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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

CIVIL TECHNOLOGY FACULTY

DEPARTMENT OF WOOD SCIENCE AND TECHNOLOGY MANAGEMENT

MAPPING OF BASIC DENSITY AND PHYSICAL PROPERTIES OF *EUCALYPTUS GLOBULUS* GROWN AROUND WEST ARSI BOKOJI

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A THESIS SUBMITTED TO THE FACULTY OF CIVIL TECHNOLOGY FOR THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTERS OF SCIENCE IN WOOD TECHNOLOGY

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Approval Sheet-I

The Thesis entitled "Mapping of Basic Density and physical property of *Eucalyptus globulus* grown around Bekoji" has officially been evaluated as meeting the requirements thesis for the Master of Wood Science Technology. Dr. Sisay Feleke was over see Mr. Kitaw Abera while he carries out the investigation.

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APPROVAL SHEET -II

We, the undersigned, members of the Board of Examiners of the final open defense by Kitaw Abera have read and evaluated his thesis entitled "Mapping of Basic Density and physical property of *Eucalyptus globulus* grown around Bekoji." This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Wood science and Technology.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy through the Department of Wood Technology to the Faculty of Civil Technology.

DECLARATION

I hereby declare that the work, which is being presented in this thesis entitled "**Mapping of Basic Density and physical property of *Eucalyptus globulus* grown around Bekoji"** is my original work carried out under the supervision of Dr.Sisay Feleke. It has not been presented in any form to other university/institute to obtain a degree. Certificate or awards and all sources of materials used for this thesis are duly acknowledged

Name of candidate signature date

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Name of advisor Signature Date

DR. Sisay Feleke ________ _________

Final approval and acceptance of the thesis is contingent up on the submission of the final copy through the department of Wood Technology to the Faculty of Civil Technology

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LIST OF ABBREVIATIONS FORMULA AND ACRONYMS.

D	Density
MC	Moisture Content
Kg	Kilogram
M^3	Meter Cube
g	gram
Cm^3	Centimeter cube
WSG	Wood Specific Gravity
DBH	Diameter Breast Height
Cm	Centimeter
HD	High Density
LD	Low Density
FSP	Fiber Saturated Point
^0F	Degree Fahrenheit
^0C	Degree Centigrade

Table of Contents

Approval Sheet-I i

APPROVAL SHEET -II ii

DECLARATION iii

ACKNOWLEDGMENTS iv

LIST OF ABBREVIATIONS FORMULA AND ACRONYMS v

List of tables viii

List of figures ix

Abstract x

CHAPTER ONE 1

1. INTRODUCTION 1

1.1. Background of the study 1

1.2. Statement of Problem 3

1.3. Objectives 4

1.4. Research Question 4

1.5. Significance of the study 5

1.6. Scope of the study 5

1.7. Limitation of the study 5

CHAPTER TWO 6

2. Literature Review 6

2.1. Description of Eucalyptus globulus 6

2.2. Basic Density 6

2.3. Wood Quality 8

2.4. Factors affect tree density 10

2.5. Effect of heart and sap wood on moisture Content (MC) 11

2.6. Density Variation along diameter 12

2.7. Other Physical property of hard wood 13

2.8. Frame Work of the study 13

CHAPTER THREE 15

3. Material and Methods 15

3.1. The study Area 15

3.2. Material and Methods 16

3.3. Heart and sap wood proportion 25
3.4. Experimental Design and Statistical Analysis 26
CHAPTER FOUR 27
4. RESULT AND DISCUTION 27
4.1. Moisture content 27
4.2. Basic density variation 27
4.3. The heartwood and sapwood 30
4.3.1. Heartwood and sapwood proportion 30
4.3.2. Moisture content 31
4.3.3. Basic density 32
4.4. Shrinkages 36
CHAPTER FIVE 39
5. CONCLUSION AND RECOMMENDATIONS 39
5.1. CONCLUSION 39
5.2 Recommendations 40
References 41

List of tables

Table 1:Tree position along height and age groups of *Eucalyptus globulus* 16

Table 2: Harvested *Eucalyptus globulus* characteristics and disc sample. 18

Table 3: Mean variations in physical properties of *E. globulus* tree. 28

Table 4: Analysis of variance for heartwood and sapwood proportions in *E. globulus* 30

Table 5: Analysis of variance for Physical properties in *E. globulus* at different age, tree height and tree diameter 33

List of figures

Figure 1: Map of the study area 15
Figure 2: Measuring tree height and diameter 17
Figure 3:Felled and Measuring trees........ 18
Figure 4: Measuring and cutting disc........ 19
Figure 5: Sampling plan for experimental measurement of physical properties *E.globulus.* 20
Figure 6: Cube preparation from discs........ 21
Figure 7: Cubes sample preparation scheme........ 21
Figure 8:Cutting Sample from discs 21
Figure 9:Adjusting machine and cutting discs........ 22
Figure 10: Oven Drying Weight 23
Figure 11: Weighting samples 23
Figure 12: Cutting Sample from discs 24
Figure 13: Measuring Anatomical direction 25
Figure 14: Measuring sapwood & Heart wood........ 25
Figure 15: variation of basic density tree age with height 29
Figure 16: Heartwood and sapwood proportions variations between age groups (a) and along the tree height levels (b)........ 30
Figure 17: Heartwood (a) and sapwood (b) proportions within each tree height level........ 31
Figure 18: Variation of Moisture content between age with tree height........ 32
Figure 19: Variation of Moisture content between tree age........ 32
Figure 20: Basic density in heartwood and sapwood along the tree height levels of *E. globulus* 35
Figure 21: Variation of basic density tree age with diameter 35
Figure 22: Variation of shrinkages; (A) Tangential, (B) Radial, (C) Longitudinal and (D) Volumetric.. 37
Figure 23: variation of shrinkage; (A) Tangential, (B) Radial, (C) Longitudinal and (D) volumetric 38

Abstract

The study on the mapping of the physical properties of Eucalyptus globulus tree of three age groups was collected from West Arsi Zone. The study was aimed at the moisture content, density and shrinkage variations along the tree height and tree diameter. The DBH of the trees increased with increasing age group ranging from 16-34 cm with the height of 26-34 m. The study was designed to have three factors, namely age, tree height and tree diameter with different levels of treatments. The disk samples were prepared at knee height (70 cm), DBH, 30%, 50% and 70% of the merchantable size of the trees. A total of 180 experimental treatments were done and evaluated for mean significance statistical difference. The moisture content of the disks and cubes of the tree varied as a statistically significant level of $p<0.002$ with higher moisture observed to the top of the trees and on younger age group 10-15-years trees. The mean density of *Eucalyptus globulus* is 880 kg/m3, where the age and across the tree diameter have significant effect the density at $p<0.001$. The cube samples prepared from the disks showed a significant shrinkage in tangential direction 6.65%, radial direction 3.9% and longitudinal directions 0.5%. A significant value of the wood shrinkage was observed in younger age group and at the samples prepared from the top portion of the tree. The trees tapered to the tip from bottom to top of the tree. The heartwood and sapwood proportion also significantly vary with the tree age and tree height.

Key word: Eucalyptus globulus, density, shrinkage, heartwood, sapwood, disk

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Eucalyptus globulus is one of the most important *Eucalyptus* species cultivated in the world and is used as raw material in the pulp and paper industry. Several breeding programs continuously improve traits of interest in *Eucalyptus globulus*, such as wood growth and density, under various environments. The species has been widely cultivated in temperate regions in which abiotic stresses such as drought and cold are the main limiting factors. The *Eucalyptu*s genus comprises about 700 species distributed naturally over a wide range of environmental conditions and is cultivated worldwide on more than twenty million hectares *Eucalypts globulus* is highly cultivated because it uses 25% less wood to produce one ton of pulp compared with other *Eucalypt species*, requires less energy in the manufacturing process and exhibits greater fiber length and thickness (Schmit et al., 2011).

Nowadays, *Eucalyptus* plots and stands are seen allover of the Ethiopian highlands covering the range of highly sloppy and degraded areas. The farmers in different agro ecological zones continued to plant the species for various purposes such as fuel wood, transmission poles for income generation and construction material for their own use (Bekele et al., 2015).

Eucalyptus is native to Australia and Tasmania but domesticated in Africa and tropical to southern temperate America. Variability is prevalent in morphology, growth habit, flower color, leaves, stems and chemical composition. In case of *Eucalyptus globulus*, pollen competition favors cross- pollination over self-pollination. Controlled pollinations with self-pollen, cross-pollen and a mixture of self-pollen and cross-pollen were conducted on three partially self-incompatible trees. Paternity of individual seeds resulting from mixed pollination was determined by isozyme analysis. (Hayat et al., 2019).

Wood properties have moderately high heritability and have also been shown in hybrids to be generally intermediate between the parents. Wood density and radial shrinkage are traits for which most hybrids appear intermediate although it is sometimes difficult to make comparisons given data from trees of different ages (Mccomb et al., 2023).

Wood property variation is one of the major problems facing the users because it lowers efficiency of use of wood as a raw material.

In general, variability within and among trees is high. It is also high within families of the same species. Environment is one of the major causes of this variation. All wood properties are determined by an interaction of the genetic potential of the tree with the environment in which the tree grows (Sakagami et al., 2013). Basic wood density (D) and initial moisture content (MC) are the two important wood properties for solid timber applications; especially structural timber application is strongly related to wood density (Sciences, 2018).

In hardwoods, wood density is determined by its anatomical structure, cell wall thickness, fiber width, vessel width and frequency, parenchyma proportion and chemical composition, thus species with similar density can differ markedly in fiber properties and cell dimensions which affect the quality of the products obtained, such as pulp and paper.

In high-density hardwoods, fibers with thicker cell walls represent a larger proportion of xylem generating a porous paper and more compressible, giving better printability and opacity In low-density hardwoods, vessels occupy a major proportion of wood and fibers have thin walls, producing a denser paper, smooth and with high tensile and burst strength. Fiber length usually does not directly contribute to density, but is an important descriptor factor of pulp quality, given its relationship with paper strength properties (Carrillo et al., 2015).

In addition wood density can vary also according to its location in the tree. Generally going outwards from the pith it continuously increases in the juvenile section, afterwards the average density reaches the highest value in the mature wood. In case of the wood species with high cutting age in the older age (80-150 years) a slight density fallback can be observed, while in case of trees with definitely colored heartwood the density of sapwood is of 5-8 % less than that of the heartwood. For this reason the effect of age is more significant than the distance of wood from the pith (Kom, 2017).

Wood density and shrinkage are often used as general indicators of the suitability of wood for many purposes, including manufacture products. This is because the density of wood is a main determinant of strength; consequently, density and strength are directly related to each other. Wood density also has an influence on wood processing, including on cutting, gluing, finishing, rate of drying and paper making, while shrinkage is important in terms of the stability of wood during and after drying (Listyanto et al., 2020).

Shrinkage refers to the reduction in wood dimension that occurs when wood undergoes drying or shrinking. It is a measure of the change in volume of wood due to moisture loss. Density shrinkage is an important property to consider in industries such as woodworking, construction, and furniture making, as it affects the dimensional stability and strength of wood products. Moisture content (MC) of wood is defined as the weight of water in wood expressed as a fraction, usually a percentage, to the weight of oven-dry wood. Weight, shrinkage, strength, and other properties depend upon the moisture content of wood. In freshly felled trees, moisture content can range from about 30% to more than 200% of the weight of the wood substance.

Wood exchanges moisture with the surrounding air; the amount and direction of the exchange (gain or loss) depend on the relative humidity and temperature of the air and the current amount of water in the wood. This moisture relationship has an important influence on wood properties and performance. Some physical properties discussed and tabulated are influenced by species as well as variables like moisture content; other properties tend to be independent of species. The thoroughness of sampling and the degree of variability influence the confidence with which species-dependent properties are known (Simpson & Tenwolde, n.d 2013).

The heartwood percentage has significantly decreased from base of the stem to top of the stem, with the highest value at the base part. This is a general trend of within tree variation in heartwood proportion Furthermore, the thickness of sapwood increased from bottom to top and at a certain height sapwood thickness become stable (Arisandi et al., 2023).

Therefore this study will be most important in mapping of the basic density and physical properties of *Eucalypts globulus* in different age, height thickness ratio of heartwood to sapwood and the shrinkages along tree height and across locations of the wood discs.

1.2. Statement of Problem

Wood density affects most of the wood properties hence, proper knowledge of the density variations in wood will help to identify the areas of application in wood products. The lumber from the eucalyptus species are known for their split/cracks, warp, bow and cup formation. As a result, many sawmills and woodworking joineries don’t prefer to process it. This statement problem focuses on investigating how different growth factors such as age conditions tree height, and wood portion affect the basic density and physical properties of *Eucalyptus globulus* wood. The study aims at understanding of the variations in wood quality and properties across in selected region/area plantations, providing insights for sustainable forestry practices, wood utilization.

This research problem was involve collecting wood samples from three age groups (10-15 year age,15-20 year age and 20-25 year age) *Eucalyptus globulus,* analyzing their basic density, and shrinkage characteristics. The statement problem was regarding the basic density and physical properties of *Eucalyptus globulus* in Around Arsi Bokoji could be:

- Problem forms of basic density a long tree age of wood species
- Which age is more highly dense
- Which age of wooden sample is highly formed shrinkage
- Variety along the anatomical direction on radial, tangential and longitudinal direction of a disk

1.3. Objectives

1.3.1. General Objective

The general objective of the study is to investigate the variability of basic density and physical properties of *Eucalypts globulus* in age, diameter and along the tree height grown around Arsi Bokoji.

1.3.2. Specific Objectives

- To investigate the density of a stem of the *Eucalyptus globulus* species along height.
- To investigate the density variation across the diameter
- To study the basic density variability in age
- To map the ratio of heartwood to sapwood and their moisture content
- To study the variability in moisture content along the height, age and diameter
- To map shrinkages along tree height and across the diameter of a given age.

1.4. Research Question

This study will answer the following questions

- How do the basic density, moisture, and shrinkages of *Eucalyptus globulus* wood vary with age Portion of the tree and tree height Around Arsi Bokoji ?
- What are the relationships between basic density and physical properties of wood?

- To what extent shrinkage and moisture content of the wood interrelated?
- How do age and tree height factors influence the heartwood-to-sapwood ratio and moisture content?

1.5. Significance of the study

This study result will help the wood industry and other wood manufacturing organizations.

- The study is significant in giving information on the *Eucalyptus globulus* physical properties for various applications and its influence on wood performance in construction, furniture making, flooring, pulp and paper production, and other industries application.
- To add the Knowledge of its strength properties and suitability for load-bearing structures or if it needs reinforcement.
- To properly use and utilize the *Eucalyptus globulus* wooden resource.

1.6. Scope of the study

This study area of focus on the vicinity of a defined boundary around Bekoji. By concentrating the data collection and analysis on a specific localized region, the study can provide specific insights into the basic density, moisture content and shrinkage of *Eucalyptus globulus* trees in the three age groups (10-15 year age,15-20 year age and 20-25 year age)

1.7. Limitation of the study

There are several limitations that were considered when interpreting the results of a study on the basic density and physical properties mapping of *Eucalyptus globulus*: unavailability of record, sampling of the species based on age ranges, remoteness and insecurity faced during the study. Due to budget limitation the study was focused on density and shrinkage of the species, sample collection limited to a single locality.

CHAPTER TWO

2. Literature Review

2.1. Description of Eucalyptus globulus

Eucalyptus globulus dominates the Ethiopian afforestation and reforestation programs connected with ever increasing demand for construction, fuel wood and industrial wood production purposes. Expansion of *Eucalyptus* forest plantations worldwide, including trees on farm in Chile, Uruguay, north east Argentina, Australia, Brazil, South Africa and rest of the world has recently increasing in many folds (Bekele et al., 2015).

Eucalyptus globulus the Tasmanian blue gum, is an evergreen tree, one of the most widely cultivated trees native to Australia *Eucalyptus* or myrtles are a large group of evergreen trees and shrubs grow in tropical areas (They can reach over 100 feet in height.) *Eucalyptus* leaves are giving off a pleasant and distinct fragrance. Flowers are primarily insect-pollinated with some wind-pollination. *Eucalyptus globulus* are one of the world's most widespread hardwood trees. Due to its social, economic and environmental impacts, *Eucalyptus globulus* have been the object of several genetic, ecological and physiological studies (Azzazy, 2016).

Hybrid eucalypts generally have an overall morphology intermediate between that of the parent species with few traits being dominant, but some traits may be closer to those of one parent than the other. Wood properties have moderately high heritability and have also been shown in hybrids to be generally intermediate between the parents (Mccomb et al., 2023).

2.2. Basic Density

Use of wood to the best of its potential requires knowledge about its physical, anatomical, chemical and mechanical properties. Depending on the end use, properties considered important for characterizing wood quality may vary, yet basic density is considered the main indicator of wood quality, as it correlates with all other wood properties, including re tractability, mechanical properties and anatomy. Also, density affects all processes in which wood is present, including pulping, charring, machining, log breakdown etc.

The basic density of wood refers to the mass of a given volume of wood material, typically expressed in kilograms per cubic meter (kg/m^3) or grams per cubic centimeter (g/cm^3). It is an important parameter used in various applications, including timber engineering, wood processing, and biomass estimation.

Wood basic density (BD) from indirect density measures is important for estimating *Eucalyptus globulus* breeding values and genetic gain. Wood density is amongst the most important traits for genetic improvement of *Eucalyptus globulus* for pulpwood production. Although density of the whole tree is the target trait for improvement, its wide-scale measurement is impractical and requires destruction of valuable genetic resources. Indirect measures of whole-tree density such as density of bark-bark cores and penetration depth of a flat-nosed pin under constant pressure have therefore been widely implemented in eucalypt tree improvement programs during the past decade (England, 2010).

The basic density of calculated as follows:

$$\text{Basic density} = \frac{\textit{Oven dried weight of sample (g)}}{\textit{Volume of displaced water (cm3)}}$$

2.2.1. Green Density

Green density, also known as the green moisture content density or green weight density, is a measure of the density of wood when it is freshly cut or "green," meaning it has not been dried or seasoned. It represents the weight of the wood per unit volume at its natural moisture content. Green density is typically expressed in kilograms per cubic meter (kg/m^3) or grams per cubic centimeter (g/cm^3). It is an important parameter in the wood industry as it affects various aspects of wood processing and utilization.

Wood is a porous, hygroscopic, anisotropic, non- homogeneous biopolymer of cellular structure. Water is always naturally found in freshly cut green wood as free and bound water since it is a necessary component of the living tree. Therefore, when wood is cut from a tree in the form of lumber, veneer, particles, or fibers, it always contains moisture, the oven-dry basis percentage of which is defined as the green moisture content. Generally speaking, moisture content, M, is defined as the weight of water in wood divided by the oven-dry wood weight times 100% (Avramidis, 2023).

Wood is a biological tissue made of cells where the cell walls composed of lignin. The tracheid's are like pipes, that transport the sap along the stem and they are filled by water. Wood density varies within the plant, during the life of the plant, and between individuals of the same species. Also the branches and the outer part of the trunk tend to have a lighter wood than the pith (Chave & Sabatier, 2006).

The wood density is related to mechanical properties, dimensional stability, water flow, carbon fixation, and climate change. Hence, precise methods for its determination are more important (Castro et al., 2020).

2.2.2. Oven Dry Density

There are many definitions of wood density. Foresters measure the weight of a given volume of wood that has been 'air-dried'. Depending on the country, conventions differ about air drying: the fraction of water remaining in the wood sample may be 12%, or 15%. This causes considerable trouble in the literature. In the present study, wood density is technically defined as the ratio of the oven-dry mass of a wood sample divided by the volume of water displaced by its green volume. This can be calculated from measurements of oven-dry weight combined with measurement of green volume (Chave & Sabatier, 2006) .

2.3. Wood Quality

Eucalyptus globulus are the most widely planted species for pulpwood production in (temperate) regions of the world and there are breeding programs in numerous countries (Freeman et al., 2011).

Eucalypts globulus HD pulp, produced from the wood of the highest density, exhibits fibers with an average length of 0.85 mm, which is 20% higher than that exhibited by the pulp with the lowest pulp yield, coming from the wood with the lowest basic density and the tree stand of the lowest age; *Eucalypts globulus*–HD pulp fibers are only slightly wider than those of *Eucalypts globulus*–LD, but exhibit a fiber coarseness, which is close to 40% higher; and The pulp fibers produced from the industrial chip sample exhibit intermediate morphological characteristics (Profile et al., 2008).

2.3.1. Moisture Content (MC)

Moisture in wood is found as water vapor, free water in the cell lumens and cavities and as bound water within the cell walls. The moisture content (MC) at which the cell walls are fully saturated with bound water but no free water occurs in the structure is designated as fiber saturation point (FSP). The amount of free water depends on porosity while the amount of bound water is related to the free hydroxyl groups of the main structural compounds that can attract water molecules by electro-static forces. Although the ratio between the main structural compounds varies, the maximum amount of bound water in wood of various species changes in a narrow interval of 25-30%(Ali, 2011).

The migration mechanisms of free water and bound water are different. Free water migration is caused by capillary forces, whereas bound water's migration in the gaseous phase through the cell wall results from diffusion owing to the moisture gradient. Water diffusion in wood is affected by micro-structure, moisture content (MC) and diffusion directions(E. G. Wood, 2022).

The global production of *Eucalyptus globulus* has been rising annually to meet the increasing demands for paper. However, situations such as a lack of water resources can cause slower growth rates due to inhibition of cell expansion and reduced carbon assimilation. These situations become a challenge for the breeding of eucalyptus in selecting clones with promising traits in response to water stress (Schmit et al., 2011).

2.3.2. Drying and (Dimensional) Changes

In the living tree, wood contains large quantities of water. As green wood dries, most of the water is removed. The moisture remaining in the wood tends to come to equilibrium with the relative humidity of the surrounding air. Correct drying, handling, and storage of wood will minimize moisture content changes that might occur after drying when the wood is in service. If moisture content is controlled within reasonable limits, major problems from dimensional changes can usually be avoided. Wood in service is always undergoing slight changes in moisture content. These changes that result from daily humidity changes are often small and usually of no consequence. Changes that occur because of seasonal variation, although gradual, tend to be of more concern. Protective coatings can retard dimensional changes in wood but do not prevent them. In general, no significant dimensional changes will occur if wood is fabricated or installed at moisture content corresponding to the average atmospheric conditions to which it will be exposed (Nguyen et al., 2014).

Shrinkage across the diameter is commonly referred to as radial shrinkage, caused by removal of existing water in wood or wood products and it relates to the change in dimensions from the center of the tree trunk to the outer edge or vice versa. Radial shrinkage occurs as wood loses moisture and undergoes drying. The radial shrinkage across the diameter of a tree trunk is generally more significant than longitudinal shrinkage along the length of the wood. This is because the cell structure and arrangement in wood allow for greater dimensional changes across the diameter compared to the length.

Dry wood under goes small changes in dimension with normal changes in relative humidity, more humid air will cause slight swelling, and drier air will cause slight shrinkage. These changes are considerably smaller than those involved with shrinkage from the green condition.

Dimensional changes normally caused by shrinking and swelling by using the total shrinkage coefficient from green to oven-dry (Nguyen et al., 2014).

The shrinkage of eucalyptus wood is related to its basic density, double fiber cell wall thickness, and proportion of ray parenchyma. There is a negative relationship between volumetric shrinkage and specific gravity and lignin and extractives contents in eucalyptus wood. The internal checking of eucalyptus wood is a result of differential shrinkage and collapse (Liu et al., 2015).

2.4. Factors affect tree density

As a tree grows, its wood undergoes changes in density, strength, chemical composition, and other properties. Younger wood near the outer rings (sapwood) tends to be less dense and weaker compared to the older wood in the inner rings (heartwood), which is typically denser and more durable. Environmental factors such as soil quality, moisture availability, temperature, and sunlight can influence the growth rate and wood quality of a tree. Trees growing in favorable conditions tend to have faster growth rates and potentially higher wood quality compared to those growing in less favorable environments.

Wood density and shrinkage generally are controlled by a combination of environmental factors and silvicultural practice. Understanding the wood density of a particular species allows the wood industry and the consumer to decide the appropriateness of wood uses. The variation of wood density between and within trees is considered to be caused by a combination of factors: growth rate, climate, silviculture and breeding. Therefore, considering environmental factors and species are an important step in establishing plantations for commercial purposes with higher wood quality (Listyanto et al., 2020).

There are two different groups of hardwoods, namely ring-porous and diffuse-porous. Wood of these groups is affected differently by growth rate. that in the ring-porous hardwoods changes of basic density are influenced by the ring widths, while those of diffuse-porous hardwoods are almost independent of the ring width. The eucalypts species are belongs to the diffuse-porous hardwood group (Amarasekera, 2015).

Physical properties of wood, such as specific gravity, total porosity, shrinkage, cellular shrinkage, and others, significantly affect the wood's drying behavior. In general, the rate of water transport, length in the flow direction, and concentration difference are contributing factors that affect the water vapor diffusion coefficient. In terms of wood, moisture content gradient is the measure of the concentration, which is positively related to the specific gravity of wood (Erasmus, 2016). It is well known that different wood characteristics, for example, wood density and the presence of heartwood tissues, affect water sorption in wood (J. Wood et al., 2019).

2.5. Effect of heart and sap wood on moisture Content (MC)

The heartwood and sapwood of a tree can have different effects on moisture content (MC) due to their inherent characteristics and functions in the tree. Sapwood is the outer, living portion of the tree trunk responsible for conducting water and nutrients transportation from the roots to the leaves. Heartwood is the inner, non-living portion of the tree trunk that provides structural support to the tree. As a tree matures the heartwood forms and undergoes chemical changes, including the deposition of extractives and resins.

Heartwood is more resistant to moisture flow and is less permeable than sapwood. Some variations in the wood structure, such as cross-grain, reaction wood, and juvenile wood, also influence the drying behavior of wood. The distribution of final moisture content in kiln-dried lumber could be associated with the proportions of heartwood, sapwood, and juvenile wood, wood species, initial moisture content, drying schedules, and other factors. reported a negative correlation between initial moisture content and several anatomical characteristics, including cell wall thickness, tangential vessel diameter, ray height, and the distance from the pith (Rahimi et al., 2022).

The majority of tree species have two histologically similar, but physiologically different xylem zones, namely sapwood and heartwood. Sapwood contains living cells that are physiologically active as well as reserve materials located in the outer zone. The outer ring allows the transport of water and minerals from the roots to the cambium and leaves. Meanwhile, heartwood is located in the inner zone of the xylem, and it is physiologically inactive in terms of water conduction. Furthermore, these cells undergo metabolic changes in the transition zone between sapwood and heartwood before death, which leads to increased synthesis of secondary metabolic compounds, such as extractives also stated that the formation process is a natural growth regulation mechanism that is associated with tree development. The process also helps to maintain optimal sapwood volume. Heartwood and sapwood have different properties and proportion in the trunk, which have a significant effect on wood utilization. The presence of heartwood is often used to determine the wood value. In pulping, it has a negative effect because its extractives can affect the process and properties of the final product. Meanwhile, for solid wood applications, the properties of heartwood and sapwood affect the drying, durability, and aesthetic value of panels and furniture (Arisandi et al., 2023).

2.6. Density Variation along diameter

Dimensional instability is a major problem with wood that is exposed to wide variations of relative humidity or when in direct contact with liquid water. This can cause, in combination with anisotropicity, shape distortions and internal stresses that can manifest themselves as fissures through the structure of the wood. This problem can be avoided by dimensional stabilization, namely, the introduction of chemicals that introduce stability to wood at the microscopic level or by alteration and reduction of its hygroscopic nature and water affinity (Castro et al., 2020).

Wood density may be considered a measure of internal wood structure, reflecting the combination of features of the various cellular elements that compose wood. This trait is associated with not only mechanical wood strength and fiber walls, but also with the structure of vessel and parenchyma cells, which have thinner walls and larger lumens. Wood density therefore correlates with cavitation resistance, and the thickening of vessel and fiber walls could be related to the stress that xylem vessels must withstand during high tension periods (Barotto et al., 2017).

The density of wood can vary across the diameter of a tree trunk due to several factors related to tree growth and wood formation. Wood density typically varies radially from the pith (center) to the bark. This variation is attributed to the growth processes and changes in cell structure as the tree grows. Within a growth ring, there are typically two distinct types of wood early wood and latewood. Early wood forms during the early part of the growing season and is generally less dense than latewood, which forms later in the season. Reaction wood, such as tension wood or compression wood, can also influence density variation.

2.7. Other Physical property of hard wood

Hardwood, as a broad category of wood species, encompasses a wide range of physical properties. The density of hardwoods can vary significantly depending on the species, growth conditions, and other factors. Hardwoods are known for their hardness, which refers to their resistance to indentation or wear. Hardwood species typically display a variety of grain patterns, which can range from straight and uniform to wavy, curly, or interlocked.

Wood physical properties are referred as quantitative characteristics of wood and its behaviour to external influences rather than applied forces. The most studied physical properties for determining the wood end uses comprise density, wood-water relations, shrinkage, swelling and color (Ali, 2011).

Several early studies concentrated on variation of wood properties within trees, variation from pith to bark, and from apex to base (Amarasekera, 2015).

2.8. Frame Work of the study

The study was review existing research on *Eucalyptus globulus* its basic density and physical properties. It was outline its objectives, research questions, hypotheses, sampling strategy, measurement methods, and data collection procedures. The Eucalypts globulus trees were collected from Oromia Forest and Wild life Enterprise Arsi Branch Cilalo Galema district Damota site Compartment 306 around Bekoji. Results were presented in the context of existing literature, with implications and limitations identified. The study was concluding with a summary of findings and potential recommendations for future research.

Flow Process of basic density and physical properties of *Eucalyptus globulus*

The resaerch was executed based on the following flow diagram

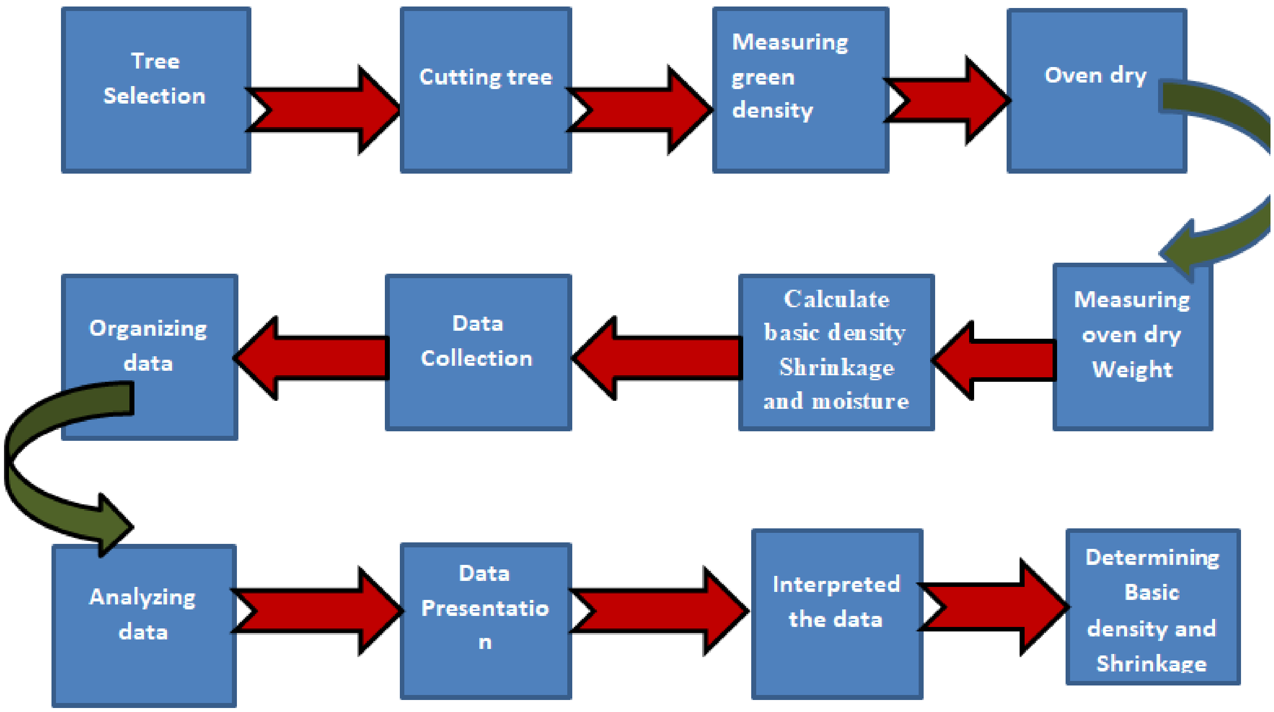

Diagram 1. Flow Process of basic density and physical properties of *Eucalyptus globulus*

CHAPTER THREE

3. Material and Methods

3.1. The study Area

West Arsi is a zone located in the Oromia Region of Ethiopia. The West Arsi Zone is situated at a highland elevation, with an altitude of 2800-3200 m as1. Bokoji is a town within the West Arsi Zone. In the highlands of west Arsi, temperatures can vary depending on the specific location and elevation. However, average temperatures are typically in the range of 16^0C to 23^0C throughout the year. The area is generally experiences a mild and pleasant climate throughout the year, with distinct wet and dry seasons. The warmest months are usually March and April, while the coolest months are December and January. The significant rainfall amount during the wet season rainy season typically occurs between June and September, with July and August being the peak months for rainfall.

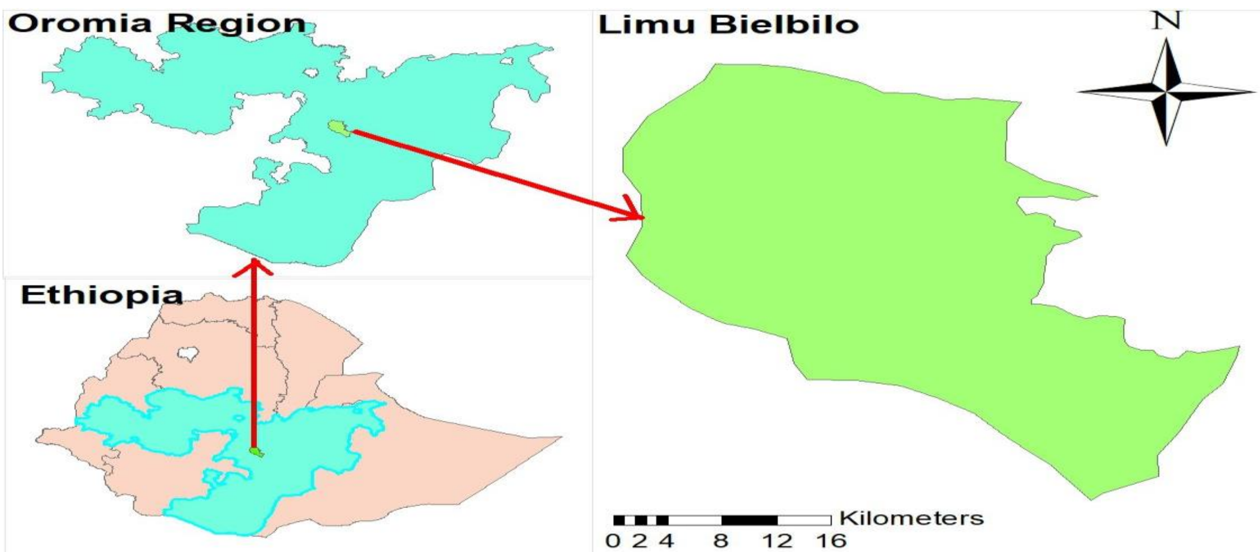

Figure 1: Map of the study area

3.2. Material and Methods

The materials and methods had better be worked out as described as follow

3.2.1. Sample preparation

The sample trees were harvested from three age groups of timber species (Table 1 to evaluate the density variation along the tree height and across tree diameter.

Three sample trees from each age were randomly and purposively sampled from selected Oromia Forest and Wild life Enterprise Arsi Branch Cilalo Galema district Damota site Compartment 306 around Bekoji sites. In order to explore the influence of age on the basic density, all sample trees were grouped into three age categories [10-15 year age, 15-20 year age and 20-25 year age] of *Eucalyptus globulus* based on availability.

Table 1:Tree position along height and age groups of *Eucalyptus globulus*

Tree Age	Tree code	Tree position along height	Diameter of the sample disc (cm) at 70 cm	Tree Height (m)
20-25 years	A1	Knee height (70 cm)	32	34
20-25 years	A2	Knee height (70 cm)	33	36
20-25 years	A3	Knee height (70 cm)	29.5	32
15-20 years	B1	Knee height (70 cm)	24	30
15-20 years	B2	Knee height (70 cm)	25.5	34
15-20 years	B3	Knee height (70 cm)	26.2	32
10-15 years	C1	Knee height (70 cm)	18.4	26
10-15 years	C2	Knee height (70 cm)	19	27
10-15 years	C3	Knee height (70 cm)	21.3	28

Figure 2: Measuring tree height and diameter

Measuring the height and diameter of a tree is essential for the purpose of sample preparation. The tree height and diameter measurements were done using clinometer and diameter caliper respectively. The height of trees were derived from the clinometer angle measurements between the ground and the top of the tree with a reference point is at breast height, which is approximately 1.3 to 1.4 meters above the ground. Three replicates of *Eucalyptus globulus* trees from each age group were harvested from a single site and 5 disks each having 5 cm thickness from each trees were cut for the evaluation of basic wood density and shrinkage.

3.2.2. Sample Preparation

Trees were felled and samples collected in April 2024. The diameter at breast height (DBH), total height and 'merchantable' height were measured. Three replicates of *Eucalyptus globulus* trees from each age group were harvested from a single site and 5 disks having 5 cm thickness were cut using chain saw machine, (figure 5), for the evaluation of basic wood density and shrinkage.

Figure 3:Felled and Measuring trees

The method of felling tree was depend on the size of the tree, the surrounding environment, and the desired outcome. Before felling a tree, evaluate its size, condition, and the environment around it.

Table 2: Harvested *Eucalyptus globulus* characteristics and disc sample.

Eucalyptus globulus						
• Age group	10-15 Years	15-20 years	20-25 Years		Total number of discs and tree	
• Average tree height (Meter)	27	32	34		9	
• Average DBH, cm	18.8	24.4	3..2			
• Discs at	Knee height (70 cm)	DBH (137 cm)	30%	50%	70%	45

Note: 5 discs from each tree at different heights X 3 (age groups) = 15 discs X 3 (replicates) = 45 discs.


Figure 4: Measuring and cutting disc

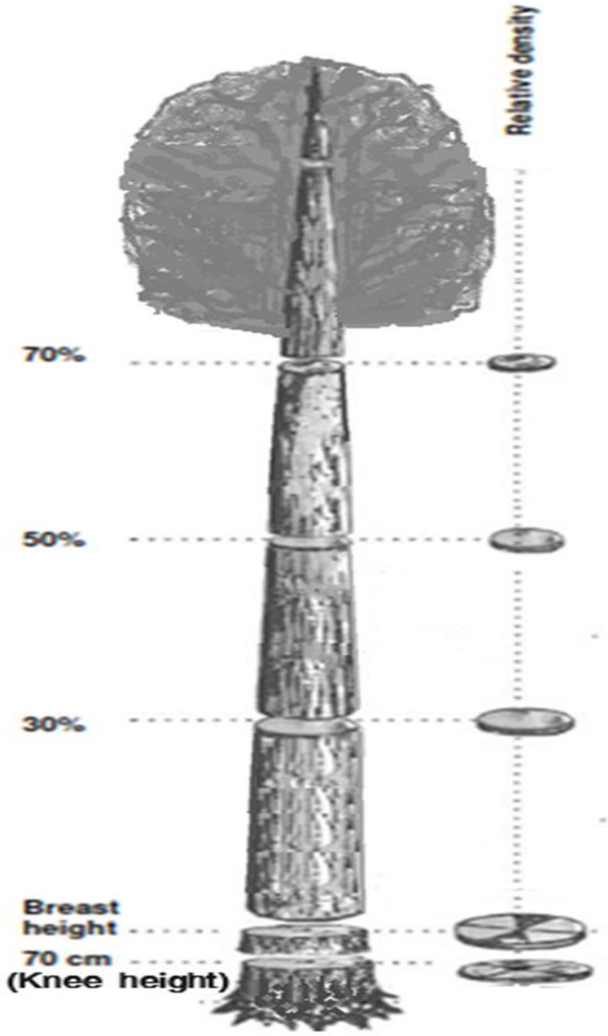

Figure 5: Sampling plan for experimental measurement of physical properties *E.globulus.*

The harvested *Eucalyptus globulus* trees in three age categories (10-15 year age, 15-20 year age and 20-25 year age) based on the predetermined design, as illustrated in (Fig. 5) 45 (forty five) discs from 9 (nine) trees were prepared . In order to reduce the moisture loss of the cut disk samples, marked discs were put in a polyethylene bag, sealed and transported to the Bekoji TVET for weight and volume measurements, and for further sample preparation as illustrated in Figure 6, and drying purpose.

Figure 6: Cube preparation from discs

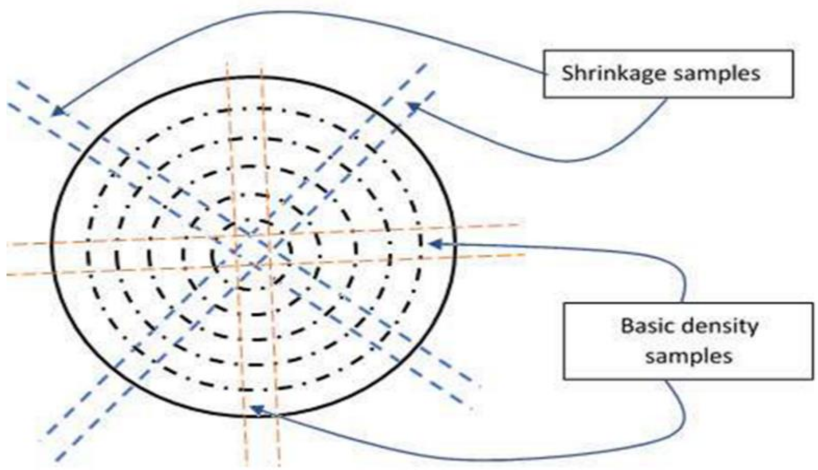

Figure 7: Cubes sample preparation scheme

Figure 8:Cutting Sample from discs

A total of 45 discs sample ripping on circular saw fig. 8 and fig.-9 for density and shrinkage determination following the schematic design on figure 7. All the sample cubes have equal dimensions in tangential, radial and longitudinal direction 50 mm.

Figure 9:Adjusting machine and cutting discs

3.2.3. Moisture content

Marked cube samples were dried in drying oven at 105 $\pm 2^0$C until they attain constant weight between successive measurements and their weight and volume was measured again (Figure 10). The moisture content of the samples calculated on dry matter base and expressed in percent.

$$Moisture\ content, \% = \frac{fresh\ weigth - dry\ weight}{dry\ weight} 100\%$$

Figure 10: Oven Drying Weight

3.2.4. Density

Oven dry density is the density of wood when it has been completely dried in an oven to remove moisture. To measure the oven dry density of a wood oven dried sample weight was measured using digital balance (figure 11). The volume of the sample was determined by displacement method immersing in graduated volumetric beaker partially filled with distilled water so that the volume of the sample disks was directly read from the displacement of water. However, there are several methods to identify the basic density of a material, depending on the nature of the substance.

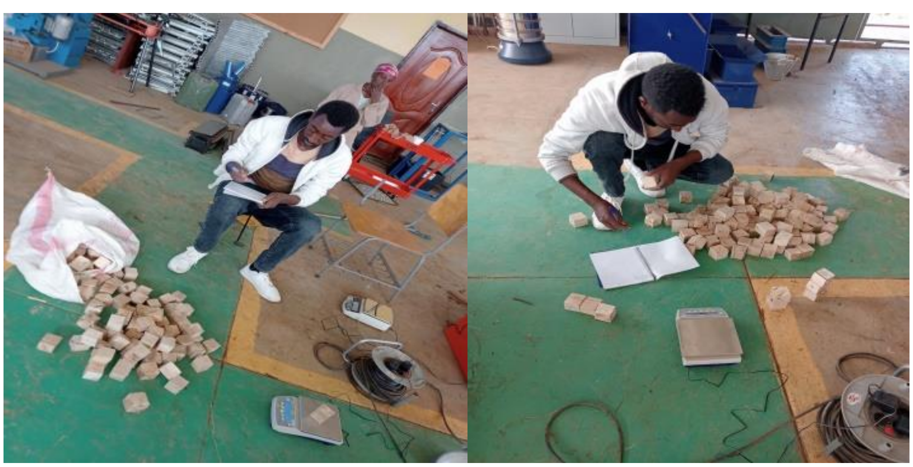

Figure 11: Weighting samples

The basic density of a material refers to its mass per unit volume, typically expressed in kilograms per cubic meter (kg/m³).

$$Oven - dried\ density = \frac{Oven\ dry\ weight\ of\ specimen}{Oven\ dried\ volume}\left[\frac{Kg}{m^3}\right]$$

For gradient basic density and shrinkage determination samples were cut out from each of the disks, as shown in **Fig. 11** and their weights and volume was measured accurately. Thereafter, the samples were put in an oven set at 105 ± 2^0C until they attain constant weight between successive measurements (a difference of 0.005) and their weight and volume were measured again. Wood basic density for each disc was determined as the ratio of oven-dry mass to green volume; while oven dried density was calculated as the ratio of oven dried weight to volume. The density of the disk was calculated from the formula below

$$Basic\ density = \frac{Oven\ dry\ weight\ of\ specimen}{Green\ volume}\left[\frac{Kg}{m^3}\right]$$

3.2.5. Shrinkage measurements

Shrinkage was the loss or reduction in the dimensions of samples. Sample material was taken from the same tree height as given in Table 2 for basic density. The 50 mm thick disks were cut on a circular saw, square to the pith, then parallel to the grain (Figure 12).

Figure 12: Cutting Sample from discs

The shrinkage specimens dimensions was established based on ISO standard and adequacy of disks for multiple specimens at each of the relative positions.

Figure 13: Measuring Anatomical direction

First dimensions of the specimen were measured in a green condition in the three anatomical directions (radial, tangential and longitudinal), figure 13. Following green-condition measurements, the specimens where oven dried at 105±2 ^{0}C for 24 hours, then each of the dimensions for each of the specimens was measured again. Shrinkage in the given anatomical direction was expressed as a percent dimensional loss, based on the original green length/dimension.

3.3. Heart and sap wood proportion

Heartwood and sapwood were measured the different regions of the trunk of a tree, and their proportion. The sapwood was typically lighter in color and higher in moisture content compared to heartwood and heartwood is the inner portion of tree trunk. Measuring all of sapwood and heartwood disc (45 discs) were carried using meters. After that the ratio of heartwood to sapwood was determined.

Figure 14: Measuring sapwood & Heart wood

Generally on each of the disks the heartwood and sapwood was measured and their proportion established.

3.4. Experimental Design and Statistical Analysis

Purposive and random sampling method was used to collect sample stands. Three factors: tree age, tree position and tree diameter, were employed to conduct this experiment. Therefore, to conduct this experiment, the effects of age, tree position and diameter of *E.globulus* tree Species was evaluated. Statistical analysis software, Minitab 17, was used to analyze the data analysis of variance (ANOVA) procedure and Duncan's multiple range taste (DMRT) was used for mean comparison at $p \leq 0.05$ level. All experiments were conducted on triplicate.

CHAPTER FOUR

4. RESULT AND DISCUTION

The *Eucalyptus globulus* collected for this study have three age groups of 10-15 years, 15-20 years and 20-25 years. The trees height varied from 24 to 37 m with diameter at breast height range of 16.7 -31.8 cm. Lemenih and Bekele (2004) in their study on investigating the energy values for selected Eucalyptus species found that the DBH ranged from 17.6 to 23.8 cm and heights of 23 m to 43 m for samples aged from 11-21 years of *Eucalyptus globulus*.

4.1. Moisture content

The moisture content of freshly harvested *E.globulus* trees ranged from 33.8% to 64.4%. The moisture content of the trees significantly varies with age and height position of the at $p < 0.001$. The highest moisture content were recorded in the sample discs of youngest *E.globulus* tree, and the moisture content was higher at the top section of the tree. Thus the moisture content of in the *E.globulus* trees increase significantly from bottom to top and as moved from the pith to the outer side. This phenomenon indicates that the high region of sapwood parts which is active in transportation of wood and nutrients up and down will have high moisture content.

4.2. Basic density variation

The mean basic density of the *Eucalyptus globulus* trees significantly vary with tree age and tree portion from pith to outer. Higher density was observed in the pith and older trees. This indicates that the central part of the tree denser and similarly as the tree gets older and older the density increases that means older trees become richer and richer in heart wood. The basic density of *E.globulus* was not significantly affected by tree height (**Table 3**). The Tukey HSD comparison test for density of the top portion sampled at 70% of the tree stem shows only significantly higher than the rest portion, while other parts of the tree didn’t show a significant difference. There was general increment of basic density with the tree height (Figure 16).The analysis of variance showed that the tree height had significant ($p<0.001$) effects basic density of *E.globulus* wood (**Table 5**).

The basic density of *E. globulus* was significantly affected by age groups (**Table 3**). There were general increment of basic density with the tree age groups (**Figure 15**). On the other hand, in case of both heartwood and sapwood the densities were slightly increased towards the inner parts than the outer part sapwood this means that as the trees get older and older the proportion or formation of heartwood increase as a result the density of the *E.globulus* will increase with the tree age groups (**Figure 16**). The average of basic density of 10-15, 16-20, and 21-25 years old *E. globulus* is [0.842g/m^3, 0.923g/m^3 and 0.984g/m^3], respectively (**Table 3**).

The interaction effect between tree age groups and tree height levels had significant ($p < 0.001$) effect on the basic density (**Table 5**). However, the interaction effect between age group and tree diameter didn't show significant effect on the basic density (**Table 5**). In addition, the interaction effects of all the factors (tree age group, tree height level and tree diameter) didn't show significant effects on the basic density; except it affect the tangential shrinkage at $p<0.05$ level (**Table 5**). Wood density often used as general indicators of the suitability of wood for many purposes, including manufacture products (Uday et al., n.d.2020). The findings reported by (Deng, Zhang, Lei, et al., 2014) revealed that the age of the tree and height of the tree had significant effect on basic density of wood, as change the age of tree density also changes.

The results revealed that basic density significantly increased with an increase of age groups of *E. globulus* tree (**Figure 15**). The Tukey HSD test showed that there were significant differences between 10-15 and 16-20, 10-15 and 21-25 tree age groups; but insignificant difference was observed between 16-20 and 21-25 tree age groups (**Figure 21**). This may noticed that the *Eucalyptus globulus* timber quality is better at the age of $\leq$20 years. In the case of both heartwood and sapwood the mean values of basic density were slightly increased from 10-15 to 16-20 groups and more increased to the tree age groups of 21-25 (**Figure 21**).

Table 3: Mean variations in physical properties of *E. globulus* tree.

Age group	Properties	Tree height level				
		70 cm	DBH	30%	50%	70%
21-25	MC	10.301±0.26	11.83±0.131	12.41±0.38	13.08±0.13	13.73±0.16
	BD	1.00±0.01	0.999±0.015	1.01±0.02	0.990±0.034	1.02±0.033
	TS	6.52±0.03	6.57±0.09	6.72±0.05	6.69±0.05	6.79±0.10
	RS	3.53±0.03	3.67±0.05	3.80±0.05	3.92±0.06	4.11±0.05

	LS	0.48±0.03	0.53±0.03	0.61±0.02	0.64±0.02	0.69±0.02
	VS	10.24±0.05	10.48±0.13	10.81±0.07	10.92±0.08	11.23±0.11
16-20	MC	13.48±0.36	14.46±0.416	15.22±0.25	15.69±0.64	15.99±0.288
	BD	0.897±0.021	0.897±0.010	0.909±0.039	0.924±0.039	0.99±0.011
	TS	6.38±0.04	6.49±0.05	6.67±0.06	6.79±0.04	6.89±0.04
	RS	3.77±0.04	3.90±0.04	4.07±0.05	4.19±0.07	4.40±0.03
	LS	0.40±0.03	0.50±0.03	0.59±0.02	0.66±0.03	0.72±0.03
	VS	10.27±0.07	10.59±0.08	10.99±0.09	11.28±0.11	11.62±0.08
10-15	MC	16.40±0.62	16.73±0.71	18.40±0.61	20.04±1019	21.56±1.36
	BD	0.829±0.028	0.85±0.024	0.818±0.028	0.843±0.029	0.87±0.012
	TS	6.47±0.06	6.63±0.03	6.76±0.06	6.89±0.04	7.02±0.08
	RS	4.20±0.03	4.31±0.03	4.44±0.05	4.52±0.04	4.70±0.06
	LS	0.45±0.03	0.54±0.03	0.63±0.03	0.68±0.02	0.77±0.03
	VS	10.80±0.09	11.14±0.06	11.45±0.11	11.71±0.07	12.07±0.10

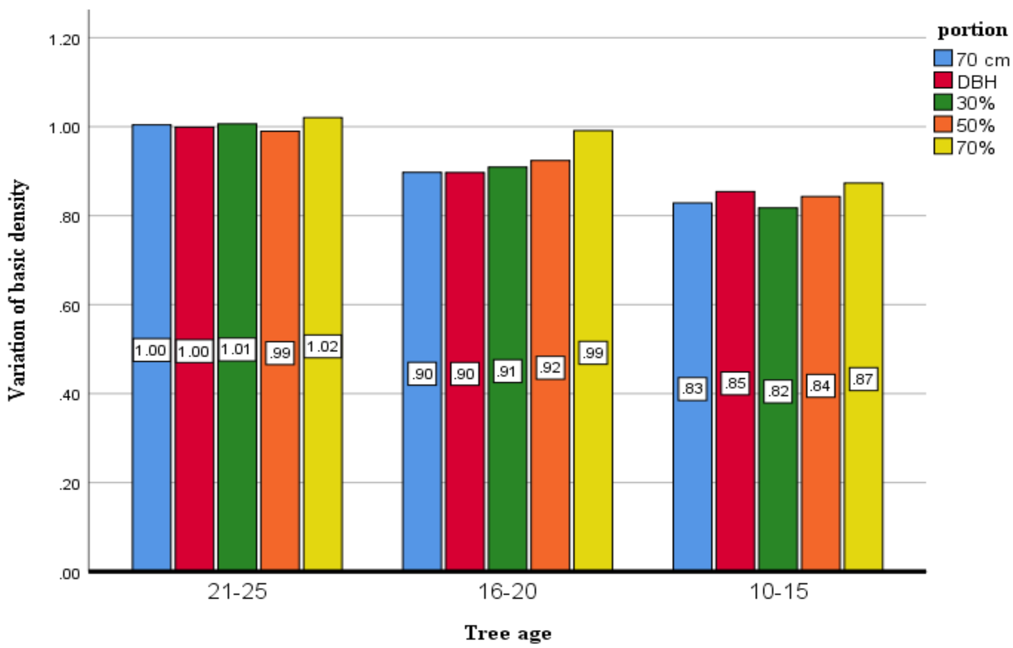

Figure 15: variation of basic density tree age with height

4.3. The heartwood and sapwood

4.3.1. Heartwood and sapwood proportion

The analysis of variance shows that both heartwood and sapwood proportions were significantly affected by the age groups and tree height levels (Table 4). However, the interaction effect between age groups and tree height levels didn't show significant effect (Table 4). The heartwood portion mean value showed an increasing trend with the increment of age; in contrary, the sapwood proportion mean value shows a decreasing trend with the increase of the age groups (Figure 16). A similar study on *Eucalyptus* species, that the sapwood revealed more uniformity (lower index) than heartwood and these results confirm the first impression obtained in this study. Moreover, it can be noted that heartwood had a greater contribution in the index for the entire disk.(Cherelli & Sartori, 2018)

Table 4: Analysis of variance for heartwood and sapwood proportions in *E. globulus*

Source of variation	DF	Mean squares and Statistical significances	
		HWR (%)	SWR (%)
Age group (AG)	2	158.328^{***}	158.328^{***}
Tree height (TH)	4	1304.129^{***}	1304.129^{***}
AGxTH	8	6.264^{ns}	6.264^{ns}

*** statistically significant at P<0.001; ns- not significant

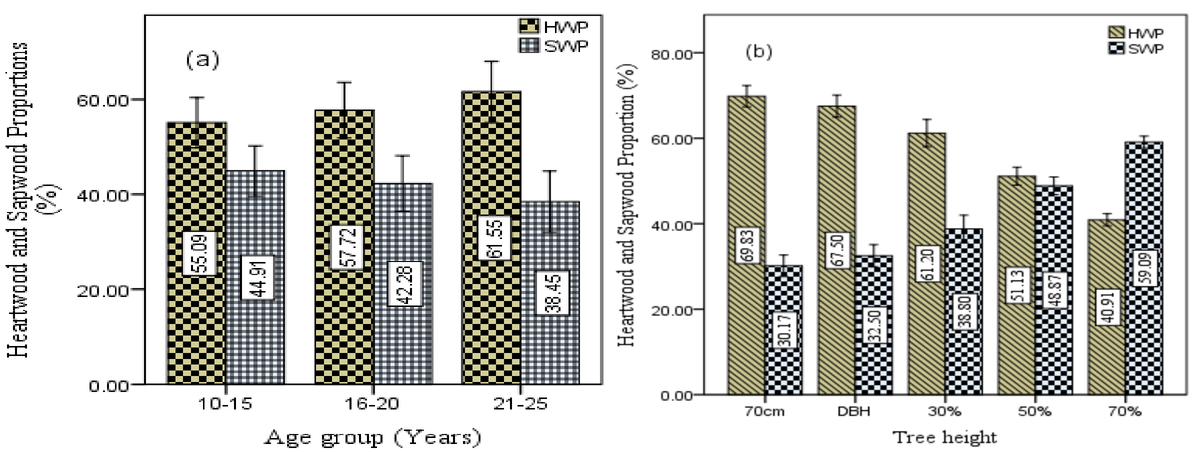

Figure 16: Heartwood and sapwood proportions variations between age groups (a) and along the tree height levels (b)

The proportions of heartwood in the stem along the tree height were decreased within the tree from the base (70cm) to the top (70%) of the tree height for all age groups (**Figure 17a).** While the sapwood proportion were showed an increasing trend from the base (70cm) towards the top (70%) of the tree height levels for all age groups (**Figure 17b**).

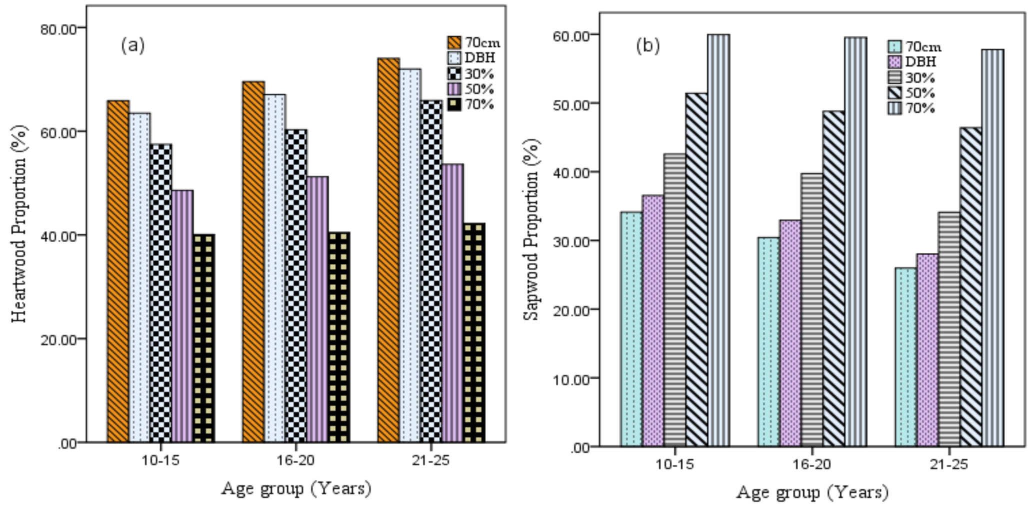

Figure 17: Heartwood (a) and sapwood (b) proportions within each tree height level

4.3.2. Moisture content

The analysis of variance shows that the moisture content (MC) of the sample cubes significantly affected by age groups, tree height level and tree diameter (Table 4). The results show that the MC of the sample decreased with increasing of age groups and tree height levels from the tip to the base of the tree (J. Wood et al., 2019).

The results show that the mean values of moisture content in the samples vary between heartwood and sapwood samples. In case of all age groups and tree heights levels the MC in sapwood was higher than in the heartwood parts. Heartwood is more resistant to moisture flow and is less permeable than sapwood (Rahimi et al., 2022)

The moisture of *E. globulus* were significantly affected by tree height and age (Table 4). There was general increment of moisture with the tree height. (Figure18). That means, moisture was increased in line with the increase of the tree height. There was general increment of moisture with the tree height (Figure 18). That means, moisture was decreased in line with the increase of the tree age (Figure 19).

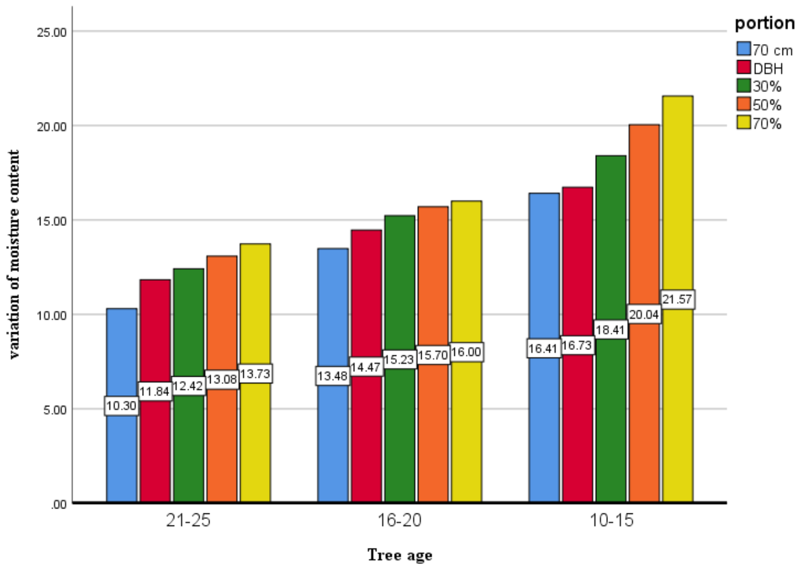

Figure 18: Variation of Moisture content between age with tree height

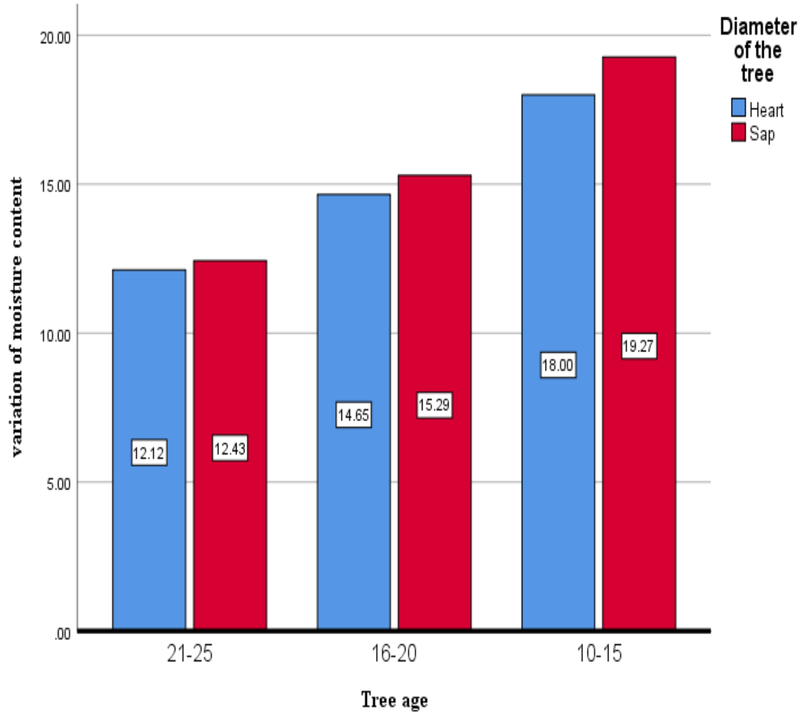

Figure 19: Variation of Moisture content between tree age

4.3.3. Basic density

The analysis of variance showed that basic density significantly ($p<0.001$) affected by tree age and tree diameter (heartwood and sapwood) of *E. globulus* (**Table 5**). However, the interaction effect between tree height and tree diameter didn't show significant effect on the basic density (**Table 5**).

Generally, for the age group 10-15 years the mean value of basic density was increased from the base (70cm) to the DBH and decreased 30% then increase from 50% the top of (70%) of the tree height levels. And for the tree age group (16-20), the basic density mean value was decreased from the base (70cm) to the DBH then increased from 30% to the top (70%) the tree height level (Table 4). While the third tree age group (21-25) was decreased from the base (70cm) to DBH then increased 30% after that decreased 50% finally increased the top of (70%) the tree height level (Table 3). Similarly, WD was significantly influenced by relative heights, tree age, and social class.(Deng, Zhang, & Lei, 2014)

The Tukey HSD mean comparison, the heartwood part showed significantly higher basic density than the sapwood part (**Figure 20**). The mean values of basic density obtained in heartwood for age groups 10-15, 16-20 and 21-25 were [0.829g/cm^3, 0.92g/cm^3 and 1.01g/cm^3], respectively (**Figure 21**). While the mean values of basic density obtained in sapwood for age groups 10-15, 16-20 and 21-25 were 0.82g/cm^3, 0.92g/cm^3 and 1.0g/cm^3, respectively (**Figure 21**)

Table 5: Analysis of variance for Physical properties in *E. globulus* at different age, tree height and tree diameter

Source of variation	Dependent Variable	Sum of Squares	df	Mean Square	F-value	P-value
Age group	moisture content	109.704	2	54.852	512.455	000
	Basic density	.007	2	.004	525.058	.000
	Tangential shrinkage	.410	2	.205	81.658	.000
	Radial shrinkage	11.844	2	5.922	4201.852	.000
	Longitudinal shrinkage	.052	2	.026	54.307	.000
	Volumetric shrinkage	15.103	2	7.551	1804.319	.000
Treeheight	moisture content	106.771	4	26.693	249.377	.000
	Basic density	.007	4	.002	258.073	.000
	Tangential shrinkage	4.454	4	1.113	443.251	.000
	Radial shrinkage	6.942	4	1.735	1231.379	.000

	Longitud. shrinkage	1.816	4	.454	950.555	.000
	Volumetric shrinkage	31.893	4	7.973	1905.072	.000
Tree diameter	moisture content	6.151	1	6.151	57.461	.000
	Basic density	.000	1	.000	57.865	.000
	Tangential shrinkage	.125	1	.125	49.582	.000
	Radial shrinkage	.097	1	.097	68.512	.000
	Longitud. shrinkage	.037	1	.037	78.442	.000
	Volumetric shrinkage	.644	1	.644	153.972	.000
Agegroup * Treeheight	moisture content	16.146	8	2.018	18.855	.000
	Basic density	.001	8	.000	18.215	.000
	Tangential shrinkage	.405	8	.051	20.156	.000
	Radial shrinkage	.074	8	.009	6.538	.000
	Longitud. shrinkage	.051	8	.006	13.289	.000
	Volumetric shrinkage	.652	8	.082	19.475	.000
Age group * Tree diameter	moisture content	2.573	2	1.287	12.019	.000
	Basic density	.000	2	7.825E-5	11.332	.000
	Tangential shrinkage	9.341E-5	2	4.670E-5	.019	.982
	Radial shrinkage	.000	2	.000	.167	.846
	Longitud. shrinkage	.002	2	.001	1.661	.193
	Volumetric shrinkage	.000	2	.000	.041	.960
Treeheight * Treediameter	moisture content	1.195	4	.299	2.790	.028
	Basic density	7.107E-5	4	1.777E-5	2.573	.040
	Tangential shrinkage	.028	4	.007	2.741	.031
	Radial shrinkage	.030	4	.008	5.352	.000
	Longitud. shrinkage	.002	4	.000	1.043	387
	Volumetric shrinkage	.011	4	.003	.670	614
Agegroup * Treeheight * Treediameter	moisture content	2.105	8	.263	2.458	.016
	Basic density	.000	8	1.604E-5	2.322	022
	Tangential shrinkage	.019	8	.002	.949	478

	Radial shrinkage	.011	8	.001	.984	450
	Longitud. shrinkage	.006	8	.001	1.651	115
	Volumetric shrinkage	.031	8	.004	.932	492

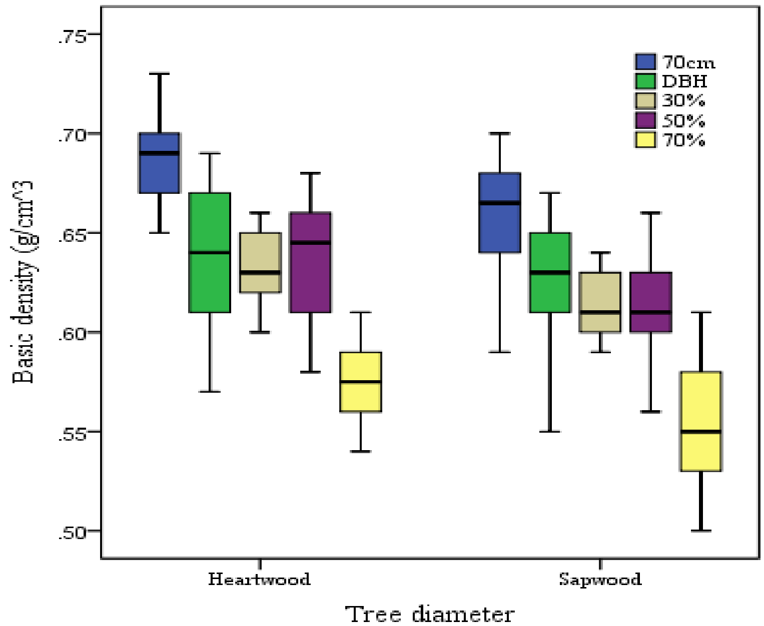

Figure 20: Basic density in heartwood and sapwood along the tree height levels of *E. globulus*

The basic density in both cases of the heartwood and sapwood parts data values at the base (70cm) different from the top (70%) part of *E. globulus* tree (Figure 20). This may be due to maturity at base and juvenility at top of the tree. The wood basic density was determined by the mass weighing method and the indirect volume measurement (Cremonez et al., 2019).

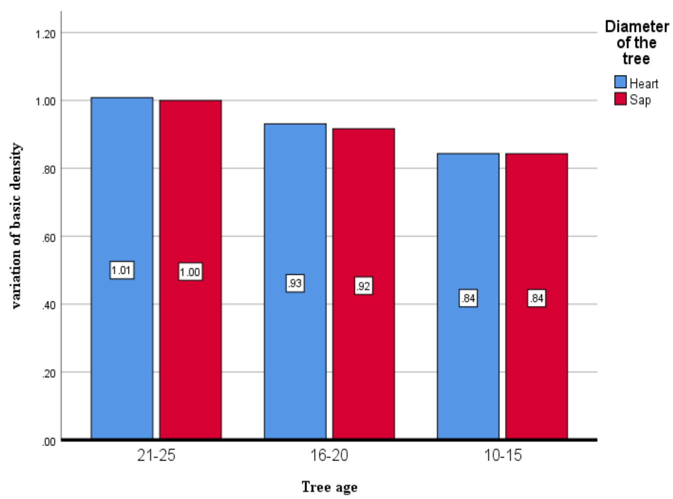

Figure 21: Variation of basic density tree age with diameter

4.4. Shrinkages

The analysis of variance shows that the age group had significant effect on TS, RS, LS and VS of *E. globulus* wood (**Table 5**). The interaction effect between age group and tree height had significantly affected TS, RS, LS and VS (**Table 5).** On the other hand, the interaction effect between age group and tree diameter effects on TS and VS; but not effects on RS and LS. The interactions of all factors age group, tree height and tree diameter didn't show significant effects on TS, RS, LS and VS of *E. globulus* wood. Similar study revealed that all shrinkage values were determined from the ratio of change in dimension from the swollen condition to oven-dry condition to swollen dimension(Shupe et al., 1998). The results also revealed that in case of both heartwood and sapwood the mean values of TS, RS, LS and VS were decreased with the increase of age of the tree (**Figure 22a, 22b, 22c, 22d)**. This might be associated with the formation of more heartwood which is low in its moisture content. The percentage values of TS for age groups of 10-15, 16-20 and 21-25 were 6.76%, 6.64% and 6.66% respectively: for RS were 4.43%, 4.07 and 3.80%, and for LS there were 0.59, 0.58 and 0.62, respectively. For VS of 10-15, 16-20 and 21-25 were 11.44, 10.96 and 10.74, respectively (**Figure22**). Generally, the percentage values of TS, RS, LS and VS were decreased as the increase of age groups of the tree. The result shows that the tree height level and tree diameter had significant ($p < 0.001$) effects on TS, RS, LS and VS of *E. globulus* wood (**Table 5**). Table 5 also showed that the interaction effect between tree height and tree age group had significant ($p < 0.001$) effects on TS, RS, LS and VS. The interaction effect between tree diameter and age group tree had only significant ($p < 0.05$) effect on TS but not on RS, LS and VS (**Table 5**) Similarly, the related findings reported that the interaction effects between tree height and tree diameter didn't show significant effects on TS, RS, LS and VS. On the other hand, the interactions of all the study factors tree height, tree age group and tree diameter didn't show significant effects on TS, LS and VS; but significant effect on RS. Wood normally shrinks as the MC decreases from the FSP, but for wood prone to collapse, it shrinks even when the MC is above the FSP(E. G. Wood, 2022).

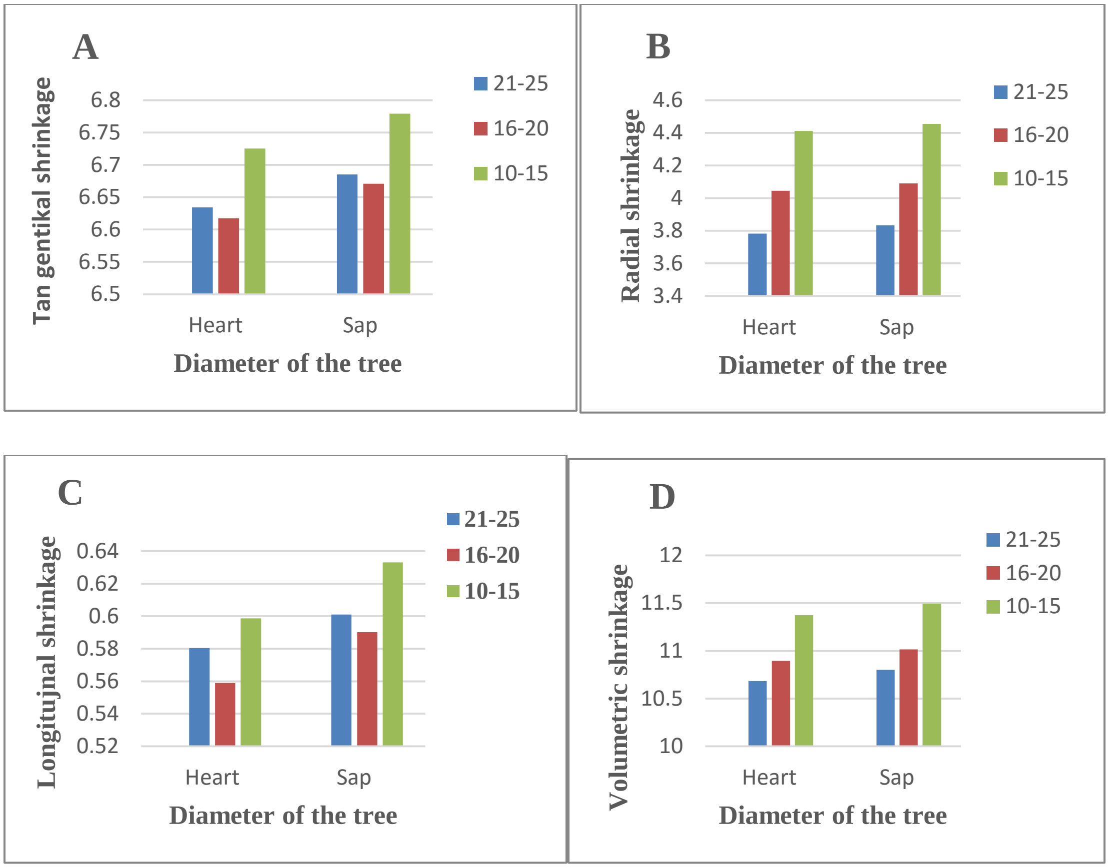

Figure 22: Variation of shrinkages; (A) Tangential, (B) Radial, (C) Longitudinal and (D) Volumetric

The results indicate that the TS, RS, LS and VS percentage values showed increasing trend from the base to the top for both heartwood and sapwood parts of *E. globulus* tree (**Figure 23).**his result shows that the tree age and height have significant effect on shrinkage characteristics. A similar study revealed that the ratio of tangential to radial shrinkage (T/R ratio) of all species was more than 1.6 (figure 23) (Listyanto et al., 2020). According the findings of Listyanto et al (2020) this result might be due to the hygro-expansion coefficient of tangential shrinkage which is usually greater than twice that of the coefficient of radial shrinkage. This may be a function of fibril arrangement, especially the thickness of the S2 layer. Less shrinkage in the radial direction has been proposed to be due to the greater microfibril angle in radial walls than in tangential and a high proportion of latewood, which forces weak earlywood to shrink more tangentially than independently of the latewood. In general, the variation in shrinkages of the *Eucalyptus globulus* wood increase from base to top of the tree (Figure 23) This again associated with the variation in wood moisture content as discussed in the previous moisture section.

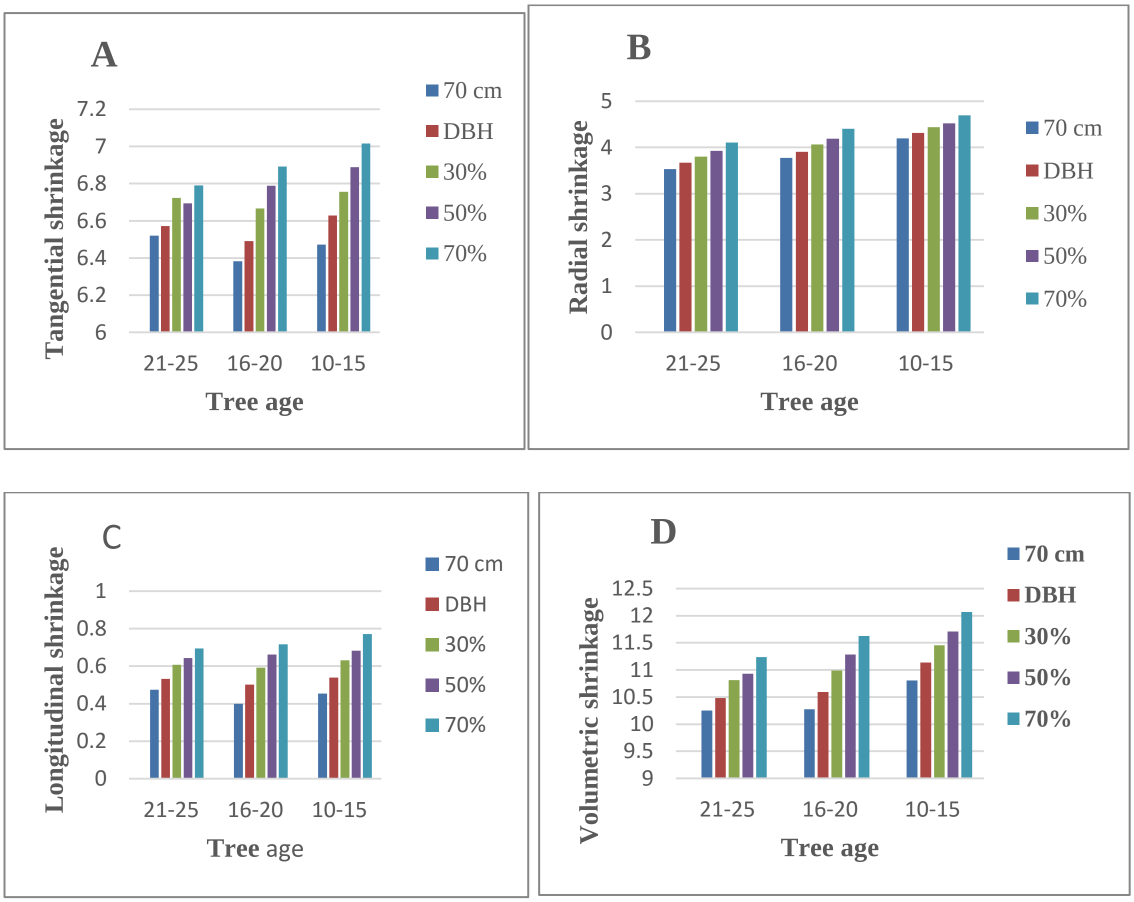

Figure 23: variation of shrinkage; (A) Tangential, (B) Radial, (C) Longitudinal and (D) volumetric

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

Density was the mass of a material per unit volume typically expressed in units like grams per cubic centimeter (g/cm^3) or kilograms per cubic meter (kg/m^3), indicating the mass of the material per unit volume. Oven dry density was the density of wood when it has been completely dried in an oven to remove all moisture from the samples of wood. To measure the oven dry density of a wood sample, you can follow the process Calculate the green density by dividing the weight of the sample by its volume and the volume of the wood sample based on its dimensions. Shrinkage, on the other hand, is often expressed as a percentage, representing the change in dimension or volume relative to the original size. Shrinkage, on the reduction in size or volume of samples the dimensional changes that occur when the wood loses moisture. Measure the radial, tangential, and longitudinal shrinkage, expressed as a percentage of the original dimensions. Measure the moisture content of the wood sample was represents the amount of water present in the wood. Heartwood and sapwood are different regions within the trunk of a tree, and their proportion can vary depending on the tree age categories (10-15 year age, 15-20 year age and 20-25 year age) Sapwood is typically lighter in color and higher moisture content compared to heartwood. Heartwood is the inner central portion of the tree trunk usually darker in color. It has a lower moisture content compared to sapwood.

5.2 Recommendations

The study of *E.globulus* is not replicated in provenance or geographical locations due to the time and budget limitation. Therefore, similar study required to be replicated in location. From this point of view the following recommendations forwarded:

- Study the variability of mechanical properties of the *E.globulus* in age, and height
- Other eucalyptus species to be researched in similar way.

Study in reduction of seasoning defects.

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