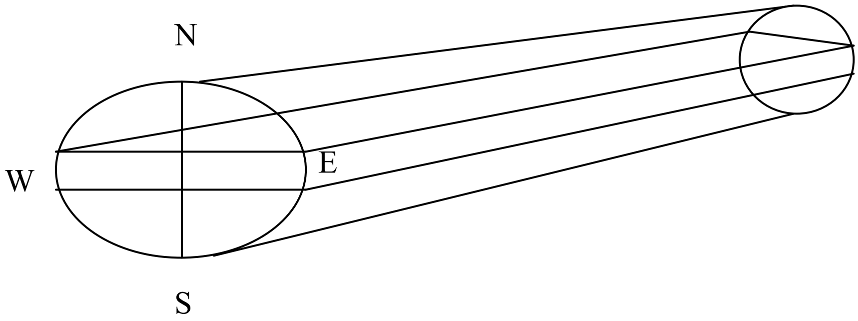


Figure 9: Sawing of billets into cants

Figure 10: Sawing of cants and preparation of test specimens

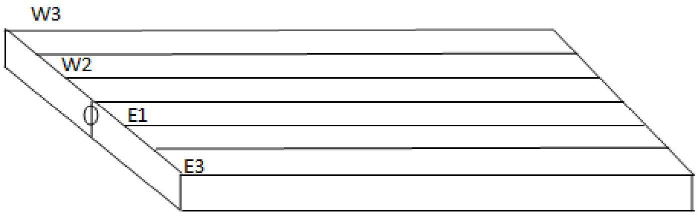


Figure 11: Sawing and labelling of scantlings

3.2.3 Determination of wood properties

The properties of *C. zeyheri* and *L. capassa* determined were wood basic density, fiber length and strength namely static bending, shear parallel to the grain, compression parallel to the grain and cleavage. The dimensions of test specimens for different tests are shown in Table 2.

Table 2: Dimensions of test specimen for wood properties

Property	Specimen dimensions (mm)	Number of specimens
Basic density	20 x 20 x 10	94
Fibre length	20 x 20 x 20	94
Static bending	20 x 20 x 300	94
Shear parallel to the grain	20 x 20 x 20	94
Compression parallel to the grain	20 x 20 x 60	94
Cleavage	20 x 20 x 45	188

3.2.3.1 Wood basic density

Wood basic density was determined following standard procedures described by Panshin and de Zeeuw (1980) and ISO 3131 (1975). From each scantiling, a test specimen measuring 20 mm x 20 mm x 10 mm was cut. Water displacement method was used to determine basic density in which test specimens were soaked in water to attain green state (Fig.12) and the weight of each test specimen was determined after oven drying samples at a temperature of $103^{o}C \pm 2^{o}C$. The weight was obtained by using a sensitive balance.

Then, the basic density for each sample was computed as follows:

$$\rho = \frac{Mo}{Vu} \quad \text{(Equation 1)}$$

Where,

ρ = Basic density (kgm^{-3});

Mo = Oven dry weight (kg);

Vu = Green volume (m^3).

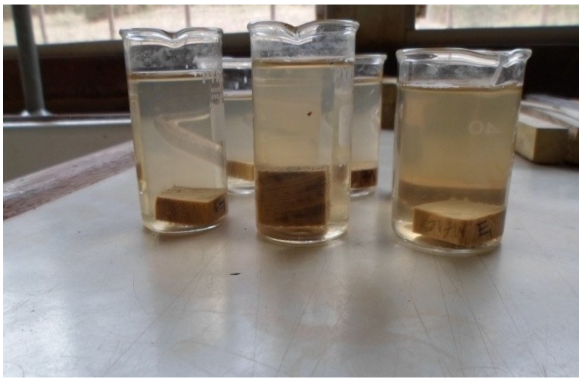


Figure 12: Test specimens soaked in water for basic density determination

3.2.3.2 Fibre length measurement

Fibre length was determined following standard procedures described by Panshin and de Zeeuw (1980). From each scantling, small representative samples (20 mm x 20 mm x 20 mm) of good quality wood were taken from East (E_1), (E_2) and (E_3); West, (W_1), (W_2) and (W3). Then, each sample was split into small splinters, mixed together and kept in test tubes. The splinters were next macerated using hydrogen peroxide (50 %) and glacial acetic acid in a 1:1 volume ratio and a sufficient quantity to cover the splinters in a glass vial to about twice their depth were mixed together. The wood samples in the solution were then heated for 48 hours at a temperature of about 70^{o}C using a water bath heater in a fume chamber (Fig. 13 a). Thereafter, macerated fibres were separated with macerating solution and then washed with distilled water, finally shaken to separate fibres. After separation, fibres were stained with safranin solution (Fig 13 c), mounted on slides and measured using a microprojector (Fig. 13 b). With a scale (incorporated inside of the microprojector) of 2 mm all clear, straight and undamaged fibres were measured to obtain the arithmetic mean for each specimen.

Figure 13: Fibre length measurement

3.2.3.3 Strength properties determination

a. **Static bending**

The determination of static bending strength which includes Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) was determined following the standard procedures described by ISO 3349 (1975) for MOE and ISO (3133, 1975) for MOR. From each scantiling a test specimen of 20 mm x 20 mm x 300 mm was taken and loaded using centre loading method to the Monsantor – Tensiometer wood testing machine using a feeding speed of 0.635 mm/min and 500 kg deflection beam. Graph plotting was done manually following the mercury column along the scale in Newtons. The load at which failure occurred, was recorded on graph paper with a magnification factor of 4 (Fig.14). From each plotted graph, MOE and MOR were calculated as follows:

Modulus of elasticity (MOE)

MOE$=\frac{Pl^3}{4\,ybd^2}$ (N/mm^2) .... (Equation 2)

Where:

P = Load in Newton's (N) at limit of proportionality;

y = Deflection in mm at mid length at limit of proportionality;

l = Span length in mm;

b = Breadth of the sample in mm;

d = Depth of the sample in mm.

Modulus of rupture

MOR = $\frac{3Pl}{2\,bd^2}$ (N/mm^2)... (Equation 3)

Where:

P = Maximum load in Newton's (N)

l = Span length in mm;

b = Breadth of the sample in mm;

d= Depth of the sample in mm.

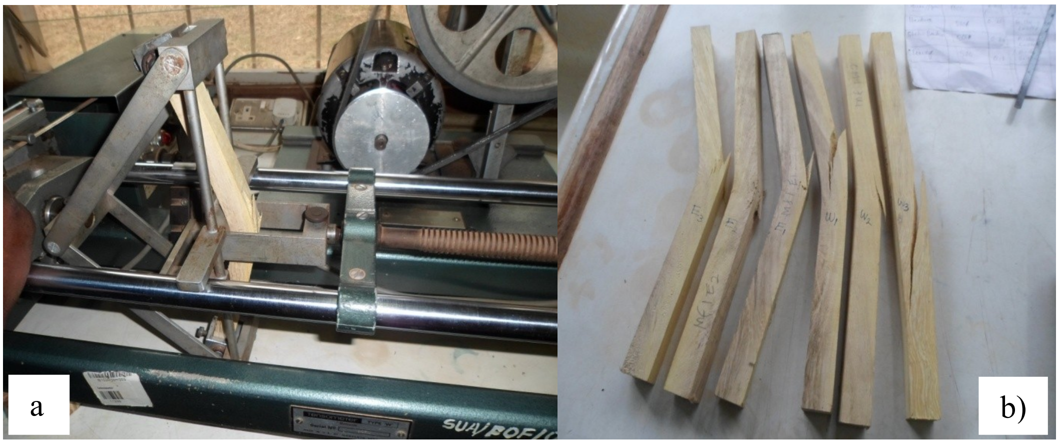


Figure 14: Static bending test (a) and test specimens after test (b)

b. Compression parallel to the grain

Compression parallel to the grain test was done by following procedure described by ISO (3787, 1976). From each scantling, a test specimen of 20 mm x 20 mm x 60 mm was taken and loaded on a parallel grain basis to the Monsanto Tensiometer machine using a feeding speed of 0.635 mm/min and 2000 kg deflection beam. Then, the maximum crushing load was recorded by plotting the graph following the rise of the mercury in the column until failure occurs. The maximum crushing strength was then calculated from maximum crushing load and recorded in $\mathrm{N/mm^2}$ (Fig. 15). Compressive strength was calculated using the following formula:

$$\sigma_{\mathrm{Cr}} = \frac{P_{max}}{A_o} \ (\mathbf{N/mm^2}) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 4)}$$

Where,

σ_{Cr} = Crushing strength in ($\mathrm{N/mm^2}$)

P_{max} = Maximum crushing load in Newtons

A_o = Area of the specimen in $\mathrm{mm^2}$

Figure 15: Compression parallel to the grain test

c. Shear parallel to the grain

Shear parallel to grain test was carried out following procedure described by ISO 3347 (1976) in which from each scantling a test specimen of 20 mm x 20 mm x 20 mm was taken and mounted on the Monsanto Tensiometer machine with a 2000 kg deflection beam and a speed of 0.635 mm/min were used. The maximum shearing strength was recorded graphically straight from the rise of the mercury along the column until failure occurred. From the maximum load causing shear, shear strength was computed by using the following formula:

$$\text{TaB} = \frac{P}{A} \qquad \text{(Equation 5)}$$

Where:

TaB = shearing strength in N/mm^2

P = Maximum load in Newtons (N) causing shear

A= Area in shear in mm^2

Figure 16: Shear tested samples

d. Cleavage strength

For cleavage strength test, procedure described by Panshin and de Zeeuw (1980) was followed in which from each scantling a test specimen of 20 mm x 20 mm x 45 mm was taken and mounted on the Monsanto Tensiometer machine with a loading speed of 2.54

mm/min and a beam of 500 kg. The graph was manually plotted by following the rise of the mercury along its column until failure occurred. Then, the point of failure was recorded as the maximum cleavage load (Fig.17). Cleavage strength was calculated using the following formula:

$$\sigma_{cl} = \frac{Pmax}{b} \quad \text{(Equation 6)}$$

Where:

σ_{cl} = Cleavage strength (N/mm).

P_{max} = Maximum load in newtons (N).

b = Specimen width (mm).

Figure 17: Cleavage test

All strength values for different tests were standardized to 12 % moisture content using the following strength conversion equation:

$$\boldsymbol{\delta_{12} = \delta_m * [\,1 + \alpha\,(M_2 - 12)\,]} \quad \text{(Equation 7)}$$

Where:

δ_{12} = strength at 12 % moisture content (N/mm^2);

δ m = strength at moisture content deviated from 12 percent (N/mm^2),

α = constant value showing relationship between strength and moisture content (α = 0.02, 0.04, - 0.04 and 0.03 and 0.04 for MOE, MOR, σc//, TaB and σcl respectively) (Bozkurt and Goker, 1987).

M_2= moisture content at time of test (%).

3.2.3.4 Relationship between basic density and wood strength and between strength and fibre length

The relationship between basic density and strength properties was established by using linear regression analysis. Fibre length results for each species were also related to strength propeties using linear regression analysis. Dinwoodie (1981) reported a relationship between strength properties themselves. Hence, in order to determine whether there is any relationship between a set of strength properties, correlation was done for MOE against MOR.

3.2.4 Data analysis

The collected data were summarized in Microsoft Excel computer programme for analysis. Data were analysed using SAS 9.2 computer software (SAS institution, 2008). Variations in basic density, fibre length and strength properties between and within the two species were analysed using analysis of variance (ANOVA). Student t-test was used to compare mean values of the two tree species to test which of the species was different. Linear regression analysis was used to show the relationship between basic density, fibre length and strength properties.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Wood Basic Density

Results showed that the mean wood basic density of *L. capassa* was 569.3 kgm^{-3} with a standard deviation of 45.17 kgm^{-3} while that of *C. zeyheri* was 580 kgm^{-3} with a standard deviation of 40.39 kgm^{-3}. Statistical analysis of basic density data showed that the mean basic density values of the two species did not differ significantly ($p<0.05$). This similarity in basic densities of the two studied species could probably entail similarity in cell size and proportions in the wood of these species (Panshin and de Zeeuw, 1980) and implies that wood of these species can be used interchangeably.

Within a tree, the density of *L. capassa* wood was found to increase from the pith (540.274 kgm^{3}) to the bark (596.015 kgm^{-3}) (Fig. 18). This increment of wood basic density from pith to the bark was also reported by Hamza *et al.* (2001) on *Artocarpus heterophylus*, Panshin and de Zeeuw (1980) on *Acacia mollissima, Betula pubescens, Eucalyptus robusta, Eucalyptus grandis* and *Terminalia superpa.* Due to this variation, probably *L.capassa* can be classified as a diffuse porous species (Panshin and de Zeeuw, 1980), this is because in diffuse porous hardwoods, the mean basic density increases from the pith to the bark and the curve representing changes may show continuous linear or curvilinear increase, or the curve may flatten in the mature wood and exhibit a decrease for the outer parts of the trunk in old trees (Panshin and de Zeeuw, 1980). However, this needs to be confirmed by anatomical studies.

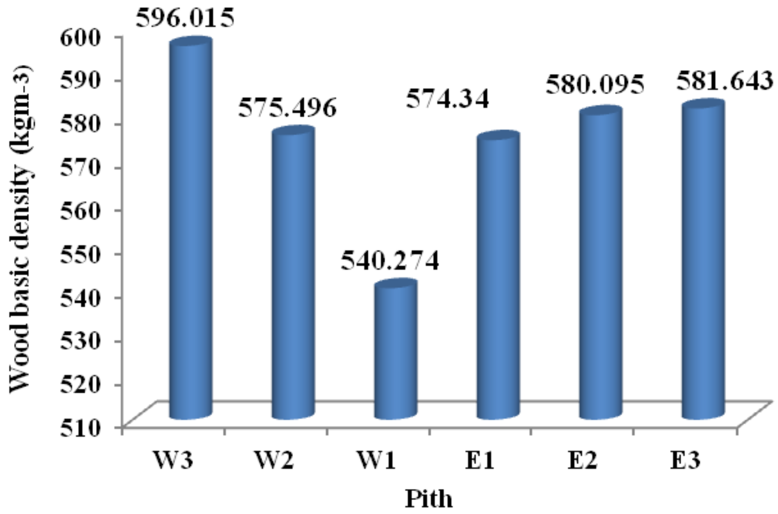


Figure 18: Within tree radial variation of wood basic density of *L. capassa.*

In the axial direction, the density of *L. capassa* decreased from the butt of the tree (568.118 kgm^{-3}) to the middle (565.697 kgm^{-3}) and then it increased to the top of the tree (571.196 kgm^{-3}) (Fig. 19). Similar situation was reported by Gillah *et al.* (2009) on *Uapaca kirkiana* from Kilombero District.

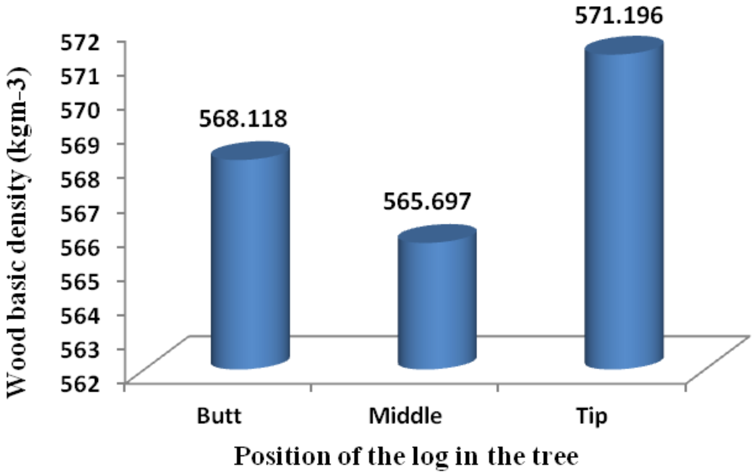


Figure 19: Within tree axial variation of wood basic density of *L. capassa*

This variation of wood basic density from bottom upwards might have been caused by growth rate, site quality, environmental condition and silvicultural management such as fertilization and thinning as it has been reported by different researchers (Lundgren, 2004;

Deng *et al.,* 2014). For instance, Lundgren (2004) found that effect of both fertilization and irrigation was significant for wood density. However, there is no record of silvicultural management in farms where samples have been taken.

In the radial direction, the density of *C. zeyheri* was found to increase from the pith 574.737 kgm^{-3} to the bark 582.86 kgm^{-3} (Fig. 20). This observation shows that *C. zeyheri* belongs in diffuse-porous wood and these results concur with the ones reported by Makonda *et al.* (2008) on *Albizia schimperiana*. However, this also needs to be confirmed by anatomical studies.

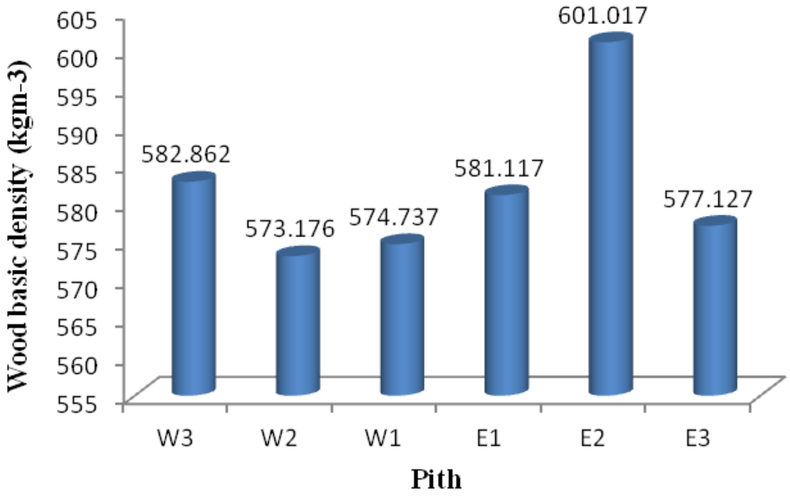


Figure 20: Within tree radial variation of wood basic density of *C. zeyheri*

In the axial direction, the density of *C. zeyheri* decreased from the butt (585.019 kgm^{-3}) to the tip of the tree (581.961 kgm^{-3}) (Fig. 21). This variation might have been caused by growth rate, site quality, environmental condition and silvicultural management as it has been reported by Lundgren, 2004 and Deng *et al.,* 2014.

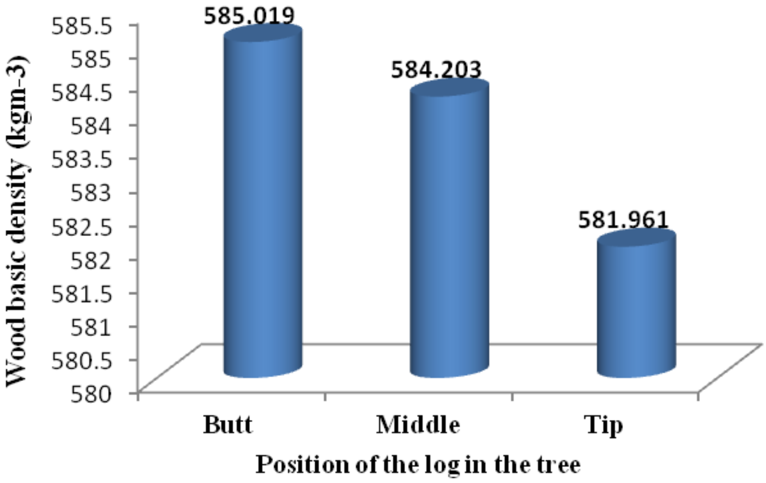


Figure 21: Within tree axial variation of wood basic density of *C. zeyheri*

According to Panshin and de Zeeuw (1980) wood density of 360 kgm^{-3} or less is considered to be light, 360 to 500 kgm^{-3} moderate and above 500 kgm^{-3} heavy wood. Thus, this shows that the two studied are heavy timber species.

Haygreen and Bowyer (1996) reported that the variations of wood density or any other wood properties in the same species arise from different factors, such as genetics, growth conditions and ecological factors. In particular, altitude, soil and climate are the most influential ecological factors. In addition, tree age, sample size, ring properties (ring width and ring orientation), and the test procedure also affect test results (Korkut, 2011).

This variation in density along the tree height from the butt to the top concurs with the work by Kollman and Côté (1968) and Panshin and de Zeeuw (1980). This may be due to the fact that the butt log of the same tree has more mature wood than the top log which consists mainly of juvenile wood (Zobel *et al.,* 1972), hence lower density.

Comparison of basic densities of *L. capassa* and *C. zeyheri* with the well known and well utilized hardwood timber species in Tanzania including *P. angolensis*, *A. quanzensis*, *K.*

anthotheca and *M. excelsa* (Bryce, 1967) revised by (Chihongo,1999) showed that both studied species had lower densities than *P. angolensis*, *A. quanzensis* (865 kgm^{-3}) and *M. excelsa* (657 kgm^{-3}), but *C. zeyheri* has a basic density which is above to that of *K. anthotheca* (577 kgm^{-3}) whereas *L. capassa* (569.3 kgm^{-3}) approaches *K. anthotheca* (Table 3). Hence, with this range of densities, *L. capassa* and *C. zeyheri* can be used in boat internal fittings, batons and other structural uses where moderately high density is a desired property.

The differences observed in mean basic densities for *L. capassa* and *C. zeyheri* may be due to genetical differences (Zobel and Talbert, 1984), but also silvicultural treatment and environmental factors may also be the cause, since these factors may promote or hinder high growth rate, resulting into increase or decrease in wood density (Erickson and Lambert, 1980). Therefore, fertilization or thinning mighty have affected the wood density. This is because, sampled trees were found in farmland. However, there is no record of silvicultural treatment and fertilization in the study area. Rajput *et al.* (1991) reported that the influence of growth conditions in many cases affect density of wood where for instance trees growing slowly because of insufficient water produce narrow growth increments consisting of thin – walled cells. Also, due to fertilization responses, 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. The difference observed might also have been caused by the higher proportion of extractives content in *C. zeyheri* than in *L. capassa*. This concurs with the results of Walker (1993) who reported that extractives have an effect on wood density.

Table 3: Comparison of mean values of basic densities for *L. capassa* and *C. zeyheri* and some well known timber species of Tanzania

Species	**Mean basic density (kgm^{-3})**
Lonchocarpus capassa	569.3
Combretum zeyheri	580
Afzelia quanzensis *	865
Pterocarpus angolensis *	657
Khaya anthotheca *	577
Milicia excelsa *	657

Source (*): Bryce (1967) revised by Chihongo (1999)

4.2 Fibre Length

Results showed that the mean fibre length for *L. capassa* was 1.38 mm with a standard deviation of 0.058 mm while that of *C. zeyheri* was 1.2 mm with a standard deviation of 0.039 mm. Analysis of variance revealed highly significant ($p<0.0001$) differences between the species. The differences observed in mean fibre length of the two studied species could be attributed to differences in anatomical structure namely cell types, size and proportions and also genetical differences (Kollman and Côté, 1968).

Fibre length influences strength properties and paper making. FAO (1973) reported that short fibres i.e. below 1 mm reduce tearing strength of paper by about 40-50% at high freeness and by about 30% at low freeness. Hence, comparison of the results of *L. capassa* and *C. zeyheri* with well known timber species including the ones which are used in pulp and paper production (Table 4), *L. capassa* (1.38 mm) and *C. zeyheri* (1.2 mm) showed longer fibres than *Eucalyptus grandis* (1.06 mm) from India (Dharm and Tyagi, 2011), *Euclayptus maidenii* (0.98 mm) and *Eucalyptus saligna* (0.94 mm) from Tanzania (Iddi *et al.*, 1998). These Eucalypts are used in the production of pulp and paper in mixture with pines. On the other hand, fibres of studied species are shorter than those of *Pinus patula*

(3.4 mm) and *Pinus kesiya* (2.3 mm) which are suitable for pulp and paper production. The fibres reported in this study can be used for pulp and paper production, since their lengths are within the limits of fibre length of broadleaves species used in pulp and paper production (FAO, 1973). The fibres of hardwoods are categorized in three groups (Hosseini and Naghdi, 2004) such as short fibres (<0.9 mm), middle fibres (0.9-1.6 mm) and long (>1.6 mm), which shows that the studied species are categorized in middle fibres.

Table 4: Comparison of fibre length values for *L. capassa* and *C. zeyheri* with some well known timber species

Species	**Fiber length (mm)**
Lonchocarpus capassa	1.38
Combretum zeyheri	1.2
*Eucalyptus grandis***	1.06
*Eucalyptus maidenii**	0.98
*Eucalyptus saligna**	0.94
*Pinus patula****	3.4
*Pinus kesiya***	2.3

Source: (*): Iddi *et al.* (1998); (**): Dharm and Tyagi (2011); (***): Bolza and Keating (1972).

4.3 Strength Properties

4.3.1 Static bending

4.3.1.1 Modulus of elasticity

Results indicated that the mean value of MOE for *L. capassa* was 8745 N/mm^2 with a standard deviation of 1573.51 N/mm^2 whereas the MOE of *C. zeyheri* was 6840 N/mm^2 with a standard deviation of 764.6 N/mm^2. Analysis of variance revealed highly significant ($p<0.0001$) differences between MOE of the two species. The differences observed in MOE between the two species might be due to genetical differences (Zobel and Talbert, 1984), extractive content (Walker, 1993) and fibre length (Dinwoodie, 1981). Desch (1973) reported that the greater the MOE the stiffer the timber and conversely, the lower the MOE the more flexible it is. This implies that wood of *L. capassa* has more stiffness than that of *C. zeyheri* and therefore it should be considered more where this property is important.

Comparison of MOE of *L. capassa* and *C. zeyheri* with the well known timber species (Table 5), *A. quanzensis* (8500 N/mm^2), *P. angolensis* (8400 N/mm^2), *K. anthotheca* (9604 N/mm^2) and *B. speciformis* (13400 N/mm^2), *L. capassa* showed lower MOE than *B. speciformis* and *K. anthotheca.* However, the comparison showed higher MOE than *A. quanzensis* and *P. angolensis*. *C. zeyheri* showed lower MOE than the well known timber species in comparison.

Table 5: Comparison of MOE for *L. capassa* and *C.* zeyheri with some well known timber species

Species	MOE (N/mm^2)
Lonchocarpus capassa	8745
Combretum zeyheri	6840
*Afzelia quanzensis***	8500
*Khaya anthotheca***	9604
*Pterocarpus angolensis**	8400
*Brachystegia speciformis***	13400

Source (**): Bryce (1967) revised by Chihongo (1999)

4.3.1.2 Modulus of rupture

The mean MOR of *L. capassa* was 101.5 N/mm^2 with a standard deviation of 18.82 N/mm^2 while that of *C. zeyheri* was 76.9 N/mm^2 with a standard deviation of 13.1 N/mm^2. The former was tougher by 32 % than the later. The analysis of variance showed that there are highly significant differences between MOR of the two species ($p<0.0001$). Therefore, on the basis of MOR the two species can not be used interchangeably. The differences observed in MOR for the two studied species could be attributed to differences in anatomical structure namely cell types and proportions and also genetical differences resulting into differences in wood structure (Kollman and Côté, 1968).

Comparison of *L. capassa* and *C. zeyheri* with well known timber species (Table 6) shows that *L. capassa* has a higher MOR than some well known timber species namely *P. angolensis*, *A. quanzensis* and *K. anthotheca* but, its MOR is lower than the that of *M. excelsa*. On the other hand, *C. zeyheri* had a higher MOR than *K. anthotheca* and it is below than other well known species.

Table 6: Comparison of MOR for *L. capassa*, *C. zeyheri* with some well known timber species

Species	MOR (N/mm^2)
Lonchocarpus capassa	101.5
Combretum zeyheri	76.9
*Pterocarpus angolensis**	94
*Khaya anthotheca**	66
*Afzelia quanzensis**	97
*Milicia excelsa**	114

Source (*): Bryce (1967) revised by Chihongo (1999)

4.3.2 Shear parallel to the grain

Mean values for shear strength parallel to the grain of *L. capassa* was 14.08 N/mm^2 with a standard deviation of 1.38 N/mm^2 whereas that of *C. zeyheri* was 16.7 N/mm^2 with a standard deviation of 1.17 N/mm^2. The later had higher shear value by 18.6 % than the former. This implies that *C. zeyheri* could be more preferred than *L. capassa* where higher shear strength is needed like for instance in design of joints and construction work. The analysis of variance revealed highly significant differences between the two species ($p<0.0001$). The differences observed in mean shear strength for the two studied species could be attributed to variation in microenvironment in which trees grew, differences in age, genetics and silvicultural treatments (Ishengoma *et al.*, 1990) and other localized site factors (Ringo and Klem, 1980).

Comparison of *L. capassa* and *C. zeyheri* with some well known timber species (Table 7), showed that *L. capassa* is only greater than *K. anthotheca* (10.1 N/mm^2) whereas *C. zeyheri* is greater than both *K. anthotheca* (10.1 N/mm^2) and *M. excelsa* (15.6 N/mm^2). Both studied species had lower shear strength than *A. quanzensis* (19 N/mm^2) and *P. angolensis* (17.2 N/mm^2).

Table 7: Comparison of shear strength values for *C. zeyheri*, *L. capassa* with some well known timber species

Species	**Shear (N/mm^2)**
Combretum zeyheri	16.7
Lonchocarpus capassa	14.08
*Khaya anthotheca**	10.1
*Pterocarpus angolensis**	17.2
*Milicia excelsa**	15.6
*Afzelia quanzensis**	19

Source (*): Bryce (1967) revised by Chihongo (1999)

4.3.3 Compression parallel to the grain

Results showed that the mean compressive strength for *L. capassa* was 40.5 N/mm^2 with a standard deviation of 2.3 N/mm^2 whereas that of *C. zeyheri* was 44.9 N/mm^2 with a standard deviation of 1.8 N/mm^2. The analysis of variance revealed significant ($p<0.0001$) differences between those two species. The differences in mean compressive strength values between the two studied species might be attributed to the presence of wood extractives in *C. zeyheri* and this is in agreement with Walker (1993). The same author pointed out that extractives influence strength properties and this is a function of the amount of extractives, the moisture content of the piece and the mechanical property under consideration. The mechanical properties pointed out here are compression and modulus of rupture. Even, during soaking samples in water for wood basic density you could see colour change of water for *C. zeyheri* justifying the presence of wood extractives.

When compared to some well known timber species both studied species have higher resistance to compression than *J. procera* (39.3 N/mm^2) and they are lower than *A. quanzensis* (69.2 N/mm^2), *P. angolensis* (57 N/mm^2), *M. excelsa* (54.7 N/mm^2) and *K. anthotheca* (48.3 N/mm^2) (Table 8). Desch (1973) reported that wood with high strength in compression parallel to the grain is suitable for timber used as columns, props, posts and spokes.

Table 8: Comparison of compressive strength values for *C. zeyheri*, *L. capassa* with some well known timber species

Species	Compression (N/mm^2)
Combretum zeyheri	44.9
Lonchocarpus capassa	40.5
*Khaya anthotheca**	48.3
*Pterocarpus angolensis**	57
*Milicia excelsa**	54.7
*Afzelia quanzensis**	69.2
*Juniperus procera **	39.3

Source (*): Bryce (1967) revised by Chihongo (1999)

4.3.4 Cleavage strength

Mean cleavage strength value for *L. capassa* was 24.4 N/mm with a standard deviation of 1.7 N/mm while that of *C. zeyheri* was 17.8 N/mm with a standard deviation of 1.5 N/mm. The mean cleavage strength of *L. capassa* was higher than that of *C. zeyheri* by 37 %. The analysis of variance revealed significant differences between the two species ($p<0.0001$). The difference in mean cleavage strength values for *L. capassa* and *C. zeyheri* could be attributed to differences in wood structures especially grain structure. FPL (2010) reported that straight grained timber split more readily radially than tangentially, and more readily dry than green, but timbers with markedly interlocked grain split more readily tangentially and are often extremely difficult to split radially. The same author also reported that the readiness of a timber to split, which cleavage denotes has a practical application in certain circumstances. For instance in firewood and material for the manufacture of tight barrels, charcoal and hand-split shingles, high cleavage is a very desirable asset; for nail or screw-holding purposes, as in packaging-case manufacture, high resistance to cleavage is an essential quality.

Comparison of *L. capassa* and *C. zeyheri* with some well known timber species (Table 9) shows that *L. capassa* and *C. zeyheri* have higher cleavage strength values than some well known timber species namely *K. anthotheca* (10.8 N/mm), *P. angolensis* (13 N/mm), *M. excelsa* (10.9 N/mm), *A. quanzensis* (14.5 N/mm) and *J. procera* (7.4 N/mm).

Table 9: Comparison of cleavage strength values for *C. zeyheri*, *L. capassa* with some well known timber species

Species	Cleavage strength (N/mm)
Lonchocarpus capassa	24.4
Combretum zeyheri	17.8
*Khaya anthotheca**	10.8
*Pterocarpus angolensis**	13
*Milicia excelsa**	10.9
*Afzelia quanzensis**	14.5
*Juniperus procera**	7.4

Source (*): Bryce (1967) revised by Chihongo (1999)

4.3.5 Inter-relationship between wood properties

4.3.5.1 Relationship between basic density and fibre length

The results of regression analysis for both *L. capassa* and *C. zeyheri* showed a positive linear relationship between basic density and fibre length (Fig. 22 and 23). The regression equations were not significant ($p<0.05$) for both species and do have R^2 values of 0.17 and 0.14 respectively. This positive linear relationship between basic density and fibre length implies that any increase on wood basic density there is an increase on fibre length. But, since the regression analysis showed no significant relationship between those two variables, basic density is considered here as a poor indicator for wood fibre length.

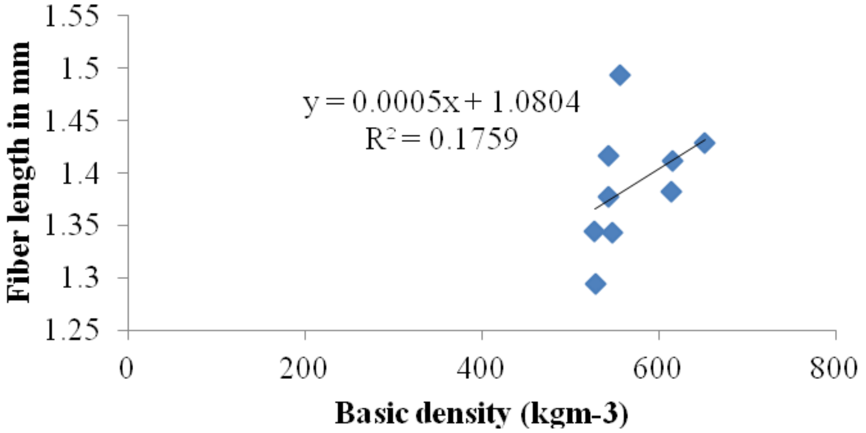


Figure 22: Relationship between basic density and fiber length in *L. capassa*

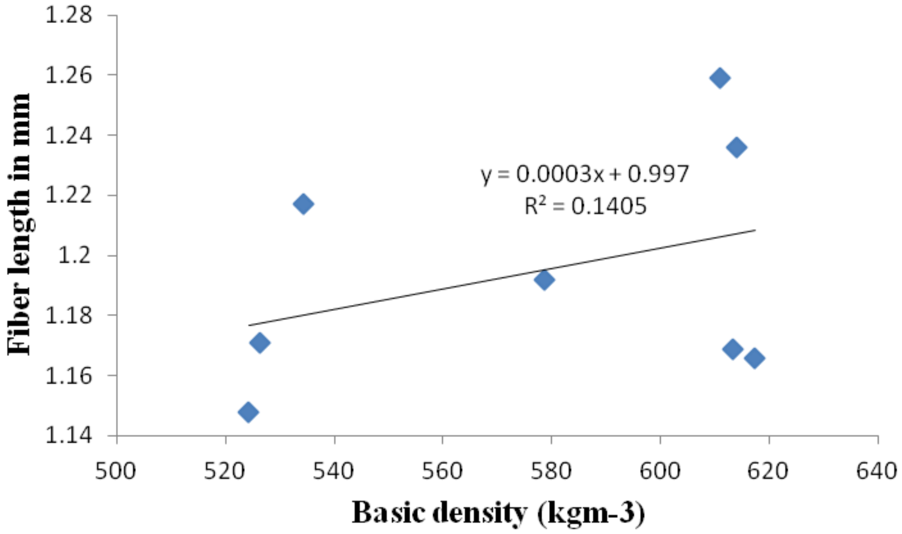


Figure 23: Relationship between basic density and fiber length in *C. zeyheri*

4.3.5.2 Relatioship between basic density and strength properties

The results of regression analysis for both *L. capassa* and *C. zeyheri* showed that there is a positive linear relationship between basic density and strength properties namely MOE, MOR, shear parallel to the grain, compression parallel to the grain and cleavage.

Figure 24 illustrates the relationship between basic density and MOE for *L. capassa* while figure 25 illustrates that of *C. zeyheri*.

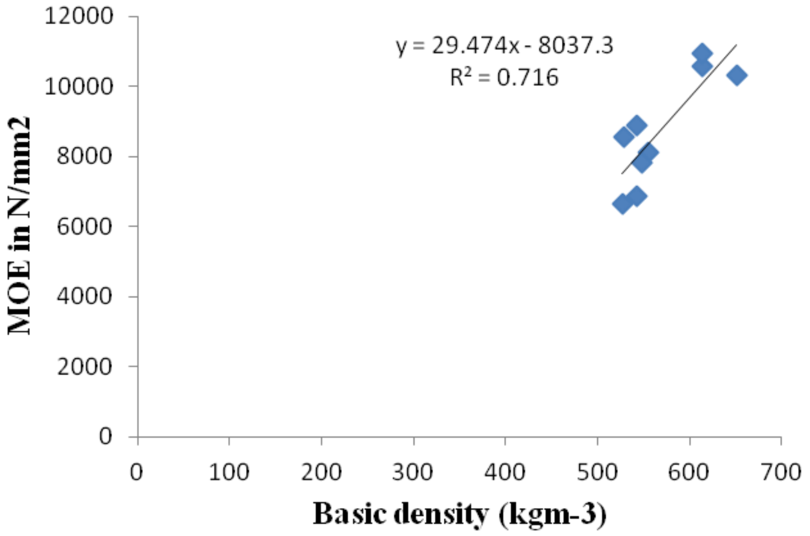


Figure 24: Relationship between wood basic density and MOE of *L. Capassa*

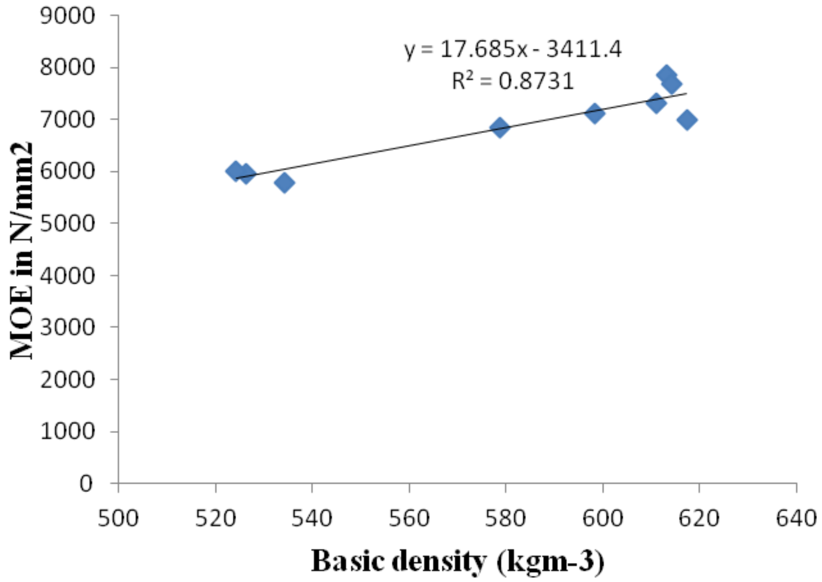


Figure 25: Relationship between wood basic density and MOE of *C. zeyheri*

Regression analysis showed that the relationship was significant ($p<0.001$) for *L. capassa* with R^2 of 0.71 whereas for *C. zeyheri* was significant ($p< 0.0001$) with R^2 of 0.87. Hence, this shows that the wood density has been a reliable indicator of MOE for both species. The dependence of MOE to density has also been reported on *M. discolor* (Gillah *et al*., 2009), *B. bussei* and *Berchemia discolor* (Bangura, 1998).

Figure 26 shows a positive linear relationship between wood basic density and MOR for *L. capassa* while figure 27 shows that of *C. zeyheri*. The analysis of variance showed that the relationship between wood basic density and MOR was significant ($p< 0.001$) with R^2 values of 0.78 for both species. This showed that wood basic density is an important factor for predicting MOR for both studied species. The reliances of MOE and MOR on wood density were also earlier reported by some researchers (Majid and Reza, 2014; Zhang, 1997; Heräjärvi, 2004; Kiaei, 2011; Izekor *et al*., 2010) for some of softwood and hardwood species.

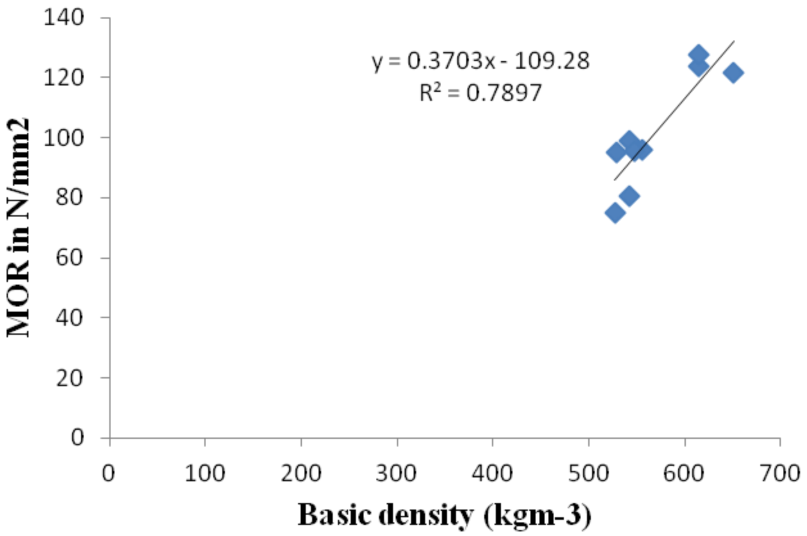


Figure 26: Relationship between wood basic density and MOR of *L. capassa*

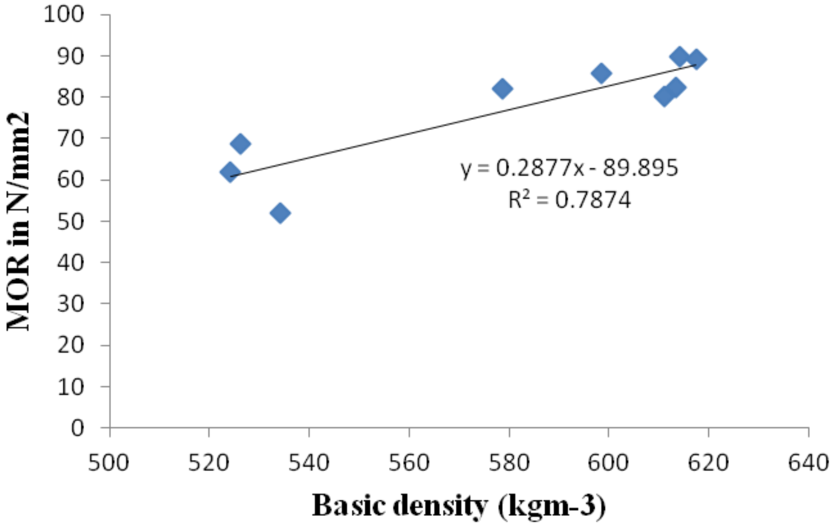


Figure 27: Relationship between wood basic density and MOR of *C. zeyheri*

Fig. 28 illustrates a positive linear relationship between wood basic density and compression parallel to the grain for *L. capassa* while figure 29 illustrates that of *C. zeyheri*. The analysis of variance showed that the regression equation for *L. capassa* was not significant ($p<0.05$) with an R^2 of 0.24 while the one for *C. zeyheri* was highly significant ($p<0.0001$) with R^2 of 0.87. This showed that the relationship between basic density and compression parallel to the grain for *L. capassa* was weak while that of *C. zeyheri* was very strong, implying that wood basic density was a reliable indicator for predicting compressive strength for *C. zeyheri*. The two cases were previously reported by different researchers where Zziwa *et al.* (2006) and Ali (2011) found a weak correlation between density and compression parallel to the grain on *C. mildbraedii* and *P. maprounaefolia* respectively while Bangura (1998) found strong correlation on two species of *B. bussei* and *B. discolor*.

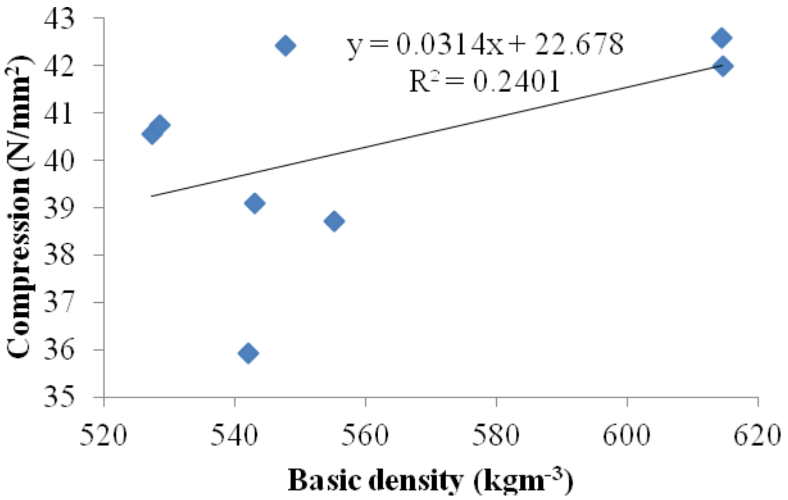


Figure 28: Relationship between wood basic density and compression parallel to the grain of *L. capassa*

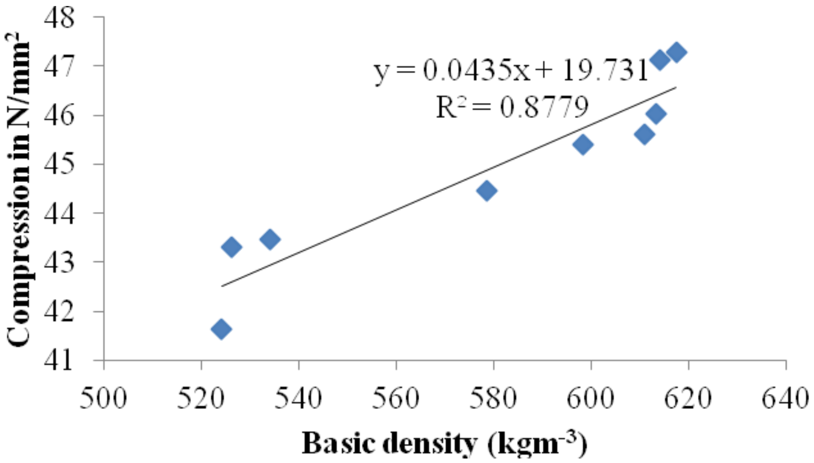


Figure 29: Relationship between wood basic density and compression parallel to the grain of *C. zeyheri*

The results from regression analysis showed also a positive linear relationship between wood basic density and shear parallel to the grain for both studied species. This relationship was significant ($p<0.001$) with R^2 value of 0.73 for *L. capassa* (Fig. 30) whereas the one for *C. zeyheri* was significant ($p<0.05$) with R^2 value of 0.63 (Fig. 31). This strong correlation between basic density and shear parallel to the grain was previously reported on *M. discolor* (Gillah *et al*., 2009) and *B. bussei* (Bangura, 1998) .

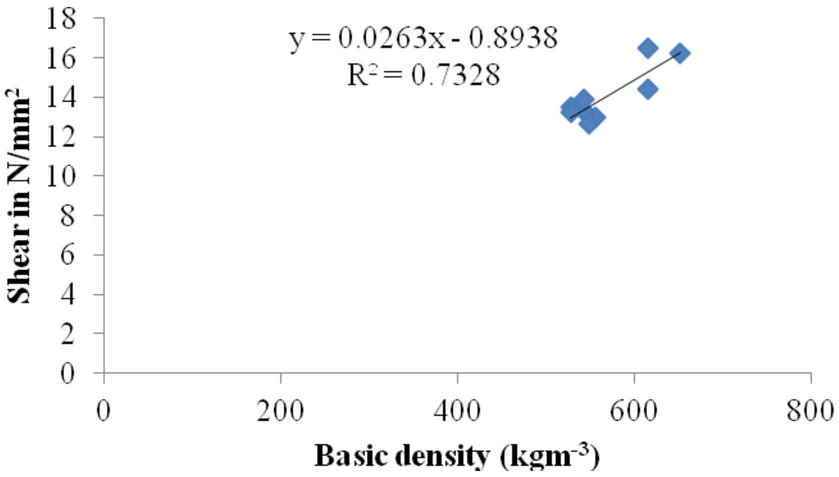


Figure 30: Relationship between basic density and shear parallel to the grain of *L. capassa*

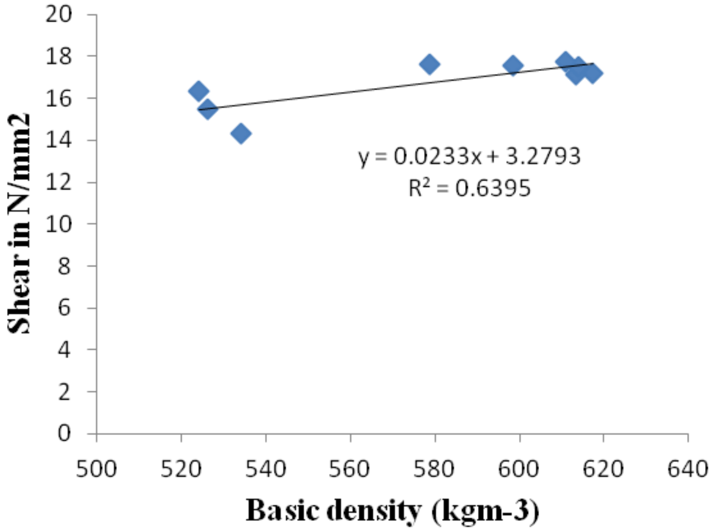


Figure 31: Relationship between basic density and shear parallel to the grain of *C. zeyheri*

Fig. 32 illustrates the relationship between basic density and cleavage strength for *L. capassa* while fig. 33 illustrates that of *C. zeyheri*. The regression analysis showed a positive linear relationship between those two variables for both studied species and it was significant ($p<0.05$) with an R^2 of 0.5 for *L. capassa* while for *C. zeyheri* it was not significant ($p<0.05$) with an R^2 of 0.25. The case of *L. capassa* was previously reported by Bangura (1998) on *B. bussei* and *B. discolor* whereas the case of *C. zeyheri* was reported by Ali (2011) on *P. maprouneifolia*. These results are similar to the observation reported by Zobel and van Buijtenen (1989) that wood density shows no strong relationship with cleavage.

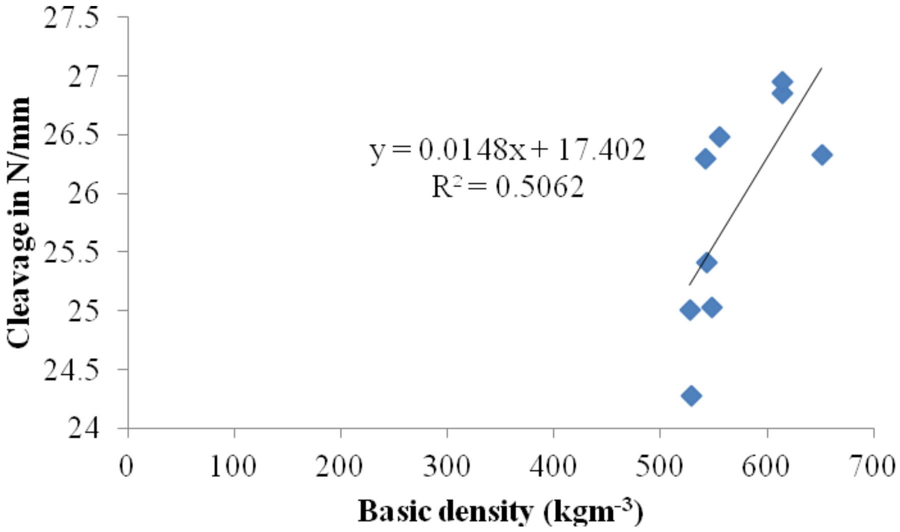


Figure 32: Relationship between wood basic density and cleavage strengh of *L. capassa*

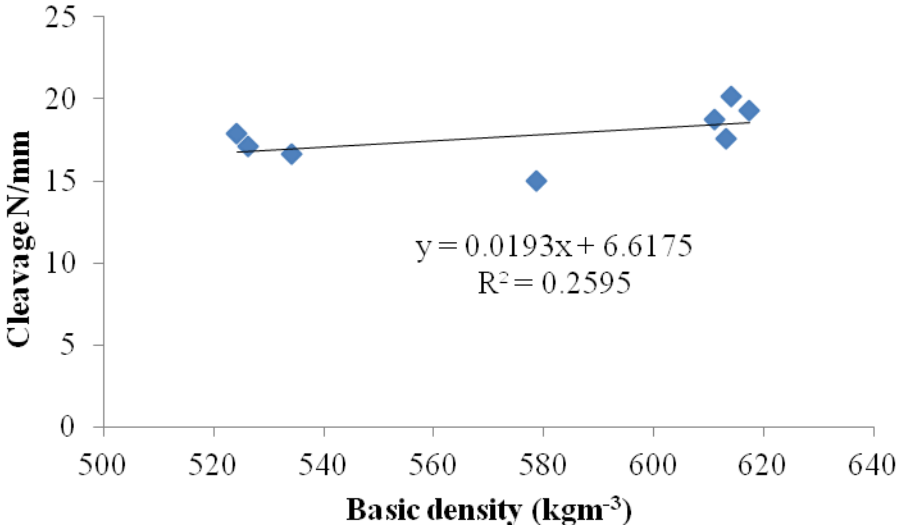


Figure 33: Relationship between wood basic density and cleavage strength for *C. zeyheri*

4.3.6 Relationship between fiber length and strength properties

Statistical analysis showed that there is a positive linear relationship between fibre length and strength properties investigated in this study (Table 10). For *L. capassa* regression equations were significant ($p<0.05$) for compression and cleavage with R^2 values of 0.87 and 0.89 respectively while for MOE, MOR and shear strength equations were not significant ($p<0.05$) with R^2 values of 0.08, 0.11 and 0.04 respectively (Table 10). On the other hand, *C. zeyheri* regression equations were also significant ($p<0.05$) for compression and cleavage with R^2 values of 0.899 and 0.891 respectively whereas for other variables namely MOE, MOR and shear equations were not significant with R^2 values of 0.12, 0.05 and 0.07 respectively. The results in Table 10 are in agreement with Dinwoodie (1981) who stated that there is a positive correlation between wood fibre length and its strength properties.

Table 10: Relationship between fibre length and strength properties for *L. capassa* and *C. zeyheri*

Strength property	Equation	R^2
Lonchocarpus capassa :		
MOE	$y = 7800.5x - 2082.9$	$R^2 = 0.0833$
MOR	$y = 107.54x - 47.707$	$R^2 = 0.1106$
Compression //grain	$y = 37.233x - 11.12$	$R^2 = 0.8783$
Shear //grain	$y = 4.9703x + 7.1827$	$R^2 = 0.0434$
Cleavage	$y = 28.006x - 14.471$	$R^2 = 0.8998$
Combretum zeyheri :		
MOE	$y = 6762.6x - 1273.5$	$R^2 = 0.122$
MOR	$y = 79.415x - 18.38$	$R^2 = 0.0573$
Compression //grain	$y = 45.011x - 9.0777$	$R^2 = 0.8993$
Shear //grain	$y = 8.2013x + 6.9267$	$R^2 = 0.0759$
Cleavage	$y = 36.561x - 26.004$	$R^2 = 0.8915$

Y= Strength property, X= Fibre length, R^2= Coefficient of determination

4.3.7 Relationship among strength properties

The results of regression analysis showed that there is a strong linear relationship between MOE and MOR for *L. capassa* and *C. zeyheri* and this relationship was significant ($p<0.0001$) with R^2 value of 0.97 and 0.72 respectively (Fig. 34 and 35). This relationship between MOE and MOR clearly show that when a wood has a high stiffness strength i.e (MOE) it can withstand shock loads i.e (high MOR). This attribute is important in tool handles and sporting goods where toughness and shock resistance property is sought (Dinwoodie, 1981).

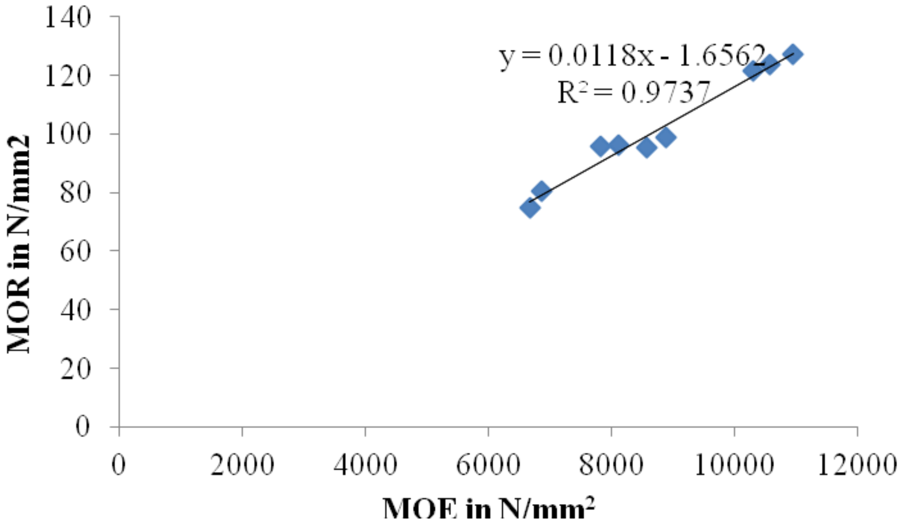


Figure 34: Relationship between MOE and MOR for *L. capassa*

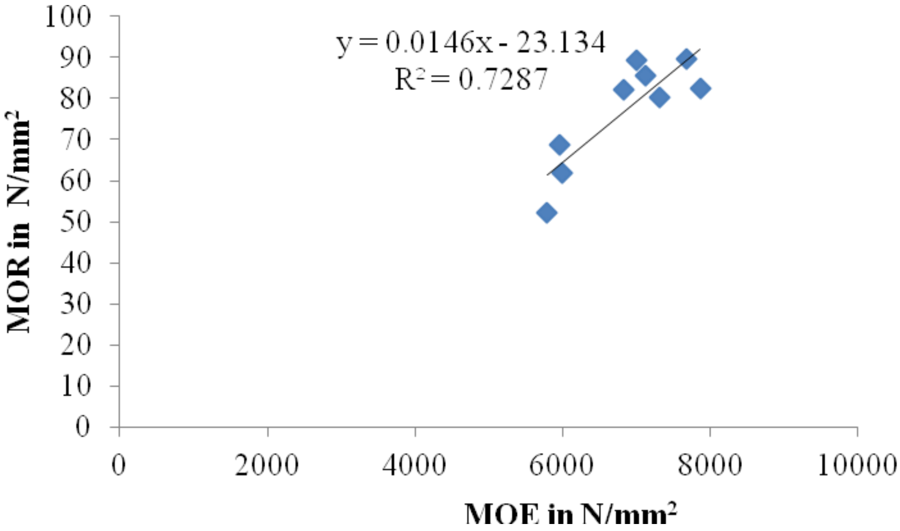


Figure 35: Relationship between MOE and MOR for *C. zeyheri*

4.3.8 Overall wood properties of *L. capassa* and *C. zeyheri*

The use of a given timber in the production of manufactured items or in the wide range of timber constructions depends mainly to the selection of the most appropriate species for the task. Iddi and Nagoda (1992) reported that the selection of the most suitable timber for a particular purpose depends on its properties.

Some strength properties (MOE, MOR, compression, shear) and basic density for *L. capassa* are lower than that of *K. anthotheca*, *M. excelsa* and *A. quanzensis*. But, on the other hand most strength properties (MOE, MOR, compression, shear and cleavage) of *L. capassa* are above or approach the ones of *P. angolensis* and *J. procera* (Table 11). Bryce (1967) revised by Chihongo (1999) reported that *P. angolensis* and *J. procera* are suitable for furniture, doors, windows, and general joinery, turnery, carvings, coffins, parquet and strip flooring, solid or veneered paneling, marine and utility plywood, clogs and decorative work and all parts of boats except those requiring steam bending. They are also suitable for pencil slate, wardrobe and drawer linings, fence posts, shingles, tank and vats. Hence, *L. capassa* can be a suitable species for replacing *P. angolensis* and *J. procera* in use.

The MOE for *C. zeyheri* is lower than those of well known timber species in comparison, but for some other properties like MOR, compression, shear, cleavage and basic density, it is above or approaches those of well known species. According to Kityo and Plumptre (1997), timber for structural use should have a density of 400 -750kg m^{-3}, MOE of 6 860 – 14 700 N mm^{-2}, MOR of 39 -132 N mm^{-2} and should be durable, easy to plane and nail. Hence, *C. zeyheri* had properties which are approximately in the specified ranges and thus can also be used for making structural elements namely tie beams, rafters and purlins in house construction.

Table 11: Comparison of wood properties for *L. capassa*, *C. zeyheri* and some well known timber species

Species	MOE	MOR	Comp	Shear	Cleav	BD	FBL
Lonchocarpus capassa	8745	101.5	40.5	14.08	24.4	569.3	1.38
Combretum zeyheri	6840	76.9	44.9	16.7	17.8	580	1.2
Khaya anthotheca *	9604	66	48.3	10.1	10.8	657	-
Pterocarpus angolensis *	8443	94	57	17.2	13	657	-
Milicia excelsa *	9345	90	54.7	15.6	10.75	657	-
Afzelia quanzensis *	10441	114	69.2	19	14.55	833	-
Juniperus procera *	8379	91	39.3	12.8	7	513	-

Source (*): Bryce (1967) revised by Chihongo (1999)

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions were made from this study:

(i) Based on their basic densities, the wood of the two species is heavy and the one of *L. cappassa* was higher than that of *K. anthotheca*. The fibre lengths of the two species differed significantly and are longer than those of *E. grandis*, *E. maidenii* and *E. saligna*.

(ii) There are significant differences between MOE, MOR, shear, compression and cleavage strength of the two species. *L. capassa* performed better than *C. zeyheri* in MOE, MOR and cleavage strength while the later was better than the former in shear and compressive strength. *L.capassa*'s MOE, MOR, shear, compression and cleavage strength were as good as to those of *P. angolensis*, *K. anthotheca* and *J. procera* whereas *C. zeyheri*'s properties are in the ranges of timbers which are used in making structural elements and in house construction.

(iii) Both studied species showed higher cleavage strength values than some well known timber species namely *K. anthotheca*, *P. angolensis*, *M. excelsa*, *A. quanzensis* and *J. procera* indicating higher preference of the studied species in the manufacture of tight barrels, charcoal and hand-split shingles, nail or screw-holding purposes and in packaging-case manufacture than the well known species.

(iv) A positive non significant linear relationship was found to exist between basic density and fibre length for both species. There was highly significant positive linear relationship between basic density and all strength properties except for *L. capassa*'s compression and cleavage. There was a positive linear relationship between fibre length and strength properties and it was significant in compression and cleavage for *L. capassa* and *C. zeyheri*. There was also a significant linear relationship between MOE and MOR for both species.

5.2 Recommendations

5.2.1 Potential uses of *L. capassa* and *C. zeyheri*

(i) Since wood properties of *L. capassa* are similar to those of *P. angolensis* and *J. procera*, wood of *L. capassa* can be used as an alternative for these over harvested species in furniture production such as doors, windows, and general joinery, turnery, carvings, coffins, parquet and strip flooring, solid or veneered paneling, marine and utility plywood, clogs and decorative work and all parts of boats except those requiring steam bending, pencil slate, wardrobe and drawer linings, fence posts, shingles, tank and vats and also in pulp and paper production.

(ii) Since *C. zeyheri* belongs into heavy timbers, it is suitable for structural application like for instance in construction where timber ability to sustain considerable amount of load without failing is necessary and in boat internal fittings, batons and other structural uses where moderately high density is a desired property. It can also be used in pulp and paper production.

5.2.2 Further research on *L. capassa* and *C. zeyheri*

In regard with the findings emanated from this study, the researcher recommends further studies should be conducted on hardness and impact bending strength, natural durability, and treatability with preservatives, finishing and working properties of these two lesser-known and lesser utilized IAGTS before real recommendations are made on their potential end uses.

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APPENDICES

Appendix 1: Basic density, fibre length and strength properties for *L. capassa* (Lc) and *C. zeyheri* (Cz)

SPP	Tno	Bdty	FBL	MOE	MOR	Comp	Shear	Clv
Lc	1.1	542.128	1.377	10573.2	123.852	42.595	16.476	22.854
	1.2	555.23	1.494	10943.1	127.456	42.006	14.436	22.952
	1.3	543.014	1.417	10303.1	121.612	40.756	16.223	21.334
	2.1	547.811	1.343	6863.06	80.468	35.918	13.335	26.294
	2.2	527.344	1.344	8098.69	96.144	38.721	12.957	26.482
	2.3	528.63	1.295	8874.35	98.83	39.095	13.922	25.416
	3.1	614.416	1.382	7821.35	95.656	42.415	12.638	25.028
	3.2	614.518	1.412	6660.54	74.942	40.56	13.512	25.011
	3.3	651.405	1.429	8567.49	95.226	43.007	13.239	24.276
	Average	**569.388**	**1.38**	**8745**	**101.5**	**40.5**	**14.08**	**24.4**
Cz	1.1	526.285	1.171	5964.07	68.712	47.277	15.483	17.142
	1.2	524.226	1.148	5997.56	61.864	46.027	16.334	17.853
	1.3	534.24	1.217	5787.26	52.103	45.414	14.313	16.627
	2.1	578.667	1.192	6832.44	82.09	47.143	17.605	14.976
	2.2	617.376	1.166	6997.15	89.287	43.314	17.189	19.266
	2.3	613.248	1.169	7865.55	82.355	41.639	17.165	17.571
	3.1	614.105	1.236	7680.32	89.769	45.623	17.498	18.735
	3.2	611.007	1.259	7316.63	80.296	43.477	17.773	18.49
	3.3	598.396	1.241	7126.29	85.702	44.458	17.547	20.124
	Average	**579.728**	**1.2**	**6840**	**76.9**	**44.9**	**16.7**	**17.8**

Appendix 2: Means, standard deviations and Coefficient of variation

(i) Species = *L. capassa* (Lc)

Obs Variable	N	Mean	Std Dev	CV (%)
Bdty	9	569.388	45.17	7.97
FBL	9	1.38	0.058	4.2
MOE	9	8745	1573.51	17.9
MOR	9	101.5	18.82	18.54
Comp	9	40.5	2.3	5.6
Shear	9	14.08	1.38	9.8
Clv	9	24.4	1.7	6.9

(ii) Species = *C. zeyheri* (Lc)

Obs Variable	N	Mean	Std Dev	CV(%)
Bdty	9	579.728	40.39	6.9
FBL	9	1.2	0.039	3.2
MOE	9	6840	764.6	11.1
MOR	9	76.9	13.1	17
Comp	9	44.9	1.8	4
Shear	9	16.7	1.17	7
Clv	9	17.8	1.5	8.4

Appendix 3: Wood properties comparison between *L. capassa* and *C. zeyheri*

Property	P value	R^2	Level of significance	*Lonchocarpus capassa*	*Combretum zeyheri*
Basic density	0.17	0.92	NS	569.3	580
Fibre length	<.0001	0.95	0.1%	1.38	1.2
Modulus of elasticity	<.0001	0.89	0.1%	8745	6840
Modulus of rupture	<.0001	0.89	0.1%	101.5	76.9
Compression	<.0002	0.83	0.1%	40.5	44.9
Shear	<.0001	0.9	0.1%	14.08	16.7
Cleavage	<.0001	0.95	0.1%	24.4	17.8

Note 1: NS = Not significant