PHYSICAL AND MECHANICAL PROPERTIES OF LESSER KNOWN TIMBER SPECIES OF MIZORAM

BY

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Submitted

in partial fulfillment of the requirement of the degree of Doctor of Philosophy in Department of Forestry of Mizoram University, Aizawl

<u>Declaration</u>

I, **Nagaraj Hegde**, hereby declare that the subject matter of this thesis entitled "**Physical and Mechanical Properties of Lesser Known Timber Species of Mizoram**" is the record of the work done by me, that the contents of this thesis did not form basis of the award of any previous degree or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University / Institute.

This thesis is being submitted to the Mizoram University for the degree of **Doctor of Philosophy** in Department of Forestry.

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This is to certify that that thesis entitled **"Physical and Mechanical Properties of Lesser Known Timber Species of Mizoram"** submitted by **Mr. Nagaraj Hegde**, for the Degree of Doctor of Philosophy in Forestry of Mizoram University, Aizawl embodies the record of his original investigation under my supervision. He has duly registered and the thesis presented is worthy of being considered for the award of the Doctor of Philosophy (Ph. D) Degree. The work has not been submitted previously for any degree to this or any other university.

(Prof. B. Gopichand)

Supervisor

Acknowledgements

At the very outset, I would like to express my deep sense of gratitude to my Supervisor Prof. B. Gopichand, Department of Forestry, Mizoram University for his constant encouragement, valuable advice and contribution of precious time during due course of the study.

I am thankful to Prof. Shiva Kumar, Dean, School of Earth Sciences and Natural Resources Management and Prof. S. K. Tripathi, Head, Department of Forestry, Mizoram University for their cooperation. I offer my sincere thanks to Prof. U.K. Sahoo, Prof. Lalnundanga, Dr. Kalidas Upadhyaya, Dr. Kewat Sanjay Kumar, Mr. Keshav Kumar Upadhyay and my special thanks goes to Dr. Suresh Kumar, Department of Forestry who rendered all possible help and support during my work.

I extend my deep sense of gratitude to Dr. S. R. Shukla and Mr. Bhushan Kelkar from IWST Bangalore, Dr. Harsha Hegde and Dr. Satish Kumar Sinha, NAU, Gujarat for their timely help to get the mechanical and anatomical tests done in their respective laboratories.

I wish to accord my thanks to Dr. Awadhesh Kumar, Department of Horticulture, Aromatic and Medicinal Plants, Prof. Senthil Kumar, Department of Biotechnology, Dr. Laldintluanga, Department of Civil Engineering, MZU for their encouragement and support.

My sincere thanks are due to all the research scholars of Department of Forestry, Mizoram University, for their time to time cooperation.

I sincerely thank all the non-teaching staff of Department of Forestry for their help and support.

At last my special thanks go to my family members especially my wife Kanchan Rawat and my little son Shivansh for endless support during the entire course of this journey.

Place: Aizawl.
Date: ________ April, 2019. (**Nagaraj Hegde**)

TABLE OF CONTENTS

List of Tables

List of Figures

List of abbreviations and symbols

Acronym/ Symbol	Full form/ Meaning
%	Percentage
@	At the rate of
CS at EL, CS at PL	Compressive/crushing strength at elastic limit/ proportional limit
CS at ML	Compressive/crushing strength at maximum load
et al.	Et alia, ‘and others’
etc	Etcetera
FSI	Forest Survey of India
g	Gram
i.e	That is
ICFRE	Indian Council of Forestry Research and Education
IS	Indian Standards
IWST	Institute of Wood Science and Technology
Kg	Kilogram
Kg/ cm^3	Kilogram per cubic centimeter (Density)
Kg/cm^2	Kilogram per square centimeter
MoE	Modulus of Elasticity
MoR	Modulus of Rupture
MSS	Maximum Shearing Stress
N	Newton
N/mm^2	Newton per square millimeter
NAU	Navsari Agricultural University
RLS	Radial longitudinal surface/section
S.G	Specific gravity
TLS	Tangential longitudinal surface/section
TS	Transverse section
UTM	Universal Testing Machine

Chapter- 1

INTRODUCTION

1.1 Mizoram forests and status of timber raw materials

North eastern part of India is unique in its biogeography. All the north eastern states are predominantly hilly. Mizoram is the southernmost located hilly state in this part of the country. As per the latest state of forests report, Mizoram has 86.27% forest cover, one of the highest among Indian states. But it is important to note that out of 18,186 sq. km. of forest, only 131 sq. km. area is under very dense forests which indicate the poor stocking of forests as reported by the Indian state of forests report (Anonymous, 2017).

In India forests are not regarded only as a source of revenue. They are the assets and need to be protected and improved for the benefit of both the people and the nation, taking into account their role in maintaining necessary ecological processes and life support system (Anonymous, 1988). Even though north eastern region particularly Mizoram is rich in green cover there is sparse scope for marketable felling of trees in Mizoram as there is poor stocking in the forests (NEDFi databank, 2011).

Working schemes have been made for extraction of timber (planks and scantling) from various Forest Divisions with fixed target quantities of sawn timbers. Such extracted timbers are transported to departmental godown at various places for selling to public. This is done to reduce the gravity of illegal timber operations at certain corners. In order to compensate such extracted timbers, the State Government is taking up afforestation activities by planting good timber bearing tree species at various Forest Divisions where working schemes have been implemented. Still there is a need for quality timbers or otherwise utility values of locally available timbers need to be known whose properties related to structural utilization is largely unknown.

Structural and commercial timber requirement of the state is mainly met by bamboo, and few timbers like Teak, *Michelia*, *Gmelina* and few more albeit insufficiently. Official extraction from natural forests in the state of Mizoram is on an average 6670 m^3 for the last ten years which is second lowest among the neighboring hilly states (ICFRE, 2010). The quantity of Indian timber import is as large as that of domestic extraction. Mainly imports are from Malaysia (57 %) and Myanmar (18 %) (Yadav and Basera, 2013). Myanmar is the bordering country with Mizoram; therefore Mizoram also is dependent on huge imports of Teak wood from neighboring country.

1.2 Wood properties

Utilization of a particular species in general terms depends on its technical quality and certain physical and mechanical properties. These properties include machining properties, form of the tree, durability, swelling and shrinkage, color, luster, texture, grain, odor, density and strength properties. Properties like strength, density are directly influence the utility of the timber whereas other properties such as color, odor, grain, and luster are important for commercial appeal. It is important to investigate these properties for variety of locally available timbers in order to explore any possibilities about their utility. Density of a timber directly affects the strength of the timber. In general moderate to heavy timbers show considerably higher strength than the low density timbers. Better compression strength along the grain makes the timber suitable to be used as pillars, columns, posts *etc.* whereas compression strength across the grain has its application in sleepers, flooring and such uses where timber is laid horizontally. Timbers used as beams in structures have to have greater bending strength. Shear along the grain and across the grain tests the fiber separation in timber when the load is given disproportionately. Tensile strength and shear strength also determine the suitability of timbers to be used in bending elements.

Hardness is the ability of the wood to resist the indentation by foreign materials. This is applicable in showing resistance against abrasiveness. Resistance offered by timbers against the sudden load determines its suitability for making sports goods and tool handles where often sudden load is applied. Brittleness of the timber determines the nail and screw holding ability of timbers. This is a very important property when the timber is used for making furniture, panels, handicrafts etc. Apart from these the physical properties such as color, luster and grain pattern decides the natural decorative feature of wood.

Research on wood properties has in most cases contributed to creation of better products (Kauman, 1990). Knowledge of wood properties is essential for specific utilization of timber. As the properties like density, shrinkage, ability to resist load, hardness *etc*. indicate the quality of wood, it makes the job of engineers, carpenters and builders easy to choose between variety of timber species for different purposes. Properties of wood whether it is physical, mechanical, chemical or anatomical, help in identification as well. Given that wood is a popular and valuable material, it is vital that professionals be able to make a distinction between the wood of one species from another. Wood can be recognized by using physical properties like density, hardness, odor, texture and color. Consistent wood identification often requires the ability to distinguish basic differences in cellular arrangement and wood structure (Rao and Juneja, 1971). A comprehensive delineation of wood properties is necessary for assessing the use of a timber species for processing and for the detection of wood samples (Ratih and Sri, 2010). Wood is an anisotropic material. Its properties changes within the species also sometimes from stem wood to branch wood, pith to periphery, heartwood to sap wood *etc*. When we go for reasoning the wood properties variation within or between the species of timber, it is important to note that these properties are dependent on one another to varying degrees; for instance, it is proved beyond doubts that density affects most of the mechanical properties of wood. Several reports have shown that cell wall constituents, micro-fibril angle affect the strength of wood, thereby structural and other specific utilization of wood. Therefore, correlation and comparison studies in this valuable raw material become very important. For this reason, assessment of properties of any new timbers has to be accompanied with the comparison of such properties with the commercially available timbers whose properties are frequently reported owing to its widespread utilization.

1.3 Lesser known timbers of Mizoram

Some of the most important timbers in the mainstream utilization in the state of Mizoram are *Tectona grandis, Terminalia myriocarpa, Toona ciliata, Gmelina arborea, Michelia champaca, Hevia brasiliensis, Phoebe haenesiana, Pinus khasiana, Albizzia procera etc*., largely these are supplied by plantations from nearby states like Meghalaya and through import from bordering country Myanmar. Vast assemblages of trees in the forests of Mizoram are under-utilized and regarded as 'miscellaneous timbers or Jungle wood'. Wood quality or potential uses of these timbers remain poorly known (Bhat *et al*, 2008). In majority of the cases these woods are considered inferior due to a variety of reasons and are not preferred for specific purposes other than small constructions and packing cases *etc*. Though, it is sensible to reckon that such jungle wood species together make up considerable part of the total forest assets. Hence, increased utilization of these lesser known timbers could be a solution for scarcity of traditionally used timbers. According to Tamolang *et al*., (1982), it is evident that some of these less popular hardwoods are potentially effective alternatives for mainstream timbers. In some cases few timbers less known once, gained much importance later in the commercial market.

Thus, testing of properties of under-utilized tree species for their timber value has great significance to prudently utilize our limited resources. Further, several potential timbers are poorly exported because of lack of supply. However, there is plenty of scope for enhancing their utility at a regional level. By adopting improved processing, the quality of these timbers could be enhanced in terms of its dimensional stability, service life and working traits such that they can be utilized for a specific newer use. Besides utilization, study of properties of local timber species has got both informative and academic worth. With a goal of giving an insight into alternative timber yielding species in the state of Mizoram which could eventually be brought into mainstream utilization upon testing of their properties and assigning suitability criteria, the present work was undertaken with the following objectives:

Objectives

1. To determine the physical and mechanical properties of selected lesser known species of Mizoram
2. Correlation of the strength properties of selected timber species with density and cell wall constituents
3. To compare the physical and mechanical properties of lesser known species with commercially used timber species and suggest possible utility

Chapter- 2

REVIEW OF LITERATURE

Over the years several researchers in India and abroad have studied the physical and mechanical properties of commercially used as well as lesser known/underutilized timber species. Most of the research findings throw light on the importance of study of wood properties in assigning specific timber for specific utility. Even though the available literature pertaining to the present study is limited, important research articles are reviewed under the following headings:

2.1 Physical and mechanical properties

2.2 Cell constituents

2.3 Correlation and Comparison studies

2.1 Physical and mechanical properties

Physical properties include density of wood, shrinkage behavior in three primary directions of wood, moisture content and general features of wood. They decide the wood quality and use (Sekhar, 1988). Different species of wood have different properties and rarely two woods are similar in all the aspects of wood quality (Konwer *et al*., 2001). Mechanical properties are strength properties i.e. resistance of wood against different kinds of loads acting on different faces of wood. Major properties include bending strength, compression strength, tensile strength, shear strength, screw holding power, hardness *etc*. Various studies conducted on these aspects of wood are summarized below.

Izekor *et al*. (2010) in their study investigated the effect of density on mechanical properties of 15 years, 20 years and 25 years old *Tectona grandis* wood. They found the density to be affecting the strength properties positively and also found higher MoE, MoR and compressive strength in the 25 year old wood. Further, the properties increased from pith to periphery and decreased from base upwards.

Alam *et al*. (2016) studied the effect of drying schedule on physical and mechanical properties of *Mangifera indica*, *Gmelina arborea* and *Swietenia macrophylla*. Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) of these woods were reported to be increased significantly under new drying schedule compared to the green wood. Water absorption and thickness swelling were lowered when dried with new drying schedule. Drying defects were comparatively lower in new drying schedule compared to accelerated drying schedule even though the drying rate was slow.

Wahab *et al.* (2014) investigated the strength properties of some Malaysian timbers using small clear samples as well as structural timber and found the correlation between them linear. They introduced the sort-plot technique to select appropriate model for modulus of elasticity and modulus of rupture.

Rabbi *et al*. (2015) has shown that vacuum treated wood shown considerable improvement in the properties like Moisture content and density. However, the increase in density is due to the retention of wood preservative in the wood samples.

Bhat *et al*. (2008) in their handbook of lesser known timbers described the properties of 77 timber species in the domestic market particularly in Kerala. 52 of the species among these were imported timber species. For these timber species they provided the gross features, physical properties and compression strength parallel to grain.

Anish *et al*. (2015) analyzed the effect of growth rate on some properties of teak wood procured from 14 different locations from within and outside India grown under different locality conditions. In their findings properties like shrinkage, moisture content and specific gravity were higher in fast grown timbers compared to slow grown timbers, whereas vessel dimensions and extractive contents were higher in slow grown timbers.

Rana *et al*. (2015) studied some important physical and mechanical properties of coconut palm from the Khulna region of Bangladesh. They compared these properties for air dried and oven dried samples. MoE, MoR were higher in air dry samples whereas compression strength was higher in air dry samples.

Dadzie *et al*. (2016) analyzed the physical, mechanical and anatomical properties separately for branch wood and stem wood of *Khaya ivorensis* and *Entandrophragma cylindricum* found that branch wood had significantly higher density than stem wood but strength properties were found to be higher in stem wood. Fiber proportions in both stem wood and branch wood were positively correlated with the density, MoE and MoR, however, compression strength and bending strength were less influenced by anatomical properties.

Saravanan *et al*. (2014) compared the Physical and Mechanical properties of *Melia dubi*a with *Tectona grandis* at varying age gradations. Five year-old *M. dubia* samples recorded maximum density of 500.20 kg m^{-3} and specific gravity of 0.60. This study established the appropriateness of five year old *Melia* wood for making plywood, packing cases, pencil and light weight furniture as it registered maximum value for all the physical and mechanical parameters.

Shanavas and Kumar (2006) evaluated properties of three tree species from Agroforestry systems of Kerala, namely, *A. auriculiformis*, *A. mangium*, and *Grevillea robusta*. Wood basic density of *A. auriculiformis* was greater than that of A. *mangium* & *G. robusta*, where as moisture content was higher in *G. robusta* followed by *A. mangium* & *A. auriculiformis*. Wood density increased from pith outwards radially except for *G. robusta*. Though moisture content reduced from the inner to outer position of the specimens for *A. mangium*, no particular pattern was obvious in this for the other two species. Shrinkage along radial direction followed a pattern as wood moisture content. Most of the strength properties followed a pattern related to that of density. Properties like work to proportional limit and work to maximum load in static bending, compressive strength at proportional limit in parallel to grain, compressive strength at proportional limit in perpendicular to grain, hardness of *A. auriculiformis* were greater than that for teak wood.

Falemara *et al*. (2012) emphasized on the significance of identification of wood for the industrial users of wood (primary and secondary), museums, as well as to scientists in various fields like ecology, forestry and wood technology. They were of the opinion that consistent wood identification generally calls for the ability to know basic differences in cell arrangement and wood structure. In their study properties (physical) of 10 indigenous Nigerian wood species was determined and distinction in all the traits was recorded. Similarly, Zbonak *et al.* (2007) in their evaluation of six Eucalyptus genotypes compared growth, density and anatomical differences in wood. They studied the above said differences in coppiced and parent trees of Eucalyptus. Study proved that the timber of mother tree and coppice were comparable in terms of vessel features and wall thickness of fibre. Incidentally they found that the mother trees had fibers with significantly smaller sized lumen. As a result, the wood density of the mother trees of eucalyptus trees was higher compared to that of coppice.

Anoop *et al*. (2014) assessed physical, mechanical and anatomical traits of *Swietenia macrophylla* using freshly felled, air dried and oven dried samples. Results revealed the *Swietenia* logs had a bark thickness of 2.9±2.1 mm. Heartwood (%) was found to be 89±3 % and the sawn wood recovery was about 54%. Most of the wood properties differed in the radial directions from pith outwards. They also correlated the Physical and mechanical properties with microscopic properties. Majority of the wood properties were similar to that of teak. This study also recommended the potential use of mahogany for afforestation in Kerala owing to its comparable properties with commercial timbers.

Wahab *et al*. (2012) evaluated the density, dimensional stability of a tropical cultivated bamboo of 3 years age (*Gigantochloa scortechinii*). They also studied the tension and shear properties of this bamboo. Naji *et al*. (2011) deliberated the effect of growth rate on density and microscopic characteristics of Rubberwood. They carried out the study in two separate clonal trials. They opined that the connection between growth rate and properties of wood is of great importance in the management of rubber plantations for wood as well as fiber production. They evaluated anatomical features and basic density, their correlation in two different clones as well as from pith to bark variations. In first clone, Wood density of 0.65 was recorded and $0.54 g.cm^{-3}$ was recorded in the second clone. From pith to bark increasing trend was observed between density and fiber characteristics. Similarly, vessel parameters were also directly correlated with density of plant.

Dadzie *et al*. (2016) investigated anatomical and physical properties of stem wood and branch wood of two hardwood species namely *Pterygota macrocarpa and Terminalia superba.* The samples obtained from two natural forest patches were subjected to microscopic studies for measuring vessel (diameter and frequency) and fibre (length, proportions) parameters. They found the wood density in branch wood of *Terminalia* was higher than that of *Pterygota*. They observed significant difference in fibre proportions from branch wood to stem wood.

Chowdhury *et al*. 2012 studied the variations in microscopic features and its relationship with density in ten year old *Casuarina* wood. They conducted sampling at different depths in the wood from pith outwards. Vessel lumen diameter increased from pith outwards where as vessel frequency decreased in those sample points from pith outwards. Fibre content (%) and vessel content (%) increased gradually from pith to bark but that of parenchyma decreased towards bark.

Bhat (1994) examined wood quality features of twenty one lesser-known timber species in Kerala forests. They investigated gross properties like grain, color, texture, specific gravity, sap wood to heartwood percentage and few anatomical features. Comparable values of most of the properties studied were found with commercially available timbers in the market. In few of the studied trees like *Ormosia*, *Aporusa*, *Pterospermum* very distinct wide heartwood was found.

Remaining species found to be less durable due to the presence of indistinct heartwood. The author suggested requirement of wood preservative treatment to enhance the durability of the studied timber species. Such studies are very important to try out alternatives to replace the mainstream timbers in the time of scarcity as wood as a raw material is shrinking day by day.

Elzaki and Khider (2013) investigated the properties of wood of twenty year aged *Cupresses* species from western Sudan. They compared the specific gravity of this species with other *Cupressus* species of India and Costa Rica. They found the average specific gravity of 0.52 was higher than other two compared species which had specific gravities 0.45 and 0.43 respectively. They also studied the wood-bark ratio both by mass and by volume. They were found to be in the normal range for all the tropical softwood species compared. Among the three cypress species Indian cypress had higher MoR of 793 Kpa/cm^2 compared to the Costa Rican cypress with 693 kpa/cm^2. In case compression strength and shear strength the Sudan cypress was higher than both the compared species.

Kiaei, M. and Samariha, A. (2011) determined few of the physical, anatomical and mechanical properties for *Pinus eldarica* wood. They gave a regression model involving wood density as independent variable and strength properties as dependent variable. They found that a strong relationships between density and MoR as well as compression strength whereas, MoE showed weak or no linear correlation with that of wood density. When the results were compared with other locations of Iran there was significant variation in all the properties studied.

Uday *et al*. (2011) studied the potential suitability of Malabar Neem wood (*Melia dubia*) for the manufacture of plywood. Their investigation revealed better physical properties of peeled veneers (shrinkage behavior) and higher glue adhesion strength with both PF and UF resins.

Bhatt *et al*. (2015) studied the tensile strengths of some important timber species like Teak, Sal, Dark red, Light red and Yellow Meranti. The investigations revealed that the indigenous Sal followed by Teak had shown highest tensile strength compared to the imported Meranti.

Sekhar and Rajput (1967) observed the radial, tangential and volumetric shrinkage of various timber specimens with reference to specific gravity and fiber saturation point. The major finding was that the shrinkage behavior is governed by the specific gravity of the wood substance.

Tang (2007) opined that *Fraxinus* wood may be used in furnitures, sports goods and tool handles owing to its strength and elastic nature. Using the alternate drying and wetting methods the author analyzed the shrinkage & swelling percentage of the wood. They estimated the density of the species to be around 730 kg/m^3. Percent shrinkage and swelling was estimated after recording the dimensions before and after wetting the specimens. Finally the results were compared with the other varieties of the same species and white ash found to be showing lower shrinkage and swelling values thereby being most stable dimensionally.

Rew (2008) in his study assessed the specific gravity of 12 tree species of agroforestry importance. As per their evaluation specific gravity of scattered trees in the agricultural lands ranged between 0.42 and 0.85, majority of the species having values less than 0.6 (specific gravity). The author emphasized the necessity of specific gravity to be an important factor while choosing the tree component in the agroforestry systems as the factor in most cases is a major indicator of potential utility of timber.

Dhillon and Sidhu (2007) determined the specific gravity of poplar wood samples from two locations which were collected at 1.37 m height from ground level (breast height). They found out significant differences in the specific gravity among the clones from two locations. Specific gravity of wood was ranging from 0.403 to 0.475 and from 0.356 to 0.436 in Central plain Semi-Arid Regions respectively.

Lokman and Mohd Noor (2010) worked on *Acacia mangium* from five different provenances of Malaysia. They observed the specific gravity changes from pith outwards. In their study they observed specific gravity near pith was very less (0.20) and towards bark specific gravity was about 0.8. However, in a report by Sanwo (1986) it was deduced that growth rate did not significantly influenced the specific gravity in their work on teak planted in Nigeria. Also, Kadambi (1972) reported that varying degree of thinning (Very heavy and moderate) had no effect on strength properties.

Increase of specific gravity with height of the tree as well as inner to outer radius was reported by Pande *et al*. (2012) where they studied ten different clones of Poplar from Rudrapur, India. In their study they noticed a striking feature where female mother trees were shoving higher density than the male parent trees.

Bhat and Priya (2004) elaborated the provenance variation in the wood properties of *Tectona grandis* from different regions in the southern Western Ghats of Kerala. As per their findings Modulus of Elasticity and Modulus of Rupture were higher in a particular provenance where growth rate of teak was slow. Incidentally it had high percentage of cell wall. In addition to this relation Rahman *et al*. (2005) have mentioned that higher strength and density was observed in *Tectona* trees with maximum ray volume.

Olufemi and Malami (2011) in their study of mechanical properties of *Eucalyptus camaldulensis* reported the density of the tree to be on an average 977.58 kg m^{-3}, bending strength to be 133.33 Nmm^{-2}. However, samples collected from three different locations were differing significantly for all the properties of strength. In addition they reported the MoE to be 15219.89N mm^{-2}.

Kiaei and Samariha (2011) studied the oven-dry density, MoE, MoR, compression strength (parallel to the grain) of five temperate broadleaved tree species i.e. *Quercus castaneaefolia*, *Fagus orientalis*, *Carpinus betulus*, *Alnus glutinosa* and *Fraxinus excelsior*. *Alnus* was reported to be having lowest values in all properties among the selected trees. In order of greater strength values *Carpinus, Fagus, Fraxinus* and *Quercus* were reported to be having considerable values of MoE, MoR, density.

Thulasidas and Bhat (2012) did a comparative study in properties of teak trees grown in home garden with those in forest plantation. They studied various strength properties like MoE, MoR and compression strength. Differences of MoE and MoR values were not significant when two sources were compared. Among the home garden sources they further divided the sites as dry, wet and moderate. Teak trees grown in drier sites shown higher strength compared to those from plantation and other home gardens. They also correlated the strength properties with density and found a positive correlation in compression strength.

Ali *et al*. (2012) compared various strength properties of *Artocarpus heterophyllus* with Teak. They studied the properties like hardness, compression strength (along and across the grain), and nail holding capacity, Shear strength in both green and dry conditions. In both the cases all the strength properties studied were lower than that of Teak.

Awan *et al*. (2012) studied the wood properties of farm-grown *Eucalyptus* in comparison to traditional timbers like *Dalbergia*, *Acacia* and *Deodar*. The values of wood density (0.681 g cm^{-3}), MOR (1046 kg cm^{-2}), compressive strength parallel to grain (88 kg cm^{-2}) and compressive strength perpendicular to grain (56 kg cm^{-2}), tensile strength (610 kg cm^{-2}) and impact bending (578 kg cm^{-1}) of *E. camaldulensis* were recorded.

Hossain and Awal (2012) carried out extensive studies on the physical properties, strength properties and durability of a number of timber species namely Teak, Sal, SilKorai (*Albizia procera*), Rain Tree, Jamun, Jackfruit and Mango woods. The test results revealed that Sal, Teak and Jamun were suitable for by means of as compression strength and also showed the best performance in tensile stress. In static bending Sal, Albizia, Teak and Jamun have been found appropriate.

Skarvelis and Mantanis (2013) studied the properties of temperate hardwood *Fagus sylvatica* from Greece. Static bending strength was found to be 105.49 N/mm2, Compression parallel and perpendicular to the grain were 55.43 N/mm^2 and 48.54 N/mm^2 respectively.

Anoop *et al*. (2014) studied the properties of exotic Big Leaf Mahogany (*Swietenia macrophylla)* in Kerala. Results of bark thickness and heartwood percentage were 2.9 mm ad 83 % respectively. Significant difference was observed in wood properties all along from pith outwards. Many of the properties studied were in line with that of standard Teak wood. They also correlated strength properties with the anatomical properties.

Nordahlia *et al*. (2014) evaluated some wood properties of *Azadirachta excels* wood extracted from seedling origin and raised from root cuttings. They studied Moe, MoR, Compression and Shear strength. MoR was better in vegetative propagated wood where as MoE was found higher in seedling originated trees. Among the two wood sources the former was also showing better quality parameters in compression and shear strength. However, among both the wood sources properties increased significantly from basal portion of the stem towards top of the stem.

Huda *et al*. (2014) studied the inter-clonal variation in wood properties from 7 clones of poplar from Canada. They found hybrid clones poplar among all the clones was better in most of the strength properties. Another observation was the genetic gain of these properties in the hybrid clone ranged from 2 – 13.5 percent.

Okoh (2014) investigated various properties like density MoR, Moe and Compression strength of 4 timber species namely, *Terminalia superba* , *Terminalia ivorensis, Quassia undulata* and *Recinodendron heudelotii*. Out of these four the former two were threatened and the latter two were lesser known timbers. They found significant differences in the density, and other strength properties of lesser known species. The same were insignificant in the two threatened species of timber. Hence they recommended both the lesser known timber as potential replacements for the two *Terminalia* species which are becoming rare and threatened.

Zahabu *et al*. (2015) conducted various experiments on plantation teak in Tanzania. They studied the effect of different plant spacing (2 m x 2 m, 3 m x 3 m and 4 m x 4 m) on wood properties as well as growth parameters. Density was found to be unaffected by spacing but heartwood content slightly improved with the higher spacing. Even the wood strength properties were unaffected by increased spacing. Major recommendations were to use the moderate spacing of 3m by 3m and for lower spacing regular thinning in an immature stand was advised.

2.2 Cell constituents

Chemical properties are known to affect the inherent mechanical properties of wood as suggested by number of studies across the world.

Erickson and Arima (1974) studied the wood quality parameters of Douglas Fir and found that faster growth increased the lignin content by around 0.7 % when compared to the normally grown trees. Holocellulose and alpha cellulose contents increased from pith outwards in test trees. They observed that up to twenty years of growth there was the said variation and after that the variation properties gradually decreased.

Khurana *et al*. (1983) noted significant variations chemical contents like holo-cellulose, lignin content and ash content in dioecious trees of Poplar naturally occurring in natural forest and ravine lands. In a study conducted by Wilde and Paul (1959) 10 % variation was found among the poplar trees in terms of density and cell wall components. They discussed that the reason may be the site factors where the tree were grown. In the same species Mullins and Mcknight (1981) reported 53 % cellulose content, 31 % hemicelluloses content and 16% lignin content.

Narayanamurti and Das (1955) found in the wood of *Dalbergia sissoo* that the inner heartwood yielded more extractive content than that of sap-wood. Narayanamurti and Verma (1964) used the solvent (Hot and cold water, Alcohol-benzene) extracts of Sissoo wood on extracellular enzymes like amylase, invertase and cellulase obtained from fungi *viz; Polystictus versicolor* and *Ganoderma lucidum* in varying concentrations. In the same species Yasin and Qureshi (1989) extracted using hot water and cold water from the saw dust collected from bark along with 7 other timber species. They found higher hot water solubility (9.05 %) as against the cold water solubility which showed lower solubility (1.14 to 5.18 %).

From the proximate analysis of *Albizia lebbeck* samples Manmohan and Mukhergee (1965) found that cellulose was 52.47%, liginin content was 22.90% and ash content was 0.72%. Further, by sulphate process of pulping they reported 50 % of pulp yield and 17 % of pentosan content.

Kawamura and Bland (1967) reported that differences in lignin content in a number of species of *Eucalyptus* were because of the reason that there are climatic fluctuations in the tropical temperate zone. In supplement to this Unkalkar *et al.* (1975) reported that water and alcohol-benzene solubility tend to show rapid decline from base up wards in middle aged *Eucalyptus* hybrid.

Sharma and Dobhal (1969) studied the variation in catechin content in *Acacia catechu.* Their major finding was extractive content particularly catechin content increased with age. As reported by Karnik *et al*. (1971) A. catechu wood contains 30-35 % of cellulose where as holocellulose content was as high as 74 %. They further observed the solubility of wood substances to be more in hot water than in cold water.

Singh *et al*. (1972) reported that *Lagerstromia* and *Terminalia* are suitable for manufacture of various types of paper owing to their chemical properties. Results indicated the presence of hot water solubility (5.0, 4.9), alcohol benezene solubility (3.7, 1.7) ash content (19, 1.1)), pentosans (13.8, 14.5) and lignin content (26.3, 27.4) respectively for two species.

Guha and Pant (1981) conducted chemical analysis of *Ailanthus excelsa* to test its suitability as raw material for paper and pulp manufacture. Ash content was found to be 2.14%, hot water solubility was 3.6% and lignin was reported to be 30.08%.

Stinger and Olson (1987) took samples from random trees at varying heights. They found that total extractives contents were not varying significantly with height. However, ethyl alcohol-benzene and hot water extractives content inversely proportional to the height of sampling.

Upreti *et al*. (1999) found higher water soluble extractive content in the wood of Bijasal (*P. marsupium*) and opined that it is therefore unsuitable for using in exterior conditions where there is a risk of leaching. They also tried some water repellants (inorganic salts) to reduce the leaching loss.

Sharma and Sharma (2003) studied the chemical properties of three species of *Eucalyptus* namely *E. camaldulensis, E. teriticornes and E. globulus*. Comparing the samples from bottom to top of the tree lignin content decreased while holocellulose content increased in *E. tereticornis*. In the other two species solubility in caustic soda was ranging from 15 to 18 %. In *E camaldulensis*, Mahdavi *et al.* (2004) found that cellulose content being 47.44 %; lignin content being 30.87 % and extractive content was 6.96 %.

Adamopoulos *et al*. (2005) took wood samples from basal, middle and top portions of *Robinia pseudocasia* tree to determine the variations in the cell wall constituents. From hot water extraction they found that extractive content was higher in heartwood than sapwood. From methane extract the trend was opposite. In heartwood extractive content increased from base upwards where as the opposite trend was observed in case of sapwood. Lignin content was also greater in heartwood compared to sap wood. Heartwood lignin content was decreased from bottom to middle and top portion unlike extractive content.

Carballo *et al*. (2005) in their study assessed the chemical constituents in the wood of three Eucalyptus species *namely E. pellita*, *E. saligna* and *E. citriodora*. *E. citriodora* shown higher content of cellulose and lower extractives and lignin compared to the other two species and thus concluded this to be most suitable species for pulp and paper industry. Another study on chemical properties of *E. saligna* wood samples collected from different heights was carried out by OreaIgarza *et al*. (2005). They estimated ash content, extractives, cellulose, hemicelluloses and lignin contents at different heights of commercial bole of the tree. , Extractive and lignin content increased with the height, cellulose found to decreasing with height. But the chemical structure of cellulose was found to be varying with height.

Russell *et al*. (2005) worked on *E. globulus* to see the effect of plant spacing on the chemical properties. They observed higher spacing resulted in increased cellulose content and extractives. Lower spacing helped increase of hemicelluloses content while ligin content seemed to be unaffected by planting distance.

Barbosa *et al*. (2007) used the crude extracts from *Scleronema micranthum* and *Pouteria guianensis* against the termites and found effective. They found extractive content in bark was 2.5 % and in leaves was 4.5 %. Diaz *et al.*, (2007) demonstrated that pulping time and cooking chemical cost can be reduced if lignin content in the lignocellulosic material is low. They also established a negative correlation between extractive content and pulp yield in the wood.

Willow wood (Salix) is famous for its suitability in making new hybrids and varieties. Szczukowski *et al.* (2008) in their study of chemical constituents of *Salix viminalis* reported high cellulose content in the range of 46 % to 51 %. However, in the inter-specific hybrid between *Salix viminalis* and S. *purpurea*, 43 per cent cellulose was observed. Lignin content ranged from 22.91 % to 26.97 %. Amount of Holocellulose ranged from 72 % to 78 %.

Lopez *et al*. (2008) reported in the Agroforestry species Subabul (*Leucaena leucocephala*) that various chemical components like extractives, holocellulose and lignin were 4.6 %, 75.9 % and 21.4 % respectively.

Bamboo is a well known raw material for pulp and paper industries owing to its suitable chemical composition. Yang *et al*. (2009) in their study *Bambusa chungii* from eight different provenances reported a significant difference among the source in extractive content and lignin. They found negative correlation in yield of bamboo culms and *vis a vis* extractive content.

Raiskila (2008) evaluated different clones of Norway spruce raised by cuttings in three different quality sites and reported that clones from fertile site shown highest lignin content in the sapwood. However, the clones from degraded sites produced lower amount of lignin in their sapwood.

Hindi and Bakhaswain (2010) used vegetative parts of date palm (*Phoenix dactylifera*) for estimation of chemical constituents. They also used the various wood resources namely, *Conocorpus erectus,* Subabul, *Simmondsia chinensis,* Neem and *Moringa peregrine*. They determined fiber length, specific gravity and chemical composition for these different natural sources. All the traits investigated significantly varied. Subabul was the best resource due to its high holocellulose content of 70.82%. Specific gravity of Subabul was found to be 0.597.

Adi *et al*. (2011) studied the chemical properties of three Sal (Meranti) species locally named Sangkan, Bakau, and Bunga kulit Hitam from Riau. They reported hihest holocellulose content from Sangkan (72.97 %) followed by Bakau (75.28 %) and Bunga kulit Hitam (69.88 %). Out of these cellulose contents was found to be 43.55 %, 51.14 per cent, and 43.25 per cent, respectively. Sangkan sal had the highest lignin content of 35.99% followed by Bakau with 34.21% and Bunga Kulit Hitam having 32.18%. Bunga Kulit Hitam had the highest extractive content of 2.24% followed by Sangkan with 1.66% and Bakau was showing 1.08%.

Al-Meffarej *et al.* (2011) investigated the influence of spacing and tree height of *Leucaena leucocephala* on its chemical composition. Broader spacing resulted in higher values of cellulose (46.9%), ash contents (2.53 %) and extractives (8.92 %). Closer spacing resulted in higher hemicelluloses content (21.05 %). Lignin was not found to be affected by spacing.

Kasmani *et al*. (2011) evaluated chemical properties of *Eucalyptus camaldulensis*. They took the wood samples from different age groups of trees. The results of the study revealed that with age increase cellulose content, extractive content and lignin content increased significantly. However, higher hemicelluloses and ash content were found in lower aged trees. Similar results in *Eucalyptus camaldulensis* was also reported by Mohammadi *et al.* (2011).

Samariha and Kiaei (2011) in their study on chemical properties of *Ailanthus altissima* wood reported lower values of chemical properties in branchwood when compared to slightly higher values in stem wood.

Miranda *et al*. (2012) used the bark of *Eucalyptus globulus* for pulping by kraft method. The results indicated the unsuitability of the bark over wood for pulping. The reason being the presence of polar extractives in bark (5.3%) was very high compared to that of wood (1.6%) despite of having higher fiber length than wood. Finally relatively lower yield was observed from the kraft pulp of bark.

Browning (1963), evaluated the cellulose content (%) of five species namely *Qualea dinizii, Lucuma dissepala, Protium heptaphyllum* and *Cecropia juranyan*. The values of holocellulose were varying from 69.3% to an upper limit of 73.8%. These results were in agreement with Barauna *et al.* (2014) who reported holocellulose content (%) in the wood of *Brosimum parinarioides* as 63.3%. they also found the lignin content to be 30.51%, which were in agreement with results obtained by Miller (1999), in which case the lignin content (%) ranged from 21 % to 33%. Total extractives (%) in *Brosimum* wood were in line with most of the Amazon timbers.

2.3 Correlation and comparison studies

Wood properties change from and within species. Properties like density and cell components invariably affect the strength properties to a great deal. Comparison studies also become very important to rank the wooden raw material for general and special purposes. Because the wood as raw material is ever shrinking, it is always useful to have variety of options for each purposes to which wood is put into use. Several comparison and correlation studies add useful information for scientific utilization of wood.

Wang *et al.* (1996) correlated the growth characteristic and wood quality characteristics of poplar (*Populus*). They found significant positive correlation between fibre characteristics, density and DBH.

Nasser (2008) observed a significant positive correlation between wood density and strength properties in *Melia azedarach* both in mature wood as well as juvenile wood. Correlation coefficient (r) values for juvenile wood ranged from 0.57 to 0.90. For mature wood these values ranged from 0.67 to 0.91. Similar trends were observed in the works of with El-Osta *et al*. (1981), Schniewind and Gammon (1986) and Pometti *et al.* (2009). All these researchers agreed that mechanical properties of wood are positively correlated with specific gravity of wood.

Nasser (2008) observed that the chemical properties of *Melia azedarach* wood were closely correlated with mechanical properties like Modulus of Rupture, Modulus of Elasticity and maximum crushing strength. Negative correlation was found between percent hemicellulose and each of MoE, MoR and crushing strength. These results were in agreement with those of El-Osta *et al*. (1981) and El-Sayed *et al.* (2009). Similar trends were observed for juvenile wood but for the 'r' values belong to hemicellulose and ash contents were not significant. Extractives content (%) showed significant positive correlation with each of mechanical properties for both juvenile wood where 'r' values were ranging from 0.55 to 0.83 as well as mature wood where 'r' values ranged from 0.50 to 0.89. these results indicated higher the extractives content (%) of wood the higher the mechanical properties which led them to suggest that extractives have an important role in reinforcing the cell walls. In contrary to these results, Badran and El-Osta (1977) observed dissimilar trends. This incongruity may be because of the reason that it is difficult to locate the exact origin of the extractives in the wood. They further explained that if lumen of the cell contains major extractives that may not affect the mechanical properties of the wood. However, if these extractives were to be located inside the region of cell wall structure, they could possibly affect the strength of the timber as reported by El-Osta *et al.*, (1981). Hernandez and Salazar (2006) argued that to avoid this complication the variations in strength properties of wood shall be explained both in terms of specific gravity and extractives content (%).

Kiaei and Samariha (2011) studied the anatomical properties like fibre length, fibre width, wall thickness of cell and its lumen diameter. They also studied physical properties like density and mechanical properties such as modulus of rupture (MoR), modulus of elasticity (MoE), and compression strength parallel to the grain of different temperate hardwood species like *Quercus castaneaefolia*, *Fagus orientalis*, *Carpinus betulus*, *Alnus glutinosa* and ash *Fraxinus excelsior*. The relationship between physical properties (wood density) and anatomical properties with strength properties were determined by correlation coefficients. Results indicated that the different tree species had significant effect on *vis a vis* wood properties. There were positive correlation between wood density and fiber properties and strength properties for different species. The highest values of wood density, MoR, MoE and compression parallel to the grain were found in *Carpinus, Fagus, Fraxinus,* and *Quercus*. The lowest mechanical strength was found in Alnus wood.

Uetimane and Ali (2011) studied the microscopic structural features of bamboo *Pseudolachnostylis maprounaefolia* and correlated them with physical and strength properties. The results revealed that fibre length was the only anatomical property which was having significant correlation with all the measured properties. Density was found to be having positive correlation with strength properties.

Thulasidas and Bhat (2012) evaluated the properties of Teak collected from home-garden found that compression strength was higher compared to the samples collected from teak plantations. Compressive strength was correlated with density and there was a significant positive correlation. They further observed fibre and lumen dimensions were also affecting the strength properties positively. The results of their study recommended the farmer choice to fell homestead teak at short-rotation of 35-years was not affecting the wood physical and mechanical properties.

Adeniyi *et al*. (2013) reported there was a simple negative correlation between vessel diameter and features like cell wall thickness, specific gravity, Modulus of Rupture and Modulus of Elasticity, in three different timber species namely, *Triplochiton scleroxylon*, *Ceiba pentandra* and *Bombax*. In these light weight timber species they observed that larger the pore size the lower was the strength properties. This negative relationship between pore size and mechanical properties were supplemented with the findings of Jacobsen *et al*. (2007) and Hugo *et al*. (2009). They were of the opinion that variation in wood specific gravity is mainly due to the variation in wood fibre dimensions particularly lumen diameter which is positively related to cell size and to cell wall thickness.

Maya and Narasimhamurthy (2015) in their study established significant negative correlation between lignin percentages to fibre diameter. They found no relationship between fibre length and lignin content. Further, no significant difference was found between cellulose proportions and fibre morphological features.

Sharma *et al.* (2014) observed variation in properties like fibre length and density in Terminalia myriocarpa (Combretaceae) from pith outwards. There was significant positive correlation in these properties except for vessel length which was not correlated. Based on their results of anatomical parameters at different points on the same radii, they could find out the distinction between the juvenile and mature wood to be 4 cm.

Riyaphan *et al*. (2015) found significant negative correlations between the chemical constituents (hemicellulose, lignin, and pentosan) and strength properties (cleavage strength, tensile strength) in Rubber wood. The cellulose content and lignin content were negatively correlated. Among strength properties, the significant correlation was found between MoE and MoR. Cellulose content was also significantly correlated with certain strength properties like cleavage, tensile strength and static bending. However, strength properties were not found significantly correlated with hemicelluloses and other chemical constituents.

Carrillo *et al*. (2015) studied fifteen year old *Eucalyptus globulus* trees, having wood density varying from 474 kg m^3 to 575 kg m^3. They conducted fibre measurement at breast height. Correlation between the fibre length and wood density was significant and positive. Positive correlation was also found between wall thickness and density as well as between fibre length and coarseness of wood.

Ajuziogu *et al*. (2014) studied the correlation between anatomical features and strength features in 10 commercially important timber species of Nigeria. The genera studied were *Gmelina, Ceiba, Diospyros, Brachystegia, Mansonia, Milica, Khaya, Periscopis, Afzelia* and *Gossweilerodendron*. Fibre length was found to be negatively coreelated with strength properties like compression, tension and hardness whereas fibre diameter was not found to be affecting the strength properties significantly. Vessel frequency showed significant positive correlation with the strength properties, but its effect was non significant with cleavage force. Similarly vessel diameter was found to be inversely related to the strength properties.

Chapter- 3

MATERIAL AND METHODS

3.0 Material and Methods

3.1 Species selection

Five species of lesser known timbers *viz., Schima wallichii, Duabanga grandiflora, Callicarpa arborea, Castanopsis tribuloides, Anogeissus acuminata* were selected for the study of wood properties. The criteria was to select locally available and well distributed timber species which are lesser known or underutilized in the commercial market and those lacking any report about their properties. However, some information about local utility as timber was gathered to have indication about their possible specific utility after testing of properties. A brief description about the selected species is given below.

***Schima wallichii* (DC) Korth**, (Family: Theaceae) locally called Pa khai is used locally to make paddy mortars (Sawmliana, 2013). *S. wallichii* is one of the dominant tree species in the forests of Mizoram. It is a fairly large sized evergreen tree with rough fissured bark (Fig 3.1- A). Timber of the tree is currently less used in furniture industry.

***Duabanga grandiflora* (DC) Walp.**, (Family: Sonneratiaceae) is a large semi evergreen tree with drooping branches, locally called as Zuang (Sawmliana, 2013). The leaves are very large and hence it is also commonly called lampati (Fig 3.1- B). The tree finds its use locally in scaffolding, mortars, small constructions but not known for furniture and other structural uses.

***Callicarpa arborea* Roxb.**, belongs to Family Lamiaceae commonly known as beautyberry is a middle sized evergreen tree (Fig 1- C) widely distributed throughout Mizoram up to an elevation of 1300 m. Locally it is called as Hnah-kiah (Sawmliana, 2013). Currently less used for structural purpose except for fence posts and charcoal making. Bark and leaves of this tree find their use as medicines locally for the ailments like diabetes, ulcers etc.

Anogeissus acuminata **(Roxb. Ex DC) Guill.** belongs to Family Combretaceae locally called as Zai-rum (Sawmliana, 2013) is a deciduous tree with drooping branches (Fig 3.1 - D) occurs widely throughout Mizoram usually below 1000 m altitude. The tree flowers during Jan-Feb and fruit bearing is in April-May. The bark of the tree has medicinal uses where the decoction is used in curing stomach troubles, fever and diarrhoea. Timber is locally known only for less uses like tool handles, posts etc (Gamble, 1992).

Castanopsis tribuloides **(Sm.) A. DC.,** belongs to family Fagaceae locally called as Thing-sia (Sawmliana, 2013). It is medium to large evergreen tree (Fig 3.1 - E) with lanceolate, entire leaves. This tree can be found throughout the state even up to an elevation of 1800 m. The tree flowers and fruits during Aug – Nov. The nuts of this plant are locally eaten by man and also wild animals. Wood is so far used only as firewood even though the wood is hard.

3.2 Sample collection and preparation

Destructive method was adopted to collect the small clear wood samples for both physical and mechanical properties analysis. Wood samples from matured trees with heartwood formation were collected for the study from natural forests as well as from felled trees in construction sites.

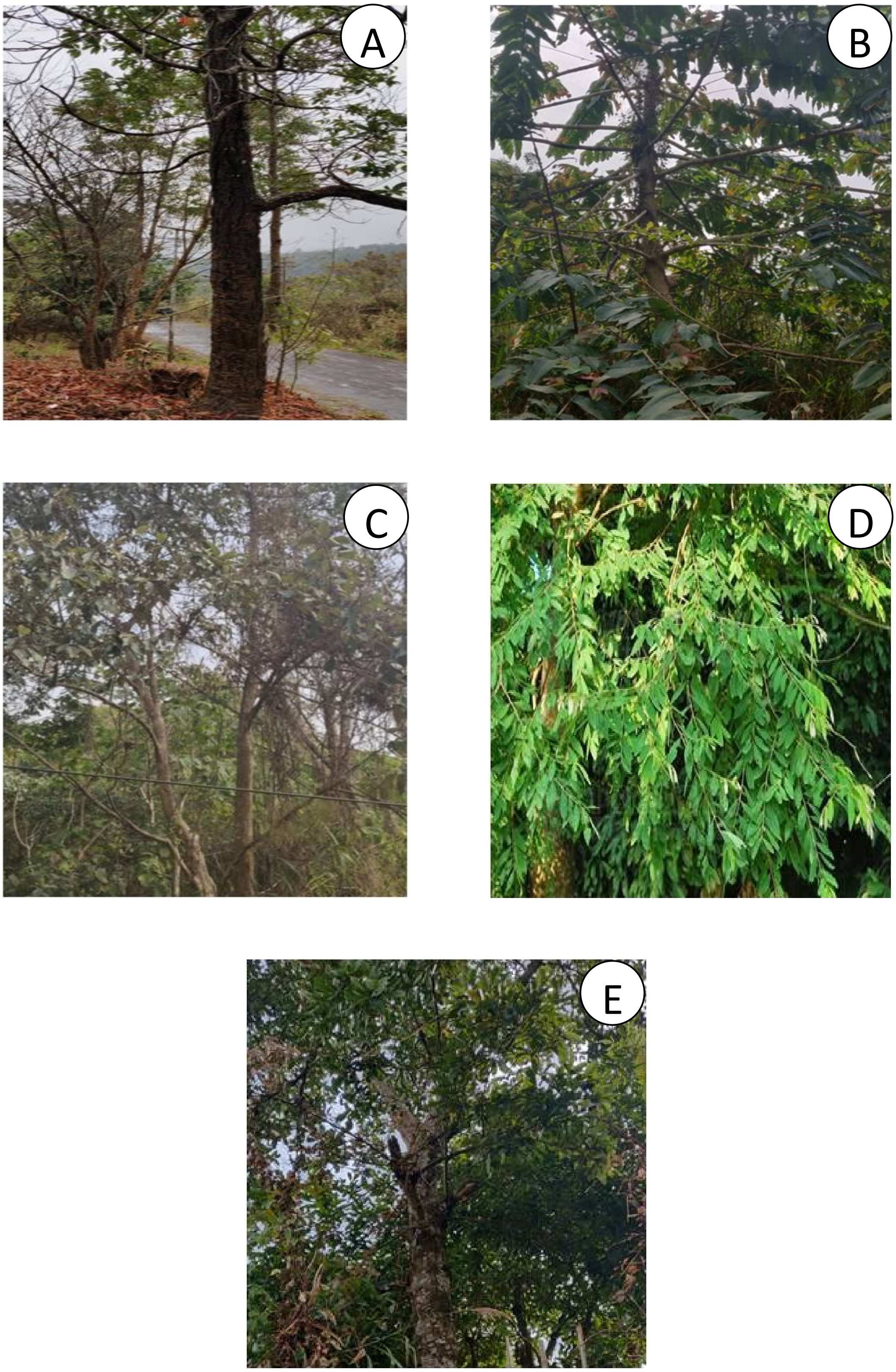

Figure 3.1 photographs of test species, A- *Schima wallichii***, B-** *Duabanga grandiflora***, C-** *Callicarpa arborea***, D-** *Anogeissus acuminata***, E-** *Castanopsis tribuloides*

The blocks of 1 m length were cut into scantlings of 40 cm × 5 cm × 5 cm dimensions for preparation of test samples from pith outwards in one radial direction. The scantlings were air dried for a period of 4-6 months. Replication for all the physical and mechanical tests was 15 and for cell constituents it was 10. Further, for different mechanical tests small clear samples of different dimensions were prepared as per the Indian Standard (IS: 1708) (**Table 3.1**).

Table 3.1. Dimensions of different small clear specimens for physical and mechanical tests (IS: 1708)

Parameter		**Sample dimension (lbt)**
Moisture content	:	2.5 cm × 2 cm × 2 cm
Density	:	6 cm × 2cm × 2 cm
Shrinkage and Swelling	:	6 cm × 2cm × 2 cm
Static bending	:	30 cm × 2 cm × 2 cm
Compression parallel to the grain	:	8 cm × 2 cm × 2 cm
Compression perpendicular to the grain	:	10 cm × 2 cm × 2 cm
Tensile strength	:	30 cm × 5 mm × 5 mm
Shear strength	:	3 cm × 2 cm × 2 cm
Hardness indentation test	:	10 cm × 2 cm × 2 cm
Screw holding power	:	15 cm × 5 cm × 5 cm

Process of sample preparation from logging to conversion is illustrated in the **Fig. 3.2.**

Figure 3.2. Sample preparation

3.3 Methodology

3.3.1 Gross features

Colour: Distinction in colour of heartwood and sapwood for all the species was observed and documented. Further, the color of heartwood was noted.

Texture: Arrangement of wood elements leading to give wood coarse, medium coarse or smooth texture was recorded on basis of visual observation.

Luster: Ability of wood surface to reflect light when viewed at different angles will give the wood either high or dull luster was recorded on basis of manual observation.

Grain: General alignment of wood elements giving different grain patterns like straight grain, interlocked grain, spiral grain; wavy grain etc was visually observed.

Odor: Any characteristic odor whether long lasting or not was recorded.

3.3.2 Moisture content:

The samples were weighed accurately to the margin of 0.001 g and then dried to constant temperature in an oven at standard temperature of 103 ± 2°C. Samples were weighed at an interval of 24 hours. The drying was stopped when the variation between two consecutive weights was not exceeding 0.002 g. Oven dry weight was recorded as final weight.

$$\text{MC (\%)} = (\text{Initial weight} - \text{Final weight}) \, / \, (\text{Final weight}) \times 100$$

3.3.3 Density:

For the estimation of basic density, the specimen was first weighed to 0.001 g accuracy on an electronic scale. The dimensions of rectangular specimen were measured to 0.01 cm accuracy with the help of a digital caliper and finally volume was estimated by multiplying the three dimensions of the specimen. The density was expressed as Kg/m^3.

$$\text{Density} = W/V$$

Where, W= weight at the time of test, and

V= volume of the test specimen

3.3.4 Shrinkage

The dimensions of rectangular specimen were measured to 0.01 cm accuracy and volume was calculated by multiplying all the dimensions of the specimen. The specimens were placed in oven till reaching required moisture content (~12%).

$$\text{Volumetric shrinkage} = (V_i - V_f)/(V_i) \times 100$$

$$\text{Tangential shrinkage} = (T_i - T_f)/(T_i) \times 100$$

$$\text{Radial shrinkage} = (R_i - R_f)/(R_i) \times 100$$

Where, V_i is initial volume, R_i and T_i are initial radial and tangential dimensions whereas V_f, T_f and R_f are respective values at required moisture content.

3.3.5 Static bending

Continuously increasing load was applied on the specimen in the center in such a way that the movable head provided in the testing machine moves at a constant rate of 1.0 mm min^{-1}. It should be noted that weight is applied on the tangential face of the test specimen.

Computer generated graph and data were used to calculate Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were calculated from the formulae given below.

$$\text{MOE } (\text{N/mm}^2) = \text{pl}^3/4\Delta\text{bh}^3$$

$$\text{MOR } (\text{N/mm}^2) = 3\text{Pl}/2\text{bh}^2$$

Where,

p = Load at the proportional limit, the point in stress-strain curve where linearity changes to non - linearity;

l = span/ length of test sample (mm)

b = breadth of the test sample (mm)

h = thickness of the test sample (mm)

P = maximum load

Δ = deflection in mm at the proportional limit

3.3.6 Compression parallel to grain test

Continuously increasing weight was applied axially on the end grain surface of the specimen in such a way that the movable head of the testing apparatus moves at a constant rate of 0.6 mm min^{-1}. Maximum value of load at the point of failure was recorded. The value of maximum crushing load was noted and crushing strength per unit area was evaluated from equations given below.

$$\text{Maximum crushing stress (MCS)}\ (N/mm^2) = P/A$$

Where, P = Load at proportional limit (N), and

A= Cross sectional area (mm^2)

3.3.7 Compression perpendicular to grain test

Continuously increasing weight is applied on the radial surface of the specimen such that the head of the apparatus moves at a constant rate 0.6 mm min^{-1} on a steel plate of 5 cm width placed in the center across the radial face of the specimens. Deflection (mm) was noted at regular intervals of load until a total deformation of 2.5 mm or at the maximum load.

$$\text{Compressive stress at Elastic limit (CS at EL)}(N/mm^2) = P/A$$

Where, P = Load at the proportional limit (N), and

A = area of cross section (mm^2)

3.3.8 Hardness

The test was carried on testing machine equipped with an apparatus to penetrate into the specimen. A steel bar with hemispherical end or steel ball of 1.128 cm diameter to a depth of 0.564 cm, that is, the area of the projected circle is 1 sq cm. One penetration each was made on tangential, radial and end surface. The load (N) at the time of 0.564 cm depth was recorded.

3.3.9 Tensile strength

The specimen was held firmly between the grips provided in the apparatus to avoid slipping of the specimen and continuous load was applied at a constant rate of 1mm/min. Elongation was measured correct to 0.002 cm at regular intervals of load. Final reading of load (N) at the failure of specimen was recorded. Tensile stress at proportional limit was calculated using the following formula.

$$\text{Tensile Stress at Proportional Limit } (\text{N/mm}^2) = \text{P/A}$$

Where, P = Load at the limit of proportionality (N), and

A = Cross sectional area (mm^2)

3.3.10 Shear Strength

The test was carried out on a UTM equipped with a shearing tool in the rig. The specimen was supported in the rig by means of a cross bar such that the edges of the specimen are vertical and part of end surface not to be shared off rests on the support throughout the test. The load was applied continuously during the test in such a way that the loading head moves at a constant rate of 0.4 mm per minute. The maximum load required for shearing the area was recorded. The load (N) divided by the area (mm^2) gives the maximum shearing stress (MSS**)** in the test surface (radial or tangential).

3.3.11 Screw holding Power

The test was conducted on UTM provided with a device to grip the test piece with the fixed head and the screw to the movable head of the machine. The specimen was made to be held firmly on the machine, with the nail or screw gripped in gripping device. The load was applied continuously so that the movable head moves at a constant rate of 2 mm per minute until the screw is pulled completely out of the specimen.

Recording of Data - The maximum load of pulling out the screws was recorded for tangential, radial and end grain surfaces. The average values of load (N) for radial and tangential surfaces were taken as 'side values'.

3.3.12 Alcohol- benzene solubility (Anonymous, 1959b)

Un-extracted test specimen weighing 2.0 g based on oven dry weight was taken in a porous thimble and kept in the soxhlet apparatus. For the extraction, 250 ml alcohol: benzene mixture (1:2 v/v) was used and extraction was run for 20 hours. After extraction, the material was taken out from the porous thimble and dried to constant weight. The alcohol-benzene solubility was calculated as follows:

$$\text{Alcohol} - \text{benzene solubility}\ (\%) = \frac{(\text{W}_1 - \text{W}_2) \times 100}{\text{W}}$$

Where, W_1 stands for Oven Dry weight of the sample before extraction, and

W_2 stands for Oven Dry weight of the sample after extraction

3.3.13 Klason lignin content (Anonymous, 1959c)

Klason lignin on extractive free milled wood samples (screened-1; 40-60 mesh; 250-400 µm) was determined according to T 222-OS-74. Test specimen (2.0 g O.D.) was treated with 15 ml sulfuric acid w/w (72.0 %) for 2.0 hours at 20^0C with occasional stirring. Then the contents were transferred to a conical flask (1000 ml), distilled water (560 ml) was added to bring down acid concentration to 3.0 %. Further, the contents were refluxed for 4.0 hours and were filtered through IG_3 crucible. After that the content was washed carefully with hot distilled water to remove the remains of sulfuric acid and finally dried to constant weight at 105 ± 2^0C. Lignin content was calculated as follows:

$$\text{Lignin (\%)} = \frac{(W_1 - W_2) \times 100}{W}$$

Where, W_1: stands for weight of crucible after extraction,

W_2: stands for weight of crucible before extraction, and

W: stands for Oven Dry weight of test specimen.

3.3.14 Holocellulose (Anonymous, 1959a)

Sample weighing 5.0 g based on oven dry weight was taken in an Erlenmeyer flask having 160 ml distilled water. Glacial acetic acid (0.5 ml) and Sodium chlorite (1.50 g) was added in the flask and refluxed at 70 to 80^0 C for an hour. Further, more sodium chlorite (1.50 g) and glacial acetic acid (0.5 ml) were added. This process was repeated for 4 times till the test material became white. White dust was then filtered in G_2 crucible and washed with distilled water and acetone. Finally the contents were dried to constant weight in oven at 105 ± 2^0C.

$$\text{Holocellulose (\%)} = \frac{(W_1 - W_2) \times 100}{W}$$

Where, W_1: weight of the crucible after extraction,

W_2: weight of the crucible before extraction.

W: Oven Dry weight of the test specimen.

3.3.15 Correlation and Regression Studies

Correlation of strength properties with density and cell constituents, regression with density were done using statistical software OPSTAT.

3.3.16 Comparison of strength properties with Important timber species

Using the past literature available, strength properties of selected timbers were compared to the well known timber species. Primarily, the properties were compared with the standard Teak, and then about twenty timbers species of commercial importance.

Note:

- All the mechanical tests were conducted on the **SHIMADZU** Universal Testing Machine (100KN), **Dak Series** UTM (50 KN) and **Traditional** UTM (50 KN) in IWST, Bangalore.
- Facilities for Anatomical sections were provided by **NAU**, Gujarat.

Figure 3.3 & Figure 3.4 are showing different samples for various physical and mechanical tests and testing apparatus respectively.

Figure 3.3. Samples for various physical and mechanical tests; A- Compression parallel**, B-** Moisture content and density**, C-** Static bending**, D-** Compression**, E-** Hardness indentation **F** & **G**- Tension, **H -** Screw holding power, **I -** Shear

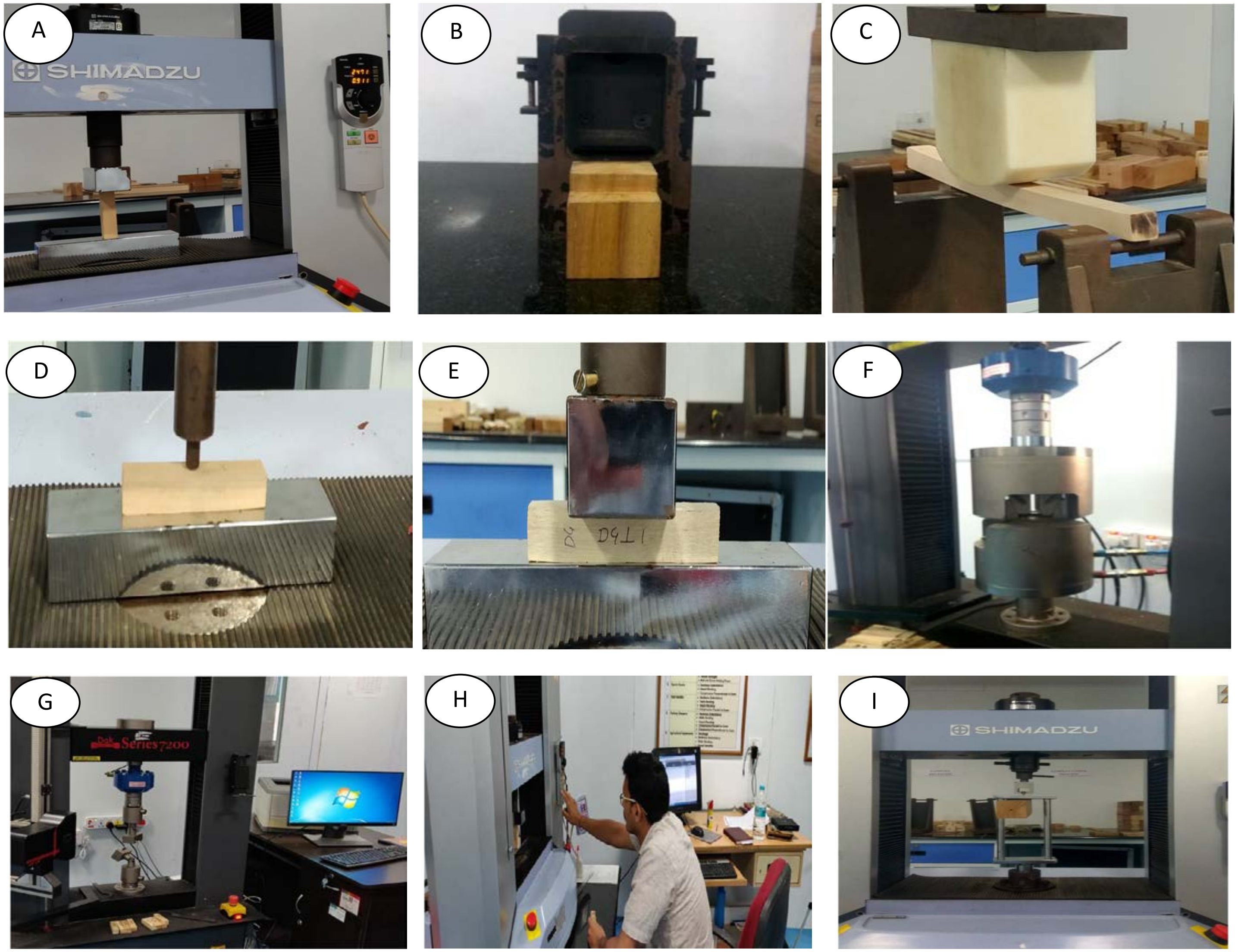

Figure 3.4. Testing apparatus; A- Compression parallel**, B-** Shear parallel**, C-** Static bending**, D-** Hardness**, E-** Compression perpendicular, **F** & **G**- Tension, **H**- Shimadzu UTM, **I**- Screw holding power

Chapter- 4

RESULTS AND DISCUSSION

4.1 Gross features

General features or gross features recorded on the basis of observation under the hand lens from three principal wood surfaces are summarized in the **Table 4.1**. *Callicarpa arborea* and *Duabanga grandiflora* shown the brighter heartwood color and there was little distinction between heartwood and sapwood color. *Anogeissus acuminata* and *Schima wallichii* had comparatively darker heartwood color; light yellow and reddish brown respectively. *Castanopsis tribuloides* shown dull brown heartwood color. *A. acuminate*, *c. arborea* and *D. grandiflora* shown considerable luster where as other three timbers were dull in reflecting light. Good luster is attributed to the size of the ray cells (Rao and Juneja, 1971) which were bigger in *D. grandiflora*. Among the timber species *A. acuminata* and *S. wallichii* were of fine texture where as others were coarse. Among the timbers *A. acuminata* falls in the class of heavy timber, *C. tribuloides* and *S. wallichii* under moderately heavy class whereas *D. grandiflora* and *C. arborea* were light to very light timbers. There was no characteristic odour among all the test species. Alignment of the wood elements was straight in *C. arborea,* straight to interlocked in *D. grandiflora* and *C. tribuloides* and *A. acuminata* and *S. wallichii* were of interlocked grains. Simple finger nail indentation test revealed that *A. acuminate, C. tribuloides* and *S. wallichii* were hard and other two were soft. All the test species were diffuse porous woods.

Figure 4.1 shows the transverse sections of five selected species for the observation of vessels and other features. Vessel size was visibly larger in *C. tribuloides* followed by *D. grandiflora*, *C. arborea* and comparatively smaller in *A. acuminata* and *S. wallichii*.

Table 4.1. Gross features of selected lesser known timbers

	Anogiessus acuminata	*Callicarpa arborea*	*Castanopsis tribuloides*	*Duabanga grandiflora*	*Schima wallichii*
Color	Pale yellow	Dull grey	Pale brown	Creamy white	Pale Reddish brown
Luster	Moderate	Moderate	Dull	Lustrous	Dull
Texture	Fine to very fine	Moderately coarse	Coarse	Coarse	Fine to very fine
Weight	Heavy to very heavy (>750 Kg/m3)	Light weight (<550 Kg/m3)	Moderately heavy(550 to 750 Kg/m3)	Light weight (<550 Kg/m3)	Moderately heavy(550 to 750 Kg/m3)
Odor	No characteristic odor	No characteristic odor	No characteristic odor	No characteristic odor	No characteristic odor
Grain	Interlocked	Straight	Straight to interlocked	Straight to interlocked	interlocked
Hardness	Hard to very hard	Soft	Hard to very hard	Soft	Hard to very hard
Vessels	Diffuse porous	Diffuse porous	Diffuse porous	Diffuse porous	Diffuse porous

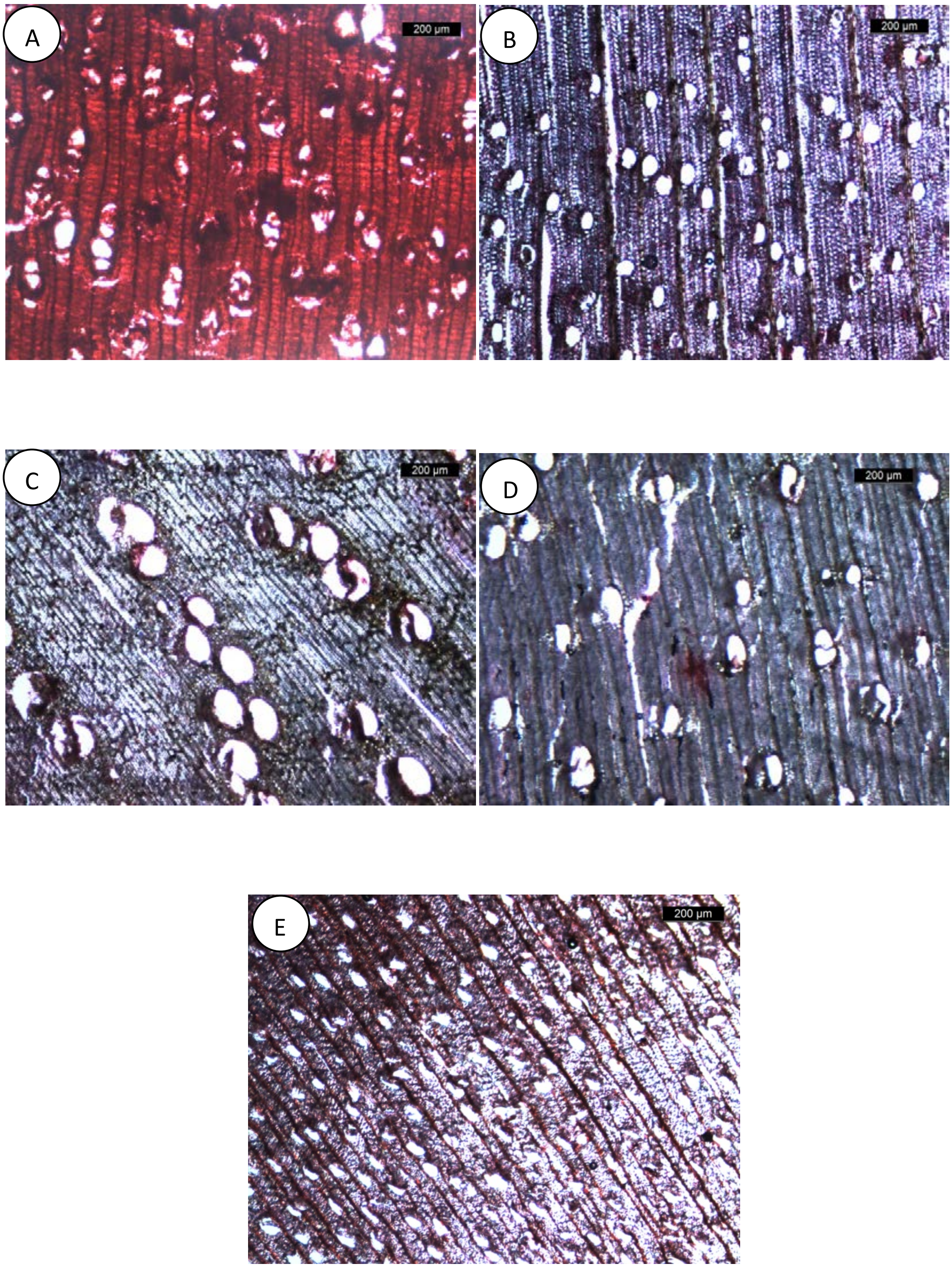

Figure 4.1 Transverse sections of Test species; A- *Anogeissus acuminata*, **B-** *Callicarpa arborea*, **C-** *Castanopsis tribuloides*, **D-** *Duabanga grandiflora*, **E-** *Schima wallichii*

Table 4.2 shows the vessel diameter (µm) and frequency (Number per mm^2). Solitary vessels were observed in *C. tribuloides, C. arborea* and *S. wallichii* whereas *A. acuminata* and *D. grandiflora* shown vessels in short radial multiples. Ray cells were found to be prominent in *D. grandiflora*, *A. acuminata* and *C. arborea.* Thickness of ray cell (RLS) and ray spindle width (TLS) can be seen in **Figure 4.2** and **Figure 4.3** respectively. It is important to note that properties like pore size are reported to be negatively correlated with strength properties. Adeniyi *et al.* (2013) observed among *Triplochiton scleroxylon, Ceiba pentandra* and *Bombax* that bigger pore size accompanied lower values of MOR and MOE.

Table 4.2. Vessel diameter and frequency of selected lesser known timbers

Species	Vessel Diameter (µm)	Vessel frequency (Number/ mm^2)
Anogiessus acuminata	51.43	10.8
Callicarpa arborea	77.71	7.21
Castanopsis tribuloides	180.56	5.23
Duabanga grandiflora	113.14	6.21
Schima wallichii	49.71	14.62

4.2 Moisture Content and Density

Highest density of 849.61 was recorded in *A. acuminata* followed by *S. wallichii* (734.95 kg/m^3), *C. tribuloides* (651.1), *C. arborea* (526.57) and lowest was in *D. grandiflora* (482.84). The moisture content of all the test species ranged from 12-14% (**Table 4.3**). Specific gravity or density of a wood is a measure of the wood substance contained in a given volume (Tsoumis, 1999) and therefore it affects majority of the strength properties of wood.

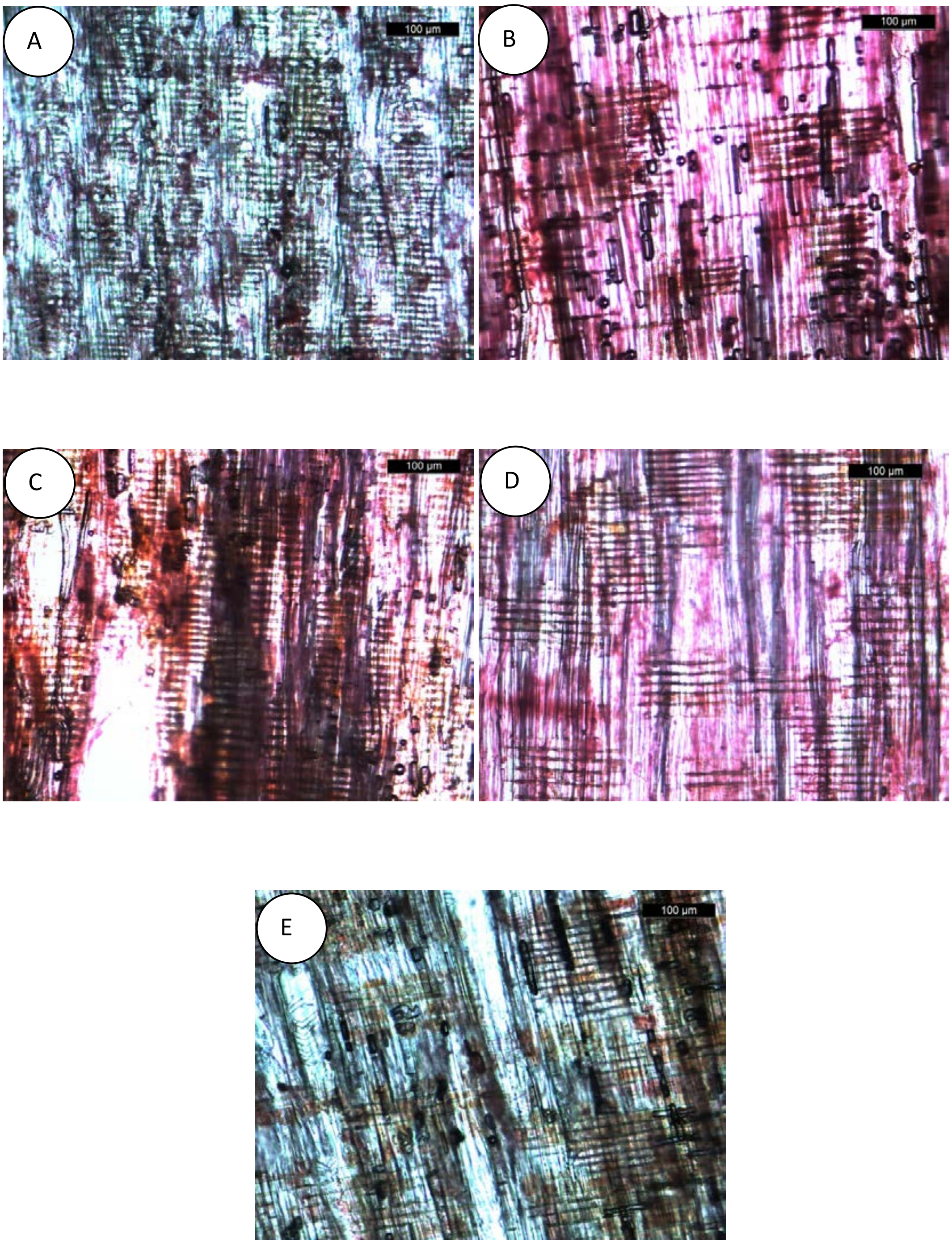

Figure 4.2. Radial Longitudinal sections of Test species; A- *A. acuminata*, **B-** *C. arborea*, **C-** *C. tribuloides*, **D-** *D. grandiflora*, **E-** *S. wallichii*

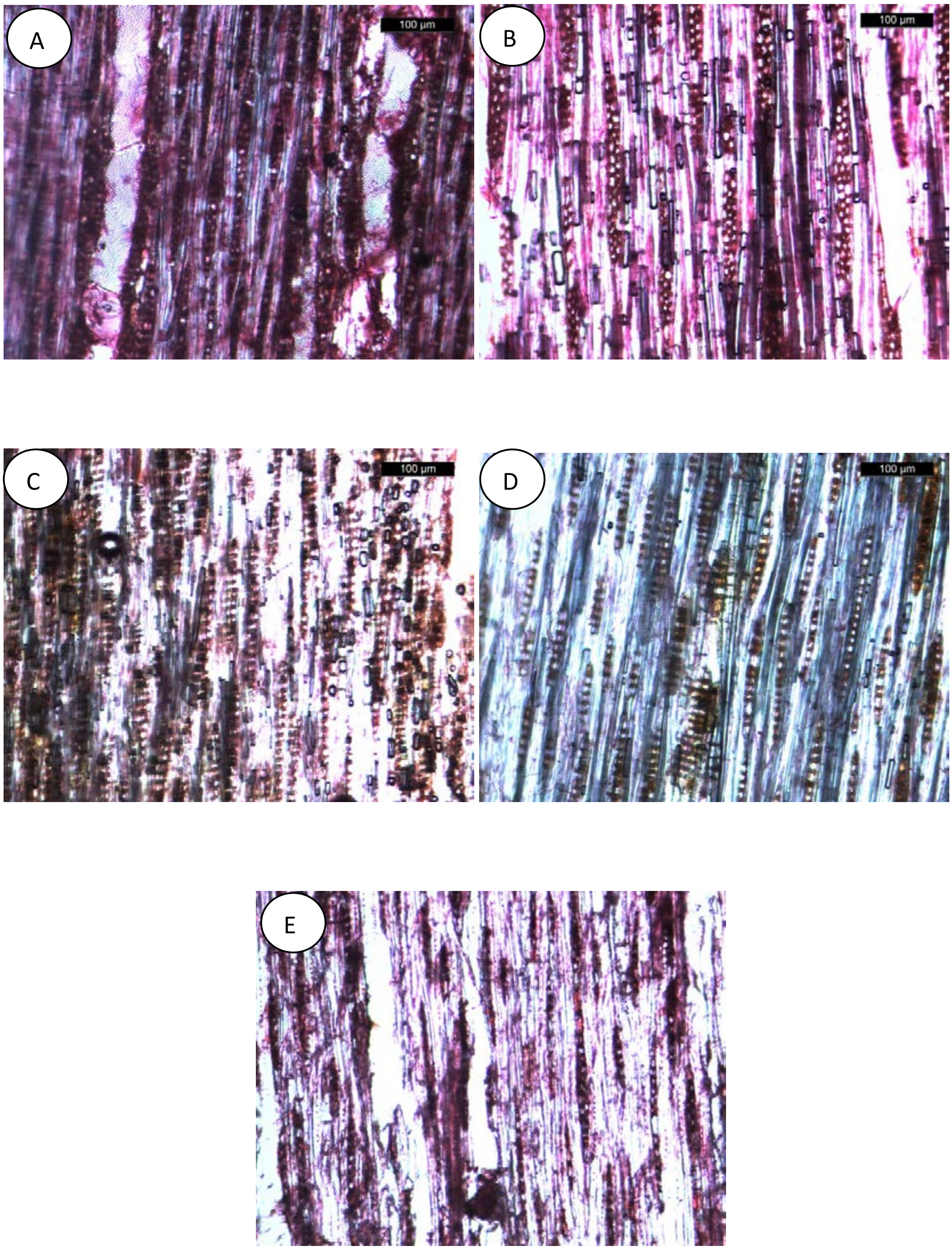

Figure 4.3. Tangential longitudinal sections of Test species; A- *Anogeissus acuminata*, **B-** *Callicarpa arborea*, **C-** *Castanopsis tribuloides*, **D-** *Duabanga grandiflora*, **E-** *Schima wallichii*

Table 4.3. Moisture content and density of test timber species

	A. acuminata	*C. arborea*	*C. tribuloides*	*D. grandiflora*	*S. wallichii*
MC (%)	12.9±1.51	13.60±2.13	13.88±1.37	14.52±1.50	13.15±1.44
Density (Kg/m^3)	849.61±25.45	526.57±24.04	651.10±21.89	482.84±30.94	734.95±28.06

4.3 Shrinkage

In all the species radial shrinkage was least followed by tangential and volumetric. Among the species *S. wallichii* (1.23%, 2.56 %, and 3.28%) and *A. acumainata* (1.37 %, 2.63 % and 3.34%) showed least shrinkage and highest shrinkage across the surfaces was shown by *D. grandiflora* (2.49 %, 3.5 % and 6.63 %) (**Table 4.4**). This may be attributed to the lower density and bigger pore space in the species. Anish *et al*. (2015) were of the opinion that shrinkage and swelling were higher in fast grown species. However, according to Hegde *et al*. (2018) wood finishes like paints, varnishes etc are effective in reducing shrinkage.

Table 4.4. Shrinkage (%) in test timber species

Shrinkage (%)→ **Species ↓**	**Radial**	**Tangential**	**Volumetric**
Anogiessus acuminata	1.37± 0.35	2.63 ± 0.17	3.34 ± 0.22
Callicarpa arborea	1.62 ± 0.31	3.47 ± 0.32	5.60 ± 0.32
Castanopsis tribuloides	1.39 ± 0.34	2.74 ± 0.13	4.60 ± 0.29
Duabanga grandiflora	2.49 ± 0.18	3.50 ± 0.22	6.63 ± 0.25
Schima wallichii	1.23 ± 0.27	2.56 ± 0.19	3.28 ± 0.23
CD @ 0.01	**0.392**	**0.289**	**0.353**

4.4 Static bending Strength

Static bending strength is an important mechanical property having its application in construction, flooring, packing cases, furniture, pallets, tool handles, sleepers and agricultural implements as per IS:1708 (1986). Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) were estimated in the bending test under static load. The results from the **Table 4.5** indicate that *S. wallichii* has shown comparatively higher MoE (8824 N/mm^2) and MoR (102.05 N/mm^2) than all other test species. However, in comparison with the standard (Teak) it has greater MoR but lower MoE. Apart from *S. wallichii, A. acuminata* has shown next higher values of MoE and MoR. *C. tribuloides* even though shown lesser MoR, has shown higher MoE. *C. arborea* (6223 n/mm^2) and *D. grandiflora* (7505 N/mm^2) have shown far lower bending strength. Izekor and Modugu (2010) showed the MoR of 25 year old Teak to be 134.69 N mm^{-2} and modulus of elasticity as 12845.57 N mm^{-2}.

Table 4.5 Static bending strength in test timber species

Species	Load at Elastic Limit (N)	Deflection (mm)	Maximum Load (N)	MoR (N/mm^2)	MoE (N/mm^2)
A. acuminata	849.98 ± 94.18	3.43± 0.34	1930.68± 178.40	96.99 ± 9.00	8060.66 ± 981.75
C. arborea	890.72 ± 70.67	4.68 ± 0.41	1692.72 ±147.88	85.18 ± 7.58	6223.36 ±797.88
C. tribuloides	815.74 ± 44.67	3.00±0.10	1566.52±66.91	77.73±3.27	8652.42±513.51
D. grandiflora	537.36±39.31	2.34±0.12	1421.33±62.96	71.87±3.22	7505.67±567.61
S. wallichii	1364.11±162.58	5.00 ± 0.24	2038.84 ±216.64	102.05±11.16	8824.18±1321.18
CD@0.01				**7.208**	**847.982**
Compare (Teak)				***95.9***	***11906***

4.5 Compression parallel to grain

Compression strength parallel to grain is applicable in construction, furniture, tool handles and sleepers. (IS: 1708, 1986). **Table 4.6** shows the values of crushing strength at elastic Limit (CS at LP) and crushing strength at Maximum load (CS at ML). The results reveal significantly higher crushing strength at proportional limit (CS at LP) shown by *A. acuminata* (59.93 N/mm^2) followed by *S. wallichii*, (54.68 N/mm^2) and *C. tribuloides* (52.77 N/mm^2). In case of Crushing strength at Maximum Load (CS at ML), similar trend was observed where *A. acuminata* (72.75 N/mm^2) was showing highest strength followed by *S. wallichii* and *C. tribuloides*. It is important to note that these three species have shown comparatively higher values than Teak. However, *C. arborea* and *D. grandiflora* have shown significantly lower strength. Similar findings were reported by Miller (1999) in lesser known hardwoods of South East Asia.

Table 4.6. Compression parallel to grain in test timber species

Species	Load at EL (N)	Defl. Del (mm)	Max Load (N)	CS at LP (N/mm^2)	CS at ML (N/mm^2)
A. acuminata	23899.86±2008.12	3.014±0.18	28993.72±1488.79	59.93±4.78	72.75±4.09
C. arborea	13318.144±966.56	2.38±0.30	15708.37±1713.25	33.87±2.60	39.98±4.83
C. tribuloides	20646.73±1292.45	2.45±0.31	23120.54±1497.95	52.77±3.38	59.17±5.17
D. grandiflora	13173.52±1442.25	2.50±0.23	15907.09±1556.26	33.79±3.82	40.83±4.50
S. wallichii	22047.68±1715.31	2.79±0.23	24921.47±1471.58	54.68±5.63	61.77±4.90
CD @0.01				**3.998**	**4.506**
Compare (Teak)				***36.83***	

4.6 Compression perpendicular to the grain

Compression strength perpendicular to grain is applicable in construction, sports articles and sleepers. (IS: 1708, 1986). **Table 4.7** shows the values of crushing strength at Elastic Limit (CS at LP) and crushing strength at Maximum load (CS at ML) when load was applied perpendicular to the grain. The results reveal significantly higher compressive strength parallel to grain shown by *A. acuminata* (14.69 N/mm^2 and 16.07 N/mm^2) followed by *C. tribuloides* (13.53 N/mm^2 and 15.60 N/mm^2) both in case of CS at ML as well as CS at LP compared to other three test species and comparatively higher values than standard (Teak). However, strength values of C. *arborea* (8.86 N/mm^2 11.4 N/mm^2) and *D. grandiflora* (9.17 N/mm^2 11.41 N/mm^2) and *S. wallichii* (10.73 N/mm^2 11.74 N/mm^2) were at par with each other and shown significantly lower strength compared to *A. acuminata* and *C. tribuloides*. Saravanan *et al*. (2014) reported the compression strength of *Melia dubia* (10 N/mm2) at par with the results obtained in the current study.

Table 4.7. Compression perpendicular to grain in test timber species

Species	Load at EL (N)	Defl. Del (mm)	Max Load (N)	CS at LP	CS at ML
A. acuminata	14690.23±1826.86	2.31±0.19	16072.26±3135.51	14.69±1.82	16.07±3.14
C. arborea	8863.54±686.131	1.67±0.15	11485.44±1373.94	8.86±0.69	11.4±1.37
C. tribuloides	13528.77±1254.90	2.05±0.15	15599.69±1068.84	13.53±1.25	15.60±1.07
D. grandiflora	9168.914±1072.11	1.92±0.13	11417.67±1315.23	9.17±1.07	11.41±1.32
S. wallichii	10638.2±1891.30	2.35±0.10	11634.15±1599.93	10.73±1.95	11.74±1.67
CD@ 0.01				**1.375**	**1.782**
Compare (Teak)				***9.90***	

4.7 Hardness Indentation Test

Results of Hardness Indentation test on end grain surface, tangential face and radial face are shown in the **Table 4.8**. Among the surfaces end grain shown greater hardness in all the test species followed by radial and tangential face. Among the species *A. acuminata* found to be hardest species with values of 8424.67 N, 7079.47 N and 7970.88 N in end grain, tangential and radial faces respectively. *S. wallichii* was the next hardest species with 6531.87 N loads. *Castanopsis* and *Duabanga* were almost at par with load ranging from 5129.01 N to 5303.81 N in the end grain, 4058.05 N to 4647.57 N in tangential face and 3908.05 N to 4935.72 N in radial face. *C. arborea* was the softest timber among all the species. In comparison to Teak *A. acuminata* was harder in all the faces, *S. wallichii* and *C. tribuloides* were harder in end grain and radial face whereas, less hard in tangential face. It is worth mentioning that in Genus *Anogeissus* the other species *A. latifolia* is reported to be one of the hardest timbers of India. Meena *et al*. (2018) reported *A. latifolia* to be harder than many commercial timbers making it suitable for tool handles, axle etc.

Table 4.8. Hardness Indentation in test timber species

Species	Hardness (End Grain) (N)	Hardness (Tangential) (N)	Hardness (Radial) (N)
A. acuminata	8424.67 ± 244.65	7079.47 ± 186.28	7970.88 ± 178.94
C. arborea	4717.37 ± 151.37	2480.91 ± 111.24	3550.50 ± 158.16
C. tribuloides	5303.81 ± 154.85	4647.57 ± 133.09	4935.72 ± 287.85
D. grandiflora	5129.01 ± 130.57	4058.05 ± 273.94	3908.05 ± 98.53
S. wallichii	6531.87 ± 130.03	4583.72 ± 183.7194	6176.36 ± 111.58
CD @0.01	**151.594**	**168.385**	**162.395**
Compare (Teak)	***4785.65***	***5138.68***	***4922.94***

4.8 Tensile strength

From the scrutiny of the **Table 4.9** showing tensile strength values parallel to grain as well as perpendicular to the grain, it is evident that *A. acuminata* (26.08 N/mm^2), *C. tribuloides* (24.11 N/mm^2) and *S. wallichii* (23.26 N/mm^2) have comparable tensile strength parallel to grain with that of Teak (24.5). *D. grandiflora* (16.13 N/mm^2) and *C. arborea* (19.18 N/mm^2) have shown lesser strength compared to Teak. In case of Tensile strength perpendicular to grain *A. acuminata* (7.27 N/mm^2) and *S. wallichii* (5.40 N/mm^2) have shown better strength than Teak (4.61 N/mm^2). However, *C. arborea* (3.13 N/mm^2), *C. tribuloides* (3.45 N/mm^2) and *D. grandiflora* (3.47 N/mm^2) were having at par strength among themselves and lesser than Teak. The results are in line with the findings of Rokeya *et al*. (2010) where they reported tensile strength of *Acacia* hybrid (*A. auriculiformes* × *A. mangium*) was higher than Teak.

Table 4.9. Tensile strength in test timber species

Species	**TS parallel to grain TS at PL (N/mm^2)**	**TS Perpendicular to grain Maximum Tensile Stress (N/mm^2)**
Anogiessus acuminata	26.08 ± 1.01	7.27 ± 0.54
Callicarpa arborea	19.18 ± 1.2	3.13 ± 1.04
Castanopsis tribuloides	24.11 ± 2.34	3.45 ± 0.41
Duabanga grandiflora	16.13 ± 1.64	3.47 ± 0.41
Schima wallichii	23.26 ± 3.05	5.40 ± 0.43
CD @ 0.01	2.667	0.857
Compare (Teak)	***24.5***	***4.61***

4.9 Shear strength parallel to grain

Shear strength parallel to grain is a property applicable in construction as mentioned in IS: 1708 (1986). From the **table 4.10** it is evident that radial shear strength was highest in *A. acuminata* (9.48 N/mm^2) followed by *S. wallichii* (9.14 N/mm^2) and *C. tribuloides* (8.96 N/mm^2) Lower radial shear strength was observed in *C. arborea* (7.13 N/mm^2) and *D. grandiflora* (7.47 N/mm^2). In case of Tangential shear, *S. wallichii* (8.4 N/mm^2) and *C. tribuloides* (8.16 N/mm^2) shown higher strength. *C. arborea* and *D. grandiflora* were at par with each other. Compared to the Teak (9.7 N/mm^2 and 10.8 N/mm^2) all the test species were having lower shear strength both in radial and tangential direction. Saravanan *et al*. (2014) reported the shear strength of *Melia dubia* to be at par with teak both in radial and tangential planes.

Table 4.10. Shear strength Parallel to grain in test timber species

Species	**Radial (N/mm^2)**	**Tangential (N/mm^2)**
Anogiessus acuminata	9.48 ± 0.42	7.62 ± 0.80
Callicarpa arborea	7.13 ± 0.88	6.99 ± 0.74
Castanopsis tribuloides	8.96 ± 0.18	8.16 ± 0.46
Duabanga grandiflora	7.47 ± 0.49	6.96 ± 0.11
Schima wallichii	9.14 ± 0.15	8.40 ± 0.29
CD @ 0.01	**0.66**	**0.73**
Compare (Teak)	***9.49***	***10.59***

4.10 Screw holding power

Screw holding power is important when timber is used for furniture, packing cases and pallets (IS: 1786). Test results for three surfaces namely radial, tangential and end grain are summarized in the **Table 4.11**. On radial face *Anogeissus acuminata* (4540 N) and *Schima wallichii* (4474 N) both were at par and shown highest screw holding power. On the tangential face screw holding power was higher in *A. acuminata* (4540 N) followed by *S. wallichii* (4540 N) and was lowest in *Calicarpa arborea* followed by *Duabanga grandiflora*. Similar trend was followed in the end grain surface as well. Saravanan *et al*. (2014) observed the screw holding power of *Melia dubia* at different age of the tree. They found the screw holding strength to be highest in the radial plane followed by tangential and end grain planes. They also reported that the strength of *M. dubia* in screw holding was comparable to that of teak.

Table 4.11. Screw holding power in test timber species

Species	Radial (N)	Tangential (N)	End Grain (N)
Anogiessus acuminata	4540.32 ± 256.71	4038.91 ± 102.92	3185.60 ± 109.62
Callicarpa arborea	2064.26 ± 61.14	1994.46 ± 104.36	1230.19 ± 152.24
Castanopsis tribuloides	3324.86 ± 212.06	3070.60 ± 57.62	2150.98 ± 108.84
Duabanga grandiflora	2412.86 ± 192.71	2244.53 ± 143.54	1313.81 ± 191.69
Schima wallichii	4474.15 ± 219.80	4201.23 ± 178.05	3015.85 ± 87.50
CD @0.01	**265.752**	**164.991**	**179.67**
Reference Value (Teak)	**3802.4**	**4018**	**2773.4**

4.11 Cell constituents

From the perusal of table 4.12 it could be comprehended that all the species varied significantly in terms of extractive content (%), klasen lignin content (%) and Holocellulose content (%). Highest extractive content (6.32 %) was found in *S. wallichii* followed by *A. acuminata* (4.12 %) and *C. tribuloides* (3.71 %). Highest lignin content was found in *S. wallichii* (29.71 %) followed by *A. acuminata* (27.4 %). Other three species were at par in terms of lignin content. Holocellulose (%) was highest in *D. grandiflora* and *C. arborea* followed by *C. tribuloides*, *A. acuminata* and least in *S. wallichii*. Kasmani *et al*. (2011) reported that with increase in age there was a significant increase in cellulose content, extractive content and lignin content in *Eucalyptus camaldulensis*. Al-meffarej *et al*. (2011) observed that broader spacing resulted in higher values of cellulose (46.9%), ash contents (2.53 %) and extractives (8.92 %) in *Leucaena leucocephala*. Closer spacing resulted in higher hemicelluloses content (21.05 %). Raiskila (2008) was of the opinion that site factors affect the chemical constituents of a species of timber.

Table 4.12. Cell constituents (%) in test timber species

Species	Extractive Content (%)	Klasen Lignin (%)	Holocellulose (%)
Anogiessus acuminata	4.12 ± 0.73	27.40 ± 4.34	67.88 ± 2.63
Callicarpa arborea	1.11 ± 0.45	25.02 ± 5.66	71.34 ± 2.12
Castanopsis tribuloides	3.71 ± 1.09	25.38 ± 2.74	68.46 ± 3.01
Duabanga grandiflora	1.12 ± 0.23	22.38 ± 1.59	76.15 ± 2.61
Schima wallichii	6.32 ± 0.63	29.71 ± 1.70	63.49 ± 1.45
CD @ 0.05*, 0.01**	**0.913****	**4.747***	**3.223***

4.12. Correlation and Regression

Important strength properties were correlated with density and cell constituents. **Table 4.13** shows the correlation of density of test species with their respective strength properties. In *A. acuminata* significant positive correlation of density was found with strength properties like MoE and MoR (Static bending), compression parallel to grain, compression perpendicular to grain and Hardness. In *C. arborea*, significant positive correlation of density was found with strength properties like MoE and MoR (Static bending) and Hardness. However, with compression parallel to grain and compression perpendicular to grain the positive correlation was not significant. In *C. tribuloides*, significant positive correlation of density was found with strength properties like compression parallel to grain, compression perpendicular to grain and Hardness where as positive correlation was not significant in MoE and MoR (Static bending). In *D. grandiflora*, significant positive correlation of density was found with strength properties like MoE, compression parallel to grain, compression perpendicular to grain and Hardness where as density was not significantly correlated with MoR (Static bending). In case of *S. wallichii*, only MoE and Compression parallel to the grain was significantly correlated while other properties were insignificant. For all the highly correlated properties with density linear regression equations were prepared and given in **Table 4.14**. Izekor and Fuwape (2011) showed density to be affecting strength properties in 15, 20 and 25 year old Teak. Nasser (2008) reported similar trends of correlation in *Melia azedarach.* The above results appear to be in agreement with Pometti *et al.* (2009), El-Osta *et al*. (1981); and Schniewind and Gammon (1986). However, Hernandez and Salazar (2006) argued that mechanical properties of wood should be explained in terms of both specific gravity and extractives content (%). Not only in wood, Uetimane and Ali (2011) studied the microscopic structural features of bamboo *Pseudolachnostylis maprounaefolia* and correlated them with physical and strength properties and found that there was a positive correlation between fibril angles and strength properties.

Table 4.13. Correlation of strength properties with density

	A. acuminata	***C. arborea***	***C. tribuloides***	***D. grandiflora***	***S. wallichii***
MoE	0.675^{*}	0.670^{*}	0.626^{NS}	0.367^{NS}	0.675^{*}
MoR	0.747^{*}	0.722^{*}	0.440^{NS}	0.977^{**}	0.533^{NS}
CS Parallel	0.807^{**}	0.491^{NS}	0.684^{*}	0.861^{**}	0.662^{NS}
CS Perpendicular	0.767^{*}	0.437^{NS}	0.865^{**}	0.723^{*}	0.764^{*}
Hardness	0.704^{*}	0.739^{*}	0.864^{**}	0.684^{*}	0.561^{NS}

*Significant @ 0.05, **Significant @ 0.01, NS= Non significant

Chemical constituents of the selected species have shown inconsistent correlation with all the strength properties. **Table 4.15** shows the correlation of strength properties with cell constituents namely Klasen lignin and holocellulose. Percent lignin content was positively correlated with strength properties like compression perpendicular and hardness but negatively correlated with MoE. In case of MoR and Compression parallel no linear correlation or very weak correlation was found. Among the test species significant negative correlation of MoE with lignin was found in *C. arborea*, *D. grandiflora* and *S. wallichii*. Compression perpendicular to the grain was significantly positively correlated with lignin content in all the test species except *C. tribuloides*, whereas, hardness was significantly positively correlated with lignin content in all the test species. Correlation with holocellulose revealed that significant positive correlations were observed with MoE and compression strength parallel to grain.

Table 4.14 Regression of strength properties with density

Species → / Properties ↓	*A. acuminata*	*C. arborea*	*C. tribuloides*	*D. grandiflora*	*S. wallichii*
Bending (MoE)	y = 28.536x - 16300 $R^2 = 0.4561$*	y = 20.322x - 4277.6 $R^2 = 0.4494$*	y = 0.1038x - 14.591 $R^2 = 0.4679^{NS}$	y = 6.8602x + 4218.7 $R^2 = 0.1347^{NS}$	y = 32.219x - 14961 $R^2 = 0.4561$*
Bending (MoR)	y = 0.29x - 150.08 $R^2 = 0.5582$*	y = 0.2626x - 51.939 $R^2 = 0.5216$*	y = 0.0644x + 35.93 $R^2 = 0.1933^{NS}$	y = 0.1035x + 22.303 $R^2 = 0.954$**	y = 0.2146x - 56.386 $R^2 = 0.2837^{NS}$
CS Parallel	y = 0.166x - 81.779 $R^2 = 0.6512$**	y = 0.06x + 1.8206 $R^2 = 0.2415^{NS}$	y = 0.1038x - 14.591 $R^2 = 0.4679$*	y = 0.1084x - 18.15 $R^2 = 0.7407$**	y = 6.86x + 4218.7 $R^2 = 0.1347^{NS}$
CS Perpendicular	y = 0.06x - 36.777 $R^2 = 0.588$*	y = 0.01x + 1.3509 $R^2 = 0.1913^{NS}$	y = 0.0487x - 18.062 $R^2 = 0.7485$**	y = 0.0255x - 3.0635 $R^2 = 0.523$*	y = 0.0539x - 29.035 $R^2 = 0.5843$*
Hardness	y = 4.73x + 3758.8 $R^2 = 0.4957$*	y = 2.08x + 2502.3 $R^2 = 0.5461$*	y = 5.455x + 1448.5 $R^2 = 0.7463$**	y = 2.0213x + 3171.7 $R^2 = 0.4673$*	y = 1.63x + 4572.7 $R^2 = 0.3147^{NS}$

*Significant @ 0.05, **Significant @ 0.01, NS= Non significant

Table 4.15 Correlation of strength properties with cell constituents

	A. acuminata	*C. arborea*	*C. tribuloides*	*D. grandiflora*	*S. wallichii*
With Lignin					
MoE	-0.32 NS	-0.862 *	-0.314 NS	-0.736 *	-0.837 *
MoR	NS	NS	NS	NS	NS
CS Parallel	NS	NS	NS	NS	NS
CS Perpendicular	0.845 *	0.746 *	0.455 NS	0.621 *	0.880 **
Hardness	0.652 *	0.686 *	0.724 *	0.810 *	0.836 *
With Holocellulose					
MoE	0.824 *	0.860 *	0.768 *	0.443	0.890 **
MoR	NS	NS	NS	0.384 NS	NS
CS Parallel	0.624 *	0.762 *	0.356 NS	0.560 NS	0.657 *
CS Perpendicular	NS	0.301NS	NS	0.404 NS	NS
Hardness	NS	NS	0.361 NS	0.440 NS	0.314 NS

*Significant @ 0.05, **Significant @ 0.01, NS= Non significant

4.13 Comparison of properties with important commercial Timber species

Important wood properties of test timbers majorly affecting its utilization were compared with the commercially well known timbers. The properties compared were density, bending strength, compression strength, Tensile strength and Hardness. Commercial timbers used for comparison were Teak, Eucalyptus, Deodar, Jamun, Rosewood, Sissoo, Rubberwood, Acacia, Axlewood, Poplar, Mango, Melia, Sal, Maple, Chirpine, Neem and Casuarina. Various literatures were used as a source like Kumar *et al*. (2017), Dadzee *et al*. (2016), Al Sagheer and Prasad (2010), Bhat *et al*. (2008), Chowdhury *et al*. (2012), Janssen (2012), Shukla *et al*. (2007), Nair and

Mukherji (1960), Shukla and Sangal (1986), Shukla and Rajput (1980), Sharma *et al*. (2005), Gnanaharan and Damodaran (1993) and Person and Brown (1932). Overall, among the test timber species *Anogeissus acuminata, Schima wallichii* and *Castanopsis tribuloides* have comparatively shown better properties than majority of the timber species compared. *D. grandiflora* and *C. arborea* both were below par in strength compared to commercial timbers.

4.13.1 Comparison of density of Test species with important commercial timber species

Density is an important property which decides the strength of timber. Densities of five test species were compared with some of the important commercial timber species and are summarized in the **table 4.16**. *A. acuminata* with highest density among the five selected species was observed to be having higher density than some of the timbers like *Tectona grandis, Acacia auriculiformes, Gmelina arborea, Populus deltoids, Mangifera indica, Azadirachta indica, Melia dubia, Casuarina equisetifolia, Anogeissus latifolia, Acer oblongum, Cedrus deodara, Pinus roxburghii, Dalbergia latifolia, Dalbergia sissoo* and *Havea brasiliensis* as per the available literatures. Its density was lower than *Shorea robusta, Syzygium cumini* and *Eucalyptus* hybrid. *D. grandiflora* being light weight timber among the test species was higher than only *Populus* and *Acer* among the compared timbers. *C. arborea* has shown lower density than *Populus*, Mango, *Acer*, *Cedrus deodara* and *Pinus roxburghii*. *S. wallihii* was having density value lower than *Shorea robusta, Syzyzium cumini, Acacia auriculiformes, Eucalyptus hybrid, Anogeissus latifolia, Dalbergia sissoo* and *D. latifolia*. *Castanopsis tribuloides* with moderate density was having higher density than half of the compared timbers.

Table 4.16 Comparison of density of Test species with important commercial timber species

	A. acuminata	***C. arborea***	***C. tribuloides***	***D. grandiflora***	***S. wallichii***
Tectona grandis	+	-	-	-	+
Shorea robusta	-	-	-	-	-
Acacia auriculiformes	+	-	-	-	-
Gmelina arborea	+	-	+	-	+
Syzyzium cumini	-	-	+	-	-
Populus deltoides	+	+	+	+	+
Mangifera indica	+	+	+	-	+
Azadirachta indica	+	-	-	-	+
Melia dubia	+	+	+	-	+
Eucalyptus sp	-	-	-	-	-
Casuarina equisetifolia	+	-	-	-	+
Anogeissus latifolia	+	-	-	-	-
Acer sp	+	+	+	+	+
Cedrus deodara	+	+	+	-	+
Pinus roxburghii	+	+	+	-	+
Dalbergia latifolia	+	-	-	-	-
D. sissoo	+	-	-	-	-
Rubberwood	+	-	+	-	+

+ indicates Test species with higher value;

- indicates Test species with lower value

4.13.2 Comparison of Static bending strength of Test species with important commercial timber species

Table 4.17 gives the comparison of static bending strength of test species with important timbers of commercial value. *A. acuminata, S. wallichii* and *C. tribuloides* have shown comparatively higher strength than 14, 12 and 09 species respectively where as *C. arborea* and *D. grandiflora* have shown better strength than only 04 species out of 18 compared timbers. Notably, *Tectona*, *Dalbergia*, *Syzygium* and *Eucalytus* are better in static bending strength than all test species.

Table 4.17. Comparison of Static bending strength of Test species with important commercial timber species

	A. acuminata	***C. arborea***	***C. tribuloides***	***D. grandiflora***	***S. wallichii***
Tectona grandis	-	-	-	-	-
Shorea robusta	+	-	+	-	+
Acacia auriculiformes	+	-	+	-	-
Gmelina arborea	+	-	-	-	+
Syzyzium cumini	-	-	-	-	-
Populus deltoides	+	+	+	+	+
Mangifera indica	+	+	+	+	+
Azadirachta indica	+	-	+	-	+
Melia dubia	+	-	+	-	+
Eucalyptus sp	-	-	-	-	-
Casuarina equisetifolia	+	-	+	-	+
Anogeissus latifolia	+	-	+	-	+
Acer sp	+	+	+	+	+
Cedrus deodara	+	-	+	-	+
Pinus roxburghii	+	+	+	+	+
Dalbergia latifolia	+	-	-	-	-
D. sissoo	-	-	-	-	-
Rubberwood	+	-	-	-	+

+ indicates Test species with higher value

- indicates Test species with lower value

4.13.3 Comparison of Compression strength of Test species with important commercial timber species

Comparison of compression strength of test species with the commercial timbers is given in the **table 4.18**. Observations indicate the superior strength of *A. acuminata* over some commercial timbers like *Acacia*, *Gmelina*, Poplar, *Melia*, *A. latifolia*, *Acer*, Deodar, Chirpine and Rubber wood. *C. arborea* and *D. grandiflora* have shown better strength only to Poplar, Maple and Rubber wood. *S. wallichii* and *C. tribuloides* have shown higher strength than 4 and 7 compared species respectively.

Table 4.18 Comparison of Compression strength of Test species with important commercial timber species

	A. acuminata	***C. arborea***	***C. tribuloides***	***D. grandiflora***	***S. wallichii***
Tectona grandis	-	-	-	-	-
Shorea robusta	-	-	-	-	-
Acacia auriculiformes	+	-	+	-	-
Gmelina arborea	+	-	-	-	+
Syzyzium cumini	-	-	-	-	-
Populus deltoides	+	+	+	+	+
Mangifera indica	-	-	-	-	-
Azadirachta indica	-	-	-	-	-
Melia dubia	+	-	+	-	+
Eucalyptus sp	-	-	-	-	-
Casuarina equisetifolia	-	-	-	-	-
Anogeissus latifolia	+	-	-	-	-
Acer sp	+	+	+	+	+
Cedrus deodara	+	-	+	-	-
Pinus roxburghii	+	-	+	-	-
Dalbergia latifolia	-	-	-	-	-
D. sissoo	-	-	-	-	-
Rubberwood	+	+	+	+	+

+ indicates Test species with higher value

- indicates Test species with lower value

4.13.4 Comparison of tensile strength of test species with important commercial timber species

A. acuminata and *S. wallichii* have shown better tensile strength than most of the compared species except Teak, *Syzyzium*, *Eucalyptus*, *Dalbergia latifolia* and *D. sissoo* (**Table 4.19**). *D. grandiflora* and *C. arborea* showing par strength were better only to Poplar, Mango, Maple and Chirpine. *C. tribuloides* was better than 10 of the 18 compared species of timber in terms of tensile strength.

Table 4.19. Comparison of tensile strength of test species with important commercial timber species

	A. acuminata	***C. arborea***	***C. tribuloides***	***D. grandiflora***	***S. wallichii***
Tectona grandis	-	-	-	-	-
Shorea robusta	+	-	+	-	+
Acacia auriculiformes	+	-	-	-	-
Gmelina arborea	+	-	-	-	+
Syzyzium cumini	-	-	-	-	-
Populus deltoides	+	+	+	+	+
Mangifera indica	+	+	+	+	+
Azadirachta indica	+	-	+	-	+
Melia dubia	+	-	+	-	+
Eucalyptus sp	-	-	-	-	-
Casuarina equisetifolia	+	-	+	-	+
Anogeissus latifolia	+	-	+	-	+
Acer sp	+	+	+	+	+
Cedrus deodara	+	-	+	-	+
Pinus roxburghii	+	+	+	+	+
Dalbergia latifolia	-	-	-	-	-
D. sissoo	-	-	-	-	-
Rubberwood	+	-	-	-	+

+ indicates Test species with higher value

- indicates Test species with lower value

4.13.5 Comparison of hardness of test species with important commercial timber species

Comparison of hardness of Test timbers to important commercial timbers is given in the **table 4.20**. All the test timber species were harder than Poplar, Maple, Chirpine, Deodar and Rubberwood. *A. acuminata* proved to be harder than most of the compared species except Sal and *A. latifolia. S. wallichii* was found to be harder than 11 of 18 compared timbers. *C. tribuloides, D. grandiflora* and *C. arborea* were harder than 9, 6 and 5 species out of 18 species respectively.

Table 4.20. Comparison of hardness of test species with important commercial timber species

	A. acuminata	***C. arborea***	***C. tribuloides***	***D. grandiflora***	***S. wallichii***
Tectona grandis	+	-	-	-	+
Shorea robusta	-	-	-	-	-
Acacia auriculiformes	+	-	-	-	-
Gmelina arborea	+	-	+	-	+
Syzyzium cumini	+	-	+	-	-
Populus deltoides	+	+	+	+	+
Mangifera indica	+	-	+	-	+
Azadirachta indica	+	-	-	-	+
Melia dubia	+	-	+	+	+
Eucalyptus sp	+	-	-	-	-
Casuarina equisetifolia	+	-	-	-	+
Anogeissus latifolia	-	-	-	-	-
Acer sp	+	+	+	+	+
Cedrus deodara	+	+	+	+	+
Pinus roxburghii	+	+	+	+	+
Dalbergia latifolia	+	-	-	-	-
D. sissoo	+	-	-	-	-
Rubberwood	+	+	+	+	+

+ indicates Test species with higher value

- indicates Test species with lower value

4. 14. Possible utility of the lesser known timbers based on the properties

Bureau of Indian Standards, IS: 1708 (1986) has identified and suggested the wood properties required to be tested for different end uses. Among the lesser known timbers tested in the current study the results have shown that with comparatively good static bending strength and compression strength *S. wallichi*, *A. acuminata* and *C. tribuloides* can be tried for variety of uses such as construction, flooring and furniture. Further, with higher hardness, *A. acuminata* can be very useful in tool handles and implements. *D. grandiflora* and *C. arborea* having comparatively lower density and strength can find their utility in light packing cases and composite wood products. **Table 4.21** suggests the possible utility that can be assigned to the tested lesser known timber species.

Table 4.21. Suggestive utility of lesser known timbers based on the test results

Species name	Local name	Current Utility *	Possible utility
Duabanga grandiflora	Zuang	➢ Fuelwood	➢ Light packaging material ➢ Plywood
Schima wallichii	Khiang	➢ Small timber	➢ Construction ➢ Flooring ➢ Tool handles ➢ Pallets ➢ Furniture ➢ Agricultural implements
Castanopsis tribuloides	Thing-sia	➢ Small timber ➢ Fence posts	➢ Construction ➢ Flooring ➢ Pallets ➢ Furniture
Callicarpa arborea	Hna-khia	➢ Limited utility	➢ Carving ➢ Light packaging material
Anogiessus acuminata	Zairum	➢ Small timber	➢ Construction ➢ Flooring ➢ Tool handles ➢ Pallets ➢ Furniture ➢ Farm tools ➢ Sports goods

*Source: Sawmliana (2013), Gamble (1992) and personal observations

Chapter- 5

SUMMARY AND CONCLUSION

First choice timber resources are shrinking day by day and have become unaffordable for common man. Even though the utilization of waste wood is given stress in the form of composite woods, the demand for the solid wood products is irreplaceable. Hence the optimum utilization of locally available timber resources is necessary for sustainable utilization. Mizoram state is no exception to the fact that quality timber resources are in short supply because of poor stocking in the forests. It is often said that bamboo is the back bone of all the north eastern states, finding its use in variety of purposes. But certain specific utilization traits like durability, strength, finishing etc. make wood an essential raw material for various end uses.

To summarize the results of the present study, five selected lesser known timber species have shown varying physical and mechanical properties to indicate their possible utility for variety of uses. Highest density among the tested species was found in *A. acuminata* followed by *S. wallichii*. Lowest density was recorded in *D. grandiflora*. Higher values of MoE and MoR under static bending strength was observed in *S. wallichii* and *A. acuminata* followed by *C. tribuloides*. Greater compression strength was shown by *A. acuminata, S. wallichii* and *C. tribuloides* both along the grain and across the grain. Hardness on end grain, tangential and radial planes was higher in *A. acuminat*a even compared to the standard Teak. *A. acuminata* followed by *S. wallichii* showed higher tensile strength. *A. acuminata, S. wallichii* and *C. tribuloides* were having comparable shear strength. *A. acuminata* followed by *S. wallichii* were having better screw holding power. *D. grandiflora* and *C. arborea* have shown higher holocellulose content.

Owing to the mechanical properties of the selected timber species following key recommendations can be made for the utility of the said timbers:

- *A. acuminata* and *S. wallichii* with similar density and comparable strength properties may be suitable for uses like construction, flooring, tool handles, pallets, furniture and agricultural implements.
- *A. acuminata* in addition with smooth texture and fine grain could be useful in handicrafts and articles. Also the color of the heartwood is attractive with slight greenish tinge.
- *D. grandiflora* had lowest of the density and low density, is suitable for all the light weight utilities like packing cases. It has good lusture which suits the timber to be used in plywood manufacture.
- *C. arborea* with lower density and smooth texture potentially can be tried in packing cases, pallets and carved wood work.
- *C. tribuloides* with its average weight and moderate to good strength is a potentially well suited timber for making furniture. It can be also tried for flooring, panels and construction.

Despite all the above recommendations holistic wood utilization depends on several other aspects of wood science. This makes the basis for future scope of research to strengthen the present findings. Some of these aspects are as following:

- Studies on durability of these lesser known timbers and their preservation from bio-deteriorating agents.
- Evaluation of important anatomical characters like micro fibril angle, cell and lumen dimensions etc.

- Seasoning behavior of the timbers: Often heavy timbers are required to dry in controlled drying conditions. This is applicable to *A. acuminata* and *S. wallichii* among the selected timbers.
- Veneering properties: Suitability of the selected timbers for veneer production and quality need to be assessed for their potential utilization in plywood manufacture.

The present study was conducted with a broader goal to improve the quality and quantity of timber utilization in North eastern region of the country. We know that in several parts of India, green felling is banned and hence optimum utilization of locally available resources should be the priority. To reduce the pressure on the mainstream timbers alternatives have to be explored and developed for sustainable supply of raw materials. Therefore, current study is half a step forward for solving the problems of scarcity with reliable quality.

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DATE OF ADMISSION	: 13.08.2015
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B.Sc.	University of Agriculture Sciences, Dharwad	2006	83.70
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Career Profile

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