FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

FACULTY OF CIVIL TECHNOLOGY

MSc. DEGREE IN WOOD TECHNOLOGY

THESIS SUBMITTED ON

BASIC DENSITY AND PHYSICAL PROPERTIES MAPPING OF *CUPRESSUS LUSITANICA* GROWN IN THE SHENEN AREA

FOR THE FULFILLMENT OF MASTER OF SCIENCE IN WOOD TECHNOLOGY

BY

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AUGUST, 2024

ADDIS ABABA, ETHIOPIA

APPROVAL SHEET

This is to certify that the thesis prepared by Getu Turi, entitled “Basic Density and Physical Property Mapping of *Cupress lusitanica* Grown in the Shenen Area” Submitted in partial fulfillment of the requirements for Master of Science in Wood Technology, complies with the regulations of the FDRE TVTI that meets the accepted standards with respect to concerning the originality and quality.

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CERTIFICATION SHEET

I hereby certify that read and evaluate this thesis prepared under my guidance by **GETU TURI** entitled, “Basic Density, and Physical Property Mapping of *Cupress lusitanica* Grown in the Shenen Area, West Shoa Zone, Oromia, Ethiopia”, I recommend that it be submitted as fulfilling the thesis requirement.

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As mentioned of the Board of Examiners of the MA. Thesis open defense examined. We certified that was have read and evaluated the thesis prepared by Getu Turi and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirements for the degree of master of Art in Wood Technology.

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ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude to my Almighty God for His good care and exceptional help in bringing me to this stage.

Secondly, I would like to thank Oromia Job Creation and Skill Bureau for taking advantage of the free opportunity to teach in MA at the FDRE Technical and Vocational Training Institute without any payment.

I am grateful to my advisor, Dr. Anteneh Tesfaye, who guided me throughout this research work by providing valuable comments, support, and thoughtful guidance, and for the unexpected support, professional expertise, and abundant advice I received from the beginning of this work until the fulfillment of it.

I would also like to express my appreciation and love to my wife, Demitu Tolesa Oweta, and my brother, Gudisa Turi Mirkena, for their moral, financial, and material support during my studies.

My special thanks also go to my friends Tadese Sirna, Dinaol Tamune, Birhanu Dabasa, Wosane Ketema, and all the others who helped me during the field work.

Finally, without the encouragement and support of Jibat TVET College, Shenen Primary School, Ambo Poly Technique College, and the Forest Products Innovation Centre of Excellence Ethiopian Forestry Development, all my studies could not have started. So, God bless them for their assistance during the data collection.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS

Amh	Amhara
ANOVA	Analysis of variance
C.	*Cupressus (Cupress)*
CDRW	Computer disc re-write
CM^3	Centimeter cube
DBH	Diameter at breast height
DMRT	Duncan's multiple range test
E.	*Eucalyptus*
GMC	Equilibrium moisture content
GPS	Geographical information system
Ha	Hectare
Kg	Kilogram
M^3	Meter cube
MC	Moisture content
MCf	Final moisture content
MM	Millimeter
Or.	Oromoo
RCD	Relative crown depth
RCW	Relative crown width
W/L	Width/length
TS	Tangential shrinkage
RS	Radial shrinkage
LS	Longitudinal shrinkage
VS	Volumetric shrinkage
SD	Standard deviation
OD	Oven-dry density,
BD	Basic density
HWP	Proportions of heartwood
SWP	Proportions of sapwood

ABSTRACT

This study explores the importance of wood density as a predictor of various wood properties, particularly in light of the inherent variability within and between wood species. While wood exhibits remarkable variability, density consistently emerges as a crucial characteristic influencing a wide range of properties. The research examines how density impacts mechanical strength, shrinkage, and even energy production, highlighting its significance for diverse wood applications. The general objective of the graduate research was to map basic density and oven-dried density and explore their relationship to the diameter at breast height (DBH) and basic properties of Cupressus lustanica wood grown in the Shenen area. The method showed the shrinkage specimen's dimensions were established based on ASTM D143-94 and the standard and adequacy of discs for multiple specimens at each of the relative positions. Using a digital Vernier caliper in green condition, the specimen's initial dimensions were measured in the three anatomical directions (radial, tangential, and longitudinal). A purposeful sampling method was used to select sample stands. Three factors, which are age (15, 20, and 25), 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 the C. lusitanica tree species were evaluated. The results showed that tree age groups, tree height level, and tree diameter (heart and sapwood) had significant ($p < 0.001$) effects on green moisture content, densities, tangential, radial, longitudinal, and volumetric shrinkages. Green moisture content, densities, tangential, radial, longitudinal, and volumetric shrinkages show a decreasing trend from the base (DBH) towards the top tree height levels (90%) for all three tree age groups. The results indicated that there was difference on oven-dry and basic density from inward to outward diameter of 15 - 20 years, 21- 25 years and > 25 years of C. lustanica. Accordingly, there was a decrease of oven-dry and basic density of C. lustanica from based on distance from pith towards bark in centimeter from 1 cm, 3 cm, 5 cm, 7 cm, 9 cm, 11 cm and 13 cm. Generally, tree age, tree height, and tree diameter (heartwood and sapwood) influence the quality of C. lustanica wood. Based on the results harvested at 15 – 20 years old and > 25 years old of age, it was recommendable for the species to obtain the best lumber quality.

Keywords: *Cupressus lustanica, density, sapwood-heartwood proportions, shrinkage, tree age group, tree height level*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

We always want to estimate or predict as many properties of wood as possible from a single variable that can easily be measured. This type of magic is easy and possible for homogeneous materials, to which wood hardly belongs. Wood is an amazing material that can be used to create a wide range of items due to its flexibility and diversity(Zobel & van Buijtenen, 1989). The variability exists between species, within species, in a given stand, and even in the same tree along the height and across the stem from pith to bark (Bamber & Morrison, 1983). While wood's inherent diversity makes it very useful, it also poses a significant obstacle to the effective use of wood as a raw material (Rowell, 2005). Thus, the variability of wood is not only one of its attractions but is also the reason why we will never be able to precisely predict its performance.

The characteristics of wood also depend on one another within this diversity. Certain important properties may have a stronger influence on many other properties. One of the wood's few essential characteristics is its density. It is frequently possible to evaluate the performance of the item it represents or the type of finished product that will be made from it by using wood density, or specific gravity. For instance,(Zobel and van Buijtenen, 1989) found in their book that the modulus of rupture will change by approximately 1000 Kg/m^3 for every 0.02 change in specific gravity. (Zobel & van Buijtenen, 1989) go on to clarify in the same book that a change of 0.02 in specific gravity results in a change of 100 pounds in the dry weight of a cord of pulpwood, or around 50 pounds of pulp. They also emphasized the relationship between specific gravity and the strength and quality of solid wood products, which are particularly significant in sawn wood. They also demonstrated how the specific gravity of wood affects its energy production.

Citing (Zobel and van Buijtenen, 1989, Polge and Keller (1970), demonstrated similarly that mechanical strength and shrinkage are positively connected with the density of oak in Europe, one of the most significant hardwood species for the industry. It was discovered that specific gravity and knottiness were the decisive elements in selection for strength in the softwood species spruce (*Picea abies*). They said that bending strength tests conducted in Queensland on boards derived from four Australian exotic pine species demonstrated the significance of specific gravity. After conducting a thorough analysis, Zobel and van Buijtenen, (1989) also showed that the most important element influencing the tensile strength of *Douglas-fir* (*Pseudotsuga menzies*) was its specific gravity. They also found that basic density was most likely the most common inherent wood feature for most of the objects.

Niklas (1997) demonstrated a strong relationship between the density of the green heartwood of the Black locust (Robinia pseudoacacia) and its mechanical characteristics. It was also discovered that there was a strong correlation between the mechanical characteristics and the wood samples' specific gravity. Based on these findings, he concluded that, in the absence of comprehensive mechanical testing, the mechanical properties of Black locust wood can be estimated using either the density of fresh wood or the specific gravity of air-dried wood using straightforward regression curves. Niklas (1997) demonstrated how the accuracy of predicting other attributes based on density magnitudes depends on the moisture content.

In a similar vein, (Vieilledent *et al*., 2018), explain the problem with this moisture dependence by stating that wood density has always been determined using 12% moisture. However, it makes more ecological sense to interpret the 12% magnitude as the basic wood density (basic density), or the dry mass to green volume ratio (oven - dry density). They claim that the benefit of doing this is that by obtaining a fundamental wood density, you may determine the volume of dried biomass from living trees. They showed how a straight forward linear proportionate equation may be used to derive basic density given 12% moisture content.

Similar to this, the most recent National Forest Inventory of Ethiopia estimated above-ground biomass using DBH along with measured basic density and its approximations (MEFCC, 2018). There are several industrially significant timber species in Ethiopia whose specific gravity and density can be utilized as predictors due to their similar variability in characteristics. According to research, *Cupressus (Cupress)* is the leading softwood, and *Eucalyptus globulus* and *Eucalyptus camaldulensis* are the most commonly used hardwood timber species for industrial purposes (Getachew Desalegn, *et al*, 2012). Bekele, (2015), stated the species that are contributing to Ethiopia's wood industry, eucalyptus has the largest proportion (45%) in spatial extent, followed by cypress (41%). Another study, the National Forest Inventory of MEFCC (2018), lists the 30 most abundant species in terms of tree species occurrence frequency and abundance of stem volume in the entire timber species of Ethiopia. In this study, *E. camaldulensis* ranked 10th (3.7%), while *E. globulus* was placed 12th (3.1%) among the 30 most abundant tree species by frequency of occurrence in Ethiopia. *Cupressus (Cypresses)* was placed 26th (1.5%) in the same ranking order, being the only one among the exotic and introduced softwood timber species recognized for its significant contribution to both ecological and economic values.

E. grandis and *E. saligna* are two of the other most industrially utilized species currently. Plantation inventory data of the Oromiya Forest and Wild Life Enterprise (OFWE*)* indicated that *C. lustanica, E. globulus,* a group of *Eucalyptus* species, *E. camaldulensis*, *Pinus patula*, *E. saligna,* and *E. grandis* have timber volume shares of 47, 18, 13, 9, 4, 3, and 2%, respectively. The percentage distribution of timber volume among the industrially important species follows the same trend in the Amhara Regional State.

Studies unequivocally showed that *Eucalyptus* species exhibit a high degree of variety. A study carried out by (Githiomi & Kariuki, 2010) examined the relationship between age, height, and the difference in wood basic density between sapwood and heartwood of *E. grandis* harvested from plantations in Kenya's Central Rift Valley. The study, which involved 4–10-year-old *E. grandis,* found that age and tree height had a substantial impact on basic density. A similar study was carried out by (Miranda *et al*., 2001) to look into variability in the density of *E. globulus*. The wood density of *E. globulus* was measured as a basic density in 7-year-old trees from 37 provenances grown in three sites on cores taken at breast height, and it was found that the wood density was highly significantly influenced by provenance and very significantly by the site. The fluctuation of wood and bark density and production in coppiced *E. globulus* trees in a second rotation was examined once more in a recent study (Miranda and Pereira, 2016). The wood of the coppiced *E. globulus* trees was found to have an average density of 582 kg/m^3, which was 2.5% lower than that of the single-stem trees in the first rotation. They discovered that within the tree, the wood density continuously grew until it reached 11.3 m, after which it significantly reduced from stump level to breast height level. Therefore, in addition to age and position along the height, there is variation dependent on the type of coppice. For certain qualities, these changes may exhibit scale-dependent behavior; yet, for others, the only way to uncover this scale dependency or invariance is by doing scientific research and gathering empirical data for each significant timber species. One of the industrially significant timber species, *C. lustanica*, for which research on the relevance and validity of dependence and invariance has not yet been completed, Ethiopia. To utilize the basic density (which is defined as mass per unit volume), it has the SI unit kg/m^3 and is an absolute quantity) and specific gravity (the ratio of a material's density with that of water at 4 °C (where it is most dense) and is taken to have the value 1 kg/m$^{3)}$. It is therefore a relative quantity with no units. In this case, density and specific gravity are numerically equal for *C. lustanica* in the prediction and estimation of other significant wood qualities of the species. It is required to record all the variability that exist in these parameters during an exploratory density survey(Zobel & van Buijtenen, 1989; Koddenberg, 2016).

1.2. Statement of the problem

Parallel to the existence of variability, there are also universal or scale-invariant properties that relate some parts of a tree to others or some properties of wood to others. Allometry is a universal relationship that connects properties such as DBH with above-ground biomass, DBH with crown size, and basic density with tree height and crown size. António *et al.*, (2007) showed that the predictive ability of allometric models significantly increases when tree height and crown length (crown components) are incorporated in addition to DBH in a study involving *E. globulus*. They are also able to show a clear effect of the stage of development of tree stands on allometric relations in a tree. Consequently, allometry can be employed to find a universal relationship existing between the basic density and various properties of the wood of *C. lustanica* obtained from selected locations along the height and transversally from pith to bark. However, such dependencies can also be scale-dependent and may not be universal, like allomeric relations, which can only be revealed through empirical relations. Therefore, it is indispensable to investigate the existence of such scale dependency or allometric scale invariance for *C. lustanica* to alleviate the uncertainty emanating from the variability of properties that can affect ecological assessments and management strategies António *et al.,* (2007).

1.3. Objectives of the study

3.1.1. General objective

The general objective of the graduate research was to map basic density and oven-dried density and explore their relationship to the diameter at breast height (DBH) and crown biomass to looking into the possibility of forecasting other basic properties of *C. lustanica* wood grown in the Shenen area.

3.1.2. Specific objectives

- To map the density of a stem of the *C. lustanica* wood along the height
- To map the ratio of heartwood to sapwood and the moisture content of *C. lustanica*
- To investigate the density variation across the diameter
- To map longitudinal, tangential, radial and volumetric shrinkage along tree height and across locations

1.4. Research questions

This study will answer the following questions:-

- How does basic density vary from pith to bark?
- How does the ratio of heartwood to sapwood relate to their respective moisture content in *C. lustanica?*
- What are the key factors that influence the variation in density across the diameter of a tree?
- How does longitudinal, tangential, radial and volumetric shrinkage vary along tree height and across different locations?

1.5. Scope of the study

Scope of the study Shenen, area, West Shoa, is located approximately 200 km west of the capital city of Addis Ababa. The study was conducted on *C. lustanica* wood between tree age 15-20, 21-25, and >25 years old, grown in the Shenen area. The study aims to provide a detailed understanding of the wood characteristics, which refer to various properties and features that define the structure, appearance, and performance of wood as a material, focusing on density, basic density map, moisture content, DBH, *cypress* species, oven-dried density, and shrinkage (tangential, radial, and longitudinal) attributes. This research involved fieldwork, data collection, and analysis to generate a comprehensive mapping of these properties across the specified geographical region. The research was conducted by felling nine selected *C. lustanica* trees and taking 45 sample discs, which were covered with plastic bags, taken to the Forest Products Innovation Centre of Excellence of Ethiopian Forestry Development, and introduced to the laboratory in an oven-dry machine. A density map was prepared from the laboratory results. The main purpose of this study was to determine the basic density and physical property (refers to a characteristic of a substance that can be observed or measured without changing its chemical composition) mapping of *C. lustanica* grown in the Shenen area.

1.6. Significance of the study

The study will help forest (wood) researchers and future generations as reference to conduct similar research on other species and areas. Density is a key indicator of wood quality and can influence its mechanical properties. Basic density is a specific type of density measurement used in the wood industry. It helps assess wood quality, with a higher basic density often indicating better mechanical properties. It is particularly useful for predicting the strength and stiffness of wood. *Cupressus* species *(cupress)* are important in the timber industry. Different species may have varying wood properties, including density and durability. Understanding these species helps in selecting the right wood (types of wood or species) for specific applications. Generally, this study is essential in the assessment, selection, and utilization of wood in various industries. It helps (providers or stakeholders) in predicting wood behaviour, ensuring quality in manufacturing processes, and making informed decisions in forestry and timber management.

1.7. Limitation of the study

One of the limitations of the study are Jibat district, Shenen town, west Shoa zone, and Oromia Regional State was the security situation in the study area was very dangerous. The researcher got the trees without payment from the Jibat district agriculture office, but in a security situation, the researcher didn’t use them. The limitation of the study was the scarcity of chain saws. In the case of the chainsaw, the researcher used a two-man saw. It was very hard work, and the researcher lost much energy. The second limitation in this study was that one of the trees the researcher bought for the study was mostly eaten by fungi, consuming from 40% to 90% of the tree height, and the researcher bought another one and replaced it.

The biggest obstacle to the researcher studies was a lack of funds. The researcher time was short and it's going to be summer. The researcher started working with own money, and the researcher had a lot of trouble running out of money. Especially the daily labor and other charges ate the Forest Products Innovation Centre of Excellence to conduct tests entail much expenses.

CHAPTER TWO

LITERATURE REVIEW

2.1. Description of *Cupressus lusitanica*

In Ethiopia, *C. lustanica* is one of the most commonly planted tree species, after *Eucalyptus*. Lumber from the *C. lustanica* species, which is mostly used for construction, furniture, poles, and posts, is produced by most sawmills. Light flooring, ship and boat building, auto bodywork, interior trim, joinery, toys and novelty items, boxes and crates, drainage boards, veneer and plywood, hardboard, and particle board are some other applications for it. Whether used with hand tools or machinery, this kind of wood saw is user-friendly and performs effectively (Rawat and Tekleyohannes, 2021).

Wood is a hygroscopic material, and its MC is equilibrium with its surroundings in the final use. For timber that shall be used in a dry indoor climate, this implies around 8% MC, and for timber used in constructions around 18% MC. It is also well known that wood shrinks when it dries to MC below the fiber saturation point and that the shrinkage is anisotropic (Vikberg and Elustondo, 2016).

Timber's physical and chemical properties vary depending on the species, place, and tree stand characteristics. They also alter as trees age and stands develop. Compared to softwood species, hardwood species have a substantially higher wood density. Wood fiber characteristics have been demonstrated to be influenced by a number of factors at the tree scale, including knot size, type, and location; crown development; branch size and placement; stem diameter; ring width; and cambial age of the wood (Van Leeuwen *et al.*, 2011).

Cypress wood is prized for its inherent durability, stability, and beautiful grain. Its wood-density gradient is comparatively constant when compared to other species (Todoroki *et al.*, 2015).

C. lustanica is a variable species growing naturally in Mexico and several other Central American countries where it is widely distributed to altitudes of 1000- 2000 m, usually on moist slopes or near streams (Nocetti *et al.*, 2017).

According to Maclaren, (2004), numerous species and cultivars of *Cupress* seem to have commercial potential. The most well-known are *C. macrocarpa, C. lustanica,* and *Leyland's*.

C. lustanica, sometimes called cedro blanco, is a *Cupress* from northern Central America and Mexico. It was introduced en masse in Costa Rica in the 1980s for use in erosion control, windbreaks, and lumber plantations and has quickly become a staple part of the national landscape. Despite its non-native status, the *Cupress* has also made its way into reforestation and conservation efforts due to its hardiness as a pioneer species and quick time to grow to maturity (Meter, 2016).

Compared to native species, the tree develops more quickly. It, therefore, greatly benefits the nation's economy and society. Additionally, it is superior to other exotics in the same family, such as; the canker-prone *C. macrocarpa*. In the Kenyan highlands, this tree grows at a pace of 18 cubic meters per hectare annually. The wood is simple to deal with in both hand and machine tools. It polishes, stains, and nails with ease (Ishengoma *et al.*, 1994).

With that in mind, should the *Cupress* have any detrimental effect on the environment or potential for invasiveness, it would be sensible to remove them. One of the forest's commercial wood tree species, *C. lustanica* is a significant supplier of raw materials to the forest products sector. Accurate models for tree and stand development are necessary for intensive forest management to produce timber (Getachew Desalegn *et al*., 2012; Tsega *et al*., 2019).

The timber of *C. lustanica* can be considered medium-density structural and general purpose. It has high dimensional stability and is suitable for special solid end-uses, having the finest grain between conifers which delivers high-quality finishing, being also naturally resistant to fungal decay and insects, which implies 10-15 years of ground life for heartwood and well over 15 years for above ground uses. Beyond the high-quality timber, the species is fast-growing and relatively resistant to canker (Dobner, 2021).

One of the forest's commercial wood tree species, *C. lustanica*, provides a significant supply of raw materials for the forest products sector (Tsega *et al*., 2019). In locations not suitable for agriculture, *Cupress* is planted in plantations to yield very high-quality wood that is widely used in shipbuilding, joinery, furniture, and building construction, primarily for roofing poles (Hashemi and Kord, 2011).

2.2. Height and other Properties of *Cupressus lustanica*

The height of *C. lustanica* trees is 35 – 40 meters. In older trees, the crown has pendulous branches and is broad and pyramidal. Thick, reddish-brown bark features longitudinal cracks. The pendulous, quadrangular shoots flatten the sprays of leaves. The foliage typically has a tall, pointed apex and is blue-green, four-ranked, oval, and tightly compressed. Cones are globose, about 12 mm across, blue-green when young, turning dark brown when ripe, opening, and falling later. They are made up of 6–8 scales with a prominent, reflexed umbo in the center that is erect on the upper scales. Around 75 brown seeds form a cone shape, and each seed has a slender wing and a resin gland that is about 4 mm long (Bato *et al*., 2020).

2.3. Basic Density of *Cupressus lustanica*

Based on the most widely used wood basic density measure, which is calculated as the weight of any given volume of a substance divided by the weight of an identical volume of water, the basic density of *C. lustanica* was ascertained from fresh samples (Eba *et al.*, 2017).

Basic density refers to the mass of wood per unit volume when measured in its green state, which includes moisture content. It helps evaluate how much moisture the wood can hold and its general structural properties, also known as specific gravity (a ratio that compares the density of a material (like wood) to the density of water). It gives a measure of how heavy the material is relative to water, indicating its buoyancy and potential applications) or oven-dry density (the density of wood after it has been completely dried of moisture, meaning no water remains in it). This measurement is crucial for understanding the wood's strength, durability, and overall properties when it is used in construction or manufacturing. It is a measure of the mass of a wood substance per unit volume when the wood is completely dried. Basic density is typically expressed in gram per cubic centimeter (g/cm^3) or kilograms per cubic meter (m^3) (Samuel Mekonen, 2018).

Basic density is a fundamental property used to characterize the quality of wood. It provides information about the density of the cell wall material and is often used in the timber industry to assess wood quality and potential uses (Mussa and Bekele, 2021).

Basic density and characteristics of end-use quality, such as pulp, are tightly associated. A water displacement technique was utilized to ascertain the density of wood. The formula for calculating basic density was oven-dry weight/green volume (Hashemi and Kord, 2011).

Parameters of end-use quality, like pulp output and structural wood strength, are intimately linked to basic density. Since the basic density of the latewood zone in many conifers is more than double that of the early wood, an increase in the proportion of latewood will unavoidably increase in the basic density of the whole ring. An investigation of the basic density variation in Sitka spruce juvenile wood revealed that basic density dropped as stem height increased (Hashemi and Kord, 2011).

As wood basic density is an important indicator of wood quality and strength, present results from a trial carried out in a humid tropical site of Costa Rica offer scope for developing high-intensity thinning programs elsewhere by implementing similar management guidelines and evaluation tools under different stand conditions. In other tropical plantation species, wood basic density has been reported to decrease with increasing thinning intensity. Concluded that different thinning schedules are unlikely to reduce wood density in *C. lustanica* grown in Northern Tanzania (Kanninen, 2005).

Wood density is probably the parameter most widely used to characterize wood quality because it is correlated to many physical and technological properties. In the species grown for pulp production, wood density is usually a selection parameter in the improvement programs since it is recognized that breeding only for volume growth is not sufficient and density is a hereditary trait. At the pulp mill, high-density wood will optimize the use of pulp digest or capacity. However the wood density within a species is related to anatomy and cell biometry and these characteristics will influence paper properties, namely resistance, opacity, and bulk (Miranda *et al*., 2001).

2.4. Specific Gravity and Moisture Content

Wood that is kept away from liquid water and exposed to a continuous atmosphere will eventually achieve equilibrium moisture content (EMC) that is consistent with the surroundings. Temperature and, to a lesser extent, ambient relative humidity both affect EMC. Any climatic situation below 100% relative humidity will result in an EMC below the fiber saturation point. Surface coverings like paint, exterior stain, or varnish can delay changes in moisture content but cannot stop them. It is impacted by the circumstances under which the materials were transported and stored at the time of construction (Alex, 2009).

From the base of the tree to the top, the moisture content of the bark, wood, and branches rose. The moisture content of bark was roughly 20–25% higher than that of wood (Dibdiakova & Vadla, 2012). According to (Samuel Mekonen, 2018), after determining the wood's MC, its density can be taken into account. A material's density in physics is expressed as its mass per unit volume (kg/m^3). With wood, the problem is more complicated since variations in its MC impact both its mass and volume. As a result, both the density and MC of wood must be specified. Therefore, to examine the moisture differences throughout the tree heights, 45 green sample discs, each measuring approximately 50mm, was replicated and obtained from the bottom, middle, and top logs of the tree stem. The methods outlined in ISO 3130 shall be followed to determine the moisture content.

$$Miosture\ content\ \% = \frac{\text{Green weight} - \text{weight of oven dried}}{\text{weight of oven dried}}\ X100$$

The wood and bark of *Eucalyptus grandis* vary in density and moisture content; this is explained by using trees planted for a half-sib progeny test in southern Florida. Progenies varied significantly in terms of moisture content and density. Genetic variations were mostly responsible for variations in wood characteristics (Antin *et al*., 2013).

In the pulping and papermaking operations, moisture content the ratio of the sample's moisture mass to its oven-dried mass is an important characteristic of wood. The freshness, mechanical, and physical characteristics of wood chips are closely correlated with their moisture level (Liang *et al*., 2019).

Specific gravity is one of the main characteristics of wood because of its relationship to other mechanical and physical qualities. Tension wood always has a higher specific gravity than opposite or normal wood in all species. Less is known, although, concerning the effect on opposing wood tissues and pure and very young tension (Jourez *et al*., 2001).

The manufacturing process is greatly impacted by an uneven final moisture content, which also effects on the finished items' quality. A high moisture content is caused by the presence of wet wood as well as particular wood properties (Tenorio and Moya, 2011).

2.5. Shrinkage

Shrinkage is the amount of thickness, width, and length of a tree required for work that causes the beauty of the tree to decrease due to weather conditions. On the other hand, shrinkage means the impact of wood dimensional changes. Shrinkage is linked to the production process drying phase as well as how the solid-wood product reacts to variations in relative humidity. It is commonly recognized that wood exhibits anisotropy, or shrinking or swelling in response to changes in ambient moisture levels in varying quantities and orientations. A key sign of potential deformation during the desorption and absorption of water is the ratio between tangential and radial shrinkages (Nocetti *et al.*, 2017).

For the most part, typical wood shrinks very little throughout its length. The orientation of microfibrills is at most seven degrees away from the cell axis. When drying from green to oven-dry conditions, there is typically some longitudinal shrinkage; nevertheless, this usually amounts to only 0.1–0.2% for the majority of species and seldom surpasses 0.4% (Jorza.*et.al*, 2002).

Wood shrinks and swells because it alters its moisture content in reaction to daily and seasonal variations in the atmosphere's relative humidity. In other words, wood absorbs moisture from the air and swells in humid conditions; in dry conditions, wood loses moisture and shrinks (Eckelman, 1998).

According to Jorza.*et.al*, (2002), bound water molecules escape from the gaps between the long-chain cellulose molecules, causing the fiber wall and the wood as a whole to shrink. Then, these cellulose molecules have the ability to assemble closer. The relative density of the piece, the direction of microfibrills in the cell wall, and the amount of water extracted from the wood all influence how much shrinkage happens.

Wood is dimensionally stable above the fiber saturation point (~30% MC). Below this point, wood swells when moisture is added and shrinks as moisture is removed from the cell walls(Moore, 2011).

To create and design shrinkage and swelling allowances, furniture producers and designers rely on unit shrinkage statistics. Samples in a green state were used to assess shrinkages, and following drying, a consistent weight was achieved. Specimens from the bottom, middle, and top of the timber were prepared for this investigation (Getahun and Sahu, 2014).

One of the main causes of structural and aesthetic issues with furniture is the dimensional changes that come along with wood's shrinking and swelling. In response to daily and yearly variations in the relative humidity of the atmosphere, wood experiences both swelling and shrinking. Specifically, in humid air, wood absorbs moisture and swells, and in dry air, it loses moisture and shrinks (Eckelman, 1998).

All *Cypress* species have wood with minimal shrinkage, moderate natural durability, and good stability, which makes them ideal for a variety of specialized applications, such as external joinery and weatherboards. Drying the *Cupress* shouldn't be an issue if the processor knows the species and source of the wood to be dried and chosen the appropriate method. Generally, the finest outcomes will come from first air drying to 30% M.C. and then final kiln drying (Haslett and Williams, 2015). An essential step in the production process is wood drying. It impacts the adhesive wettability, workability, finish, and dimensional stability of lumber. Additionally, it strengthens wood's resistance to decay and enhances its qualities as an insulator of electricity, heat, and sound. Adequate control over every stage of the drying process is necessary to guarantee that the final moisture content (MCf) varies as little as possible. The manufacturing process is greatly impacted by MCf heterogeneity, which also effects on the manufactured items' quality (Tenorio and Moya, 2011).

2.5.1. Longitudinal Shrinkage

Wood is an anisotropic material, meaning that the three directions in which its dimensions change are tangential, radial, and longitudinal, respectively. Because microfibrills are oriented parallel to the cell wall's axis, tangential dimensions change at the fastest rate. Longitudinal shrinkage is minimal for the majority of actual applications, while radial shrinkage is the second greatest (Vikberg and Elustondo, 2016).

Wood's dimensional fluctuation is caused by changes in the moisture content of the wood below the fiber saturation threshold. Longitudinal shrinkage in tension wood can reach 1%, which is excessively high. Tension wood shrinkage may be several times greater than that of the opposite or normal wood (Jourez *et al*., 2001)

The longitudinal shrinkage difference from pith to bark is a major cause of distortion in drying lumber. But when the variation in shrinkage along the timber is taken into account, the difference in longitudinal shrinkage between two faces of the timber can explain spring or bow characteristics considerably better (Hashemi and Kord, 2011).

The main cause of many issues with wood during drying and use is shrinkage of the wood. The walls shrink with a moisture level of 25 to 30 percent, which is when water starts to exit the cell walls. Wood will continue to shrink and swell with variations in relative humidity even after drying. Drying stresses arise from wood's varying radial, tangential, and longitudinal shrinkage, as well as the fact that shrinkage begins in the outer fibers of the wood before the inside fibers. Cracks and warps may form as a result of these forces (Walter M. *et.al*, 2004).

A computerized caliper was used to mark and measure the basic density specimen blocks' radial, tangential, and volume dimensions. After that, the blocks were oven-dried for a whole day at 105°C. After the blocks had dried in the oven, they were weighed, and the same digital caliper was used to measure the dimensions and the previously designated spots once more. The volumetric, radial, and tangential shrinkages of the same blocks from green to 12% MC were calculated and expressed as a percentage of the saturated dimension to its 12% MC dimension (Ababa, 2020).

2.6. Tree Allometry and Crown Shape

The age of an organism (ontogeny) affects the connection between size and form (allometry), which has a significant impact on species fitness and, in turn, ecosystem structure. There is a clear vertical stratification of light in rainforests, with as little as 1.5% of open sunshine reaching the lower strata. Success in such a low-light environment can therefore be predicted to depend on tree size, leaf size, geometry, and crown architecture and position. Plants in this layer frequently depend on sun specks for establishment, which are unpredictable both in time and space (Osunkoya *et al.*, 2007).

The allometric equation describes the biomass of trees as a function of their dimensions: $y^{1/4} \simeq kx^{\alpha}$ where k and a are parameters, x is a variable defining tree dimension, and y can be total above ground biomass or any of the tree components considered in the study (stem wood, stem bark, leaves, and branches). Taking logarithms and then differentiating, it can be shown that the allometric equation assumes that the relative growth rate of one plant part is proportional to that of another. This is an interesting biological feature of linear allometry, even if there is little evidence to suggest any substantial mechanistic basis for this relationship (António *et al.*, 2007).

(Wang *et al.*, 2008), investigated the variation in anisotropic shrinkage of *Pinus radiate* wood cultivated in plantations. Their findings demonstrated that longitudinal shrinkage ranged from 0.02 to 2.34%, peaking close to the pith, falling towards the bark, and varying more noticeably at 0.1 m height. Additionally, as the stem's height above the ground increased, the longitudinal shrinkage trended downward. According to (Hashemi and Kord, 2011), tangential and radial shrinkage increased as the number of growth rings from the pith increased. However, there was no discernible trend in the variation along the stem height.

To determine which crown form (vertical and horizontal dimensions) would minimize the cost of supporting a particular crown size (weight, mass, and area) at a certain height, data on trunk allometry are typically employed. Different forest light conditions have been linked to allometric patterns in tropical tree species, leading to divergent growth strategies and allocation patterns to crown and trunk dimensions (Spångberg and Nylinder, 1997)

According to (Van Leeuwen *et al.*, 2011), the crown shape (m), which is a measure of the total branch mass and the position and number of branches along the stem, indicates how many knots are in the timber and, consequently, how useful it may be for making different types of wood products. To simulating wood creation and forecasting quality qualities, the dimensions of the living crown are frequently substituted with more straightforward metrics like tree height, age, and BDH. The competitive strength and photosynthetic capability of individual trees are determined by the crown dimensions, which are governed by stand density. The depth of the crown and the differences in leaf densities inside it impact the levels of self-occlusion, mortality, and production at various canopy layers (Van Leeuwen *et al*., 2011).

Data from forest inventories are converted into biomass estimates at the tree level using allometric equations, and a biomass estimate at the plot level is derived by adding up all the data for the individual trees. Pan-tropical multi-species equations are being employed instead of current allometric equations for tropical trees in African moist forests, which are limited to a few specific species or sites, to estimate biomass from inventory data (Niklas, 1995).

The capacity of trees to absorb and use light is essential to their ecological success. Tree competitive advantage is strongly impacted by the form of the crown and the ensuing spatial arrangement of the leaves, which in turn affects light absorption, water transportation, mechanical support, reproduction, and wind resistance. The varied light conditions present in the forest have been linked to allometric patterns observed in tropical tree species, leading to divergent growth strategies and allocation patterns to crown and trunk dimensions (Journal and Mar, 2016).

One important functional characteristic that affects the hydraulic and mechanical behavior of stems and roots is the density of plant tissues. It also affects ecological functions like biomass distribution within plant groups and carbon storage. Previous research has demonstrated, for instance, that tissue density has a significant impact on a plant's capacity to withstand bending or torsional forces and is correlated with important mechanical properties like the elastic modulus, the modulus of rupture, and the maximum compressive or shearing strength (Niklas and Spatz, 2010).

In closed forests, the impact of competition on tree allometry is particularly significant as, in contrast to open forests, vertical stem growth is typically promoted at the expense of lateral crown expansion in densely populated areas. It is also known that mean tree allometries in mixed forests fluctuate with tree size, either as a result of averaging over a variety of species with varied growth trajectories or as a potential reaction to changes in physical and environmental restrictions throughout ontogeny. It is also acknowledged that competition gradient, biogeographic history, and climate change all contribute to between-stand differences (Antin *et al*., 2013).

For more than a century, foresters have been fascinated by the shapes of tree tops and their functions in stem structure and tree growth. The 1970s saw a surge in the ecological community's interest in tree crown morphology. Life history strategy and mechanical constraints were taken into account after architectural and ecological niche viewpoints. From an ecological perspective, the crown shape has been attributed to both genetically programmed, predictable branching processes and stochastic, competing ones (Shenkin, 1801).

Tree dimensional relationships, or allometry, have an impact on growth and survival in a variety of ways, including light interception and mechanical damage resistance. Height or crown breadth affects the amount of light intercepted by saplings in the understory. But for support, both types of growth require a rise in structural biomass (King, 1991).

In plant ecology, tree crown allometry is commonly used to assess ecosystem functions. It defines scaling relationships between the crown dimensions (crown area, crown depth, and crown volume) and other readily quantifiable variables, such as stem diameter. The power-law model has been used to characterize plant allometry between two tree dimensions for a wide variety of plants, and the significance of the power-law scaling exponents for tropical trees has been hotly contested (Kvietková *et al.*, 2015).

2.8. Conceptual Frame work of the study

The research wants to find out what the basic density and physical properties mapping of *Cupresses lusitanica* grown in the Shenen area are based on certain relationships among independent variables, including tree age, tree position/tree height, and tree diameter, whereas dependent variables are basic density, oven dry density, moisture content, and shrinkage of *Cupresses lusitanica* tree variation.

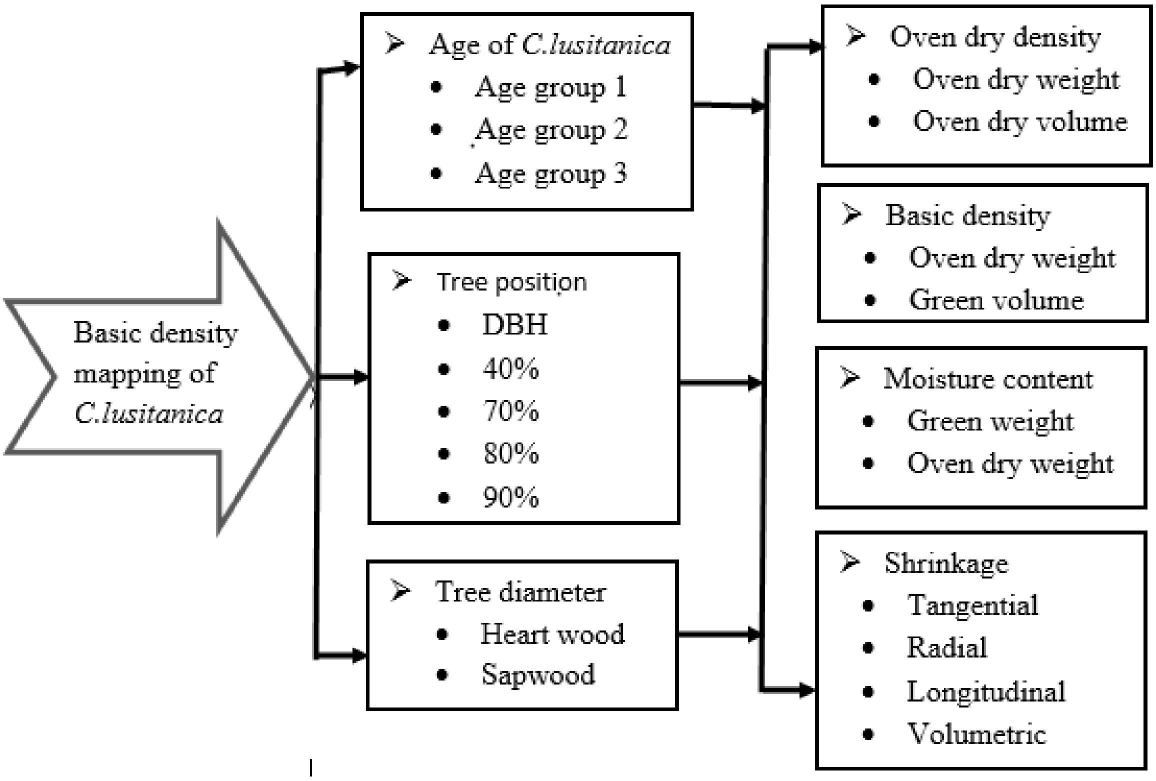

Figure 1: Conceptual frame work of basic density and physical properties mapping of *C. lusitanica*

CHAPTER THREE

METHODOLOGY AND METHODS

3.1. Description of the Study Area

The raw material used in this research were wood from 15-25 age *C. lustanica* grown in the Shenen area of Western Showa Oromia Regional state, throughout Shenen, Jibat woreda, far away at 200 km west of Addis Ababa, the capital city of Ethiopia. It covers an Area of 30 km^2 (Burju *et al.*, 2013a).

3.1.1. Climate and rain fall

Rainfall occurs from April to October, but heavy rainfall occurs in July (355 mm) and August (344 mm). The mean annual rainfall is 1474mm. The minimum rainfall was recorded in the months between November and March. The lowest mean rainfall recorded was in December (18 mm). The wet season includes July–October and March–April. November–February is the dry season. The average mean monthly minimum temperature was 5.30^{0}C in December, and the average mean monthly maximum was 26.40 °C in February (Kibebew and Abie, 2017).

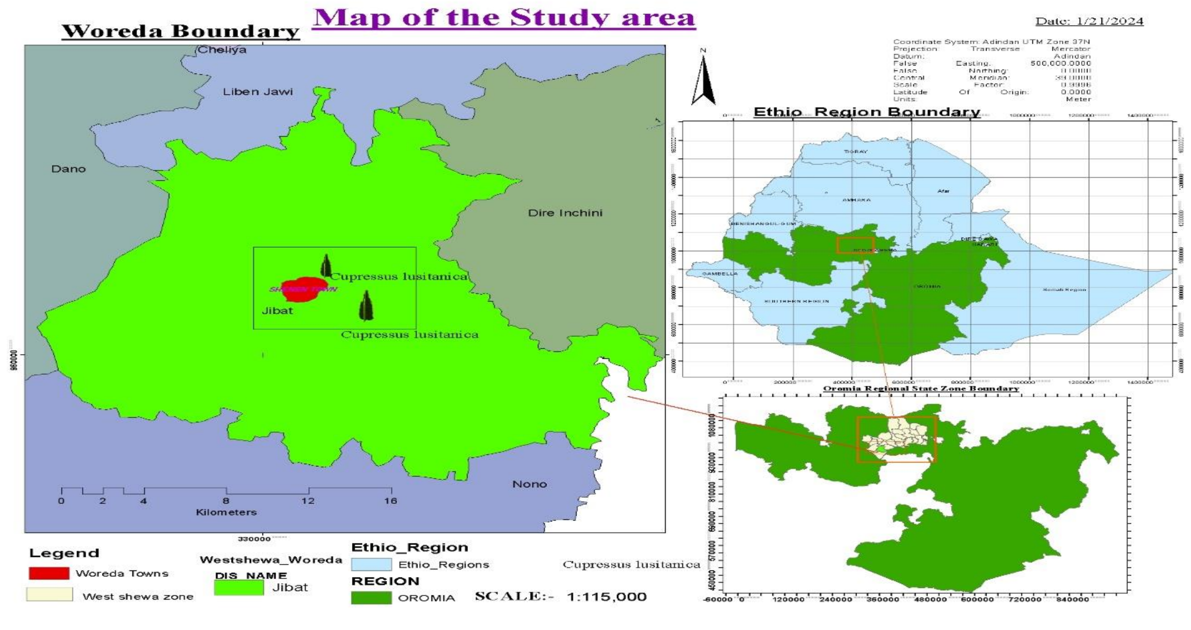

Figure 2: Map of the study area

Source: GIS expert composer at West Shoa zonal land office, (2024)

3.1.2. Topography and soil

Geographically, the Shenen (Jibat) area lies between latitudes 8^{0}35’ and 8^{0}50’ N and longitudes 37^{0}15' and 37^{0}35’ E. It ranges in altitude from 2000 to 3000) meters above sea level. The area receives a mean annual rainfall of 1521.46 mm. The mean annual minimum and maximum temperatures of the area are 8^{0}C and 23.7^{0}C, respectively, while the mean annual temperature is about 15.9^{0}C, the average mean monthly minimum temperature is 4.92^{0}C in December, and the average mean monthly maximum is 26.1^{0}C (Burju *et al.*, 2013b)

3.1.3. Vegetation and wildlife

The Jibat Forest has a sizable amount of both natural forest vegetation and plantation vegetation. In the natural forest, the most common trees were softwood and hardwood (Kibebew & Abie, 2017).According to the information author got from the Environmental Protection, Forestry, and Climate Change Authority of Jibat District, Jibat Forest covers an area of 7706.69 ha with various species of trees. The common trees found in Jibat Forest include *E. globulus, E. camandulesus, Cordia africana, Croton macrostachyus, Juniperus procera, Podocarpus falcatus, Prunus africana, Acacia decurrence, Acacia albida, Acacia sieberiana, High Land Bamboo,* and *C. lustanica.* However, the highest percentage of *C. lustanica* in Jibat forest is planted in rows and scattered next to high-land bamboo.

3.2. Survey and sampling

A random selection of *C. lustanica* logs from tree stands was made in the Shenen area, where it is growing well. Conditions of the growing sites were described and documented with an accurate record of the dimensions (height and DBH) of the trees in the woodlots from which sampled trees were harvested so as to characterize the size distribution in the sampled population of trees within the same woodlot using an ipsometer. Thereafter, nine representative trees of the sample population with good trunk and crown appearances were selected and marked for harvesting as per the experimental design disc preparation. Nine *C. lusitanica* logs from plantation stands representing 15-20, 21-25, and >25 years of age were used for this study. In this tree, for each age class, there were three trees of repetition/replications. The trees were obtained from the plantation forests of Jibat Forest, Shenen District, and West Shewa Zone. The study was conducted on the test material logs obtained from two sites, a maximum of 3 trees aged 15 - 20 years old were sampled in Jibat TVET College (Jibat TVT College is a public institution that has been providing training at levels I-IV. A maximum of 6 trees aged 20 – 25 years old and above were also selected for sampling from the Shenen primary school (Shenen Primary School is also a public institution that has been providing formal education from grade 1 to grade 8), respectively (Figure 2).

Figure 3: Sample tree selection.

Trees were chosen mainly because, with the exception of age variation, their morphological features were extremely comparable. To minimize tree-to-tree variance, sample trees with similar diameters (20–38 at breast height), varying stand spacing, reasonably straight stems, and relatively few exterior faults were selected. Before the trees were cross-cut to the appropriate logs lengths, all of the chosen sample trees were collected, marked, measured, and arranged according to their age categories. After that, each tree was cut into five sections, each measuring a different number of meters in length (DBH, 40%, 70%, 80%, and 90%).

3.3. Disc preparation

From woodlots in the Shenen area, nine *C. lustanica* trees were randomly chosen. Random selections of trees were made so that from each of the trees, five height-dependent and representative discs of *C. lustanica* were obtained, as described in Figure and table 1. The height and breast-height diameter of each of the sampled standing trees were measured and documented. Trees of good form with no obvious problems and non-defective stems were chosen. Discs of 50mm thickness were cut using two man saws from each felled tree at DBH, 40%, 70%, 80%, and 90% of the standing tree height, so that a total of 45 sample discs were obtained (9 x 5 = 45).

Figure 4 : Sample discs preparation

Table 1: Sample preparation for the study

Independent variables	Descriptions	Dependent variables (basic density, moisture content, shrinkage, oven-dry-density)
Tree age group	15-20, 21-25 and >25	15 sample from each tree age groups
Tree position/height	DBH, 40%, 70%, 80% and 90%	5 portions from each tree
Tree diameter	Heart wood and sapwood	3 replicates from each age and position
	Specimens (Basic density, moisture content and shrinkage)	(3 age groups * 5 position) * 3 replicate =15*9=135*2=270)

Methods of Work

Some sample logs of *C. lustanica* were obtained from scattered woodlots of individual farmers; while, the rest of the trees are from Jibat TVET College and Shenen Primary School in a forested area covering 564.6 ha. (Sources: Environmental Protection and Forestry Authority office climate change Jibat district forest agency.)

The following method of the study, illustrates the expected relationship the study variables. It defines the relevant objectives for the study.

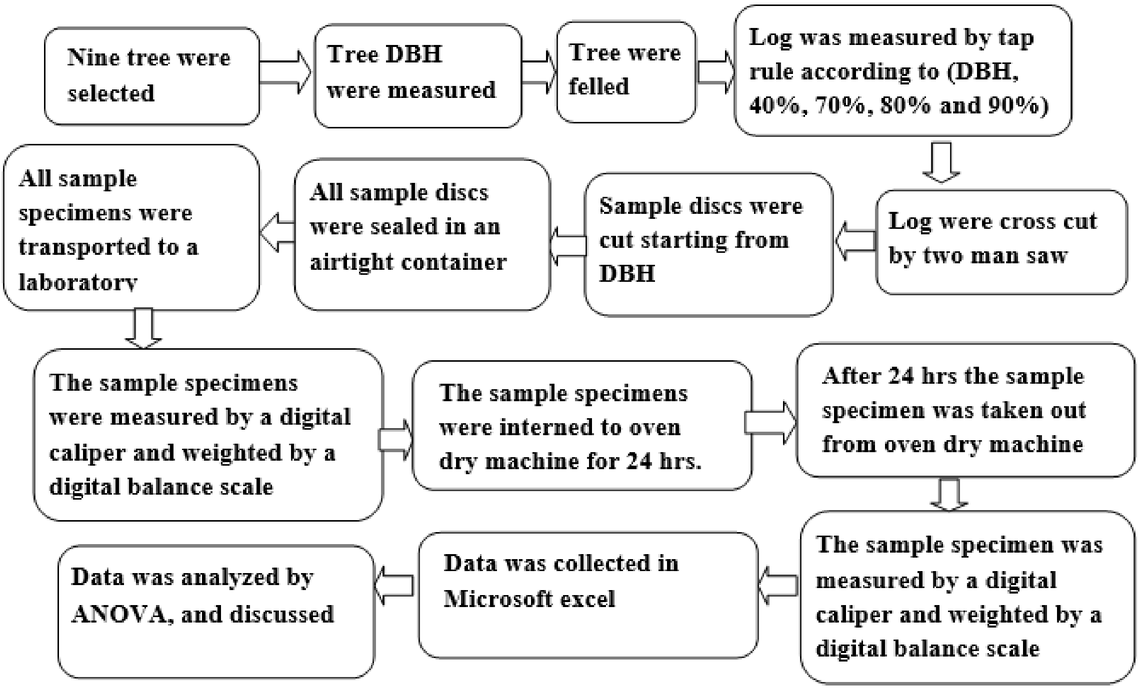

Figure 5: Work flow from sample discs preparation to analysis

Source: (Own work, 2024)

3.4. Experimental Design of the Study

Sample trees were harvested from three age groups of *C. lustanica* species (Table 1). Three age groups were used to evaluate density variation along the tree height and across the tree diameter (refers to the measure of a tree's trunk width (radial and tangential). Three sample trees from each age were randomly selected from the selected sites. To determine the validity of this experiment, nine stands were measured, and 45 samples were taken from these nine trees. The age of the tree, physical properties (shrinkage, basic density), and diameter of the tree are collected to determine the changes in these samples.

Table 2: The sample selection of *C. lustanica*

Age group	15-20 years	20-25 years	> 25 years	Total number of discs	
Average tree height (meter)	12	13.2	15.37	45	
Position of disks to be sampled along the height					
Discs (at the height for sampling)	DBH (1.37 m)	40%	70%	80%	90%

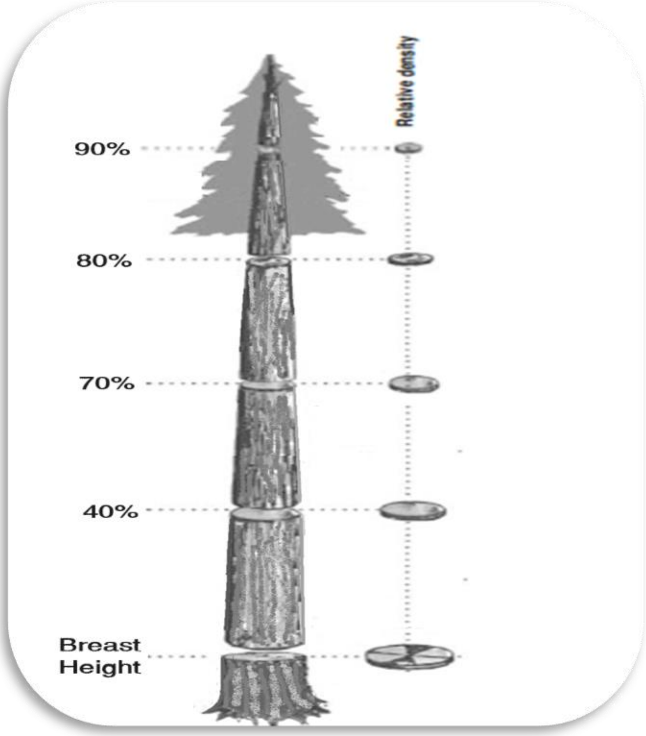

Figure 6: Sampling Portion for experimental measurement of physical properties of *C. lusitanica* along tree height

After felling the trees, sample stem discs were taken from the trees at the heights given in (Table 2). The thicknesses of the discs were about 50 mm and represented a cross-section of each stem from bark to pith. Generally, all sample specimens were sealed in an airtight container and transported to a laboratory.

3.5. Sample preparation for Density and shrinkage

The corresponding weight of each of the specimens sampled from their transversal position from pith to bark was measured on a digital balance with an accuracy of 0.01kg.

Figure 6: The weight of the specimens sampled was measured on a digital balance.

The green density of the radial strips was calculated from the formula below. For basic density and shrinkage determination, samples were cut out from each of the discs as shown in, and each of the specimens had dimensions (20 × 20 × 20 mm) in agreement with ASTM standards given for the determination of density and shrinkage as presented on Figs. 5 and 7.

First, all the dimensions of the specimens were measured. Then, the initial weights of the specimens were measured accurately (with an accuracy of 0.001 kg), followed by the calculation of volume and basic density. Thereafter, the specimens were taken into an oven set at 105 ± 2°C until they reached a constant weight, and their weight and dimensions were measured again, followed by calculations of volume and density. Wood basic density for each specimen was determined as the ratio of oven-dried mass to green volume, while oven-dried density was calculated as the ratio of oven-dried weight to oven-dry volume.

$$Basic\ density = \frac{Oven\ dry\ weight\ of\ specimen}{Green\ volume}\left[\frac{gm}{cm^3}\right] \text{---------------------------------}1$$

$$Oven - dried\ density = \frac{Oven\ dry\ weight\ of\ specimen}{Oven\ dried\ volume}\left[\frac{gm}{cm^3}\right] \text{-------------------------}2$$

3.6. Shrinkage measurements

Sample material was taken from the same tree height as given in Table 1 for basic density. The 50-mm -thick discs were cut on a band saw first with a line parallel to the pith, then tangent to the growth rings (Figure 7).

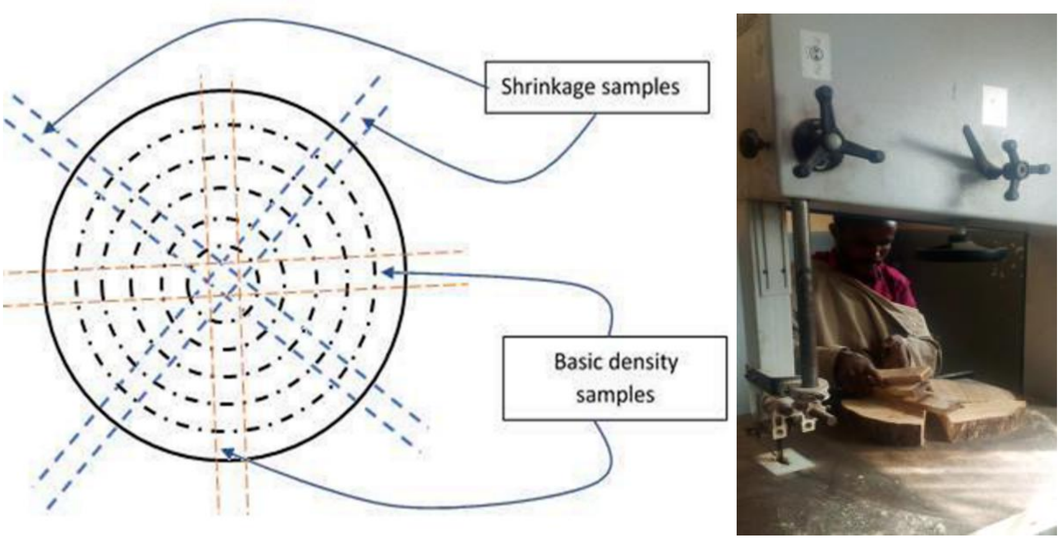

Figure 7: Sample specimen preparation for basic density and moisture content on a band saw.

Excess wood was trimmed away to reveal fresh green wood. Branch stubs are avoided as much as possible. Two strips that are perpendicular to each other but adjacent to the basic density strips as shown in Fig. 7, were also cut from the same disc from which were sampled basic density specimens.

The shrinkage specimen's dimensions were established based on ASTM D143-94 and the standard and adequacy of discs for multiple specimens at each of the relative positions. The first dimensions of the specimen were measured (using a digital Vernier caliper) in green condition in the three anatomical directions (radial, tangential, and longitudinal).

Figure 8: The first dimensions of the specimen were measured (using a digital Vernier caliper) in green condition in the three anatomical directions (radial, tangential, and longitudinal).

Following green condition measurements, the specimens were oven-dried at 105 ± 2 °C for 24 hours, and then each of the dimensions for each specimen was measured again (Hashemi and Kord, 2011). Shrinkage in the given anatomical direction was expressed as a percent length loss based on the original green length/dimension.

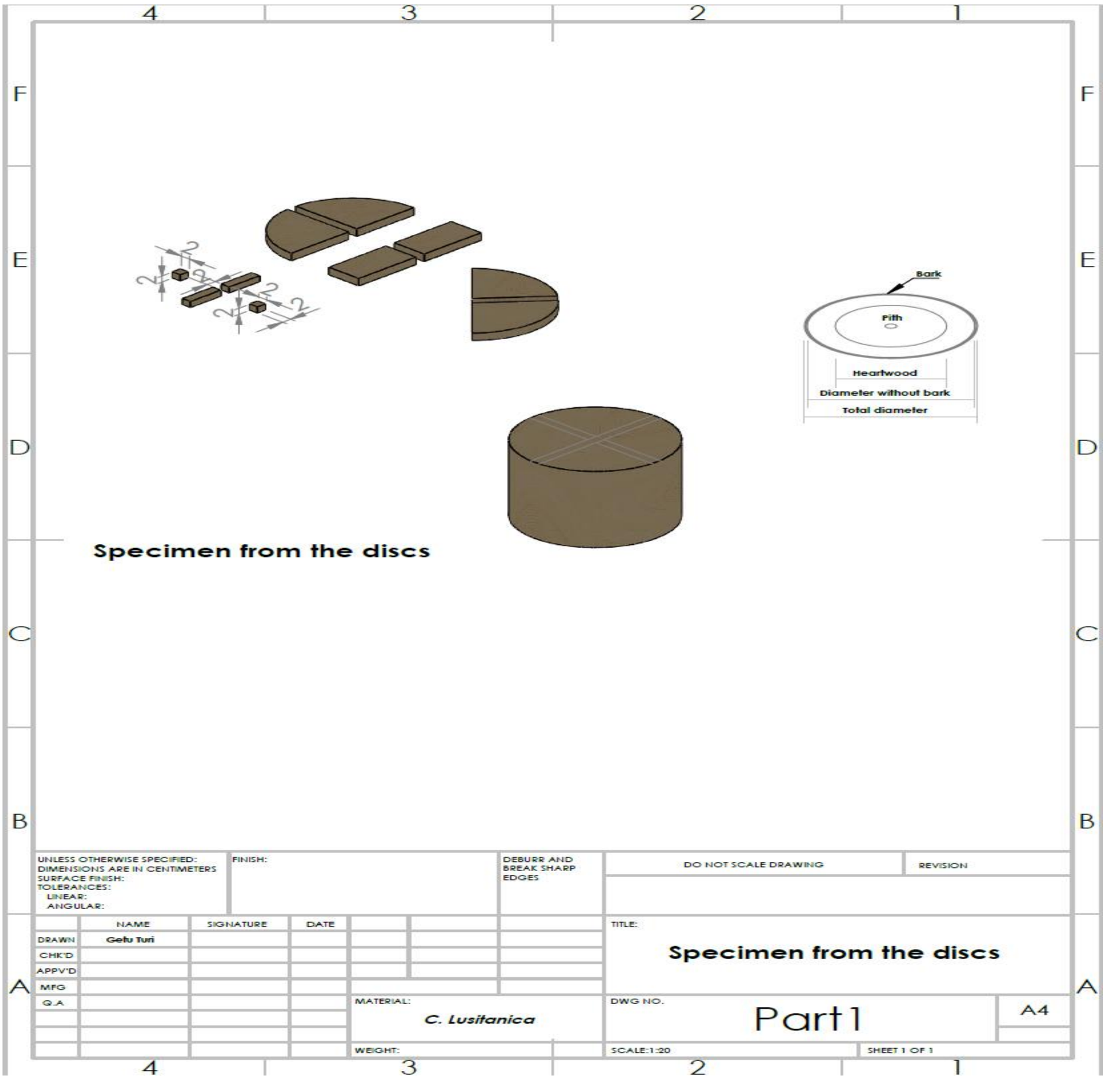

Figure 9: Specimens' preparation from sample discs

3.7. Laboratory measurements

The densities were measured based on oven-dry weight per green volume of samples. The green MCs were measured by oven-drying procedures and expressed on an oven-dry weight basis. All laboratory measurements on each tree were based on the mean of three replications of five stem discs.

3.8. Experimental Design and Statistical Analysis

A purposeful sampling method was used to select sample stands. Three factors, which are age (15, 20, and 25), 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 the *C. lusitanica* tree species were evaluated. Statistical analysis software (ORIGIN was recommended) was used to analyze the data**.** Thus, the analysis of variance (ANOVA) procedure, Duncan's multiple range test (DMRT), and Microsoft Office Excel for chartin**g** were used for mean comparison.

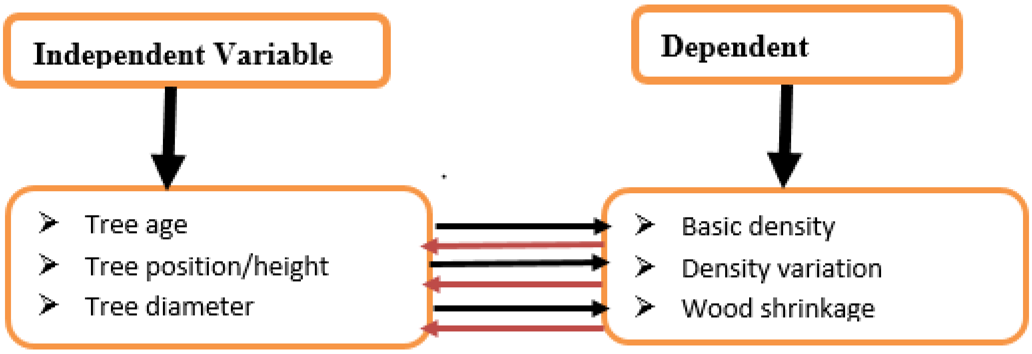

Figure 10: Illustration of experimental design

3.9. Experimental Materials

3.9.1. Raw material

There are nine stand *Cupress lusitanica* in this study. It was used to take discs. Digital balance was used to measure spacemen weight. Digital Vernier caliper was used to measure spacemen thickness. A permanent marker was used to mark discs were cut. A two man saw was used to cross cut logs and discs.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Basic Density and Physical Properties Mapping of *C. lusitanica* Tree

4.1.1. Green Moisture Content variation between age groups

The analysis of variance showed that the tree age group had a significant effect ($p < 0.001$) on the green moisture content (GMC) *of C. lusitanica* wood (Table 3). The results revealed that the GMC decreased with an increase in tree age groups (Figure 11a). The same variation trend for this finding was reported by (Enterprise, 2022). This pattern of variation might be associated with variations in the proportion of heartwood among age groups. (Millers, 2013) noted that the decrease in MC with the increase of age is predominantly influenced by the increase of the heart wood proportion with the increment of tree age. This finding also confirmed that the heartwood proportion increased with the increment of tree age groups obtained in this result (Figure11).

Table 3: Analysis of variance for Physical properties in *Cupressus lustanica* at different age, tree height levels

Source of variation	DF	Mean squares and Statistical significances						
		GMC (%)	OD (g/cm^3)	BD (g/cm^3)	TS (%)	RS (%)	LS (%)	VS (%)
Age group (AG)	2	69306.76^{***}	0.038^{***}	0.030^{***}	13.858^{*}	4.446^{*}	0.032^{ns}	18.045^{*}
Tree height (TH)	4	6323.77^{*}	0.005^{*}	0.005^{*}	5.912^{ns}	3.102^{ns}	0.101^{***}	8.527^{ns}
Tree diameter (TD)	1	80811.07^{***}	0.041^{***}	0.036^{***}	10.05^{ns}	5.396^{ns}	0.160^{***}	10.353^{ns}
AG x TH	8	624.88^{ns}	0.001^{ns}	0.001^{ns}	0.366^{ns}	0.598^{ns}	0.013^{ns}	0.665^{ns}
AG x TD	2	2315.45^{***}	0.000^{ns}	0.000^{ns}	0.821^{ns}	0.129^{ns}	0.017^{ns}	7.946^{ns}
TH x TD	4	1850.33^{*}	0.002^{ns}	0.002^{ns}	4.805^{ns}	0.636^{ns}	0.037^{ns}	2.731^{ns}
AG x TH x TD	8	1590.68^{ns}	0.001^{ns}	0.001^{ns}	4.947^{ns}	0.714^{ns}	0.010^{ns}	11.289^{*}

Note: ^{ns} is Not significant at $p>0.1$, * significant at $p<0.05$, ** significant at $p<0.01$, *** significant at $p < 0.001$, DF-degree of freedom. Where, GMC is green moisture content, OD is oven-dry density, BD is basic density, TS is tangential shrinkage, RS is radial shrinkage, LS is longitudinal shrinkage, and VS is volumetric shrinkage

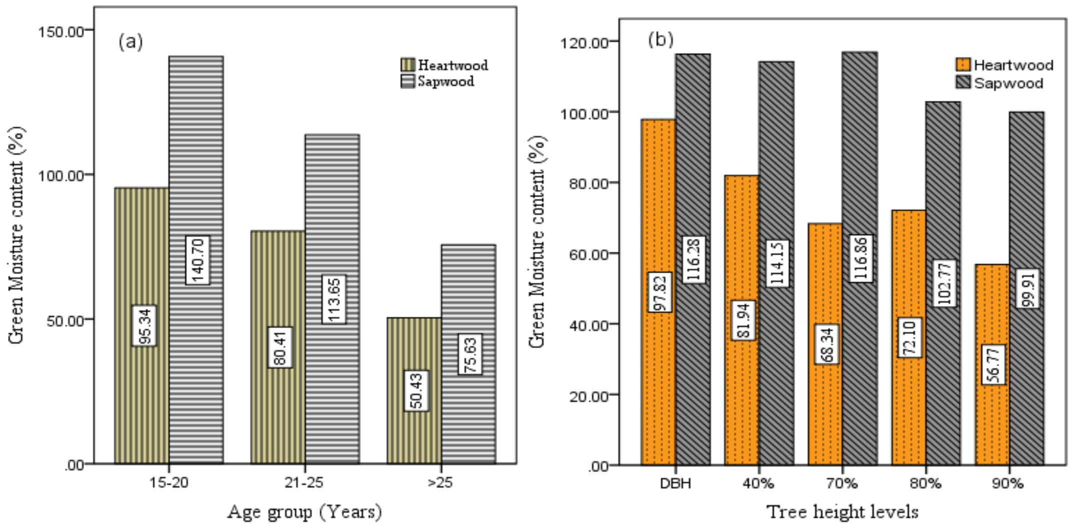

Figure 11: GMC variations in heart & sapwood of three age groups (a) and GMC variations in heart & sapwood at different tree height levels (b)

4.2. Green Moisture Content variation within a tree

The analysis of variance showed that tree height level and tree diameter had significant ($p < 0.001$) effects on the GMC of the *C. lusitanica* tree (Table 3). The results showed that the percentage mean values of the GMC decreased from the base (DBH) to the top (90%) of the tree height level in both the heart and sapwood parts of the tree (Figure 11b). On the other hand, the highest GMC was observed at the base (DBH), while the lowest GMC was registered at the top (90%) of the tree height levels for both the heart and sapwood parts of the tree (Figure 11b). This variation is observed in all three age groups (Table 4). The same variation to this study was reported in the same species of this study, *C. lustanica* wood (Moya and Munoz, 2010; Belina, 2017; Samuel Mekonen, 2018). Similar variation along tree height levels to this study was also found in other softwood species (Kaba *et al*., 2022). This variation may be associated with the differences and changes in anatomical features during the maturation period. The narrowing nature of the tree towards the top of the tree height level results in a reduction of its inner portion with fewer parenchyma cells (a region in which more moisture is found) and a high number of fibres having a small size. The results showed that a higher percentage of GMC was obtained in the sapwood part compared to the heartwood part for all three tree age groups. Similar differences have been observed in other conifer tree species, like spruce and pine(Millers, 2013).

In general, in coniferous trees, sapwood often has a GMC that is much higher than heartwood (Haygreen and Bowyer, 1996). This finding also confirms this result.

Table 4: Means variations in physical properties of *C. lustanica* tree height levels

Age group	Properties	Tree height level									
		DBH		40%		70%		80%		90%	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
15-20	MC (%)	126.65	26.347	121.91	38.74	120.59	38.75	114.88	44.22	106.07	46.66
	OD (g/mc^3)	0.483	0.032	0.487	0.027	0.481	0.035	0.476	0.022	0.475	0.025
	BD (g/mc^3)	0.396	0.031	0.393	0.030	0.393	0.032	0.392	0.019	0.389	0.026
	TS (%)	5.689	1.503	5.614	1.857	5.775	1.345	5.327	1.887	4.972	1.357
	RS (%)	3.173	1.050	3.009	1.026	2.837	1.266	2.933	1.107	2.948	1.047
	LS (%)	0.293	0.202	0.221	0.114	0.191	0.093	0.169	0.039	0.165	0.060
	VS (%)	9.485	1.6959	9.388	2.3539	9.1156	2.7747	8.3633	2.3869	8.4861	1.9116
21-25	MC (%)	107.29	47.806	100.74	46.126	98.132	44.146	96.959	40.534	82.009	49.799
	OD (g/mc^3)	0.524	0.023	0.522	0.045	0.522	0.045	0.512	0.056	0.501	0.049
	BD (g/mc^3)	0.440	0.026	0.436	0.051	0.433	0.035	0.420	0.045	0.413	0.044
	TS (%)	5.602	1.866	5.476	1.806	5.013	1.744	4.972	1.055	4.701	1.188
	RS (%)	3.716	1.421	3.309	1.170	3.429	0.983	3.011	0.743	2.813	0.826
	LS (%)	0.203	0.163	0.180	0.077	0.181	0.072	0.165	0.059	0.163	0.064
	VS (%)	8.859	2.362	9.025	2.704	9.014	2.405	8.462	2.649	8.247	2.042
>25	MC (%)	87.199	24.445	71.478	24.102	59.082	18.490	50.461	12.640	46.932	11.370
	OD (g/mc^3)	0.539	0.064	0.520	0.052	0.517	0.055	0.505	0.048	0.496	0.029
	BD (g/mc^3)	0.435	0.043	0.420	0.045	0.418	0.028	0.406	0.042	0.398	0.025
	TS (%)	5.118	2.592	4.939	2.322	4.633	1.963	4.561	2.056	4.222	1.627
	RS (%)	3.476	1.450	3.649	1.610	3.466	1.429	3.448	1.477	2.862	1.043
	LS (%)	0.325	0.182	0.202	0.118	0.184	0.088	0.184	0.100	0.173	0.106
	VS (%)	10.082	1.703	9.953	2.216	9.413	2.670	9.211	2.186	9.292	1.702

Note: Where, SD is standard deviation, DBH is diameter at breast height, GMC is green moisture content, OD is oven-dry density, BD is basic density, TS is Tangential shrinkage, RS is Radial shrinkage, LS is longitudinal shrinkage, and VS is Volumetric shrinkage

4.3. Density Variation from Pith to Bark

The table 5 results indicated that there was a difference of oven density from inward to outward diameter of 15-20 years of *C. lustanica*. Hence, there was a decrease of oven dry density based on distance from pith towards bark in centimeters from 1 cm, 3 cm, 5 cm, 7 cm, 9 cm, 11 cm, and 13 cm (0.49 ± 0.029, 0.48 ± 0.04, 0.48 ± 0.025, 0.48 ± 0.02, 0.48 ± 0.041, 0.46 ± 0.021, and 0.48 ± 0.028), respectively. Likewise, the results indicated that there was a decrease of 21 - 25 years *C. lustanica* oven density based on distance from pith towards bark. A decrease of > 25 years *C. lustanica* oven density was also observed from based on distance from pith towards bark in centimeters 1 cm, 3 cm, 5 cm, 7 cm, 9 cm,11 cm, and 13 cm (0.529 ± 0.0411, 0.494 ± 0.053, 0.523 ± 0.037, 0.518 ± 0.0554, 0.517 ± 0.52, 0.52 ± 0.072, and 0.516 ± 0.041), respectively.

Table 5: Density variation across pith to bark

Age of tree in years	Density variation across pith to bark mean ± standard deviation													
	Mean oven dry density (g/cm^3) based on distance from pith towards bark in centimeter (cm)							Mean basic density (g/cm^3) based on distance from pith towards bark in centimeter (cm)						
	1	3	5	7	9	11	13	1	3	5	7	9	11	13
15-20 years	0.49 ± 0.029	0.48 ± 0.04	0.48 ± 0.025	0.48 ± 0.02	0.48 ± 0.041	0.46 ± 0.021	0.48 ± 0.028	0.391 ± 0.0337	0.398 ± 0.03	0.392 ± 0.0248	0.399 ± 0.0246	0.392 ± 0.026	0.383 ± 0.0268	0.392 ± 0.027
21-25 years	0.530 ± 0.052	0.529 ± 0.057	0.516 ± 0.045	0.514 ± 0.046	0.513 ± 0.042	0.50 ± 0.03	0.50 ± 0.045	0.439 ± 0.0417	0.44 ± 0.05	0.419 ± 0.047	0.425 ± 0.04	0.43 ± 0.03	0.4 ± 0.03	0.42 ± 0.04
>25 years	0.529 ± 0.0411	0.494 ± 0.053	0.523 ± 0.037	0.518 ± 0.0554	0.517 ± 0.52	0.52 ± 0.072	0.516 ± 0.041	0.417 ± 0.027	0.411 ± 0.035	0.425 ± 0.03	0.41 ± 0.041	0.413 ± 0.0377	0.411 ± 0.054	0.415 ± 0.038

The table 5 results also showed that there was a difference of basic density from inward to outward diameter of 15 - 20 years, 21 - 25 years, and > 25 years of *C. lustanica.* Accordingly, there was a decrease of Basic density 15-20 years of *C. lustanica* based on distance from pith towards bark in centimeter from 1 cm, 3 cm, 5 cm, 7 cm, 9 cm, 11 cm, and 13 cm (0.391 ± 0.0337, 0.398 ± 0.03, 0.392 ± 0.0248, 0.399 ± 0.0246, 0.392 ± 0.026, 0.383 ± 0.0268, and 0.392 ± 0.027), respectively. As well, the results indicated that there was a decrease of 21 - 25 years *C. lustanica* basic density based on distance from pith towards bark in centimeter from 1 cm, 3 cm, 5 cm, 7 cm, 9 cm, 11 cm, and 13 cm (0.439 ± 0.0417, 0.44 ± 0.05, 0.419 ± 0.047, 0.425 ± 0.04, 0.43 ± 0.03, 0.4 ± 0.03, and 0.42 ± 0.04), respectively. A decrease of > 25 years *C. lustanica* basic density was also observed based on distance from pith towards bark in centimeter from 1 cm, 3 cm, 5 cm, 7 cm, 9 cm, 11 cm, and 13 cm (0.417 ± 0.027, 0.411 ± 0.035, 0.425 ± 0.03, 0.41 ± .041, 0.413 ± 0.0377, 0.411 ± 0.054, and 0.415 ± 0.038), respectively.

In agreement of the present results, (Harvald & Olesen, 1987) noted that the basic density varies considerably in radial direction. Hence, In Sitka spruce the basic density is very high in the innermost rings and is subject to a marked decrease going outward from the pith until a minimum is reached about rings 8 to 12, after which it rises gradually towards the bark. Accordingly, the difference in basic density attribution by the same pattern of basic density level variation (a decrease from pith to ring 11), the basic-density level within the innermost 12 rings is higher, and the internal differences between basic-density levels are considerably larger in Sitka than in Norway spruce (Harvald & Olesen, 1987).

In the same manner, (Raymond, 2006) investigated that Densitometry data (from pith to bark) for trees collected in the Macquarie region (Raymond and Anderson, 2005) were used for an in-depth evaluation. A loss of information occurs, particularly for the first 10 rings of the pith. In this region, density is more variable from ring to ring than is the case beyond the 10th ring. After ring 10, the five ring-segment approach mirrors the densitometer traces adequately and the information loss is minimal.

4.4. Density variation between age groups

The results revealed that the oven-dry and basic density of *C. lustanica* were significantly ($p < 0.05$) affected by the tree age group (Table 3). The interaction effect between age group and tree height level had a significant ($p < 0.001$) effect on the oven-dry and basic density (Table 3). However, the interaction effect between age group and tree diameter didn’t show a significant effect on oven-dry and basic density; except the tangential shrinkage was significant at the $p < 0.001$ level (Table 3). In addition, the interaction effects of all factors didn’t show significant effects on the basic density, except for the tangential shrinkage at the $p < 0.05$ level (Table and Figure 12).

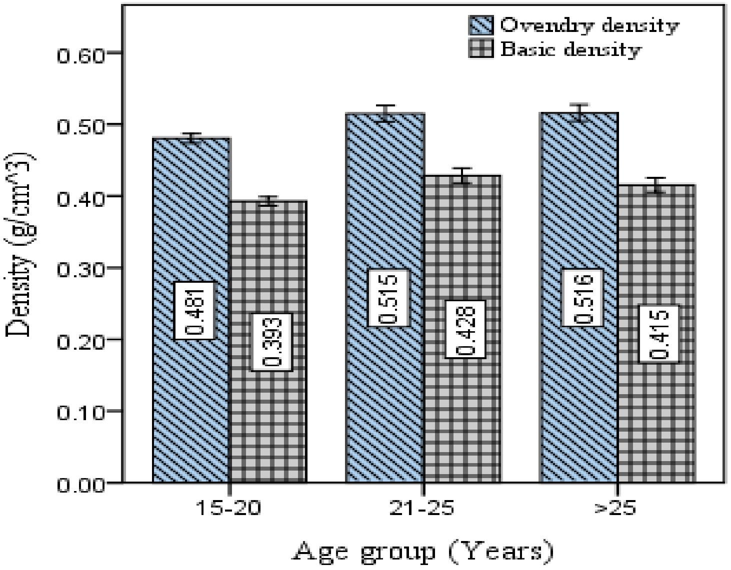

Figure 12: Oven-dry and basic density variations between age groups of *C. lustanica* tree

The oven-dry and basic density mean values showed an increasing pattern with the increase in the age groups of the *C. lustanica* tree (Figure 12). The average oven-dry density values (mean values) for age groups of 15 - 20, 21 - 25, and > 25 years old were 0.481, 0.515, and 0.516 g/cm^3, respectively. Whereas the basic density mean values were 0.393, 0.428, and 0.415 g/cm^3 for the age groups of 15-20, 21-25, and >25 years old, respectively (Figure 12).

The average oven-dry density values (mean values) reported in 15 - 20 -year-old *C. lustanica* was 0.513 g/cm3, as reported by (Elzaki and Khider, 2013), which is nearest to the results obtained in the tree age groups of 21 – 25, and > 25 years old, which are 0.515, and 0.516 g/cm^3, respectively.

The mean value of basic density reported in 15 - 20-year-old *C. lustanica* is also nearest to this finding obtained in the tree age group of 21 – 25 years old (Elzaki and Khider, 2013).

(Sseremba *et al.*, 2016) stated this difference/variation might be explained by the increased growth of anatomical features such as fiber diameter, whose increased growth depicts the increased density. Wood strength is directly related to the density of wood, and as density increases, the strength of the wood and wood quality also increase (Mussa and Bekele, 2021). Thus, of the age groups of 15 - 20, 21 – 25, and > 25 years old *C. lusitanica* tested in this study, the age group of 21 – 25 years old had a high oven-dry and basic density. (O’connor, 2007) stated that high density is an indicator of strength, stiffness, and quality of wood, and it has been used for furniture and construction works. Consequently, the high density obtained in this study at the age group of 21 – 25 years old had a better wood quality and could be used for furniture and construction applications.

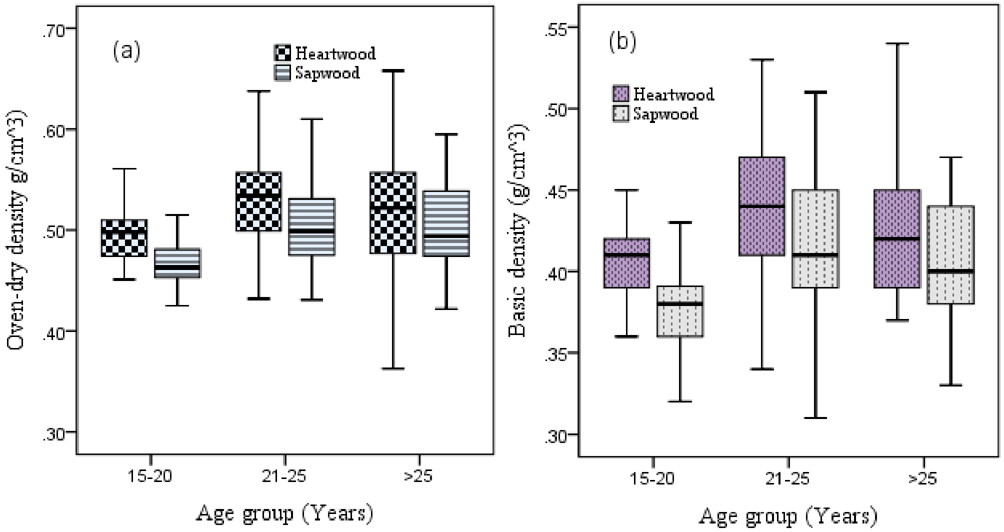

Figure 13: Oven-dry (a) and basic density (b) variations in heartwood and sapwood of the three age groups *C. lustanica* lumber tree

4.5. Density variation within a tree

The variance analysis showed that basic density was significantly affected by tree height level ($p < 0.05$) and tree diameter (heartwood and sapwood) ($p < 0.001$) of *C. lustanica* (Table 3). However, the interaction effect between tree height and tree diameter didn't show a significant effect on the basic density (Table 3).

For each one of the three tree age groups, the average mean values of oven-dry and basic density demonstrated a decreasing tendency from the base (DBH) to the top (90%) tree height levels of *C. lustanica* (Table 4). The same pattern of variation to this finding was reported for the same species in this study, which is a decrease from the base to the tip of the tree, with the highest values at the base and the lowest at the top (Moya and Munoz, 2010; Eba *et al.*, 2017). This pattern of variations might be due to maturity at the base (DBH) and juvenility at the top (90%) of the tree height levels.

According to (Getahun and Sahu, 2014), within a tree, juvenility increases from the base towards the tip, and as juvenility increases, inversely, density decreases from the base to the tip of the tree. Density in the juvenile wood zone is low because there are relatively few late wood or summer wood cells, and a high proportion of cells have thin wall layers (Hay green and Bowyer, 1996).

On the other hand, due to the maturity of wood tissues in the base of the tree portion, density showed a decreasing trend towards the top of tree height levels. In many conifer trees, the density of the latewood zone is more than twice that of early wood; thus, any increase in the proportion of latewood inevitably leads to an increase in the whole ring's basic density.

. This shows that the high density of the base of the tree should be used for structural purposes where high strength is required (Getahun and Sahu, 2014).

The oven-dry and basic density mean values found in the heartwood part were higher than the oven-dry and basic density mean values obtained in the sapwood part for all three age groups (Figure 13a, 13b). A similar difference to this finding was reported in the same species in this study. This may be due to the presence of extractive materials in the heartwood part of the tree.

4.6. Shrinkage variation between age group

Among the more significant factors influencing timber quality is shrinkage. Wood shrinks differently in tangential, radial, and longitudinal directions. The analysis of variance showed that the age group had a significant effect on the TS, RS, LS, and VS of *C. lustanica* wood (Table 3).

The interaction effect between age group and tree height significantly affected TS, RS, LS, and VS (Table 3). The mean values of TS, RS, LS, and VS increased with the increase in tree age groups (Figure 14). The same variation in trend was observed in the same species in this study, which increased from 25 to 30 years old (Eba *et al*., 2017).

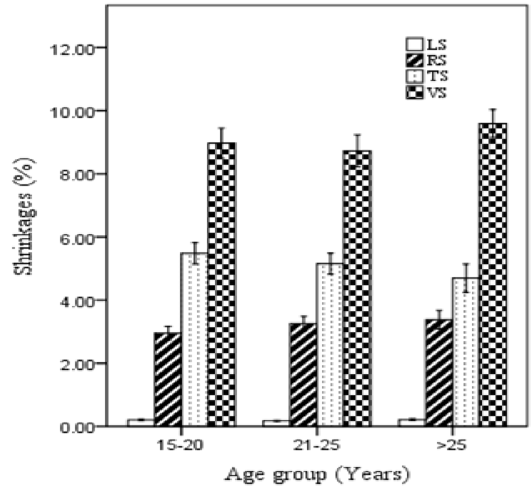

Figure 14: Variations of TS, RS, LS, and VS between age groups of the *C. lustanica* tree

4.7. Shrinkage variation within a tree

The results of the ANOVA showed that the tree height had a significant effect on TS, RS, LS, and VS (Table 3). In the three age groups, TS, RS, LS, and VS mean values decreased from the base to the top of the *C. lustanica* tree (Table 4). The same trend was reported for TS and RS in the same species in this study (Samuel Mekonen, 2018). This variation might be due to the variation of the moisture content from the base to the tip of the tree. The reason for the high amount of shrinkage at the base of the tree height level is associated with the amount of MC found in the stem, since the highest MC implies the larger cell cavities in the tree, thus the larger cell cavities shrink more as compared to the smaller cell cavities. The high amount of moisture removed from the tree leads to a high dimensional reduction (shrinkage).

The shrinkage values showed considerable differences among different directions, i.e., tangential shrinkage (perpendicular to the grain and parallel to the growth rings) is always greater than radial shrinkage (perpendicular to the growth rings), and longitudinal shrinkage (along the grain) is considered negligible.

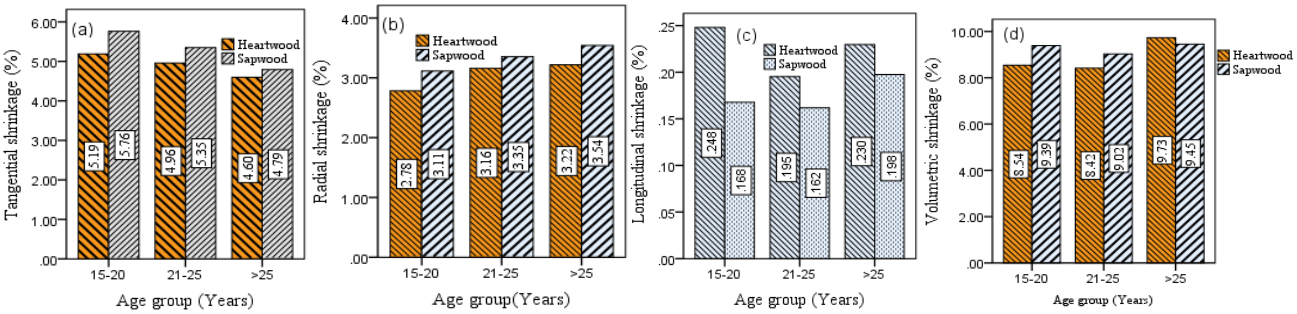

Figure 15: TS, RS, LS, and VS variations in heartwood and sapwood for the three tree age groups of the *C. lustanica* tree.

The mean values of TS in heartwood and sapwood show a decreasing trend with increasing tree age groups (Figure 15a). In contrast, the mean values of RS in heartwood and sapwood show an increasing pattern with the increase in tree age groups (Figure 15b).

The cases of LS and VS show inconsistent variations with the increase in tree age groups (Figures 15c, 15d). Regardless of the variations within a tree, the overall mean values of TS, RS, LS, and VS for 15-20 tree age groups were 5.48%, 2.95%, 0.21%, and 8.97%, respectively. The overall mean values of TS, RS, LS, and VS for 21 – 25 tree age groups were 5.15%, 3.26%, 0.19%, and 8.72%, respectively. Whereas for age groups > 25 years old, they are 4.69%, 3.38%, 0.21%, and 9.59% for TS, RS, LS, and VS, respectively. The nearest mean values to this finding were reported in tangential (5.80%), radial (3.20%), and volumetric shrinkages (8.20%) in 20-year-old *C. lustanica* (Elzaki and Khider, 2013).

Generally, tangential, radial, and longitudinal shrinkage mean values vary between 2-5%, 5-8%, and < 1% for conifer wood, respectively (Taylor *et al.*, 2008). The results of this finding in tangential, radial, and longitudinal shrinkages were in the ranges of generally recognized mean values.

The ratio of tangential to radial shrinkage for 15 - 20, 21 – 25, and > 25 tree age groups was 1.86, 1.58, and 1.39, respectively. The nearest ratio of TS/RS to this finding was reported in 20-year-old *C. lustanica*, which is 1.81 (Elzaki and Khider, 2013). Thus, ratios of tangential to radial shrinkage indicate the suitability of *C. lustanica* lumber for different applications. In general, the ratio of shrinkage in the tangential and radial directions is 2:1, respectively. The findings of this study also support this results.

4.8. Heartwood and sapwood Proportion between age groups

The analysis of variance shows that both heartwood and sapwood proportions were significantly ($p < 0.001$) affected by age groups (Table 6). However, the interaction effect between tree age group and tree height didn't show a significant effect on both heartwood and sapwood proportions (Table 6).

The heartwood proportion showed an increasing trend with the increase in age groups; however, the sapwood proportion showed a decreasing trend with the increase in age groups (Figure 16). The same pattern of variations was observed in the age range of 40 to 100 years old for the pine (*Pinus sylvestris*) tree and from 40 to 60 years old for the *spruce* (*Picea abies*) tree (Millers, 2013).

The same trend for this finding was observed in *Tectona grandis* wood (Pérez Cordero and Kanninen, 2003).

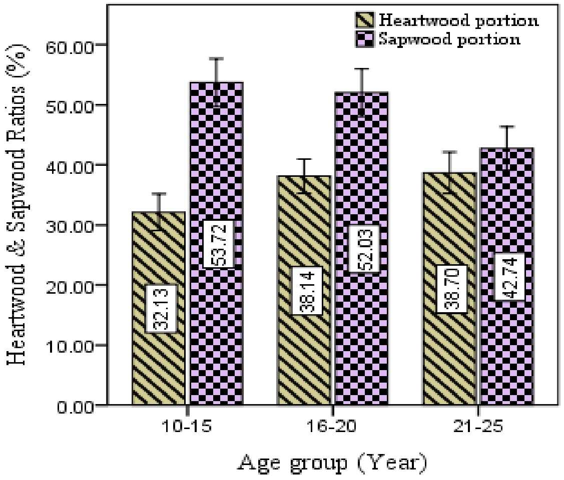

Figure 16: Variation of Heartwood and sapwood proportions in different tree age groups.

Table 6: Analysis of variance for Heartwood and sapwood proportions *in C. lustanica* at different age groups and tree height levels

Source of variation	DF	Mean squares and Statistical significances	
		HWR (%)	SWR (%)
Age group (AG)	2	198.96^{***}	524.19^{***}
Tree height (TH)	4	235.30^{***}	329.84^{***}
AG x TH	8	4.967^{ns}	32.758

Note: $^{ns:}$ not significant at $p > 0.1$; *** significant at $p < 0.001$; DF: degree of freedom. Where, HWR (heart wood ratio) and SWR (sapwood ratio)

4.9. Heartwood and sapwood Proportion within a tree

The analysis of variance showed that tree height level had a significant ($p < 0.001$) influence on the proportion of heartwood and sapwood (Table 6). However, the interaction effects between the tree height and tree age groups showed an insignificant effect on the heartwood and sapwood proportions (Table 6). Figure 17 showed that for all three tree age groups, the proportions of heartwood within the stem's its cross-section declined within the tree from the base (DBH) to the top (90%) of the tree height levels. While the sapwood proportion showed an increasing trend from the base (DBH) towards the top (90%) of the tree height levels for all three tree age groups (Figure 17), the same trend of variation was observed in the same species in this study (Moya and Munoz, 2010).

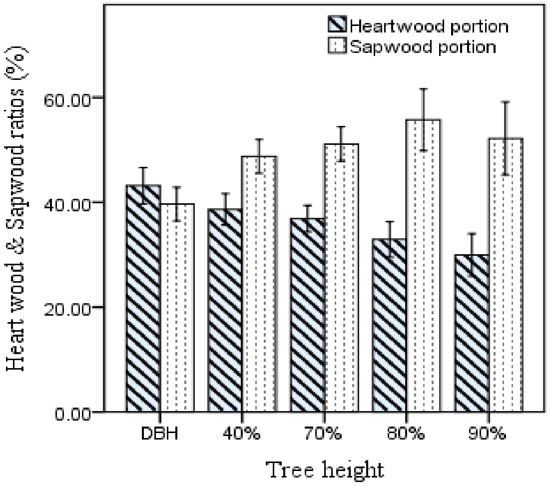

Figure 17: Variation of heartwood and sapwood proportions in different height levels of *C. lustanica* tree.

CHAPTER FIVE

CONCLUSIONS AND RECCOMENDATIONS

5.1. CONCLUSIONS

The green moisture content of the *C. lustanica* tree significantly decreases with the increase in tree age groups. Within a tree, green moisture content decreases significantly from the base towards the top of *C. lustanica* tree height levels, while it increases from pith to the bark (heart to sapwood part) for all three tree age groups.

There was a decrease of oven and basic density from pith to bark of 15 - 20 years, 21 - 25 years, and > 25 years *C. lustanica*. Oven-dry and basic density mean values increase with tree age groups of 15-20 to 21 – 25 years old and become slightly constant with age groups > 25 years old. Generally, tree age, tree height, and tree diameter (HW and SW) influence the quality of *C. lustanica* wood. Based on the results harvested at 20 – 25 years of age, it was recommendable for the species to obtain the best lumber quality.

For all three tree age groups, lower portions of the tree have lower mean values near the top (90%) and higher mean values at the base (DBH) of the tree height levels. This is generally true for both the oven-dry and basic densities. The densities obtained in the heartwood part were slightly higher than in the sapwood part of the tree for the three tree age groups. The tangential and longitudinal shrinkage decreases with the increase in tree age groups, while the radial and volumetric shrinkage increases with the increase in tree age groups. The proportions of heartwood (HWP) and sapwood (SWP) in the stem cross-section are inversely related. As HWP decreased within the tree from the base (DBH) to the top (90%) of the tree height levels, the SWP increased from the base to the top of the tree for all three tree age groups. Generally, the HWP increases with increasing age but decreases with increasing tree height, while the inverse is true for SWP.

In general, the physical properties (moisture content, density, and shrinkage) of *C. lustanica* wood are affected by the age group, tree height levels, and tree diameter, which influence the quality and utilization of the tree. This finding showed medium to low density, low shrinkage, and moderate dimensional stability. Consequently, this tree species could be used for furniture and construction applications. In *C. lusitanica* trees, there were notable variations in wood density as well as longitudinal, radial, tangential, and volumetric shrinkage between the radial location and height. The authors report that the volume loss in *C. lusitanica* was minimal at 90% of height level and near the pith, and maximal at the dbh of height level and the cross section bark surface.

5.2. RECCOMENDATIONS

Based on its moderate density, low shrinkage, and moderate dimensional stability, *C. lusitanica* wood is suitable for furniture and construction applications. Further research was needed to investigate the specific effects of growing site, age, height, and diameter on the physical properties of *C. lusitanica* wood. This information could help optimize the utilization of this species for different purposes and improve the quality of wood products. Based on the results harvested at 15 - 20, 21– 25 and > 25 years of age, it was recommendable for the species to obtain the best lumber quality. Based on the present study findings, it is recommended to consider age groups, tree height, wood density, moisture content, and shrinkage properties when selecting and using wood for different applications in Ethiopia. When working with *C. lusitanica,* wood scientists, foresters, and producers of wood products can all benefit from the resulting density map, which can help them better understand the natural diversity in wood qualities and maximize their use.

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Appendix I. Biography of the Author

The author was born in West Shoa of Oromia Regional State at Jibat woreda, in August 1980E.C. He completed his primary education in Witate Primary School in 1988-1996 E.C and his Secondary School education at Shenen Secondary School in 1997-1998 E.C. After successfully passing the Ethiopian Higher Education Entrance Certificate Examination, he joined higher education Ambo Technical Vocational Education and Training College of graduated with level-IV in Furniture making management November 2008 June 2010 G.C. Soon after that, he was employed in West Shoa zone, Bako TVET College in training position for about a year, and Dire Bedas TVETC for 3 years. After he joined FDRE TVTI, he graduated on June 29, 2010 E.C, with B.A. degree in the field of Wood Technology.

After his graduation, he got employed in Dire Enchini woreda West Shoa Zone of Oromia Regional State at Dire Bedas TVET College, until he joined the Post graduate study program in FDRE TVTI in 2015-2016 E.C to in Masters of Wood Technology.

Appendix II. The Process of data collection

Figure 18 Process of data collection from field work up to laboratory experiment work Process of data collection from field work up to laboratory experiment work.

Appendix III.

Raw data sheet for physical properties *C. lustanica tree*

Table 6: Data for physical properties of *C. lustanica* tree

Tree Age group	Tree height	Tree diameter	Moisture content (%)	Oven dry density (g/cm^3)	Basic density (g/cm^3)	Tangential shrinkage (%)	Radial shrinkage (%)	Longitudinal shrinkage (%)	Volumetric shrinkage (%)

Table 7: Summery of data sheet for ratio of heart wood and sapwood

Tree Age group	Tree height	Ratio of heart wood (%)	Ratio of sap wood (%)