

**Characterization of wood physical and anatomical features for  
the development of identification keys for twenty tree species of  
South India**

**By**

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**(2020-17-003)**

**THESIS**

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**2023**

## **DECLARATION**

I hereby declare that the thesis entitled “**Characterization of wood physical and anatomical features for the development of Identification Keys for Twenty selected currently used timbers of South India**” is a bonafide record of research done by me during the course of research and that this thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar titles, of any other University or Society.

Place: Vellanikkara

Date: *18 March 2023*



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## **CERTIFICATE**

Certified that the thesis, entitled **“Characterization of wood physical and anatomical features for the development of Identification Keys for Twenty selected currently used timbers of South India”** is a record of research work done independently Ashline Shaji (2020-17-003) under my guidance and supervision and that it is not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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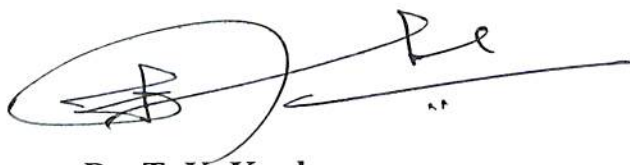
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*Ashline Shaji*

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# **INTRODUCTION**

## 1. INTRODUCTION

Wood has been a crucial part of human civilization, serving as a building material, furniture, paper, tools, weapons, and fuels for millennia. The demand for wood continues to rise, driven by factors such as the growing global population, increasing human needs for packaging, furnishings, energy, and shelter, the need to address climate change, global market competition, changing demographics, and advancing technology. This demand has led to unscientific and often illegal methods of harvesting, causing widespread deforestation. Illegal logging and trade accounts for a staggering 51-152 billion dollars per year, making it the third largest criminal enterprise globally, after drugs and counterfeit goods. Illegal logging is a widespread issue in tropical countries, where it can make up to 90% of the total log removal and up to 30% of the global timber production (INTERPOL, 2019). The Amazon, Central Africa, and Southeast Asia are among the regions most affected by deforestation and illegal logging, according to the same source.

Illegal logging and the trade in illegally procured wood products are significant contributors to deforestation and the threat to the world's biodiversity. To curb the unsustainable rate of deforestation, many countries are implementing laws to ensure the legality of the wood's origin and sustainable logging practices. Timber traders face challenges in complying with growing demands for due diligence concerning the origin of their timber. Proper regulation is essential to ensure the survival of commercially valuable and endangered species designated by CITES or listed as "endangered" by the IUCN (Johnson and Laestadius 2011).

The lack of government resources and capacity is a significant obstacle in reforming the forestry sector. Timber laundering, despite its severe impact, often goes unnoticed due to a lack of government attention. This is exacerbated by the lack of expertise among customs agents and government inspectors, who may not possess the necessary skills and knowledge to identify species, determine their origin, and distinguish between legal and illegal species. They may also be unfamiliar with the regulations governing international trade and transportation.

To tackle the problem, the first step is to identify the procured wood samples and, later, identify the origin of the wood and the ways to stop further wood trafficking. This is where the value of wood anatomical studies becomes apparent. Wood anatomy is the study of the proportion and distribution of various types of cells that constitute the physical form of the

wood, which is essential for wood identification and utilisation (Seralde, 2006). Wood anatomical features are generally considered not prone to changes under normal circumstances, and therefore, it forms the basis of wood identification. Wood anatomists have traditionally identified timber by examining the internal structure of wood (Carlquist, 2001). Combinations of anatomical traits can be used to distinguish taxa as they are influenced by both genetic and environmental factors. Both macroscopic and microscopic analysis is possible, but typically, microscopic inspection is necessary to make a diagnosis. This has naturally been carried out more with reference to the economically important timbers of certain geographical regions than with botanical groups.

A study on wood anatomical variation is quite helpful as the internal structure of wood profoundly influences the properties of wood (Burley and Palmer, 1979). Different features of interest in this scenario include cell size, arrangements of different elements, cell proportion and, most importantly, specific gravity. The usual pattern of variation in wood element dimensions can be seen not only within a species but also within a tree (Dinowoodie, 1961; Pande *et al.*, 2012). This has been exploited in various ways for the needs of mankind. Chaudhari *et al.* (2018), revealed that a piece of wooden stick was used as a piece of evidence to solve the case. Thus, it is impossible to overstate the relevance of wood identification in supporting laws, treaties to protect endangered tree species and curtail international illicit logging.

Numerous publications are exploring innovative approaches to identify wood, such as DNA sequence analysis, mass spectrum analysis, and machine learning using microscopic and macroscopic images. However, traditional macroscopic and microscopic wood identification techniques, which have been used for centuries, remain the most widely used and reliable methods for identifying unknown wood. These methods rely on identifying diagnostic features and referencing a well-stocked and reliable wood collection. While digital photographs of wood surfaces cannot replace actual wood samples, they are a quicker and more convenient option. Several free online resources, such as The Wood Database, Insidewood, and Hobbit House, provide macroscopic cross-section photographs of wood. These images are taken using XyloScope, a digital imaging tool developed at the Forest Products Laboratory of Madison, Wisconsin (Hermanson *et al.*, 2019; Ravindran *et al.*, 2020). This tool captures 6.35 x 6.35 mm cross-sectional regions that mimic a piece of wood seen through a 10x hand lens. These new methods, along with macroscopic identification keys and atlases, such as those developed by

Ilic (2019), Richter & Oelker (2002), Hoadley (1990), Ruffnatto & Crivellaro (2019), and Hermanson and Wiedenhoef (2011), are revolutionizing wood identification.

The IAWA (International Association of Wood Anatomists) List of Microscopic Features for Hardwood Identification is an important standard list of terminology and features that can be utilised in descriptive wood anatomical research and identification as determined by comparison to reference sources. The dichotomous key, perforated card key and computer-aided identification key are the most often used keys for wood identification. The most basic and user-friendly keys are the dichotomous ones. These kinds of keys have been employed in biological identification for many years. When the Forest Products Research Laboratory developed a key for the identification of hardwoods based on microscopic traits in 1936, they also developed the multiple-entry perforated card kind of key (Wheeler *et al.*, 1989).

Hence, the preparation of an anatomical key is vital in the field of wood industries for the identification of the suitable material or the tree. The confusion in the identification of timbers is greatly reduced by the anatomical keys of various timbers. The identification keys are made using the pronounced anatomical variations of each species. In the domain of wood science, an awareness of the variety and distinctive qualities of various timber species is quite helpful. The anatomical keys can help in molecular research, like DNA barcoding and molecular markers, among other things. According to the characteristics of the vessel, ray, and the specific gravity of the wood, anatomical examinations are conducted. Typically, only genus-level identification may be made using wood anatomical analysis (Gasson, 2011). According to Hermanson and Wiedenhoef (2011), a new area of research with great promise for timber identification is automated wood anatomical analysis (also known as "machine vision") using sophisticated image capture and processing algorithms. This technique may make species-level identification easier. The most popular technique for taxonomic identification is wood anatomical analysis. It is employed both in the field and in the lab for diagnosis. Numerous fields, such as plant systematics and evolution, can benefit from data on wood anatomy. In this study, 20 selected timber species of Kerala were considered for the identification and preparation of anatomical keys. They are *Albizia odoratissima* (Linn. f.) Benth., *Acacia nilotica* (Linn.) Wild. Ex Delile, *Acrocarpus fraxinifolius* Arn., *Aegle marmelos* L. Correa, *Ailanthus triphyssa* (Dennst) Alston, *Alstonia scholaris* (Linn.) R. Br., *Artocarpus hirsutus* Lam., *Azadirachta indica* A. Juss., *Bombax ceiba* Linn., *Bridelia retusa* (L.) A. Juss., *Canarium strictum* Roxb., *Cassia fistula* Linn., *Casuarina equisetifolia* J. R. & G. Forst., *Ceiba pentandra* L. Gaertn., *Cocos nucifera* Linn., *Hopea parviflora* Bedd., *Lagerstroemia*

*lanceolata* Wight., *Mangifera indica* Linn., *Melia dubia* Cav., *Neolamarkiana cadamba* Roxb., and *Thespesia populnea* (L.) Soland. ex Correa.

In this backdrop, the objectives of the study were:

- To evaluate wood physical and micro-anatomical features of twenty selected, currently used timbers of South India.
- To develop dichotomous and IAWA keys for the identification of the selected timber species.

## **REVIEW OF LITERATURE**

## 2. REVIEW OF LITERATURE

The study of wood anatomy through microscopic examination began in the 17th century, with Robert Hooke's observations of different types of charcoal and petrified wood in his book "Micrographia" in 1665. However, Marcello Malpighi, Nehemiah Grew, and Antoni van Leeuwenhoek were the true pioneers of plant anatomy. Grew and Malpighi's works, collected in "The Anatomy of Plants" by Grew in 1682 and "Opera Omnia" by Malpighi in 1686, respectively, made significant contributions to the understanding of three-dimensional wood structure. Grew took a systematic approach, describing the vessels of various sizes and distribution patterns found in different species, while Malpighi's botanical writings were later summarized and partially translated by Mobius in 1901. Together, their work illustrated and described numerous hardwood species and some softwoods.

In the beginning of nineteenth century wood anatomy and wood technological studies started to flourish. In 1900, two publications that had a significant impact on subsequent work were released. Systematic Anatomy of the Dicotyledons (Solereder, 1908) was the first, and it was published in 1899. It concentrated on the anatomical aspects of the plant families and the descriptions of plant components. The Anatomy of the Dicotyledons was revised later in 1950 by Metcalfe and Chalk. Outstanding additions to wood anatomy can be found in both versions.

When the first instalment of Moll's 'Micrography of Javanese Woods' was published in 1906, it marked a second turning point. Together, these two articles created a research pattern that moved anatomy beyond the realms of phylogeny and taxonomy and into a comparative phase. Studies that contributed to scientific classification and species grouping were founded on comparative anatomy. According to its anatomy, the major "key" author for identifying timber is a subject for literary inquiry, and the key has a dichotomous nature. These keys are practical because there are fewer people to sort and no ongoing additions are necessary. However, where the numbers are high, there is a requirement for a universal key that enables an endless expansion in the number of entries.

This was called as 'A Universal Index to Wood' (Swain, 1926). It was made up of a series of six schedules, each of which contained a list of qualities with a unique number next to each one. The most useful system was created by Clarke in 1938, consists of a card with marginal holes that correspond to the structural parameters and the creation of one or more cards as needed for each timber (Metcalfe and Chalk, 1950). This was used by Chalk to record data for the Anatomy of the Dicotyledons and by Phillips for the keys made at Risborough,

first for softwoods in 1941 and then for hardwoods (Brazier and Franklin, 1961). New techniques frequently offer a more accurate perspective and a deeper comprehension of wood. Whether it is simple or complex, they claimed that the anatomist must examine wood and interpret what he sees logically; this must be a necessary prerequisite if the material is to be handled and used effectively. While new methods frequently advance our understanding of wood behaviour, many of its key technical features can be understood and predicted by carefully examining its overall structure, even without the aid of modern technology. The three main facets of comparative plant anatomy—systematic, phylogenetic, and ecological wood anatomy are experiencing a period of resurging interest and productivity.

## **2.1. SIGNIFICANCE OF WOOD ANATOMICAL STUDIES**

There is increasing awareness in the proper utilization of the world's forest resources, especially from the tropical areas. Many of the commercially significant timbers are well recognised in South-East Asia and West African countries, but it is unknown in Central and South America. The assistance of an expert anatomist for technical sorting and categorization of timbers is indispensable for effective utilisation. A greater reliance on plantation forests is the second crucial development that is required. The breeding stock is being carefully chosen, and in the not-too-distant future, this will result in increased yields of high-quality timber. It is essential to understand more about the wood's heritability traits, which calls for proper development with known genetic origins that is either controlled or of clonal pollination. Discovering the connections between the structure and performance is another critical area. This is vital because it can help with the more effective selection and use of timber where such characteristics are necessary.

## **2.2. IDENTIFICATION STUDIES OF INDIAN TIMBERS**

In the past decade, there was an emphasis on comparative anatomy, to help advance the development of the use of the tropical forest resources, effectively. In the years succeeding World War II, research on the relationship between the growth and the wood structure has garnered considerable attention. It was brought about by a growing realisation in many nations of the necessity to produce managed forests as a primary source of wood while maintaining acceptable technical performance. Regarding the future of wood anatomy, it plays a crucial part in creating and utilising wood technology for its effective use. It primarily contributes to the effective production of plantation wood as well as the usage of numerous underutilised timbers in developing countries.

The earliest known record of identifying Indian timbers was published by Troup (1909), a forest economist at the Forest Research Institute in Dehra Dun. His publication focused on providing information on 553 of India's most important timbers for global trade, with the aim of helping foresters and other users identify timber based on its general characteristics and suitability for specific purposes. Troup's work served as a valuable resource for those needing to make informed decisions about the use of Indian timbers.

Wallich, the Superintendent of the Calcutta Botanic Garden, created the first "List of Indian Woods" in 1832, which included 457 species of Indian woods with descriptions of each one of them. On various botanical missions and expeditions, the Governor-General of India sent him. He collected samples of local woods, which were carried to London and stored at the India House. Each species is described primarily in terms of its distinctive wood characteristics. Two priceless tables of trials on the durability of some of the most significant types of Indian timber, conducted by Mr. Kyd in Calcutta and Major H. Campbell in the gun-carriage plant at Cassipur, close to Calcutta, are attached to the catalogue (Prakash, 2016).

Lushington (1919) examined the overall anatomical characteristics of the Madras Presidency's woods, including a description of the local wood species and details on frequently imported woods. In this book, a comparison of domestic and foreign timbers was also made. Gamble (1922) provides a concise overview of the commercially significant Indian woods. With the help of photomicrographs of cross sections of wood, he described common field identification characteristics as odour, colour, hardness, weight, grain characters, etc.

The common commercially important timbers of India and their uses by Trotter (1929) I.F.S, forest economist of the Forest Research Institute, Dehra Dun, includes descriptions of the 86 species of common Indian woods as well as information on their seasoning, strength, sources of supply, price, and other factors.

The anatomy of 320 commercially significant species of timber from 53 groups is described in the book "Commercial Timbers of India" by Pearson and Brown (1932). The book includes detailed anatomical information along with information on each timber's distribution, physical characteristics, supply, mechanical characteristics, and uses. Photomicrographs of cross-sections of timbers are used to support the description, which is then categorised according to its intended application. Chowdhury (1945) provides a brief discussion of the general structural properties of 26 Burmese timbers, including teak and Andaman padauk, including growth ring characteristics, parenchyma types, pore arrangement, and ray

characteristics. Trotter provided a guidebook with information on 150 commercial woods that are popular in India. This information comprises the name of the species, the common name, the trade name, the weight, the strength, the quality of seasoning, the durability, the use, the source of supply, the price, and a description of the wood's characteristics. He classified the timbers to help the users to select the timber species that best fit their needs (Chowdhury, 1945).

The Wood Anatomy Branch of FRI, Dehra Dun published the "Indian Woods" - A thorough collection series (Purkayastha, 1982; Purkayastha, 1985). It discusses the composition, characteristics, classification, and applications of timbers found in India and Burma. In addition to a description of trees, a description of the structure of wood species from shrubs has also been provided.

Harikrishnan (1960) recorded the intricate anatomical details and gross features of 25 timbers of Madras that are significant for commerce. It discusses the basic characteristics of common wood species and specifies the applications for which each species is suitable. The significance of dichotomous keys in the identification of timber samples were examined by Ghosh (1960), who also provided instructions on how to utilise the key. Fruits of various ages were dissected under a binocular microscope, cut into hand and microtome pieces of varying thickness, and dyed using conventional procedures. The identifying keys for fifty economically significant India timbers were developed by Rao and Juneja (1971).

The anatomical description of the Andaman Islands' valuable commercial timbers was developed by Purkayastha *et al.* (1976). It gives a thorough explanation of 36 woods, outlining their basic characteristics, physical characteristics, microanatomy, supply and uses. This guidebook is intended to make it simpler to identify Andamans timbers that are valuable commercially, both in the lab and outdoors.

Nazma *et al.* (1981) published a handbook of 162 commercially valuable timbers common to Kerala. It covers the broad characteristics and physical anatomy of timber that can help in timber identification. The trade name, local name, strength, distribution, tree features, working properties, and utilisation of these timbers are mentioned in addition to the identification characters.

Bhat (1994) examined the traits of 21 lesser-known timber species found in Kerala forests. Along with wood anatomy, factors like grain, colour, texture, heartwood content, shrinkage, and basic density were all taken into consideration. The majority of the woods they examined had densities similar to those of common structural and joinery woods. His research

shows that a significant fraction of lesser-known native hardwoods have timber value that can be utilised to make the most use of the resource.

The Handbook of Lesser-Known Timbers, released by Bhat *et al.* (2007), provides useful resource for timber users to learn more about the Lesser-Known Timbers in the Timber Market, particularly in Kerala. The manual lists the qualities and applications of 77 woods, of which 52 species are imported.

“Anatomical key for the identification of important timbers of Kerala” by Anoop, *et al.*, (2005) gives a detailed description of 50 commonly used timbers in Kerala and major imported wood species. Field keys, microscopic card keys and IAWA list of card keys are listed and it includes photo micrographs and gross view of the timber of the listed specimens.

Saxena and Gupta (2011) conducted research on the wood anatomy of the salvadoraceae family from the Indian subcontinent, paying particular attention to the vessel wall's ultrastructure. Their research highlights the microstructure of Salvadoraceae species found in the Indian Subcontinent, including *Azima tetracantha*, *Salvadora oleoides*, and *S. persica*. Identification for the separation of the species has been made based on the anatomical characteristics of wood. SEM analyses identified vesturing in the inter-vessel pits of some *Salvadora* species.

Sharma *et al.* (2011) studied the variations in wood anatomy in various Meghalayan *Quercus* species. They discovered that vessels are single or multiples of two that are visible in radial or diagonal patterns. They concluded that the *Quercus* species exhibit scalariform perforation plates and vasicentric tracheids. They also discovered that only *Q. acutissima* has aggregate rays, whereas *Q. semiserrata* and *Q. lanceifolia* had multiseriate rays. All *Quercus* species, with the exception of *Q. fenestrata* and *Q. acutissima*, have both heterocellular and homocellular rays. Except for *Q. acutissima*, for all the species examined, axial parenchyma are of the apotracheal diffuse type, with apotracheal diffuse being present in aggregate, unilateral, and banded paratracheal parenchyma.

The Status of anatomy and physical properties of wood in poplars was examined by Pande (2012). He discovered that although *P. ciliata*, *P. alba*, *P. euphratica*, and *P. deltoides* shares similar anatomical structure, the colour differentiation in the wood was described as being grey or brownish grey in *P. ciliata*, sapwood white, heartwood red-colored, and nearly black at the pith in *P. euphratica*, and white to off white in *P. alba* in *P. deltoides*.

Pande (2012) conducted a study on the anatomy and physical properties of wood in poplars. The study found that while *P. ciliata*, *P. alba*, *P. euphratica*, and *P. deltoides* shared similar anatomical structures, there were distinct differences in the coloration of the wood. *P. ciliata* was described as having grey or brownish-grey wood, *P. euphratica* had white sapwood, red heartwood, and nearly black pith, and *P. alba* had white to off-white wood. *P. deltoides* was not described in terms of coloration. This research provides important insights into the variability of poplar wood and can be used to inform decisions related to its use in various applications.

Singh *et al.* (2013) conducted research on the changes in the anatomical characteristics of various Assamese *Terminalia* species. They examined the changes in the wood components of four species of *Terminalia*, *T. arjuna*, *T. bellerica*, *T. chebula*, and *T. myriocarpa*. All *Terminalia* species were found to have diffuse porous wood, with clear growth rings in *T. bellerica* and *T. myriocarpa* and indistinct growth rings in *T. arjuna* and *T. chebula*. Except for *T. myriocarpa*, all of the examined *Terminalia* species had minimum and maximum vessel frequencies of 2 per mm<sup>2</sup> and 14 per mm<sup>2</sup>, respectively, whereas the minimum and maximum rays per mm were 8 per mm and 16 per mm. Only in *T. myriocarpa* Tyloses were found. The results of the analysis of variance revealed that all of the chosen species' wood element dimensions differ significantly from one another. Fiber length had a significant and negative association with fibre diameter, a nonsignificant and positive correlation with fibre wall thickness, and a significant and positive correlation with vessel length and wood density.

Anoop *et al.* (2014) conducted a study on the physical, mechanical, and anatomical characteristics of *Swietenia macrophylla* Roxb, a possible alien species for South India. The examination of *S. macrophylla*'s physical, mechanical, and anatomical characteristics, as well as their interactions, are the main subjects of this study. They also found that the timber quality of the aforementioned species differed when grown outside of its native habitat. Making wise management decisions for these species' raising and management will be aided by growth measures compared to data on wood quality factors.

Muthumala and Amarasekera (2014) prepared a dichotomous key for 56 common local timber species and 11 major imported timber species in Sri Lanka based on anatomical features of IAWA (International Association of Wood Anatomist) List 1989.

Singh *et al.* (2015) conducted a study to evaluate the anatomical characteristics of *Cinnamomum*, *Litsea*, and *Phoebe* species within the Lauraceae family collected from the

forests of Upper Assam, NE India. Their findings indicated that the wood structure was consistent among genera, with diffuse porous wood, solitary vessels, alternate intervessel pits, scanty paratracheal parenchyma, septate fibers, oil/mucilage cells, homocellular rays, and heterocellular rays being common features. However, significant variations were observed in the anatomical characteristics of *Cinnamomum* and *Litsea* species. For example, *C. tamala* and *C. bejolghota* showed indistinct growth rings, while *C. ceicidodaphne* and *C. zeylanicum* had distinct growth rings. In *L. monopetala*, distinct features included indistinct growth ring boundaries, spiral thickenings in vessel elements, crystals in fibers, aggregate rays, and sheath cells. *L. cubeba* and *L. salicifolia* both had scalariform perforation plates, but *L. cubeba* had perforated ray cells with scalariform perforation, which differentiated it from *L. salicifolia*. This research provides valuable insights into the anatomical characteristics of different species within the Lauraceae family and can be used to inform decisions related to their use in various applications.

Gupta (2016) conducted research on the variation in the wood anatomy of hardwood species gathered from Jharkhand's coal mines. This study calls for thorough anatomical analyses in addition to certain physical characteristics of 19 hardwood species gathered from India's largest coal mine sites. This study uses statistical testing to reveal several aspects of wood anatomy in relation to mining stress. Vessel morphology and other eco-anatomical characteristics were also calculated, and vulnerability revealed a noteworthy variation between the three zones. Anjily wood's vessel morphology values suggested that the species is mesic in nature. This study can provide crucial information about the wood qualities of *Artocarpus hirsutus* due to the lack of knowledge on these attributes for this species.

Singh *et al.* (2017) conducted a study on four *Artocarpus* species, namely *A. chaplasha*, *A. heterophyllus*, *A. lakoocha*, and *A. nitidus*, collected from the forests of Assam and Mizoram, NE India, to investigate their anatomical variation qualitatively and quantitatively for identification purposes. All the species had diffuse-porous wood with indistinct rings, solitary vessels, simple perforation plates, alternate intervessel pits, and laticifers in the form of black streaks among fibres and rays. They also had vessel ray pits similar to intervessel pits, vasicentric and lozenge aliform parenchyma. *A. chaplasha* had ray flecks and latex ducts in rays, and gelatinous fibres were observed in both *A. chaplasha* and *A. nitidus*. Sheath cells were observed in *A. lakoocha* and *A. nitidus*, while axial parenchyma of confluent and winged aliform nature was present in *A. heterophyllus*. Tissue proportions among species showed that *A. nitidus* had the highest percentage of fibres, *A. heterophyllus* had the highest percentage of

vessels and rays, and *A. nitidus* had the highest percentage of parenchyma. Maximum vessel frequency was noted in *A. chaplasha*, while maximum rays were noted in *A. nitidus* and *A. lakoocha*. The study found statistically insignificant variations within species for quantitative traits, although considerable variations were observed between species. Most anatomical features exhibited weak correlations that were not significant, but specific gravity showed a positive correlation with ray width and a negative correlation with fibre diameter.

In a study conducted by Sharma *et al.* (2017), the wood anatomy of several species in the Fagaceae family from North-East India was examined. The anatomical characteristics of *Castanopsis kurzii*, *Lithocarpus fenestrata*, *Quercus griffithii*, *Quercus lamellosa*, and *Quercus spicata* were analyzed to determine variations within and between genera. The study found that vasicentric tracheids, apotracheal diffuse, and diffuse-in-aggregate axial parenchyma were common characteristics among the genera. *Lithocarpus* was distinguished from *Quercus* and *Castanopsis* by the presence of exclusively solitary vessels with diffuse porous wood and indistinct growth rings, scalariform perforation plate, scalariform and opposite intervessel pits, long vessels with helical thickenings restricted to their tails, vessel-ray pits with much reduced borders, and heterocellular and biseriate rays. *Castanopsis* was similar to *Quercus* but lacked aggregate rays. All selected *Quercus* species were closely related, with simple perforation plates, opposite intervessel pitting, vessel-ray pits with reduced borders, vertical (palisade), gelatinous fibers, and aggregate rays. However, *Q. griffithii* could be distinguished from *Q. lamellosa* and *Q. spicata* by diagonally arranged vessels, chambered crystalliferous axial parenchyma, and homocellular rays. *Q. spicata* differed from other species by the absence of gelatinous fibers and the presence of axial parenchyma in the form of bands alternating with fibers.

Helmling *et al.* (2018) extensively studied the vessel characteristics of 38 species among which two were monocots- *Dendrocalamus latiflorus* Munro (Poaceae) and *Cocos nucifera* L. (Arecaceae). They studied the shape of the vessel elements, tail of the vessel element, perforation plates, pit types, tyloses, helical thickenings and vessel and fibre dimensions of the selected species.

Mertz, (2021) used wood identification to identify the ancient temple structures in Ladakh, located in the Western Himalayas. Microscopic wood identifications were performed on the five Buddhist temple structures, three vernacular houses, two stupas, and two holy trees located in Ladakh and from the 110 wood samples collected, 4 wood species- *Pinus*

*wallichiana*, *Populus sp.*, *Salix sp.* and *Juniper sp.* were identified using microscopic analysis of sections taken using a microtome.

Vaishnav *et al.* (2022) examined *Phoebe hainesiana* and found that it is a diffuse-porous wood with indistinct growth rings. The vessels are solitary, radially dispersed in multiples of 2-7 and clustered. The wood of the species is categorised as "class-II" because to its durability. The wood species seasons well without any seasoning defects. It is moderately refractory in nature. The basic density of wood ranges between 450 kg/m<sup>3</sup> to 800 kg/m<sup>3</sup>, and intraspecific wood density varies significantly.

The findings of Sinha *et al.* (2022) in *Santalum album* showed that the stem wood and root wood had similarities in appearance, but there were slight differences in vessel diameter, which was more prominent in root wood than in stem wood. Stem wood had higher ray frequency and fibre length than root wood. The bark had distinct oil cells without oil globules associated with ray parenchyma cells, while oil globules were observed in the lumens of procumbent ray cells and axial parenchyma in stem wood. Ray cells in stem and root wood were of the heterogeneous type, but they were homogeneous in the bark. Rhomboidal crystals were occasionally seen in root wood's axial parenchyma and ray cells but not in stem wood's chambered cells of the same type. Sporadic crystals were also found in the axial parenchyma and cortical cells of the bark.

### **2.3. PHYSICAL PROPERTIES OF WOOD**

Physical properties of wood include specific gravity, shrinkage behaviour in three primary planes (tangential, transverse and radial) of wood, moisture content and other general features of wood. They decide the wood quality and its end-use (Sekhar, 1988). Wood properties vary significantly among different species of wood, and it is rare to find two woods that are similar qualities in all aspects (Konwer *et al.*, 2001).

#### **2.3.1. Specific gravity**

Specific gravity is defined as the amount of wood substance or biomass deposited per unit volume of living tree trunk, and thus is a factor influencing the amount of forest biomass (Woodcock, 2000). Wood specific gravity (WSG) or density of a wood is a measure of the wood substance that is contained in a given volume as described by Tsoumis (1999). WSG is also defined as the density of oven dry wood relative to the density of water, whereas wood density is the weight per volume, which includes the weight of water contained by the wood (Gao *et al.*, 2017). As wood density reflects a plant's carbon expenditure in its water-conducting

tissues compared to the size of the stem (Chave *et al.*, 2009), it is an important characteristic linked to many elements of a plant's ecology, including life history strategy, functional physiology, mechanical qualities, and architecture (Poorter *et al.*, 2010). Recent years have seen a rise in interest in WSG as plant biologists search for broad-spectrum functional features and evaluate the ecological and evolutionary significance of these traits (Muller-Landau, 2004; Chave *et al.*, 2009; Swenson and Enquist, 2007). Wood density is one of the important factors that determine the economic utility of wood for paper and pulp making as well as for solid wood purposes. The basic density is also used to estimate carbon stored in the woody stems of trees and has an appreciable influence on many solid wood properties and conversion processes, including cutting, gluing, finishing, rate of drying and paper making.

The wood density is considered as one of the most significant property which determines the end use of the wood (Buijtenen 1982; Bamber and Burley, 1983). Guth (1980) correlated wood density with strength properties of wood, pulp yield and pulp quality. For most of the end uses like pulp and paper production or for solid wood products uniform wood density is the most preferred quality. In hardwood species, stiffness and strength are determined mainly by wood density, as well as by cellulose microfibril angle, the proportion of lignin, extractives, and interlocked grain; and the extent of spiral grain (Huang *et al.*, 2003).

Specific gravity is one of the most extensively studied property mainly due to its relative easiness of measurement and generally high heritability. Zobel and Jett (1995) reported that density in eucalypts has been under strong genetic control, with individual heritability ranging between 0.4 and 0.84. Genetic correlations between basic density and growth rate have been weak but often unfavourable (Zobel and Jett, 1995).

Several studies have examined the correlation between humidity and density, specifically in relation to the specific gravity of wood. Variations were observed within and between species in different regions. For instance, trees from drier regions had a higher average density (averaging at 0.78) than those from more humid areas. Barnes *et al.* (1998) investigated this correlation in *Pinus caribea* and found a strong 88 percent correlation between wood density and soil moisture deficit. Similarly, Plumptre (1984) noted that *P. caribaea* grown in climates with a pronounced drought had a higher density.

According to Scott and MacGregor (1952), teak trees grown in Trinidad from seeds imported from Burma had lower specific gravity than those of other seed origins. However, it is expected that growth rate has a greater impact on specific gravity variation than the seed

source difference. Sahri *et al.* (1998) found that mechanical properties and specific gravity in *Acacia mangium* and *Acacia auriculiformis* were influenced by species, provenance, and site. In a study by Sheikh *et al.* (2020), carbon stocks were estimated in temperate forests dominated by *Cedrus deodara* along altitudinal gradients in the Central Himalaya using standard protocols that estimated specific gravity based on stem core by the maximum moisture method. This helped in understanding and estimating the biomass and soil carbon storage potential of the forests.

In a study conducted by Sekhar and Rajput (1967), the radial, tangential, and volumetric shrinkage of different timber specimens were examined in relation to specific gravity and fiber saturation point. The study revealed that the specific gravity of the wood substance plays a significant role in governing the shrinkage behavior.

Hindi and Bakhaswain (2010) conducted research on the chemical constituents of various natural sources, including the vegetative parts of the date palm (*Phoenix dactylifera*), *Conocarpus erectus*, *Leucaena leucocephala*, *Simmondsia chinensis*, *Azadirachta indica*, and *Moringa peregrina*. They assessed the chemical composition, fibre length, and specific gravity of each plant species, and found that these traits varied significantly among the different sources. The results showed that *Leucaena leucocephala* had the highest holocellulose content of 70.82% and a specific gravity of 0.6, making it the most suitable species for their study.

Rew (2008) evaluated the specific gravity of 12 different tree species that are important for agroforestry. He found that specific gravity values for scattered trees in agricultural lands varied between 0.42 to 0.85, and most of the species had values below 0.6. Rew highlighted the importance of specific gravity as a crucial factor in selecting tree components for agroforestry systems, as it is a key indicator of the potential utility of the timber.

In a study by Lokman and Aagan (2010) on *Acacia mangium* from five different provenances of Malaysia, they found that specific gravity near the pith was 0.20 and increased to 0.8 towards the bark. However, Sanwo (1986) concluded in their report on teak planted in Nigeria that growth rate did not significantly affect specific gravity. Additionally, Kadambi (1972) reported that different levels of thinning (heavy and moderate) did not impact strength properties.

Pande *et al.* (2012) reported an increase in specific gravity from the inner to outer radius and with height of the tree in their study of ten different clones of Poplar from Rudrapur, India. Interestingly, the female mother trees exhibited higher density than the male parent trees.

Elzaki and Khider (2013) conducted a study on the wood properties of twenty-year-old Cupressus species from western Sudan. They compared the specific gravity of this species to Cupressus species from India and Costa Rica and found that the Sudanese species had a higher average specific gravity of 0.52 compared to the other two species with specific gravities of 0.45 and 0.43, respectively. The wood-bark ratios, measured by both mass and volume, were within the normal range for all the tropical softwood species studied. The Indian cypress had a higher modulus of rupture (793 Kpa/cm<sup>2</sup>) compared to the Costa Rican cypress (693 Kpa/cm<sup>2</sup>). In terms of compressive strength and shear strength, the Sudanese cypress was found to be higher than both of the compared species.

Saravanan *et al.* (2014) conducted a comparison of the physical and mechanical properties of Melia dubia and Tectona grandis at different age levels. The study found that five year old M. dubia samples had a maximum density of 500.20 kg m<sup>-3</sup> and a specific gravity of 0.60. Based on these results, the study concluded that five-year-old Melia wood is suitable for the production of plywood, packing cases, pencils, and lightweight furniture, as it exhibited the highest values for all physical and mechanical parameters.

Anish *et al.* (2015) conducted an analysis of the impact of growth rate on various properties of teak wood sourced from 14 different locations within and outside India, and grown under different site conditions. The study revealed that fast-grown timbers exhibited higher shrinkage, moisture content, and specific gravity compared to slow-grown timbers. Conversely, slow-grown timbers had higher vessel dimensions and extractive contents.

Dhillon and Sandhu (2020) measured the specific gravity of poplar wood samples collected at 1.37 m height (breast height) from two different locations. The study found significant differences in specific gravity among the clones from the two locations, with the specific gravity of wood ranging from 0.40 to 0.48 in one location and from 0.36 to 0.44 in the Central plain Semi-Arid Regions.

### **2.3.2. Colour**

Colour of the wood is a feature that can be identified without much expertise. Colour enables us to get a preliminary idea of the wood, regarding its identity. This method has been used since ages to identify the woods by people locally. It is impossible to classify all of the heartwood colours due to the range of hues, tints, and combinations that exist. Heartwoods typically has one of the following colours: brown, red, yellow, white, or a shade or combination of these. Heartwood that is primarily white, grey, or brown is extremely common; heartwood

that is red or yellow is less common; and heartwood that is orange (*Pseudotsuga*) or very dark brown (*Cryptomeria japonica*) is rather uncommon. Many taxa have heartwood that is not just one colour but a mixture of colours. Some of the characteristic colours or colour combinations include: chocolate brown in *Taxus* spp. (Taxaceae), reddish-brown in *Sequoia sempervirens* and *Fitzroya cupressoides* (Cupressaceae); purplish-brown in *Juniperus virginiana* and *Calocedrus decurrens* (Cupressaceae) (Phillips 1941; IAWA, 1989; Richter and Oelker, 2002).

Dadswell and Burnell (1932) found colour to be a varying factor, as there were wide variations in shades within a species. Thus, in recording colour for any sample, no reference was made to a colour index—only general colour approximations were used. The colour of a freshly cut longitudinal face of each of the samples examined was recorded for the particular sample, and from these results the average colour range for the species was determined, in so far as the number of samples examined allowed. As mentioned earlier, colour has been used as a preliminary distinguishing factor for the separation of the woods of the genus *Eucalyptus* into two main groups. It is, however, necessary to record the colour of each sample in order to obtain information regarding those species which, on the basis of colour variation, might fall into both of the colour groups designated.

Fahn *et al.* (1986), compiled a book that includes treatments of some 180 species native to the area West of the Jordan River, extending to Mt. Hermon in the North and the Sinai Peninsula in the south. The book focused on identification, "wood anatomical" descriptions, habit, distribution, anatomical characters, and archaeological records, as well as ecological considerations. Identification includes a key to species and lists of Gnetales and dicotyledons with selected diagnostic features (ecological trends, comparison with other woody floras, trends within genera). There are 320 micrographs of wood sections on 82 plates in an atlas at the conclusion of the book. The tomb of the pharaoh Tutankhamun was covered with the woods of Cypress and Cedar as it had attractive colour and texture (Rifai and Hadidi, 2010).

Ilic (2019) compiled a book where in, it discussed the angiosperms and gymnosperms of Australia from an evolutionary context. The book contained comprehensive illustrations of 129 forest trees, together with information on their geographic distribution, common and botanical names, botanical family names. Anecdotes concerning the historical and regional significance of the tree's habit and botanical field traits were included. The wood is discussed for each species along with details on its valuable timber characteristics and, in some cases, rarely mentioned possible uses, which nicely exemplifies the adaptability of the Australian

species. The appearance of the wood's smooth side-grain surfaces (backsawn or occasionally quartersawn) is depicted in colour images along with amusing anecdotes and first-hand accounts. The addition of exquisite end grain macrographs of expertly polished wood is one of this book's most distinctive features.

### 2.3.3. Odour

Odour is a distinctive smell. Every wood has odour which is the direct result of the compounds formed within the wood. Biopolymers such as cellulose, hemicellulose, and lignin constitute the majority of the substance in wood. These include proteins, amino acids, fatty acids, terpenes, resins, acids, steroids, phenols, aldehydes, ketones, lactones, and other extractable chemicals in smaller concentrations. These are the major chemical groups from which aromatic compounds are formed. Despite the fact that there are several research examining the volatile content of woods, few of them focus on the elements that give out odours (Schreiner *et al.*, 2017; Tissandié *et al.*, 2018; Amaral *et al.*, 2019).

Tissandié *et al.* (2018) characterised the chemistry and aroma of guaiac wood oil, which was extracted from *Bulnesia sarmientoi*'s heartwood. The compounds were primarily made up of sesquiterpene hydrocarbons and oxides, alcohols, phenols, ethers, aldehydes, and ketones were identified and quantified using GC-GC-FID/MS. By using GC-O, the primary odorants were discovered. The chemicals bulnesol (rosy) and -ionone (fruity), which contributed the most to odour effect, were noted.

Marriott and colleagues examined the composition of *Aquilaria malaccensis* oils using various multidimensional techniques. They used a 3D GC-GC×GC system to enhance the resolution of oxygenated sesquiterpenes in Agarwood, as described in studies by Wong *et al.* (2015) and Yan *et al.* (2018). Liu and co-workers described the aromatic odour of agarwood as pleasing and complex (Bakansing *et al.*, 2019).

Schreiner *et al.* (2017) and Ghadiriasli *et al.* (2018) used MDGC-MS/O to identify trace components of aromas in cedar incense (*Calocedrus decurrens* (Torr.) Florin), Scots pine (*Pinus sylvestris* L.) and oak wood (*Quercus frainetto*). Cedar incense had over 60 odour components, with 22 potent odorants from terpenoids, fatty acid derivatives, and phenols. Scots pine had 39 odorants with terpenoids, aldehydes, ketones, and lactones as main classes. The most prevalent substance was -pinene, described as resin-like. Oak wood had 91 different compounds with vinegar, green-musty, and resinous fragrance. The major cork taint odours, including geosmin, 2-methylisoborneol, 3-isopropyl-2-methoxypyrazine, 3-isobutyl-2-

methoxypyrazine, 2,4,6-trichloroanisole, and 3,5-dimethyl-2-methoxypyrazine, were identified using MDGC and GC-GC. 3,4,6-trichloroveratrole and 3,5-dichloroveratrole were also identified as off-flavors of cork. Multidimensional techniques were crucial for accurate separation, identification, and quantification. (Slabizki and Schmarr, 2013; Slabizki *et al.*, 2015). Sunny *et al.*, (2019) while examining the wood of *Dalbergia sissoo* wood revealed that it had a sweet smell.

#### **2.3.4. Lusture**

Bijalwan *et al.* (2014) conducted a study on *Anthocephalus cadamba* in India to investigate its potential for carbon sequestration. They observed that the wood of *A. cadamba* had a straight grain, fine to medium texture, and low luster. In a separate study, Hegde (2019) examined the physical and mechanical properties of lesser-known timber species in Mizoram. According to their findings, *Duabanga grandiflora* had the lowest density and was suitable for lightweight uses such as packing cases. It also had good luster, making it suitable for plywood manufacture. *Anogiessus acuminata* and *Callicarpa arborea* were classified as having moderate luster, while *Castanopsis tribuloides* and *Schima wallichii* were categorized as dull.

#### **2.3.5. Texture and figure**

Texture of wood is a wood grain visible on the section of wood and it is created by its structure e.g. annual rings, pith rays, arrangement of wood fibres etc (Pivarciova and Cernecky, 2011). Simpson and TenWolde (1999), described various physical properties of various genera of softwood of United states of America. Miller (1999) described various physical and mechanical properties of the commercially important hardwood and softwood species of United states of America.

Hegde (2019) studied the physical and mechanical properties of lesser-known timber species of Mizoram and found that *Callicarpa arborea* has smooth texture, *Anogiessus acuminata* and *Schima wallichii* were of fine texture whereas *Duabanga grandiflora* and *Castanopsis tribuloide* were grouped as coarse.

Phongkrathung *et al.* (2016) carried out studies on wood cellular characteristics of the family Anacardeaceae. he researchers found that the wood had diffuse-porous characteristics with a greater number of solitary pores and fewer multiple pores. The vessels had a round to oval shape and were arranged in tangential bands and a diagonal pattern. The wood of all the studied species had indistinct growth rings and a fine texture with straight grain. However, due

to its low density and hardness, the wood from this genus may not be suitable for heavy construction purposes.

Xie *et al.* (2010) classified wood by its texture. In this study, 1000 wood texture images were decomposed and reconstructed at 2-level by Symlet-4 wavelets, and each original image generated eight sub-images. By using the autocorrelation function, the fractal dimensions of the eight reconstructed sub-images and the original images were computed. Results showed that the overall regularity and complexity of texture were mirrored in the fractal dimension of the source images. Under a multi-resolution texture classification, the fractal dimension value of the horizontal, vertical, and diagonal directions of the detailed images might characterise the detail of texture. When the wood texture was delicate, the fractal dimension was substantially smaller, and when the wood texture was rough, it was relatively greater.

Wood identification was carried out by Wang *et al.* (2013) based on wood texture. The researchers used *Mask Matching Image* (MMI) to extract a set of features that preserved the mask matching information from the HLAC methods. Statistical and geometrical features were used to accurately extract texture information from the image. They introduced a new histogram, the length histogram, which captured richer information and enhanced discriminative power by embodying the width and height histograms. The performance of their method was compared with state-of-the-art HLAC approaches using the wood stereogram dataset ZAFU WS 24. Extensive experiments conducted on ZAFU WS 24 showed that this new approach significantly improved the accuracy of classification.

Madurangi *et al.* (2020) conducted a study on selected lesser used timber species in Sri Lanka to analyze vessel characteristics and their correlation with wood density and texture. The researchers categorized timbers into different textural classes based on vessel diameter: 0-100  $\mu\text{m}$  for fine texture, 100-200  $\mu\text{m}$  for moderate texture, and >200  $\mu\text{m}$  for coarse texture. The study showed that wood texture and density were significantly associated, and a negative relationship was observed between wood density and vessel diameter ( $r = -0.866$ ,  $p < 0.05$ ), wood density and vessel perimeter ( $r = -0.610$ ,  $p < 0.05$ ), as well as wood density and vessel area ( $r = -0.546$ ,  $p < 0.05$ ). To extract the vessel characteristics, the researchers used various analytical methods.

## **2.4. ANATOMICAL PROPERTIES**

Anatomy of wood includes the cellular structure present in the wood. It includes cells from pith to periphery- vessels, rays, fibres, parenchyma and other structures.

#### 2.4.1. Vessels

Revised: Ghouse and Iqbal (1983) conducted a study on *Acacia nilotica* and reported that vessel segment length decreased from base to top before stabilizing in the old trunk. They also observed that the length of xylem fibers increased initially before becoming relatively constant. Similarly, Wu and Wang (1988) investigated variations in fiber length and cell wall percentage along the height of *Acacia mangium* and *Acacia auriculiformis* trees. Additionally, Ku and Chen (1984) conducted comparable experiments on the aforementioned two *Acacia* species.

According to Ewers and Fisher (1989), Liana vessels are thought to be the longest and widest in the plant kingdom. Cellular analysis of several tropical and subtropical lianas revealed longer and wider vessels (*Pithecodenium crucigerum*) in stems with larger diameter.

The study by Chauhan *et al.* (2001) on various clones of *Populus deltoides* reported an increase in the dimensions of vessel elements from pith to periphery. Similarly, Pande and Dhiman (2011) observed non-significant variations in vessel element length and an increasing trend in vessel element diameter from pith to periphery in certain clones of *P. deltoides*.

On various clones of *Populus deltoides*, Chauhan *et al.* (2001) discovered an increasing trend in vessel element diameters from the pith outward. In several *P. deltoides* clones, Pande and Dhiman (2011) reported significant variation in vessel element diameter from pith to periphery showing rising tendency but non-significant variation in vessel element length.

According to Carlquist (1975), plants in dry environments tend to have shorter elements with simple perforation plates, while those in moist or alpine environments tend to have scalariform elements. In addition, xeromorphic woods generally have a higher proportion of thin vessels, as reported by Carlquist (1975) and Baas *et al.* (1983).

The safety mechanism of vessel grouping is observed in arid desert and Mediterranean regions (Carlquist, 1989). In terms of cavitation resistance, Lens *et al.* (2011) found a correlation between vascular grouping and the ability to maintain 3D conductive channels even when one vessel in the group becomes embolized. In xeric conditions, arteries and imperforate tracheary elements with thick walls and limited lumen may increase mechanical strength (Sperry, 2003).

In addition to channel diameter, Dickison (2000) notes that the pit characteristics are mostly connected to the risk of embolism. Regardless of vessel size, the small pits and small

size apertures (Baas *et al.*, 1983; Tyree *et al.*, 1994; Hacke *et al.*, 2004) offer a method to lessen the likelihood of cavitation. High vulnerability index improved water transport efficiency but increased embolism risk. Studies highlight the significance of diameter and frequency variation, as well as vessel grouping, for adjusting water movement under various environmental situations (Rajput *et al.*, 2012) Xylem development is halted when exposed to pollution stress (Rajput *et al.*, 2008).

Fahn and Werker (1990) observed that large vessels are not obligatory in lianas and quite a significant number possess small vessels. For instance, the mean vessel diameters of *Quintinia fawcneri* and *Carissa ovate* are 44  $\mu\text{m}$  and 60  $\mu\text{m}$ , respectively. The rise in vessel frequency in lianas compensates for this drop in vessel diameter, keeping the fraction of vessels higher on average than in trees. It is possible to retain high conductivity and mechanical resistance wherein walls offer the resistance required for the tissue as a whole by combining dropped vessel diameter with fibres (Tyree *et al.*, 1994).

Gartner *et al.* (1997) found that there were no statistically significant differences in height between the lower and upper sides of the lean of red alders (*Alnus rubra* Bong.) for all measured variables. In the first 8 to 12 years, there was a rapid expansion of fibre length and vessel diameter in the radial direction (from 0.8 to 1.2 mm and 47 to 60  $\mu\text{m}$ , respectively). There was a slight increase in the vessel proportion (from 23 to 28%), a slight decrease in the fibre proportion (from 63 to 57%), and no apparent change in the ray percentage from the pith to the bark. Although specific gravity varied widely among trees, it remained constant with height (0.45 to 0.51 for tree means). These results suggest that the wood properties of *A. rubra* are relatively uniform among individual trees, except for fibre length and vessel diameter, which increased considerably in the first few growth rings.

Vessel morphological characteristics are very much dependent on the environmental factors and play a crucial role in wood formation and development. In peninsular India, nine populations of teak were studied by Varghese *et al.* (2000) who also noted substantial differences in the size of vessel components in samples from Kalakkad (Tamilnadu) and Allappally (Maharashtra). According to Hagen-law, Poiseuille's vessel size should have a positive impact on growth because it improves the capacity of the vessel to transport water to the fourth power (Hacke *et al.*, 2004).

Cox *et al.* (2001) conducted a study on four dipterocarpus species, namely *Shorea acuminata*, *S. ovalis*, *S. leprosula* and *Dryobalanops aromatica*, to examine their growth and

wood quality. The trees were randomly selected from a taungya plantation established in Kenaboi Negeri Sembilan, Peninsular Malaysia. The average fibre length of *S. ovalis* was 1355  $\mu\text{m}$ , and the specific gravity ranged from 0.31 (*S. leprosula*) to 0.37 (*S. acuminata*). The correlation between vessel diameter and climate is typically seen as an adaptation to the environment. Wide, conductive vessels are believed to be suited for damp environments, while more cavitation-resistant, narrow vessels are thought to be preferred in dry environments (Carlquist, 2001; Tyree and Zimmermann, 2002).

The size of vessels plays an important role in the efficiency of sap movement, with larger diameter vessels being more efficient than those with small diameter (Alves and Angyalossy, 2002). However, vessel diameter is not only associated with sap movement but also with the mechanical resistance of different types of wood. Therefore, woods with larger diameter vessels may be weaker than those with smaller diameter vessels. Cellular heterogeneity was observed in different clones of *Eucalyptus tereticornis* within the same tree by Rao *et al.* (2002). There was no discernible trend in vessel frequency, vessel diameter, and fiber length from the bottom to the top of the tree. However, a positive correlation was found between fiber diameter, double wall thickness, and fiber length.

Rao *et al.* (2003) investigated the radial variation in cellular characteristics of *Tecomella undulata* grown in plantations. The authors reported significant differences between the pith and periphery in terms of vessel frequency, vessel diameter, and the fraction of solitary vessels. In another study, Anoop *et al.* (2005) examined *Artocarpus heterophyllus* and observed that vessels were solitary and arranged in radial multiples of two to three. The individual vessel outlines appeared circular in shape, with vessel lengths ranging from 300  $\mu\text{m}$  to 530  $\mu\text{m}$  and tangential diameters ranging from 160  $\mu\text{m}$  to 270  $\mu\text{m}$ . The mean vessel length was reported as 400  $\mu\text{m}$ .

Wheeler *et al.* (2005) suggested that in dry and semi-dry environments, the size of vessels may be limited by the need to prevent inter-vessel pitting and air seeding embolism, which occurs when gas is drawn through the pores of the pit membrane. To balance the functional requirements of minimizing vascular resistance with limiting embolism spreading, the porosity of the pit membrane between adjacent vessels may be designed. A reduction in the total pit area per vessel leads to a decrease in the average size of membrane pores, thereby increasing protection against cavitation.

Schmitz *et al.* (2006) studied the vessel characteristics in mangroves in relation with salinity and came to the conclusion that the vessel's environmental responsiveness to soil water salinity was astonishingly low during either the rainy or the dry season. However, the variation in vessel sizes is regarded to be of crucial importance for adaptation, and the average vessel diameter appears to be as clearly predicted by water availability across habitats.

Another characteristic that is crucial to understanding wood cellular structure is the vessel lumen diameter (VLD), which often exhibits radial variation from the centre to the bark area. From various studies it was observed that similar variation trend for vessel lumen diameter, i.e., the vessel lumen diameter increases from pith to outwards. In two species, *Castanea crenata* and *Quercus serrata*, Tsuchiya and Furukawa (2008, 2009) observed the relationship between radial variation in vessel lumen diameter and the stages of radial growth. They concluded that vessel lumen diameter increased during the early and middle stages and stabilised in the later stages.

According to Ramirez *et al.* (2009), there are significant differences across *Eucalyptus globules* clones in terms of vessel frequency, vessel area, and vessel coverage. Mean vessel area and vessel coverage gradually rose from the pith to the bark, except that vessel frequency dropped.

Pande and Dhiman (2010) conducted a study to compare the differences in fibre length, diameter, wall thickness, and vessel element length among ramets of *Populus deltoides* clones. The study examined intraramet, intraclonal, and interclonal differences in these characteristics among six-year-old trees grown using macro and micro-propagation procedures. The results showed that the variations in intraramet characters were not significant, and the diameters of wood elements increased radially from the pith to the periphery and from bottom to top.

Anoop *et al.* (2011) conducted a study on the variation in wood properties of three species: *Artocarpus heterophyllus* Lam., *Artocarpus hirsutus* Lam., and *Pterocarpus marsupium* Roxb., as part of a provenance trial at the Livestock Research Station in the Palakkad district of Kerala. The study found that *A. hirsutus* had higher values for ray height, ray breadth, and vessel frequency compared to the other two species. *P. marsupium* showed the highest air dry and oven dry specific gravities. *A. heterophyllus* had excellent results in terms of vessel diameter, vessel area, fibre length, and fibre diameter.

Saravanan and colleagues (2013) conducted a study on *Melia dubia* and analyzed variations in cellular properties among one, two, three, four, and five-year-old trees. They

measured vessel length, diameter, arrangement, and frequency; ray height, width, and frequency; and fibre length, diameter, wall thickness, and lumen width. Wood samples were collected from the pith, middle, and periphery wood portions. The study found that vessel length, diameter, and frequency, as well as all other cellular characteristics examined, increased significantly with age and from pith to periphery, except for lumen width. Specifically, mean values for vessel length were 235.68, 250.72, 272.76, 292.01, and 329.57  $\mu\text{m}$  for one, two, three, four, and five-year-old *M. dubia*, respectively. Mean values for vessel diameter were 192.57, 207.11, 231.10, 247.54, and 276.96  $\mu\text{m}$ , and mean values for vessel frequency were 4.00, 4.00, 4.00, 5.00, and 5.00  $\text{mm}^2$  for the respective age groups.

Sreevani and Rao (2015) observed that within tree variation in cellular characteristics of clones of *Eucalyptus tereticornis*. Fibre and vessel characteristics were observed and noticed to vary significantly from bottom to top with no definite trend. The results obtained in this study have revealed the suitability of raw material for paper and pulp.

Phongkrathung *et al.* (2016) conducted research on the cellular characteristics of wood in the Anacardiaceae family. The researchers prepared permanent slides of wood sections and tissue macerations and found that the wood was diffuse-porous, with a predominance of solitary pores and few multiple pores. They also observed that the vessels had a round to oval shape and were arranged in tangential bands and a diagonal pattern.

Ashwath *et al.* (2021) carried out a comparative analysis of wood parameters among nine populations of *Acrocarpus fraxinifolius* from Southern Karnataka. The study included an analysis of various wood properties such as bark thickness, wood density, specific gravity, fiber parameters, and vessel parameters. The study found that vessel parameters, with the exception of vessel wall thickness, varied among the populations. Specifically, the vessel length ranged from 104.78  $\mu\text{m}$  to 124.71  $\mu\text{m}$ . The study also observed variations in wood traits between the radial portions, i.e., from the pith to the periphery region.

Pertiwi *et al.* (2022) conducted research on the xylem maturation process and its impact on cell morphologies in the wood of balsa (*Ochroma pyramidale*) trees. They found that the vessel element length was 0.59 mm, while the vessel diameter measured 221  $\mu\text{m}$ .

### **2.5.2. Rays**

Rao and Juneja (1971) suggested that rays are collections or strips of horizontally aligned parenchyma cells that extend from the pith or centre of a log to the bark or periphery

and are mostly used for radial conduction and storage. They can be seen on the end surface of all woods as many, fine, whitish or light-coloured parallel lines that are perpendicular to the growth markings. They appear as spindle-shaped entities organised with their long axis upright on the tangential surface.

Carlquist (1988) mentioned that more studies comparing the frequency of rays with environmental condition are necessary as rays are normally ignored by wood technologists and forest geneticists. Ray tissue constitutes about 17% of the hardwood xylem and may reach more than 30% (Haygreen and Bowyer, 1982).

According to Anoop *et al.* (2005), a study conducted on *Artocarpus heterophyllus* revealed that rays are multiseriate ranging from 370  $\mu\text{m}$ -890  $\mu\text{m}$  in height with a mean of 610  $\mu\text{m}$  and the fibres are thin walled and non-septate. Izekor and Fuwape (2011) observed that in *Tectona grandis* wood in Edo state, Nigeria both uniseriate and multiseriate rays were present. The study of cellular characteristics of *Leucaena leucocephala* wood and its effect on Oriented Strand Board (OSB) was carried out by Nazri *et al.* (2012) showed that except for the number of vessels, the cellular characteristics were affected by age. As the age increased from eight-year-old to sixteen-year-old, the ray width increased by 21% and the number of ray cells also exhibited significant differences.

According to Islam *et al.* (2012), *Artocarpus heterophyllus* has multiseriate ray parenchyma with 2-4 layers of rays, and the ray parenchyma has abundant starch content. In addition, xylem ray parenchyma cells contained more protein compared to wood fibers and phloem parenchyma cells. Furthermore, they observed the presence of perforated ray cells in *Heuchera sanguinea*'s wood, which connects vessels on opposite sides of the ray and acts as conducting elements.

Saravanan *et al.* (2013) investigated the variations in cellular characteristics such as vessel length, diameter, arrangement, frequency, ray height, width, frequency, fibre length, diameter, wall thickness, and lumen width of *Melia dubia* cav. at different ages, including one, two, three, four, and five years old. The wood samples were collected systematically from the pith, middle, and periphery wood sections of the radial positions. The authors observed mean values for different age groups of *M. dubia* and reported that ray height ranged from 336.65  $\mu\text{m}$  to 438.23  $\mu\text{m}$ , ray width from 71.73  $\mu\text{m}$  to 98.66  $\mu\text{m}$ , and ray frequency from 7.00/mm<sup>2</sup> to 11.00/mm<sup>2</sup>, respectively.

In his study, Carlquist (2015) emphasized the importance of considering axial parenchyma when developing techniques to prevent and reverse embolisms in tracheary elements. This mechanism works in conjunction with root pressure and cohesion-tension-based water movement to maintain flow in the xylem. The occurrence of septate fibers, fiber dimorphism, and the co-occurrence of septate fibers and axial parenchyma can also substitute for axial parenchyma in cases where it is absent, and can account for water movement in the xylem as well as the supply of carbohydrates needed for massive and sudden events of foliation, flowering, and fruiting.

Elaieb *et al.* (2019) studied the relationship between physical properties (basic density, shrinkage) and wood-ray characteristics of four ring-porous hardwoods- *Castanea sativa*, *Quercus petraea*, *Quercus robur* and *Quercus canariensis*. The proportions of large and multiseriate wood rays varied among the four wood species. Wood-ray percentage appears to be positively correlated with wood basic density, radial shrinkage, tangential shrinkage, and Transverse Anisotropy Ratio for Shrinkage, according to their wood anatomical features (TARS).

Zhang *et al.* (2022) investigated the variations in parenchyma fraction along a temperature gradient, along with the relationships between the parenchyma fraction and the Non-Structural Carbohydrates (NSC) concentration at the end of a growing season in a northern subtropical region. The study found a positive relationship between the axial parenchyma fraction and NSC concentration, indicating that the axial parenchyma may play a crucial role in the storage and transport of NSC in the xylem. The results also suggest that different types of parenchyma have distinct responses to environmental conditions, which can affect the NSC dynamics in trees. These findings provide important insights into the mechanisms underlying the carbon balance and growth of trees under changing climatic conditions.

Pace *et al.* (2022) conducted a study on the wood anatomy of eight families within the Sapindales order, utilizing phylogenetic comparative methods to investigate the evolution of wood traits. They identified 23 characters and reconstructed them on the most recent time-calibrated phylogeny for the group. The study found that ring-porosity is derived within the order, primarily influenced by seasonal climates. Ancestrally, marginal parenchyma was present but largely lost in the Anacardiaceae-Burseraceae-Kirkiaceae clade. Vessels in radial chains were absent in the ancestral condition but gained at times. Scanty paratracheal parenchyma was ancestrally present, but there were multiple evolutions of more abundant

parenchyma. Anacardiaceae-Burseraceae-Kirkiaceae shared tyloses and large vessel-ray pits. Radial ducts were exclusive to Anacardiaceae-Burseraceae, while traumatic ducts were exclusive to Meliaceae-Rutaceae-Simaroubaceae. Rays were generally 2–4 cells wide and heterocellular, but several lineages evolved homocellular narrow rays or more heterocellular wide rays. Prismatic crystals were commonly located in rays in Anacardiaceae-Burseraceae while in other families, they were primarily found in axial parenchyma. Silica bodies were abundant in Burseraceae, but also present in Anacardiaceae and Meliaceae. Lianas were exclusively found in Anacardiaceae and Sapindaceae, with Sapindaceae displaying an enormous diversity of cambial variants. The study revealed several potential synapomorphies of major clades within the Sapindales and evolutionary patterns for the diverse wood anatomical features of the order. Furthermore, it emphasized the need for further detailed studies on variable characters within individual families of the Sapindales..

### 2.5.3. Fibres

Dinwoodie (1996) highlighted the importance of fibre length as a key factor that impacts the strength properties of paper. Research has extensively investigated fibre length as a quality parameter of pulpwood, considering within-tree position and tree age (Jorge *et al.*, 2000). The analysis of variability in non-wood pulping also considers fibre length as a significant factor. Fibre wall thickness exhibits similar patterns of variation in density as they are closely related to each other, and this variation is evident from tree to tree and within individual trees (Bhat *et al.*, 1990).

Bhat *et al.* (1990) conducted a study on a *Eucalyptus grandis* plantation in Kerala to investigate the wood density and fibre length of trees in four different age groups. The results showed that the average density ranged from 420 to 497 kg m<sup>-3</sup> among the age groups, with younger trees having lower wood density compared to older ones.

Bhat *et al.* (1990) reported that the average fibre length of *Eucalyptus grandis* increased by 42% from 0.81 mm to 1.15 mm as the trees aged from young to adult. However, subsequent research has shown that the fibre length of adult wood and older trees is not significantly longer than that of immature trees, disproving Bhat *et al.*'s initial findings.

Pande (2012) observed an increase in fibre length from the base to the top of *Populus deltoides* trees. This finding is consistent with previous studies reporting that *Populus* species generally have shorter fibres at the bottom and longer fibres in the middle (Kauubaa *et al.*,

1998), and that there is a trend of longer fibres from the base to the top in other tree species as well, as noted by Yang and Cheng (1990).

According to Tharakan *et al.* (2003), there is considerable variation in fibre diameter and the ratio of fibre length to diameter among different poplar clones. The study found significant differences in both fibre length and diameter among different growth rings, with an increasing trend from pith to bark. Furthermore, the fibre length and diameter displayed a decreasing trend with increasing height of the trees.

Nguyen *et al.* (2009) conducted a study on the growth and wood properties of *Acacia mangium*, *Acacia auriculiformis*, *Acacia* hybrid clones, and their combinations in a trial forest in Bavi, Vietnam. The study found that the hybrids generally outperformed their parents in terms of diameter growth, specific gravity, and length of wood fibre, with the percentage of hybrid superiority varying from 3.63 to 4.16 for diameter, 6.9 to 20.7% for specific gravity, and 6.1 to 12.8% for length of wood fibre. The length of wood fibres in these trees was observed to initially range from 0.5-0.6 mm near the pith and gradually increase to 1.0-1.2 mm near the bark.

Izekor and Fuwape (2010) conducted a study on *Tectona grandis* wood in Edo State, Nigeria, and found that as the age of the wood increased from 15 to 25 years old, the mean values of fibre length, diameter, and cell wall thickness also increased. Specifically, the mean values for fibre length were 1.45, 1.73, and 1.96 mm for wood that was 15, 20, and 25 years old, respectively, while the mean values for fibre diameter were 26.79, 29.47, and 32.83  $\mu\text{m}$ , and the mean values for cell wall thickness were 18.17 and 14.17  $\mu\text{m}$ . In contrast, the fibre lumen width decreased with an increase in age.

Tavares *et al.* (2011) found that there were differences in the characteristics of wood and bark fibers between *Acacia melanoxylon* and *Eucalyptus globulus*. The average length of the wood fibers ranged from 0.90 to 0.96 mm, while the length of the bark fibers ranged from 1.33 to 1.59 mm. Both wood and bark fiber length decreased from the bottom to the top of the tree, but there was no specific pattern for axial variation in cell wall thickness. Along the radial direction from the pith to the bark, both fiber length and cell wall thickness increased, although the wall thickness varied slightly.

Lundqvist *et al.* (2017) investigated the three drought-tolerant eucalypt genotypes for broad spectrum of properties to provide a basis for comparison on their suitability for various end-uses. The genotypes included were a *Eucalyptus grandis*  $\times$  *E. camaldulensis* hybrid, *E.*

*gomphocephala* and *E. cladocalyx*. They found that *E. grandis* × *E. camaldulensis* showed the longest fibres and the thinnest fibre walls, *E. gomphocephala* showed an average fibre length but very thick fibre walls and *E. cladocalyx* had the shortest fibres and very thick fibre walls. But they observed that fibre widths were similar for all of the genotypes.

Sunny *et al.* (2019) studied the wood characteristics of wood of *Dalbergia sissoo* wood collected from different market sites of Himachal Pradesh. The study found that the maximum vessel diameter (0.126 mm), fibre diameter (0.020 mm), and fibre length (1.66 mm) were observed in the wood samples collected from Ghumarwin, Dattowal, and Ghumarwin sites, respectively.

Antov *et al.* (2020) studied the structural application of eco-friendly composites from recycled wood fibres from the species Norway spruce (*Picea abies* Karst.) and Scots pine (*Pinus silvestris* L.). They observed that the waste fibres had lengths from 500 to 1000 µm and 7% reduced lignin content.

Ashwath *et al.* (2021) investigated wood parameters in nine populations of *Acrocarpus fraxinifolius* from Southern Karnataka, including bark thickness, wood density, specific gravity, fibre parameters, and vessel parameters. The species' basic wood density varied from 0.370 to 0.580 g·cc<sup>-1</sup>. Fibre length showed significant differences among populations, with an average of 1225.49 µm, but there was no significant difference in fibre width, fibre lumen width, and fibre wall thickness.

Dadzie *et al.* (2022) conducted research on the potential use of 7 and 9-year-old *Cedrela odorata* trees for pulp and paper production. They used sectioning and maceration methods to determine the dimensions of the fibers. Their findings indicate that there were significant differences ( $p < .05$ ) in both the measured and derived fiber morphological characteristics of *C. odorata* along the axial direction (i.e., from base to top) as opposed to the radial direction (i.e., from sapwood to heartwood).

In a study conducted by Pertiwi *et al.* (2022), the xylem maturation process and the effects of radial growth rate on cell morphologies in balsa (*Ochroma pyramidale*) trees were investigated. The authors reported that the fibres had an average length of 2.16 mm and a wall thickness of 1.03 µm.

#### **2.5.4. Dichotomous keys**

Diagnostic keys are the simplest and most readily usable keys that have been employed in biological identification since the beginning of time (Pankhurst, 1978). The family-wise dichotomous keys for the identification of the primary timbers of India pertaining to 53 families were published by Pearson and Brown (1932). With one or more attributes utilised at each couplet or dichotomy, dichotomous keys consist of a succession of paired, contrasting possibilities. One of the two statements is picked and applied to the unknown at each couplet. The key user is then guided to a different couplet, and so on until a name is ultimately reached (which, in the case of wood, may be a species, species group, genus, or group of genera/families). The beginning and order in the dichotomous key will be decided by the author in advance.

There often is only one path to one identity, and the unknown sample must fit every characteristic of the taxon as listed in the key. By assessing the information richness of wood characters and demonstrating how to utilise the characters to categorise species, computer softwares aid in the development of keys (Dallwitz and Paine, 1986). Chowdhury (1945) provided the anatomical key for identifying 26 species of Burmese timber. In his study on the importance of the dichotomous key in the identification of wood samples, Ghosh (1960) also outlined its application. For fifty common and commercially significant for woods from the Indian subcontinent, Rao and Juneja (1971) created an identification key. The Forest Research Institute (FRI), Dehradun's guidebook on "Indian Woods" offers dichotomous keys for the identification of the main timber species found in Burma and the Indian subcontinent.

Dichotomous keys instruct the user to search for the traits that the key creator believed were essential for character differentiation. Additionally, a well-made dichotomous key can support the identification of lumber rapidly. When there are few potential matches and no missing qualities in the sample, dichotomous keys are useful for identifying unknown samples. The longer the key, the more probable it is that the proper description won't be selected correctly for any given couplet; keys with more than 200 taxa are cumbersome (Pankhurst, 1991).

For commercially valuable woods, in local works, especially for woods belonging to a certain species or family, dichotomous keys are useful. Some anatomists can quickly use these keys because they can identify the genus or family a wood belongs to. Otherwise, it will be important to use a key (such as the CSIRO family key), lists that give feature occurrences by

family (Metcalf and Chalk, 1983), or reading the brief, generalised family descriptions in "Anatomy of the Dicotyledons" to identify the genus/family of the unknown sample (Metcalf and Chalk, 1950).

It is crucial that a family key link to specific publications and keys for genera and families in addition to being able to identify which family specific character combinations occur in. Although a species' characteristics and overall structure can be acknowledged, there may be variations in smaller aspects not only between locales but also within a locale and even within a tree.

## **MATERIALS AND METHODS**

### 3. MATERIALS AND METHODS

A preliminary survey was conducted to identify the availability of samples. Wood samples of 21 tree species were collected from various sawmills across Kerala and some were collected from farmers directly. After the collection, samples procured were properly seasoned, cut into small cubes of 1cm<sup>3</sup> and stored in zip lock bags.

The obtained samples were then subjected to primary examination based on their shape, size, arrangement and contents of the various cell and tissue types found in wood. An extensive collection of wood anatomical features were used to derive conclusions. Specific combinations of anatomical characteristics can act as diagnostic markers for particular taxonomic groups since each anatomical characteristic is influenced by various degrees of environmental and genetic influence. The gross features of wood can be analysed with the aid of naked eye or a small hand lens. While, microscopic identification requires sectioning a sample, staining those sections as needed, and examination under a light microscope.

The project aims at studying the physical properties as well as the gross and minute anatomical properties of 21 timbers species of Kerala. Heart wood samples of timber species used for the study are described in the Table 1.

**Table 1: Timber samples description**

| Sl. No. | Scientific Name                                | Trade Name        | Local Name           | Family                     |
|---------|------------------------------------------------|-------------------|----------------------|----------------------------|
| 1       | <i>Albizia odoratissima</i> (Linn. f.) Benth.  | Kala siris        | Kunnivaka, Pulivaka  | Leguminosae (Fabaceae)     |
| 2       | <i>Acacia nilotica</i> (Linn.) Wild. Ex Delile | Gum Arabic tree   | Karivelam            | Mimosaceae (Fabaceae)      |
| 3       | <i>Acrocarpus fraxinifolius</i> Arn.           | Pink Cedar        | Narivenga, Kurangadi | Caesalpiniaceae (Fabaceae) |
| 4       | <i>Aegle marmelos</i> L. Correa                | Bael              | Koovalam             | Rutaceae                   |
| 5       | <i>Ailanthus triphysa</i> (Dennst) Alston      | White siris       | Matti                | Simaroubaceae              |
| 6       | <i>Alstonia scholaris</i> (Linn.) R. Br.       | White cheese wood | Ezhilam Pala         | Apocynaceae                |
| 7       | <i>Artocarpus hirsutus</i> Lam.                | Aini              | Anjili               | Moraceae                   |

|    |                                                         |                         |                          |                               |
|----|---------------------------------------------------------|-------------------------|--------------------------|-------------------------------|
| 8  | <i>Azadirachta indica</i> A. Juss.                      | Neem                    | Ariyaveppu               | Meliaceae                     |
| 9  | <i>Bombax ceiba</i> Linn.                               | Red silk<br>cotton tree | Ellavu                   | Bombacaceae                   |
| 10 | <i>Bridelia retusa</i> (L.) A. Juss.                    | Seikche                 | Mullu Venga              | Euphorbiaceae                 |
| 11 | <i>Ceiba pentandra</i> L. Gaertn                        | Java kapok              | Panji Ellavu             | Bombacaceae                   |
| 12 | <i>Canarium strictum</i> Roxb.                          | Black<br>dammar         | Karutha-<br>Kunthirikkam | Burseraceae                   |
| 13 | <i>Cassia fistula</i> Linn.                             | Indian<br>laburnum      | Kanikonna                | Caesalpiniaceae<br>(Fabaceae) |
| 14 | <i>Casuarina equisetifolia</i> J. R.<br>& amp; G.Forst. | Beaf-wood               | Kattadi                  | Casuarinaceae                 |
| 15 | <i>Cocos nucifera</i> Linn.                             | Coconut                 | Theng                    | Arecaceae                     |
| 16 | <i>Hopea parviflora</i> Bedd.                           | Malabar<br>Ironwood     | Thampakam                | Dipterocarpaceae              |
| 17 | <i>Lagerstroemia lanceolata</i><br>Wight.               | Ben Teak                | Venthekku                | Lythraceae                    |
| 18 | <i>Mangifera indica</i> Linn.                           | Mango                   | Maav                     | Anacardiaceae                 |
| 19 | <i>Melia dubia</i> Cav.                                 | Malabar<br>Neem         | Malaveppu                | Meliaceae                     |
| 20 | <i>Neolamarckia cadamba</i><br>(Roxb.) Bosser           | Kadam                   | Manjakadambu             | Rubiaceae                     |
| 21 | <i>Thespesia populnea</i> (Linn.)<br>Soland. Ex Correa  | Bhendi                  | Cheelanthi,<br>Poovarasu | Malvaceae                     |

The features which are mainly used in identification is listed below:

(a) General features:

These include features all those features which can be directly observed without the aid of a microscope and can be determined by naked eye or a hand lens. The major features studied are:

1. Colour
2. Weight
3. Odour

4. Texture

5. Lustre

6. Figure

(b) Anatomical features:

These include features that can be observed with the aid of a microscope. The major features which were studied include:

A. Fibre morphology

B. Vessel morphology

C. Ray morphology

### **3.1. TECHNICAL PROCEDURES**

The anatomical features that were assessed include frequency, size and distribution of various cell types viz. vessels, parenchyma, rays and fibres.

#### **3.1.1. Sectioning (Microtomy)**

Using an electric wood cutter, 1 cm<sup>3</sup> blocks were cut, and then immersed in a Rotek water bath set at 70 °C for 24 hours. Then, from the soaking sample, little blocks measuring 1x1x1 cm<sup>3</sup> were initially chiselled out for sectioning. The blocks were then subjected to microtomy. Using a Leica Sliding Microtome (Leica SM 2000R), Transverse Sections (TS), Tangential Longitudinal Sections (TLS), and Radial Longitudinal Sections (RLS) of 15–20 µm thickness were prepared.

#### **3.1.2. Staining**

The cross, radial and tangential sections of twenty-micron thickness were differentially stained using saffranin. The best sections were selected and passed through an alcohol series of 70%, 90%, and 95% for 5 minutes each. To achieve complete dehydration, the stained slices were placed in acetone for 3 minutes before being air dried using a tissue paper. Then it is kept in 100% xylene for 3 hours. The slides were kept drying for one day. The sections were mounted using DPX in a clear slide. They were then coated with cover slips and placed in DPX mountant to create permanent slides (size 75mm X 25mm, thickness 1mm).

**Plate 1: Materials and equipment used in the study.**



**1.1 Rotek waterbath**



**1.2. wood samples**



**1.3. Leica Sliding Microtome  
(Leica SM 2000R)**



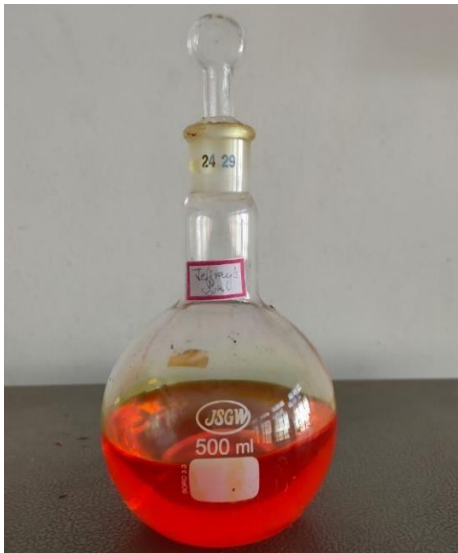
**1.4. Sectioning using microtome**



**1.5. Microslide cabinet**



**1.6. Catcam 500E microscope camera on a Motic BA210 trinocular microscope**



**1.7. Jeffery's solution**



**1.8. Samples for maceration**



**1.9. Maceration process**

### **3.1.3. Microscopy**

15–20  $\mu$ m thick transverse, radial, and tangential microtome sections were used for microscopic analysis, and observations were made using an image analysing system (Catymage image analyzer). The wood cross section was used to determine the tissue proportion, vessel frequency, and tangential diameter. The wood's structure was described using cross, tangential, and radial sections respectively.

### **3.1.4. Maceration**

Small radial chips from the sample blocks were macerated to determine vessel element length, fibre length, and fibre diameter and wall thickness as per Schultz's method (50% Nitric acid and a pinch of Potassium chlorate). Until the macerated chips were milky white, they were left in sunshine for two to four days. After shaking and washing the chips many times with water, a few drops of saffron were added. The macerated wood components were evenly distributed on a glass slide after being thoroughly mixed, and measurements of the vessel element length, fibre length, diameter, and wall thickness were made using a compound microscope.

### **3.1.5. Observations**

Fibre length, diameter, wall thickness, and vessel element length measurements were obtained from the macerated material. Cross sections were used to calculate tissue proportions such as fibre, vessel, parenchyma, and ray sizes. By sliding the slide from one end to the other in both tangential and radial directions, the total score for each cell type was obtained.

### **3.1.6. Image analysis**

Analysis of permanent slides was done with the help of Catcam 500E series microscope camera, mounted on a Motic BA210 trinocular microscope. The Catymage® image analyzer software was utilized to capture photomicrographs of the transverse, radial, and tangential sections, as well as to measure the vessels and rays. The study examined various cell elements in the wood, such as vessel, axial parenchyma, and ray parenchyma, and evaluated their arrangement, distribution, frequency, and size. Both macroscopic and microscopic characteristics were assessed, with macroscopic features described using the terminologies proposed by Rao and Juneja (1971), and microscopic features using the IAWA list of microscopic features for hardwood identification (IAWA, 1989), as well as the timbers of

Kerala, an open site of KAU. Expert wood anatomists were consulted for the final identification of the wood.

## 3.2. DATA COLLECTION

### 3.2.1. Measurement of vessel and ray dimensions

From the permanent slides prepared, measurements like vessel diameter and vessel frequency were taken from the Transverse Sections (TS) and ray width, ray height and ray frequency were measured from the Tangential Longitudinal Sections (TLS) were calculated using the image analysis software. The polygon tool was used to calculate the vessel area. The line tool was used to calculate the vessel diameter, ray width, and ray height. The frequency of the vessel was calculated by counting randomly selected area per in the section and using the following equation.

$$\text{Vessel frequency} = \text{number of vessels} / \text{mm}^2$$

Ray frequency was calculated using the line tool. The number of rays covering one-millimetre straight line gives the frequency of ray per mm.

### 3.2.2. Analysis of anatomical characters

#### “Parenchyma types

**Apotracheal parenchyma:** Apotracheal refers to parenchyma cells that occur separate from the pores. Apotracheal parenchyma can occur as single scattered cells, classified as diffuse parenchyma. These cells are too small to be seen without a microscope. However, in some wood species, several apotracheal parenchyma cells joined or aggregated together, forming thin but visible tangential lines. This formation is known as diffuse-in-aggregates parenchyma.

**Paratracheal parenchyma:** Paratracheal parenchyma can occur as single cells bordering a pore, called scanty parenchyma. These cells are too small to be seen individually without a microscope and seen along with diffuse parenchyma.

**Vasicentric parenchyma:** The most basic paratracheal parenchyma formation is a ring or circle of cells surrounding the pore, which is termed vasicentric parenchyma. The term vasicentric is simply a combination of the word's vase (suggesting a vessel or pore), and centric, which simply indicates that the parenchyma is centred on the pore. Vasicentric parenchyma isn't always visible with a hand lens. Particularly when the pores of a wood species

are especially small, (with the parenchyma being even smaller), or if the parenchyma ring is only one cell thick, it may not be clearly visible with a hand lens.

**Aliform parenchyma:** Another form of parenchyma that is closely related to vasicentric is aliform parenchyma. This term literally means “wing-shaped.” Despite the suggestive name, there are two primary variants of aliform parenchyma: the first is winged, where short appendages or wings of parenchyma extend from one or both sides of the pore.

**Lozenge parenchyma:** The second variant of aliform is lozenge, where the parenchyma surrounding the pore takes on a diamond or elongated oval shape.

**Aliform confluent:** Building on the vasicentric and aliform parenchyma patterns, another formation is confluent parenchyma. This occurs when the parenchyma is so extensive that it extends outward and makes contact with the parenchyma from neighbouring pores.

**Unilateral parenchyma:** One last, somewhat uncommon form of paratracheal parenchyma is sometimes seen in a handful of wood species. Whether the parenchyma occurs in a vasicentric, aliform, or a confluent pattern, when the parenchyma covers only one side of the pore in a semi-circular fashion, it is said to be unilateral parenchyma.

**Banded parenchyma:** When horizontal (tangential) bands of parenchyma occur either as (apotracheal) diffuse-in-aggregates, and/or as extensions of aliform or confluent (paratracheal) parenchyma, it is known as banded parenchyma. Banded parenchyma can be in continuous bands, or it can occur in interrupted or discontinuous bands. The bands can be very thick—constituting over half of the wood’s overall volume in some species—or they can be very thin and hardly visible with a hand lens. The bands can be very numerous and evenly spaced, or they can be very sparse and sporadic.

**Presence/absence of tyloses:** Tyloses are outgrowths on parenchyma cells of xylem vessels of secondary heartwood. When the plant is stressed by drought or infection, tyloses will fall from the sides of the cells and "dam" up the vascular tissue to prevent further damage to the plant.

**Aggregate rays:** Occasionally, some species will have intermittent rays that are many times wider than the rest. These mega-rays are essentially a collection of several normal-sized rays grouped together and appearing as one large ray. They are known as aggregate rays.

**Noded rays:** In some species, the rays will slightly flare out and get wider as they cross a growth ring boundary. This subtle characteristic is referred to as noded rays.

**Ripplemarks:** One final characteristic of rays involves examining the flatsawn (tangential) surface of the wood. In some wood species, (particularly those in tropical regions), the rays tend to be aligned in horizontal or diagonal tiers, also referred to as stories. This pattern is called storied rays, and it produces a visual phenomenon known as ripple marks.

**Homogenous type ray:** Ray tissue in which the individual rays are composed wholly of procumbent cells. Homogenous uniseriate and multiseriate rays are also observed.

**Heterogenous type ray:** Ray tissue in which the individual rays are composed wholly or in part of square or upright cells. There are three types of heterogenous rays. They can be described as given below:

Type I: Ray tissue having multiseriate rays with uniseriate tails longer than the multiseriate part and composed of upright and square cells and uniseriate rays composed entirely of upright or upright and square cells.

Type II: Ray tissue having multiseriate rays with uniseriate tails shorter than the multiseriate part and composed of upright and square cells or a single marginal row of upright cells and uniseriate rays composed entirely of upright or upright and square cells.

Type III: Ray tissue having multiseriate rays with square marginal cells, usually a single row only, but if uniseriate tails are present then composed entirely of square cells, and uniseriate rays, some composed entirely of procumbent cells, others of square cells or mixed square and procumbent cells. Along with all the above anatomical characters, coloured deposits and other special features were also analysed. ”

### **3.2.3. Analysis of physical properties**

Physical properties like moisture content (MC), specific gravity (SPG) and shrinkage (radial and tangential) were analysed.

**Specific Gravity** of wood is the ratio between oven dry weight of the wood and the weight of an equal volume of water. For the analysis, the wood specimens with 3x3x3 cm<sup>3</sup> dimensions were taken. The samples were soaked in water to achieve complete saturation. The saturated samples were dipped in a beaker containing water by using a needle to obtain the volume. After recording the volume, the samples were kept for drying in hot air oven for approximately 48

hrs. Oven dry weights of the samples were recorded. Specific Gravity was determined by using the formula:

$$\text{Specific gravity} = \text{oven dry weight} / \text{green volume.}$$

## **Moisture content**

### **Oven dry method**

The gravimetric approach is amongst the most widely used and oldest methods to assess wood moisture content. It necessitates the extraction of samples from the timber element. The samples are weighed before kiln-drying them at a temperature of  $103 \pm 2$  °C until constant mass is obtained. The moisture content is obtained from the ratio between the mass of water in the moist specimen and the mass of the kiln-dried specimen. The moisture content, MC %, as a percentage by mass can be determined, using the formula

$$MC \% = \frac{m_1 - m_0}{m_0} \times 100$$

Where,  $m_0$  = initial moisture content

$m_1$  = final moisture content

### **3.2.4. Analysis of gross features**

**Colour:** To assess surface colours in a defined and reproducible way, a standardized light cabinet with a neutral grey background (Munsell N7) and equipped with a D65 standard illuminant perpendicular to the surface was used. The samples were assessed parallel to the longitudinal direction of the specimens and at an angle of 45° without interference from the outside environment.

**Weight:** To assess the weight, the samples were first seasoned to obtain a constant weight by processing it to a temperature of  $103 \pm 2$  °C and were weighed using a laboratory grade weighing balance.

**Odour:** The odour of the sample if present was determined by simple smelling.

**Texture:** Visual judgement was made.

**Lustre:** Visual judgement was made.

**Figure:** Visual judgement was made.

### **3.3. STATISTICAL ANALYSIS**

The samples are to be analysed for variation among different properties. One-way ANOVA was to be performed using R software (version 4.2.2.) Post-hoc Analysis was carried out using critical difference (CD).

### **3.4. IDENTIFICATION PROCEDURES**

Recognizing the level of wood identification, whether it's family, genus, species group, or species, and determining when to be content with an identification, can be challenging tasks. Sometimes, a single piece of wood cannot be categorized into a particular genus or species. There are no universal rules, and identification is possible to varying degrees within and between families. Comparative identification is a commonly used method and forms the basis of many natural history field guides (Pankhurst, 1978). Several wood anatomical atlases, such as the CSIRO Hardwood Atlas (Ilie, 1991), provide field guides that include photographs and cross, radial, and tangential sections of about 1800 species without text descriptions. This atlas is a valuable resource as it was designed to be a portable wood anatomical slide collection.

#### **3.3.1. Comparison**

One of the most widely used methods for identifying wood is through comparative identification, which forms the foundation of many natural history field guides (Pankhurst, 1978). Tabular data is especially useful in demonstrating which combinations of features are effective in distinguishing between closely related woods or those with similar appearances. Brazier and Franklin (1961) developed tables that have proven useful in identifying related species of certain genera, related genera, and unrelated woods that share similar characteristics.

#### **3.3.2. Dichotomous key**

Dichotomous keys are a type of identification tool that present a series of paired choices, each featuring one or more distinguishing features. The user selects the statement that best applies to the unknown specimen at each couplet, and the process continues until a name, such as a species, species group, genus, group of genera, or family, is reached for the wood. The starting point and feature sequence are predetermined by the key's author, and the unknown must match every characteristic of the taxon defined in the key, with only one path leading to its identification. Dichotomous keys are useful when there is a small number of possible matches for an unknown species or for material with all features. They are especially valuable as regional resources or for commercially significant woods, as well as for woods within a

particular family or genus. Jean Baptiste Lamarck developed the first text-based dichotomous keys, which were later refined by notable scientists in the fields of botany and zoology, and were commonly used for identification purposes until the late 1950s.

### **3.3.3. Multiple entry keys**

The simplest multiple entry key is the called synoptical key, which lists each diagnostic, feature of the taxa which have that feature. The advantage of synoptical keys is that the sequence of characters used in an identification procedure is inspired by the unknown sample, not by the author of the key. The first application of multiple entry card keys was for wood identification (Pankhurst, 1991). In such card keys, there is one card per taxon. The cards have perforated edges, with each numbered perforation representing one feature. If a particular wood has a particular feature, the edge of the card is notched to indicate its presence. To identify an unknown species, a needle is passed through a stack of cards at a perforation representing a feature seen in the wood. Cards of species with the feature absent stay on the needle, while the cards with the feature present fall out. The sorting process is repeated until only a single or a few cards remain.

### **3.3.4. Computer-aided wood identification**

Institutions often identify woods from their local region and therefore require a comprehensive database and reliable means of identification. This study utilized a major website, "Inside wood" for wood identification. The IAWA list of microscopic features for hardwood identification was referenced for describing microscopic features, and the "Handbook of Lesser-Known Timbers" by Bhat *et al.* (2007) was consulted. As the number of features in the IAWA list exceeds the number that can be accommodated on marginally perforated cards, it allows for a more complete description of woods and enables the distinction of a greater number of species. An anatomical key for the 10 commercially important timbers currently used in Kerala was prepared using the above materials and methods, providing detailed information on their general features and gross anatomical properties to aid in their identification and efficient utilization. Additionally, a dichotomous field key based on general features and gross anatomical features is provided.

## **RESULTS**

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## 4. RESULTS

Twenty-one different timber species collected from various timber markets across Kerala were studied in this work. Microscopic characteristics of the wood, such as abundance vessels, abundance and pattern of parenchyma, resin canals and tyloses (as seen in the Transverse section); types, nature of vessels, the height and cell inclusions of the rays (as seen in Tangential Longitudinal section) were found to be much dependable characters for identification.

### 4.1. Description of general and anatomical characters.

#### 4.1.1. *Acacia nilotica* (Linn.) Wild. Ex Delile

|              |                                                                                                                                                                                                   |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name   | : Babul                                                                                                                                                                                           |
| Local name   | : Karuvelam                                                                                                                                                                                       |
| Family       | : Mimosaceae                                                                                                                                                                                      |
| Tree         | : Small statured, attains a height of about 9 meters and about 32 cm In diameter. Bark is black or dark brown in colour, deep and narrow longitudinal fissures which are rough and runs spirally. |
| Distribution | : Naturally found in deciduous forests of India and grows occasionally in the drier regions of Kerala.                                                                                            |

#### General Features

|            |                                                                                                                                                       |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Colour     | : Sapwood- pale yellow, heartwood- reddish-brown; Heartwood and sapwood sharply demarcated.                                                           |
| Grain      | : Straight to interlocked                                                                                                                             |
| Texture    | : Medium                                                                                                                                              |
| Hardness   | : Moderately hard to hard                                                                                                                             |
| Drying     | : Green-conversion and proper-stacking under shade is necessary during precipitation. Kiln-seasoning offers no constrains under mild drying schedule. |
| Shrinkage  | : Shrinkage from Green to oven-dry condition<br>a) Radial shrinkage : 2.5%<br>b) Tangential shrinkage : 6.0%                                          |
| Durability | : Durable                                                                                                                                             |

Treatability : Heartwood is treatable but complete penetration of preservatives is not always obtained.

### **Anatomical features**

Growth rings : Indistinct

Porosity : Diffuse porous

Vessels : Mostly solitary or in radial multiple of 2, 3 or more, occasionally in clusters; Scanty in number (6 per mm<sup>2</sup>); filled with dark brown gummy deposits. Tangential diameter ranges from 72.85 µm to 155.73 µm with an average of 120.51 µm. Perforation plate – simple; vestured pits. Inter vessel pitting- alternate; Shape of alternate pits polygonal. Gums and other deposits present in heartwood vessels.

Parenchyma : Paratracheal – vasicentric, terminal parenchyma present; Prismatic crystals in chambered axial parenchyma cells; Four (3-4) cells per parenchyma strand.

Rays : Irregularly spaced and non-storied; Seriation- mostly biseriate with some triseriate rays; Heterogenous- Body of ray cells is procumbent with one row of square marginal cells; Ray width ranges from 30.44 µm to 63.06 with a mean of 43.98 µm; Ray height ranges from 522.73 µm to 2041.6 µm with a mean of 1141.32 µm; Ray frequency is about 8 per mm

Fibres : Non-septate fibres present; Fibres thin- to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 909 µm to 1124 µm with an average of 1053.96 µm. The average total diameter is 15.44 µm and the average wall thickness is 5.35 µm.

Uses : Construction work often involves the use of rafters in buildings, bridges, and agricultural implements. Additionally, posts, beams, and tool handles are commonly made from wood. Tent accessories, cart building, parts of boat hulls, sports goods, and piles are also frequently constructed using wood.

#### 4.1.2. *Acrocarpus fraxinifolius* Arn.

|              |                                                                                                      |
|--------------|------------------------------------------------------------------------------------------------------|
| Trade name   | : Acrocarpa, Mundani                                                                                 |
| Local name   | : Narivenga, kurangadi                                                                               |
| Family       | : Caesalpiniaceae                                                                                    |
| Tree         | : Very large to large statured, attains about 31-35 meters in ht and About 95 cm in dia. Buttressed. |
| Distribution | : West coastline, West coast semi- evergreen forests and Tropical evergreen forests.                 |

#### General Features

|              |                                                                                                                                                      |
|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Colour       | : Sapwood- yellowish to greyish white; Heartwood light pinkish or reddish-brown.                                                                     |
| Grain        | : Straight to slightly interlocked                                                                                                                   |
| Texture      | : Coarse                                                                                                                                             |
| Hardness     | : Moderate hard                                                                                                                                      |
| Drying       | : Moderately refractory; Kiln seasoning is recommended.                                                                                              |
| Shrinkage    | : Shrinkage from Green to oven-dry <ul style="list-style-type: none"><li>a) Radial shrinkage : 3.1%</li><li>b) Tangential shrinkage : 5.3%</li></ul> |
| Durability   | : Non-durable                                                                                                                                        |
| Treatability | : Heartwood only partially treatable                                                                                                                 |

#### Gross features

|              |                                                                                                                                                                                                                                                                                                                                                                                                                     |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                                                                                                                                                                                                                                                                                        |
| Porosity     | : Diffuse-porous                                                                                                                                                                                                                                                                                                                                                                                                    |
| Vessels      | : Mostly solitary or in radial multiple of 2 to 3; Scanty in number (5 per mm <sup>2</sup> ); Lightly tylosed; Tangential diameter ranges from 138.21 µm to 300.6 µm with an average of 224.34 µm. Perforation plate – simple; vestured pits. Inter vessel pitting- alternate; Vessel-ray pits with distinct borders; Vessel ray pitting is similar to inter-vessel pits in size and shape throughout the ray cell. |
| Parenchyma   | : Paratracheal – lozenge-aliform, winged-aliform, confluent is present. Axial parenchyma is also present in marginal or in seemingly marginal bands; Four (3-4) cells per parenchyma strand.                                                                                                                                                                                                                        |

|        |                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rays   | : Irregularly spaced and non-storied; Seriation- multiseriate rays; Heterogenous- Body of ray cells is procumbent with one row of square marginal cells; Prismatic crystals in square ray cells; Ray width ranges from 27.38 $\mu\text{m}$ to 55.4 $\mu\text{m}$ with a mean of 38.99 $\mu\text{m}$ ; Ray height ranges from 188.36 $\mu\text{m}$ to 415.37 $\mu\text{m}$ with a mean of 306.03 $\mu\text{m}$ ; Ray frequency is about 8 mm. |
| Fibres | : Septate fibres present; Fibres thin- to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 553.23 $\mu\text{m}$ to 1352.55 $\mu\text{m}$ with an average of 806.98 $\mu\text{m}$ . The average total diameter is 19.09 $\mu\text{m}$ and the average wall thickness is 5.61 $\mu\text{m}$ .                                                                                                                    |
| Uses   | : Mostly used for fence and poles posts; construction of buildings; tool handles; heavy-backing cases, tea chests, crates, Class-I general purpose plywood; shutters for doors; blockboards; core and face veneers.                                                                                                                                                                                                                          |

#### 4.1.3. *Aegle marmelos* L. Correa

|              |                                                                                                                                |
|--------------|--------------------------------------------------------------------------------------------------------------------------------|
| Trade name   | : Bael                                                                                                                         |
| Local name   | : Koovalam                                                                                                                     |
| Family       | : Rutaceae                                                                                                                     |
| Tree         | : Small to medium statured; Attains 9 - 14 meters in ht and about 30 cm in dia; Bark is greyish in colour and corky in nature. |
| Distribution | : Occasional in Southern dry mixed deciduous forest.                                                                           |

#### General Features

|                         |                                                                                                                                                                                                    |                     |        |                         |        |
|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------|-------------------------|--------|
| Colour                  | : Yellowish-brown to yellowish-white sapwood and heartwood not distinguishable.                                                                                                                    |                     |        |                         |        |
| Grain                   | : Straight to spiral.                                                                                                                                                                              |                     |        |                         |        |
| Texture                 | : Fine                                                                                                                                                                                             |                     |        |                         |        |
| Hardness                | : Hard - very hard                                                                                                                                                                                 |                     |        |                         |        |
| Drying                  | : Green conversion followed by stacking under shade recommended.                                                                                                                                   |                     |        |                         |        |
| Shrinkage               | : Shrinkage from Green to oven-dry <table data-bbox="718 1904 1197 2016"> <tr> <td>a) Radial shrinkage</td><td>: 4.3%</td></tr> <tr> <td>b) Tangential shrinkage</td><td>: 8.2%</td></tr> </table> | a) Radial shrinkage | : 4.3% | b) Tangential shrinkage | : 8.2% |
| a) Radial shrinkage     | : 4.3%                                                                                                                                                                                             |                     |        |                         |        |
| b) Tangential shrinkage | : 8.2%                                                                                                                                                                                             |                     |        |                         |        |

Durability : Non- durable

#### **Anatomical features**

Growth rings : Indistinct

Porosity : Diffuse porous

Vessels : Mostly in radial multiple of 2, 4 and more, moderately in clusters; Numerous in number (37 per mm<sup>2</sup>); Occasionally filled with orange-yellow gum; Tangential diameter ranges from 73.34 µm to 119.8 µm with an average of 93.82 µm. Perforation plate – simple; Inter vessel pitting- alternate; Vessel ray pitting is similar to inter-vessel pits in size and shape throughout the ray cell.

Parenchyma : Paratracheal – largely scanty, vasicentric; Axial parenchyma in marginal or in seemingly marginal bands present; Prismatic crystals in chambered axial parenchyma cells; Four (3-4) cells per parenchyma strand.

Rays : Irregularly spaced and non-storied; Seriation- mostly biseriate with some triseriate rays; Homogenous rays- only procumbent rays; Ray width ranges from 17.42 µm to 47.59 µm with a mean of 34.12 µm; Ray height ranges from 198.37 µm to 404.76 µm with a mean of 287.05 µm; Ray frequency is about 10 per mm.

Fibres : Non-septate fibres present; Fibres thin- to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 703.75 µm to 1149.75 µm with an average of 900.88 µm. The average total diameter is 29.58 µm and the average wall thickness is 8.28 µm.

Uses : Temporary construction ; agricultural implements; carvings; tool handles; charcoal.

#### **4.1.4. *Ailanthus triphysa* (Dennst) Alston**

Trade name : White siris

Local name : Perumaram, Matti, Pongiliyam, Maharukh

Family : Simaroubaceae

- Tree : Large sized, about 20 to 28 meters in ht and 80 to 85cm in dia. Bark is grey in colour, smooth textured in young trees and becomes rough as the tree matures.
- Distribution : Sporadic distribution in West coast semi-evergreen and Southern moist mixed deciduous forests.

### **General Features**

- Colour : Yellowish-white in colour, lustrous, heartwood and sapwood not distinct.
- Grain : Straight-grain
- Texture : Coarse
- Hardness : Soft
- Drying : Can be seasoned with ease; to avoid fungal stains, green conversion and rapid seasoning recommended.
- Durability : Perishable

### **Anatomical features**

- Growth rings : Indistinct
- Porosity : Diffuse porous
- Vessels : Mostly in radial multiple of 2 to 4 with few solitary vessels; Scanty in number (3 per mm<sup>2</sup>). Tangential diameter ranges from 106.69  $\mu\text{m}$  to 241.72  $\mu\text{m}$  with an average of 187.99  $\mu\text{m}$ . Perforation plate – simple; vested pits. Inter vessel pitting- alternate; Shape of alternate pits polygonal. Vessel ray pitting is similar to inter-vessel pits in size and shape throughout the ray cell.
- Parenchyma : Paratracheal – vasicentric, aliform to aliform-confluent; Four (3-4) cells per parenchyma strand.
- Rays : Irregularly spaced and non-storied; Seriation- mostly Multiseriate rays; Heterogenous; Rays of 2 distinct sizes; Ray width ranges from 95.22  $\mu\text{m}$  to 170.74  $\mu\text{m}$  with a mean of 133.49  $\mu\text{m}$ ; Ray height ranges from 370.45  $\mu\text{m}$  to 974.24  $\mu\text{m}$  with a mean of 593.96  $\mu\text{m}$ ; Ray frequency is about 6 per mm.
- Gum duct : Occasionally vertical traumatic Gum ducts are present.

|        |                                                                                                                                                                                                                                                                    |
|--------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fibres | : Non-septate fibres present; Fibres thin- to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 954 µm to 1554.07 µm with an average of 1196.24 µm. The average total diameter is 25.09 µm and the average wall thickness is 9.59 µm. |
| Uses   | : Packing cases; match splints and boxes; slate frames; toys; Class III veneers, core cross bands and face veneers for blockboards.                                                                                                                                |

#### **4.1.5. *Albizia odoratissima* (Linn. F.) Benth.**

|              |                                                                                                                                                       |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name   | : Kala siris                                                                                                                                          |
| Local name   | : Kunnivaga, Nellivaga                                                                                                                                |
| Family       | : Mimosaceae                                                                                                                                          |
| Tree         | : Medium sized, about 20 to 25 meters in ht and 90 to 100cm in dia, Bark is grey in colour with dark patches. Rough textured and irregularly cracked. |
| Distribution | : Southern dry mixed deciduous, West coast semi-evergreen forests and Southern moist mixed deciduous.                                                 |

#### **General Features**

|                         |                                                                                                                                                                                                     |                     |         |                         |        |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|---------|-------------------------|--------|
| Colour                  | : Sapwood white or yellowish-white, lustrous, heart wood dark brown with dark streaks fairly.                                                                                                       |                     |         |                         |        |
| Grain                   | : Lustrous, Sapwood yellowish-white, heartwood dark brown with dark stripes.                                                                                                                        |                     |         |                         |        |
| Texture                 | : Coarse                                                                                                                                                                                            |                     |         |                         |        |
| Hardness                | : Hard to moderately hard                                                                                                                                                                           |                     |         |                         |        |
| Drying                  | : Moderately-refractory; green conversion and stacking under shade recommended                                                                                                                      |                     |         |                         |        |
| Shrinkage               | : Shrinkage from Green to oven-dry <table data-bbox="718 1769 1197 1870"> <tr> <td>a) Radial shrinkage</td><td>: 3.0 %</td></tr> <tr> <td>b) Tangential shrinkage</td><td>: 5.1%</td></tr> </table> | a) Radial shrinkage | : 3.0 % | b) Tangential shrinkage | : 5.1% |
| a) Radial shrinkage     | : 3.0 %                                                                                                                                                                                             |                     |         |                         |        |
| b) Tangential shrinkage | : 5.1%                                                                                                                                                                                              |                     |         |                         |        |
| Durability              | : Highly durable                                                                                                                                                                                    |                     |         |                         |        |
| Treatability            | : Heartwood is very refractory to treatment.                                                                                                                                                        |                     |         |                         |        |

### Anatomical features

|              |                                                                                                                                                                                                                                                                                                                                                                  |
|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                                                                                                                                                                                                                                     |
| Porosity     | : Diffuse porous                                                                                                                                                                                                                                                                                                                                                 |
| Vessels      | : Mostly solitary or in radial multiple of 2, 3 or more; Scanty in number (3 per mm <sup>2</sup> ); Heartwood vessels filled with dark brown gummy deposits. Tangential diameter ranges from 125.04 µm to 192.53 µm with an average of 157.45 µm. Perforation plate – simple; vestured pits. Inter vessel pitting- alternate; Shape of alternate pits polygonal. |
| Parenchyma   | : Paratracheal – vasicentric, lozenge- aliform, rarely confluent; Axial parenchyma is also present in marginal or in seemingly marginal bands; Prismatic crystals in chambered axial parenchyma cells; Four (3-4) cells per parenchyma strand.                                                                                                                   |
| Rays         | : Irregularly but widely spaced and non-storied; Seriation- multiseriate rays; Homogenous- all ray cells procumbent; Ray width ranges from 22.49 µm to 44.53 µm with a mean of 33.70 µm; Ray height ranges from 135.91 µm to 324.03 µm with a mean of 237.63 µm; Ray frequency is about 7 per mm                                                                 |
| Fibres       | : Non-septate fibres present; Fibres very thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 727.86 µm to 1754.19 µm with an average of 1016.81 µm. The average total diameter is 19.01 µm and the average wall thickness is 7.42 µm.                                                                                                |
| Uses         | : Plywood, decorative plywood; furniture and cabinets; shutters for doors; shafts of carts and carriages; building and bridge construction; railway sleepers.                                                                                                                                                                                                    |

#### 4.1.6. *Alstonia scholaris* (Linn.) R. Br.

|            |                                                                                                                                                                     |
|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name | : Alstonia, Shaitan wood, Devils tree                                                                                                                               |
| Local name | : Ezhilam-Pala                                                                                                                                                      |
| Family     | : Apocynaceae                                                                                                                                                       |
| Tree       | : Medium to large statured; Attains upto 30 meters in ht with a clear bole of 12 m and about 110 cm in dia. Bark- greyish-brown, rough and lenti-cellate in nature. |

Distribution : Southern moist mixed deciduous and moist teak bearing forests.

### **General Features**

Colour : White to yellowish-white or pale brown; heartwood and sapwood not distinct.

Grain : Straight

Texture : Medium to fine

Hardness : Soft

Drying : Green conversion and soaking in water before seasoning recommended.

Durability : Non - durable

### **Anatomical features**

Growth rings : Indistinct

Porosity : Diffuse porous

Vessels : Mostly in radial multiple of 3, 4 or more; numerous in number (13 per mm<sup>2</sup>); occasionally filled with tyloses, and yellowish gummy deposits. Tangential diameter ranges from 81.19 µm to 175.18 µm with an average of 128.70 µm. Perforation plate – simple; vested pits. Inter vessel pitting- alternate; Shape of alternate pits polygonal.

Parenchyma : Paratracheal – vasicentric, lozenge- aliform, confluent; Axial parenchyma is also present in marginal or in seemingly marginal bands; Prismatic crystals in chambered axial parenchyma cells; Four (3-4) cells per parenchyma strand.

Rays : Irregularly but widely spaced and non-storied; Seriation- multiseriate rays; Heterogenous- body ray cells are procumbent with mostly 2-4 rows of upright and / or square marginal cells; Ray width ranges from 35.88 µm to 70.81 µm with a mean of 54.83 µm; Ray height ranges from 163.1 µm to 462.45 µm with a mean of 281.72 µm; Ray frequency is about 7 per mm

Fibres : Non-septate fibres present; Fibres thin to thick walled; Fibres with simple to minutely bordered pits; Length ranges from 914.65 µm to

1726.22  $\mu\text{m}$  with an average of 1149.33  $\mu\text{m}$ . The average total diameter is 25.28  $\mu\text{m}$  and the average wall thickness is 6.94  $\mu\text{m}$ .

Uses : Class III Plywood and veneers; packing cases and boxes; match splints; pencil slats; wooden footwear.

#### 4.1.7. *Artocarpus hirsutus* Lam.

Trade name : Jack tree, Aini

Local name : Anjili, Anyani

Family : Moraceae

Tree : Large to very large statured; Attains 25-45 meters in ht with a clear bole of 10-20 m and up to 130 cm in diameter; Bark- dark brown and smooth.

Distribution : West coast tropical evergreen, West coast semi-evergreen and Southern secondary moist mixed deciduous forests.

#### General Features

Colour : Sapwood yellowish-white; Heartwood golden yellow to yellowish brown, lustrous when first exposed.

Grain : Straight to interlocked

Texture : Medium

Hardness : Moderately hard

Drying : Seasoning using air-and klin-seasoning offer no difficulty.

Shrinkage : Shrinkage from Green to oven-dry

a) Radial shrinkage : 3.5%

b) Tangential shrinkage : 5.4%

Durability : Durable

Treatability : Can be treated

#### Anatomical features

Growth rings : Indistinct

Porosity : Diffuse porous

Vessels : Mostly in radial multiple of 2 and more; numerous in number (14 per  $\text{mm}^2$ ); Heartwood vessels often filled with tyloses and/or white chalky deposits. Tangential diameter ranges from 89.19  $\mu\text{m}$  to 155.26  $\mu\text{m}$  with an average of 123.95  $\mu\text{m}$ . Perforation plate –

|            |                                                                                                                                                                                                                                                                                                                                                                     |
|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            | simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal.                                                                                                                                                                                                                                                                                         |
| Parenchyma | : Paratracheal – mostly vasicentric, lozenge- aliform, rarely confluent; Four (3-4) cells per parenchyma strand.                                                                                                                                                                                                                                                    |
| Rays       | : Irregularly spaced and non-storied; Seriation- biseriate rays; ray of 2 distinct size is present; Heterogenous; Ray width ranges from 24.02 $\mu\text{m}$ to 64.16 $\mu\text{m}$ with a mean of 38.74 $\mu\text{m}$ ; Ray height ranges from 621.29 $\mu\text{m}$ to 2450.27 $\mu\text{m}$ with a mean of 1219.87 $\mu\text{m}$ ; Ray frequency is about 9 per mm |
| Fibres     | : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 778.17 $\mu\text{m}$ to 1971.24 $\mu\text{m}$ with an average of 1068.88 $\mu\text{m}$ . The average total diameter is 23.92 $\mu\text{m}$ and the average wall thickness is 6.65 $\mu\text{m}$ .                                       |
| Uses       | : Shipbuilding; rafters, beams, door frames window, ceiling boards; vehicle bodies; cabinets; turnery; furniture; piles; door shutters; Class-I plywood; blockboards; marine plywood; carriages.                                                                                                                                                                    |

#### **4.1.8. *Azadirachta indica* A. Juss.**

|              |                                                                                                                                                        |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name   | : Neem                                                                                                                                                 |
| Local name   | : Arya-Veppu, Veppu                                                                                                                                    |
| Family       | : Meliaceae                                                                                                                                            |
| Tree         | : Medium to large statured; Attains about 16-20 meters in ht with a clear bole of about 50 cm in dia. Bark is dark greyish brown to greyish in colour. |
| Distribution | : Found naturally in deciduous forests of Peninsular India. In Kerala, mostly found in homegardens.                                                    |

#### **General Features**

|         |                                                                                 |
|---------|---------------------------------------------------------------------------------|
| Colour  | : Sapwood yellowish-grey to yellowish brown in colour, heartwood reddish brown. |
| Odour   | : Freshly cut wood has characteristic odour of Azadiactin.                      |
| Grain   | : Interlocked                                                                   |
| Texture | : Coarse                                                                        |

|            |                                    |
|------------|------------------------------------|
| Hardness   | : Hard to very hard                |
| Drying     | : Air-seasoning gives good results |
| Shrinkage  | : Shrinkage from Green to oven-dry |
|            | a) Radial : 4.4%                   |
|            | b) Tangential shrinkage : 6.1%     |
| Durability | : Durable                          |

#### **Anatomical features**

|              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Distinct in some and indistinct in others.                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Porosity     | : Diffuse porous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Vessels      | : Mostly solitary and occasionally in radial multiple of 2; moderate in number (8 per mm <sup>2</sup> ); Heartwood vessels often filled with tyloses and gummy deposits. Tangential diameter ranges from 106.2 µm to 192.05 µm with an average of 140.70 µm. Helical thickenings is throughout the body of the vessel. Perforation plate – simple. Inter vessel pitting- alternate; Vessel-ray pits with distinct borders; Vessel ray pitting is similar to inter-vessel pits in size and shape throughout the ray cell. |
| Parenchyma   | : Paratracheal – mostly vasicentric; Axial parenchyma is also present in marginal or in seemingly marginal bands; Prismatic crystals in chambered axial parenchyma cells; Four (3-4) cells per parenchyma strand.                                                                                                                                                                                                                                                                                                        |
| Rays         | : Irregularly spaced and non-storied; Seriation- multiseriate rays; ray of 2 distinct size is present; Heterogenous- body ray cells are procumbent with mostly 2-4 rows of upright and / or square marginal cells;; Ray width ranges from 42.01 µm to 84.07 µm with a mean of 62.52 µm; Ray height ranges from 234.02 µm to 437.64 µm with a mean of 318.08 µm; Ray frequency is about 12 per mm                                                                                                                         |
| Fibres       | : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 764.55 µm to 1165.34 µm with an average of 957.32 µm. The average total diameter is 13.86 µm and the average wall thickness is 5.11 µm.                                                                                                                                                                                                                                                      |
| Uses         | : Carvings and toys; tool handles; agricultural implements; panels and boards; furnitures.                                                                                                                                                                                                                                                                                                                                                                                                                               |

#### 4.1.9. *Bombax ceiba* Linn.

|              |                                                                                                                   |
|--------------|-------------------------------------------------------------------------------------------------------------------|
| Trade name   | : Semul                                                                                                           |
| Local name   | : Mullilavu, Poola                                                                                                |
| Family       | : Bombacaceae                                                                                                     |
| Tree         | : Very large to large sized, 26-40 meters in ht with a clear bole of 16-25 m and up to 130 cm in dia; buttressed. |
| Distribution | : West coast semi-evergreen, Moist teak bearing forests and Southern moist mixed deciduous arid.                  |

#### General Features

|              |                                                                                                                  |
|--------------|------------------------------------------------------------------------------------------------------------------|
| Colour       | : pale yellowish-brown or greyish-brown to creamy white, heartwood and sapwood not distinct, lustre is observed. |
| Grain        | : Straight                                                                                                       |
| Texture      | : Coarse                                                                                                         |
| Hardness     | : Very soft to soft                                                                                              |
| Drying       | : Seasoning is very easy; quick conversion and open stacking under shade recommended                             |
| Shrinkage    | : Shrinkage from Green to oven-dry<br>a) Radial shrinkage : 2.2%<br>b) Tangential shrinkage : 5.0%               |
| Durability   | : Perishable                                                                                                     |
| Treatability | : Heartwood easily treatable                                                                                     |

#### Anatomical features

|              |                                                                                                                                                                                                                                                                                  |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                                                                                                                                                     |
| Porosity     | : Diffuse porous                                                                                                                                                                                                                                                                 |
| Vessels      | : Mostly solitary with few radial multiple of 4; scanty in number (1 per mm <sup>2</sup> ). Tangential diameter ranges from 169.79 µm to 264.44 µm with an average of 229.69 µm. Perforation plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal. |
| Parenchyma   | : Predominantly apotracheal in diffuse aggregates- interrupted tangential lines forming reticulum with rays. Paratracheal – vasicentric; Four (3-4) cells per parenchyma strand.                                                                                                 |

|        |                                                                                                                                                                                                                                                                                                                                                                        |
|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rays   | : Irregularly spaced and non-storied; Seriation- multiseriate rays; Heterogenous; Ray is surrounded by sheath cells; Ray width ranges from 82.7 $\mu\text{m}$ to 214.3 $\mu\text{m}$ with a mean of 139.94 $\mu\text{m}$ ; Ray height ranges from 380.67 $\mu\text{m}$ to 2709.23 $\mu\text{m}$ with a mean of 1346.94 $\mu\text{m}$ ; Ray frequency is about 5 per mm |
| Fibres | : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 867.07 $\mu\text{m}$ to 1333.29 $\mu\text{m}$ with an average of 1149.68 $\mu\text{m}$ . The average total diameter is 24.96 $\mu\text{m}$ and the average wall thickness is 7.39 $\mu\text{m}$ .                                          |
| Uses   | : Class-III type plywood and veneers; match splints and boxes; building of ships; fishing floats; packing cases and boxes; toys.                                                                                                                                                                                                                                       |

#### **4.1.10. *Bridelia retusa* (L.) A. Juss.**

|              |                                                                                                                                                                        |
|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name   | : Monj, Kasi                                                                                                                                                           |
| Local name   | : Mullu -Venga                                                                                                                                                         |
| Family       | : Euphorbiaceae                                                                                                                                                        |
| Tree         | : Small to medium sized, 7-17 meters in ht and up to 64cm in dia. Bark is greyish-brown in colour, rough textured with many cracks and exfoliates in irregular flakes. |
| Distribution | : Mostly in West coast semi-evergreen, Southern moist mixed deciduous and Moist teak bearing forests                                                                   |

#### **General Features**

|            |                                                             |
|------------|-------------------------------------------------------------|
| Colour     | : Sapwood greyish-white to grey, heartwood olive-brown.     |
| Grain      | : Shallowly or deeply interlocked                           |
| Texture    | : Medium to coarse                                          |
| Hardness   | : Moderately hard                                           |
| Drying     | : Green conversion and stacking under shade is recommended. |
| Durability | : Moderately durable                                        |

#### **Anatomical features**

|              |                                                                                                                                                |
|--------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Distinct                                                                                                                                     |
| Porosity     | : Diffuse porous                                                                                                                               |
| Vessels      | : Mostly in radial multiple of 2 and more; numerous in number (24 per $\text{mm}^2$ ); Heartwood vessels often filled with tyloses. Tangential |

diameter ranges from 109.51  $\mu\text{m}$  to 187.9  $\mu\text{m}$  with an average of 149.07  $\mu\text{m}$ . Perforation plate – simple. Inter vessel pitting-alternate; Shape of alternate pits polygonal.

- Parenchyma : Paratracheal – mostly scanty; Axial parenchyma is also present in marginal or in seemingly marginal bands; Prismatic crystals in chambered axial parenchyma cells, procumbent cells and upright cells; Four (3-4) cells per parenchyma strand.
- Rays : Irregularly spaced and non-storied; Seriation- Multiseriate rays;; Heterogenous; Ray width ranges from 39.88  $\mu\text{m}$  to 72.06  $\mu\text{m}$  with a mean of 55.70  $\mu\text{m}$ ; Ray height ranges from 376.83  $\mu\text{m}$  to 2655.73  $\mu\text{m}$  with a mean of 1361.25  $\mu\text{m}$ ; Ray frequency is about 6 per mm
- Fibres : Septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 704.1  $\mu\text{m}$  to 1256.23  $\mu\text{m}$  with an average of 906.82  $\mu\text{m}$ . The average total diameter is 14.93  $\mu\text{m}$  and the average wall thickness is 5.74  $\mu\text{m}$ .
- Uses : Rafters, agricultural implements; post and floor boards in building; carts and carriages and tool handles.

#### **4.1.11. *Canarium strictum* Roxb.**

- Trade name : Black Dammar tree, White Dhup
- Local name : Kundrikam, Panta-Payin, Thelli-Payin
- Family : Burseraceae
- Tree : Large to very large statured; Attains upto 25-32 meters in ht and about 45 cm in dia. Bark is pale grey in colour and rough textured.
- Distribution : Southern secondary moist deciduous, Southern hill-top evergreen forests and West coast tropical evergreen

#### **General Features**

- Colour : Yellowish-grey to creamy-white; Heartwood and sapwood not distinct; Lustrous.
- Grain : Interlocked
- Texture : Coarse
- Hardness : Moderately hard

|                            |                                                                                                                                                                                                                                                                                       |                     |        |                         |        |
|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------|-------------------------|--------|
| Drying                     | : Vertical stacking recommended for air seasoning. Kiln-seasoning gives better results.                                                                                                                                                                                               |                     |        |                         |        |
| Shrinkage                  | : Shrinkage from Green to oven-dry <table> <tr> <td>a) Radial shrinkage</td><td>: 4.6%</td></tr> <tr> <td>b) Tangential shrinkage</td><td>: 7.3%</td></tr> </table>                                                                                                                   | a) Radial shrinkage | : 4.6% | b) Tangential shrinkage | : 7.3% |
| a) Radial shrinkage        | : 4.6%                                                                                                                                                                                                                                                                                |                     |        |                         |        |
| b) Tangential shrinkage    | : 7.3%                                                                                                                                                                                                                                                                                |                     |        |                         |        |
| Durability                 | : Perishable                                                                                                                                                                                                                                                                          |                     |        |                         |        |
| <b>Anatomical features</b> |                                                                                                                                                                                                                                                                                       |                     |        |                         |        |
| Growth rings               | : Indistinct                                                                                                                                                                                                                                                                          |                     |        |                         |        |
| Porosity                   | : Diffuse porous                                                                                                                                                                                                                                                                      |                     |        |                         |        |
| Vessels                    | : Mostly solitary with few radial multiple of 2 or 3; Scanty in number (6 per mm <sup>2</sup> ); Tangential diameter ranges from 191.52 µm to 261.34 µm with an average of 191.52 µm. Perforation plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal. |                     |        |                         |        |
| Parenchyma                 | : Paratracheal – scanty; Four (3-4) cells per parenchyma strand. Prismatic crystals in upright and / or square ray cells.                                                                                                                                                             |                     |        |                         |        |
| Rays                       | : Irregularly spaced and non-storied; Seriation- biseriate rays; Heterogenous; Ray width ranges from 19.88 µm to 49.32 µm with a mean of 32.35 µm; Ray height ranges from 220.16 µm to 552.95 µm with a mean of 395.94 µm; Ray frequency is about 7 per mm                            |                     |        |                         |        |
| Fibres                     | : Septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 856.55 µm to 1121.26 µm with an average of 921.56 µm. The average total diameter is 26.45 µm and the average wall thickness is 7.02 µm.                       |                     |        |                         |        |
| Uses                       | : Door shutters; Class-II plywood; panelling; furniture; blockboards; match splints; light packing cases; pencil slats.                                                                                                                                                               |                     |        |                         |        |

#### **4.1.12. *Cassia fistula* Linn.**

|            |                                                                                                                                                                                  |
|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name | : Amaltas                                                                                                                                                                        |
| Local name | : Kani - Konna                                                                                                                                                                   |
| Family     | : Caesalpiniaceae                                                                                                                                                                |
| Tree       | : Small to medium sized, 9-15 meters in ht and about 40 cm in dia. Bark is greenish-grey in colour, smooth textured in juvenile and rough when mature, exfoliates in hard scales |

Distribution : Moist teak bearing, Southern moist mixed deciduous forests and Southern dry mixed deciduous.

### **General Features**

Colour : Heartwood yellowish-red to brick red or reddish-brown and sapwood greyish-white to light yellowish brown

Grain : Straight to slightly interlocked

Texture : Coarse

Hardness : Very hard

Drying : Refractory to seasonings; as it develops cracks, warps and splits. Green conversion and stacking under shade recommended.

Shrinkage : Shrinkage from Green to oven-dry

a) Radial shrinkage : 5.1%

b) Tangential shrinkage : 7.3%

Durability : Very durable

### **Anatomical features**

Growth rings : Indistinct

Porosity : Diffuse porous

Vessels : Mostly in radial multiple of 2 and a few solitary vessels; Scanty in number (5 per mm<sup>2</sup>). Tangential diameter ranges from 119.23 µm to 242.13 µm with an average of 171.42 µm. Perforation plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal. Gums and other deposits present in heartwood vessels. Vessel-ray pits has distinct borders which is similar to inter-vessel pits in size and shape throughout the ray cell.

Parenchyma : Paratracheal – mostly aliform, confluent with some lozenge-aliform; Four (3-4) cells per parenchyma strand; Prismatic crystals in chambered axial parenchyma cells.

Rays : Irregularly spaced and non-storied; Seriation- biseriate rays; ray of 2 distinct size is present; Homogenous- all ray cells procumbent; Ray width ranges from 15.22 µm to 42.1 µm with a mean of 26.76 µm; Ray height ranges from 153.66 µm to 345.4 µm with a mean of 211.44 µm; Ray frequency is about 13 per mm

|        |                                                                                                                                                                                                                                                            |
|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fibres | : Non-septate fibres present; Fibres thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 740.31 µm to 1214.5 µm with an average of 937.51 µm. The average total diameter is 17.13 µm and the average wall thickness is 7.68 µm. |
| Uses   | : Locally used for building construction; charcoal; wheels and shafts of carts; turnery; plough-handles; tool handles.                                                                                                                                     |

#### 4.1.13. *Casuarina equisetifolia* J. R. & G. Forst.

|              |                          |
|--------------|--------------------------|
| Trade name   | : Casuarina              |
| Local name   | : Chula- Maram, Kattadi  |
| Family       | : Casuarinaceae          |
| Distribution | : Cultivated extensively |

##### **General Features**

|                         |                                                                                                                                                                                                    |                     |        |                         |        |
|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------|-------------------------|--------|
| Colour                  | : Heartwood dark reddish-brown to purplish and sapwood pale brown in colour                                                                                                                        |                     |        |                         |        |
| Grain                   | : Straight                                                                                                                                                                                         |                     |        |                         |        |
| Texture                 | : Medium to fine                                                                                                                                                                                   |                     |        |                         |        |
| Hardness                | : Hard to very hard                                                                                                                                                                                |                     |        |                         |        |
| Shrinkage               | : Shrinkage from Green to oven-dry <table data-bbox="715 1256 1201 1352"> <tr> <td>a) Radial shrinkage</td><td>: 3.3%</td></tr> <tr> <td>b) Tangential shrinkage</td><td>: 5.2%</td></tr> </table> | a) Radial shrinkage | : 3.3% | b) Tangential shrinkage | : 5.2% |
| a) Radial shrinkage     | : 3.3%                                                                                                                                                                                             |                     |        |                         |        |
| b) Tangential shrinkage | : 5.2%                                                                                                                                                                                             |                     |        |                         |        |
| Treatability            | : Heartwood partially treatable to preservatives.                                                                                                                                                  |                     |        |                         |        |

##### **Anatomical features**

|              |                                                                                                                                                                                                                                                                     |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                                                                                                                                        |
| Porosity     | : Diffuse porous                                                                                                                                                                                                                                                    |
| Vessels      | : Vessels are exclusively solitary; numerous in number (14 per mm <sup>2</sup> ); Tangential diameter ranges from 68.5 µm to 125.27 µm with an average of 98.47 µm. Perforation plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal. |
| Parenchyma   | : Apotracheal– mostly diffuse-in-aggregates which forms a reticulate pattern. The cells are in narrow bands or lines up to three cells wide; Eight (5-8) cells per parenchyma strand; Prismatic crystals in chambered axial parenchyma cells.                       |

|        |                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rays   | : Irregularly spaced and non-storied; Seriation- biseriate rays; Heterogenous- body ray cells are procumbent with mostly 2-4 rows of upright and / or square marginal cells; Ray width ranges from 11.87 $\mu\text{m}$ to 33.84 $\mu\text{m}$ with a mean of 19.12 $\mu\text{m}$ ; Ray height ranges from 76.39 $\mu\text{m}$ to 594.9 $\mu\text{m}$ with a mean of 223.10 $\mu\text{m}$ ; Ray frequency is about 15 per mm |
| Fibres | : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 826.24 $\mu\text{m}$ to 1137.21 $\mu\text{m}$ with an average of 928.79 $\mu\text{m}$ . The average total diameter is 13.15 $\mu\text{m}$ and the average wall thickness is 6.52 $\mu\text{m}$ .                                                                                                |
| Uses   | : Poles and beams for temporary construction; fuel wood; paper and pulp industry.                                                                                                                                                                                                                                                                                                                                           |

#### **4.1.14. *Ceiba pentandra* L. Gaertn**

|              |                                                                                        |
|--------------|----------------------------------------------------------------------------------------|
| Trade name   | : Kapok                                                                                |
| Local name   | : Panji-Ilavu, Panya                                                                   |
| Family       | : Bombacaceae                                                                          |
| Distribution | : Native of Tropical America and Africa; often grown in homesteads and in plantations. |

#### **General Features**

|            |                                                                                          |
|------------|------------------------------------------------------------------------------------------|
| Colour     | : Greyish-white or greyish-brown, heartwood and sapwood not distinct, somewhat lustrous. |
| Grain      | : Straight                                                                               |
| Texture    | : Coarse                                                                                 |
| Hardness   | : Very soft to soft                                                                      |
| Drying     | : Quick conversion and air- or kiln-seasoning gives satisfactory results                 |
| Durability | : Non-durable                                                                            |

#### **Anatomical features**

|              |                                                                                                                                                    |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                       |
| Porosity     | : Diffuse porous                                                                                                                                   |
| Vessels      | : Mostly solitary and few in radial multiple of 2; Scanty in number ( 6 per $\text{mm}^2$ ); Vessel-ray pits are restricted to marginal rows; they |

have vessel ray reduced borders to apparently simple: pits rounded or angular ; Tangential diameter ranges from 191.39  $\mu\text{m}$  to 315.74  $\mu\text{m}$  with an average of 189.92  $\mu\text{m}$ . Perforation plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal.

- Parenchyma : Paratracheal- vasicentric, Apotracheal- diffuse-in-aggregates; Four (3-4) cells per parenchyma strand. Sheath cells present.
- Rays : Irregularly spaced and non-storied; Seriation- biseriate rays; ray of 2 distinct size is present; Heterogenous; Prismatic crystals present in upright and / or square ray cells, in procumbent ray cells and in non-chambered axial parenchyma cells. Ray width ranges from 57.63  $\mu\text{m}$  to 144.63  $\mu\text{m}$  with a mean of 97.93  $\mu\text{m}$ ; Ray height ranges from 387.47  $\mu\text{m}$  to 1742.44  $\mu\text{m}$  with a mean of 837.88  $\mu\text{m}$ ; Ray frequency is about 4 per mm
- Fibres : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 938.15  $\mu\text{m}$  to 2074  $\mu\text{m}$  with an average of 1583.63  $\mu\text{m}$ . The average total diameter is 20.46  $\mu\text{m}$  and the average wall thickness is 7.67  $\mu\text{m}$ .

#### 4.1.15. *Cocos nucifera* Linn.

- Trade name : Coconut palm
- Local name : Thengu
- Family : Palmae
- Tree : A tall palm attains to a ht of about 20 meters and is approximately 25 cm in diameter. Bark smooth with prominent annulate leaf scars
- Distribution : Cultivated extensively in South India

#### **General Features**

- Colour : Red towards periphery and reddish- brown towards centre
- Grain : Coarse
- Texture : Medium to fine
- Hardness : Very hard
- Durability : Durable if treated
- Treatability : Moderate ease of treatability

**Anatomical features**

- Fibres : Fibres very thick-walled; Length ranges from 1778.17  $\mu\text{m}$  to 3971.24  $\mu\text{m}$  with an average of 2396.94  $\mu\text{m}$ . The average total diameter is 44.69  $\mu\text{m}$  and the average wall thickness is 36.6  $\mu\text{m}$ .
- Uses : Rafters, posts and other constructional items can be used in decorative furniture.

**4.1.16. *Hopea parviflora* Bedd.**

- Trade name : Hopea
- Local name : Tharnbagam, kambagam, irumbagam
- Family : Dipterocarpaceae
- Tree : Large to very large sized, 24-39 meters in ht with a clear bole of 11-18 m and up to 130 cm in dia; buttressed; Bark is light brown coloured, mottled with white, smooth in juvenile trees, changes to rusty brown and rough as the tree matures
- Distribution : Found in semi-evergreen forests and West coast secondary evergreen dipterocarp forests

**General Features**

- Colour : Yellowish-brown to reddish-brown when first exposed, on ageing to dark reddish brown with white lines at intervals, heartwood and sapwood not distinct
- Grain : Broad, shallowly interlocked
- Texture : Fine
- Hardness : Hard to very hard
- Drying : susceptible to splits and surface cracks; green conversion and stacking under shade recommended. Kiln- seasoning possible without deterioration
- Shrinkage : Shrinkage from Green to oven-dry
- a) Radial shrinkage : 3.6%
- b) Tangential shrinkage : 8.0%
- Durability : Very durable.
- Treatability : Heartwood very refractory to treatment.

### **Anatomical features**

|              |                                                                                                                                                                                                                                                                                                                          |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                                                                                                                                                                                             |
| Porosity     | : Diffuse porous                                                                                                                                                                                                                                                                                                         |
| Vessels      | : Mostly in radial multiple of 2 and more; numerous in number (8 per mm <sup>2</sup> ); Heartwood vessels often filled with tyloses. Tangential diameter ranges from 89.19 µm to 155.26 µm with an average of 136.63 µm. Perforation plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal. |
| Parenchyma   | : Paratracheal – mostly vasicentric, lozenge- aliform, rarely confluent; Four (3-4) cells per parenchyma strand.                                                                                                                                                                                                         |
| Rays         | : Irregularly spaced and non-storied; Seriation- biseriate rays; ray of 2 distinct size is present; Heterogenous; Ray width ranges from 24.02 µm to 64.16 µm with a mean of 38.74 µm; Ray height ranges from 621.29 µm to 2450.27 µm with a mean of 1219.8 µm; Ray frequency is about 7 per mm                           |
| Fibres       | : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 778.17 µm to 1971.24 µm with an average of 965.46 µm. The average total diameter is 26.54 µm and the average wall thickness is 12.16 µm.                                                     |
| Uses         | : Beams, planks for shipbuilding; rafters and trusses; tool handles; railway sleepers; poles and posts; cart and carriages.                                                                                                                                                                                              |

#### **4.1.17. *Lagerstroemia lanceolata* Wight.**

|              |                                                                                                                                                         |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name   | : Benteak                                                                                                                                               |
| Local name   | : Venthekku                                                                                                                                             |
| Family       | : Lythraceae                                                                                                                                            |
| Tree         | : Large sized, about 21-33 meters in ht and up to 107 cm in dia. Bark is yellowish-grey in colour, smooth textured, exfoliating in large papery flakes. |
| Distribution | : West coast semi-evergreen, Moist teak bearing and Southern moist mixed deciduous forests                                                              |

### **General Features**

|              |                                                                       |
|--------------|-----------------------------------------------------------------------|
| Colour       | : Sapwood grey or pink, heartwood light reddish-brown to walnut brown |
| Grain        | : Straight to somewhat interlocked                                    |
| Texture      | : Medium                                                              |
| Hardness     | : Moderately hard                                                     |
| Drying       | : Air-seasoning difficult. Kiln-seasoning recommended                 |
| Durability   | : Durable                                                             |
| Treatability | : Heartwood very refractory to treatment                              |

#### **Anatomical features**

|              |                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                                                                                                                                                                                                                                                                            |
| Porosity     | : Diffuse porous                                                                                                                                                                                                                                                                                                                                                                                        |
| Vessels      | : Mostly solitary with a few in radial multiple of 2 to 4; scanty in number ( 3 per mm <sup>2</sup> ); Heartwood vessels often filled with tyloses. Tangential diameter ranges from 134.73 µm to 226.23 µm with an average of 177.81 µm. Perforation plate – simple. Inter vessel pitting- alternate; Vestured pits present; Shape of alternate pits polygonal. Gums and other deposits are also found. |
| Parenchyma   | : Paratracheal – mostly winged- aliform, confluent; Four (3-4) cells per parenchyma strand. Prismatic crystals in chambered axial parenchyma cells.                                                                                                                                                                                                                                                     |
| Rays         | : Irregularly spaced and non-storied; Seriation- Uniseriate rays; Heterogenous; Ray width ranges from 17.16 µm to 26.02 µm with a mean of 17.16 µm; Ray height ranges from 405.21 µm to 738.11 µm with a mean of 456.22 µm; Ray frequency is about 10 per mm                                                                                                                                            |
| Fibres       | : Septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Prismatic crystals present in fibres; Length ranges from 553.23 µm to 1352.55 µm with an average of 806.98 µm. The average total diameter is 18.52 µm and the average wall thickness is 5.40 µm.                                                                                                   |
| Uses         | : Frames; furniture, flooring, fuelwood, carving, construction                                                                                                                                                                                                                                                                                                                                          |

#### 4.1.18. *Mangifera indica* Linn.

|              |                                                                                                                                                                             |
|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name   | : Mango                                                                                                                                                                     |
| Local name   | : Mavu                                                                                                                                                                      |
| Family       | : Aacardiaceae                                                                                                                                                              |
| Tree         | : Medium to large sized, 16-25 meters in ht and' 50-90 cm in dia.<br>Bark is brown or dark grey in colour and rough textured.                                               |
| Distribution | : It is cultivated extensively and found in West coast West coast<br>tropical evergreen and West coast semi-evergreen forests; and<br>West coast tropical evergreen forests |

#### General Features

|              |                                                                                                                                                                                                                                  |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Colour       | : Yellowish-white to greyish-brown, heartwood and sapwoodnot<br>distinct or sometimes heartwood distinct and dark brown,<br>somewhat lustrous                                                                                    |
| Grain        | : Straight to somewhat interlocked                                                                                                                                                                                               |
| Texture      | : Medium to coarse                                                                                                                                                                                                               |
| Hardness     | : Moderately hard                                                                                                                                                                                                                |
| Drying       | : Not refractory; green conversion followed by stacking in dry<br>ventilated area recommended. Kiln-seasoning improves the<br>appearance of the timber without degradation. Retains its shape<br>remarkably well after seasoning |
| Shrinkage    | : Shrinkage from Green to oven-dry<br>a) Radial shrinkage : 2%<br>b) Tangential shrinkage : 4.9%                                                                                                                                 |
| Durability   | : Non-durable                                                                                                                                                                                                                    |
| Treatability | : Easily treatable                                                                                                                                                                                                               |

#### Anatomical features

|              |                                                                                                                                                                                                                                                                                                                                                                      |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                                                                                                                                                                                                                                         |
| Porosity     | : Diffuse porous                                                                                                                                                                                                                                                                                                                                                     |
| Vessels      | : Mostly solitary with a few in radial multiple of 2 and more; scanty<br>in number (4 per mm <sup>2</sup> ); Heartwood vessels often filled with tyloses<br>and gummy deposits; Vessel- ray is reduced borders to apparently<br>simple: pits rounded or angular; Tangential diameter ranges from<br>112.68 µm to 271.86 µm with an average of 186.05 µm. Perforation |

|            |                                                                                                                                                                                                                                                                                                                                                         |
|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            | plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal.                                                                                                                                                                                                                                                                     |
| Parenchyma | : Paratracheal – mostly vasicentric, lozenge- aliform, winged-aliform, few confluent; Four (3-4) cells per parenchyma strand. Prismatic crystals present in upright and / or square ray cells and in procumbent ray cells                                                                                                                               |
| Rays       | : Irregularly spaced and non-storied; Seriation- Uniseriate rays with few biseriate rays; Heterogenous; Ray width ranges from 12.13 $\mu\text{m}$ to 33.56 $\mu\text{m}$ with a mean of 20.19 $\mu\text{m}$ ; Ray height ranges from 55.32 $\mu\text{m}$ to 217.63 $\mu\text{m}$ with a mean of 107.57 $\mu\text{m}$ ; Ray frequency is about 11 per mm |
| Fibres     | : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 764.55 $\mu\text{m}$ to 1165.34 $\mu\text{m}$ with an average of 957.32 $\mu\text{m}$ . The average total diameter is 13.86 $\mu\text{m}$ and the average wall thickness is 5.11 $\mu\text{m}$ .                            |
| Uses       | : Furniture, flooring, fuelwood, carving, construction                                                                                                                                                                                                                                                                                                  |

#### 4.1.19. *Melia dubia* Cav.

|            |                                                                                                                                             |
|------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name | : Malabar neem                                                                                                                              |
| Local name | : Kattu-Veppu, Mala-Veppu                                                                                                                   |
| Family     | : Meliaceae                                                                                                                                 |
| Tree       | : Large sized, up to 26 meters in ht and about 75 cm in dia. Bark is dark brown or blackish in colour and exfoliates in rectangular strips. |

Distribution : Moist teak bearing forests and Southern moist mixed deciduous

#### General Features

|            |                                                                       |
|------------|-----------------------------------------------------------------------|
| Colour     | : Sapwood grey or pinkish-white with yellow cast, heartwood light red |
| Grain      | : Straight                                                            |
| Texture    | : Coarse                                                              |
| Hardness   | : Moderately hard                                                     |
| Drying     | : Green conversion and open stacking under shade recommended          |
| Durability | : Moderately durable under shade                                      |

### **Anatomical features**

|              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Growth rings | : Indistinct                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Porosity     | : Diffuse porous                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Vessels      | : Mostly solitary with a few in radial multiple of 2 and more; moderate in number (7 per mm <sup>2</sup> ); Tangential diameter ranges from 99 µm to 175.18 µm with an average of 134.98 µm. Perforation plate – simple. Inter vessel pitting- alternate; Vessel ray pitting is similar to inter-vessel pits in size and shape throughout the ray cell. Helical thickenings is present throughout body of narrower vessel elements. Gums and other deposits present in heartwood vessels. |
| Parenchyma   | : Paratracheal – mostly scanty, vasicentric; Axial parenchyma is also present in marginal or in seemingly marginal bands; Four (3-4) cells per parenchyma strand.                                                                                                                                                                                                                                                                                                                         |
| Rays         | : Irregularly spaced and non-storied; Seriation- multiseriate rays; All ray cells procumbent; Heterogenous; Ray width ranges from 28.6 µm to 63.21 µm with a mean of 46.34 µm; Ray height ranges from 173.17 µm to 516.56 µm with a mean of 297.02 µm; Ray frequency is about 5 per mm                                                                                                                                                                                                    |
| Fibres       | : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 426.54 µm to 808 µm with an average of 614.30 µm. The average total diameter is 21.93 µm and the average wall thickness is 7.25 µm.                                                                                                                                                                                                                           |
| Uses         | : Window frames; Ceiling boards, general purpose Class I plywood; blockboards; furniture and cabinets; match splints and boxes; shoe-lasts                                                                                                                                                                                                                                                                                                                                                |

#### **4.1.20. *Neolamarckia cadamba* (Roxb.) Bosser.**

|            |                                                                                                                                                                                       |
|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Trade name | : Kadam                                                                                                                                                                               |
| Local name | : Cadamb, Attu-Teak                                                                                                                                                                   |
| Family     | : Rubiaceae                                                                                                                                                                           |
| Tree       | : Medium to large sized, 16-26 meters in ht with a clear bole of about 10m and about 55 cm in dia. Bark is dark grey in colour, with longitudinal fissures; exfoliates in thin scales |

Distribution : West coast semi-evergreen forest

### **General Features**

Colour : White with yellowish tinge to creamy white or yellowish-grey, heartwood and sapwood not distinct and Lustrous.

Grain : Straight

Texture : Texture medium to fine

Hardness : Soft

Drying : Conversion soon after felling and stacking between stickers under shade recommended

Durability : Perishable in nature

Treatability : Heartwood is easily treatable

### **Anatomical features**

Growth rings : Indistinct

Porosity : Diffuse porous

Vessels : Mostly in radial multiple of 2 and more; Moderate in number (11 per mm<sup>2</sup>); Tangential diameter ranges from 102.06  $\mu\text{m}$  to 183.87  $\mu\text{m}$  with an average of 165.35  $\mu\text{m}$ . Perforation plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal. Vessel ray pitting is similar to inter-vessel pits in size and shape throughout the ray cell.

Parenchyma : Apotracheal- diffuse in aggregates; Paratracheal –scanty; Eight (5-8) cells per parenchyma strand.

Rays : Irregularly spaced and non-storied; Seriation- multiseriate rays; Heterogenous; Body ray cells procumbent with over 4 rows of upright and / or square marginal cells; Disjunctive ray parenchyma cell walls present; Ray width ranges from 19.57  $\mu\text{m}$  to 61.04  $\mu\text{m}$  with a mean of 41.55  $\mu\text{m}$ ; Ray height ranges from 278.77  $\mu\text{m}$  to 1240.22  $\mu\text{m}$  with a mean of 620.81  $\mu\text{m}$ ; Ray frequency is about 13 per mm

Fibres : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits; Length ranges from 857.24  $\mu\text{m}$  to 1600.1  $\mu\text{m}$  with an average of 1176.64  $\mu\text{m}$ . The average total diameter is 26.69  $\mu\text{m}$  and the average wall thickness is 5.89  $\mu\text{m}$ .

Uses : construction works; Furniture; tea chests; Class-III veneers for plywood.

**4.1.21. *Thespesia populnea* (Linn.) Soland. Ex Correa.**

Trade name : Bhendi  
Local name : Cheelanthi, Poovarasu  
Family : Malvaceae  
Tree : Small to medium sized, 8-17 meters in ht and 21-45 cm in dia. Bark is grey or greyish-brown in colour, smooth or shallowly fissured in nature  
Distribution : Grows in areas near the coast and sometimes grown in the villages

**General Features**

Colour : Heartwood reddish- brown to chocolate brown or dull brown with dark streaks and sapwood white with a pale yellowish or pinkish tinge  
Grain : Straight to somewhat interlocked  
Texture : Medium  
Hardness : Moderately hard to hard  
Drying : Seasons well  
Shrinkage : Shrinkage from Green to oven-dry  
a) Radial shrinkage : 3.8%  
b) Tangential shrinkage : 6.9%  
Durability : Fairly durable  
Treatability : Heartwood refractory to treatment

**Anatomical features**

Growth rings : Indistinct  
Porosity : Diffuse porous  
Vessels : Mostly solitary with a few in radial multiple of 2 and more; scanty in number (6 per mm<sup>2</sup>); Heartwood vessels often filled with reddish gummy deposits. Tangential diameter ranges from 69.47 µm to 139.47 µm with an average of 99.54 µm. Perforation plate – simple. Inter vessel pitting- alternate; Shape of alternate pits polygonal.

Vessel ray pitting is similar to inter-vessel pits in size and shape throughout the ray cell.

- Parenchyma : Apotracheal- diffuse in aggregates; Paratracheal –vasicentric; Two cells per parenchyma strand. Fusiform parenchyma cells are present. Axial parenchyma is arranged in narrow bands or lines up to three cells wide.
- Rays : Irregularly spaced; Seriation- biseriate rays;; Heterogenous; Low rays are storied; Sheath cells present; Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells; Ray width ranges from 29.21  $\mu\text{m}$  to 54.03  $\mu\text{m}$  with a mean of 38.72  $\mu\text{m}$ ; Ray height ranges from 127.22  $\mu\text{m}$  to 455.51  $\mu\text{m}$  with a mean of 212.09  $\mu\text{m}$ ; Ray frequency is about 8 per mm
- Fibres : Non-septate fibres present; Fibres thin to thick-walled; Fibres with simple to minutely bordered pits and pits common in both radial and tangential walls; Length ranges from 738.17  $\mu\text{m}$  to 1571.24  $\mu\text{m}$  with an average of 1004.58  $\mu\text{m}$ . The average total diameter is 25.95  $\mu\text{m}$  and the average wall thickness is 8.05  $\mu\text{m}$ .
- Uses : Furniture; wooden footwear; tool handles; ship and boat building; drawing tools; carts and carriages.

## 4.2. STATISTICAL ANALYSIS

Statistical analysis to perform one-way ANOVA was done using R software (Version 4.2.2.) and post-hoc analysis was carried using CD.

### 4.2.1. Analysis Of Variance (ANOVA)

#### 4.2.1.1. Vessel parameters

Vessel parameters like Vessel Tangential Diameter (VTD), Vessel Cross Diameter (VCD), Vessel Area (VA), Vessel Perimeter (VP) and Vessel Frequency (VF) were studied.

**Table 2: Analysis of Variance (ANOVA) table for vessel parameters**

| S. no. | Species                                        | VTD                   | VCD                     | VA                      | VP                    | VF                 |
|--------|------------------------------------------------|-----------------------|-------------------------|-------------------------|-----------------------|--------------------|
| 1.     | <i>Acrocarpus fraxinifolius</i> Arn.           | 224.34 <sup>b</sup>   | 249.70 <sup>b</sup>     | 40554.80 <sup>bc</sup>  | 742.47 <sup>bc</sup>  | 5.00 <sup>gh</sup> |
| 2.     | <i>Artocarpus hirsutus</i> Lam.                | 123.92 <sup>hi</sup>  | 180.36 <sup>efgh</sup>  | 14863.87 <sup>ij</sup>  | 455.49 <sup>ij</sup>  | 14.00 <sup>c</sup> |
| 3.     | <i>Azadirachta indica</i> A. Juss.             | 140.86 <sup>fgh</sup> | 163.39 <sup>fghij</sup> | 13246.95 <sup>j</sup>   | 419.13 <sup>jk</sup>  | 8.00 <sup>e</sup>  |
| 4.     | <i>Aegle marmelos</i> L. Correa                | 93.82 <sup>j</sup>    | 119.03 <sup>m</sup>     | 10132.23 <sup>j</sup>   | 370.57 <sup>k</sup>   | 37.00 <sup>a</sup> |
| 5.     | <i>Acacia nilotica</i> (Linn.) Wild. Ex Delile | 120.51 <sup>i</sup>   | 162.33 <sup>ghij</sup>  | 15937.95 <sup>hij</sup> | 463.58 <sup>hij</sup> | 3.00 <sup>i</sup>  |
| 6.     | <i>Albizia odoratissima</i> (Linn. f.) Benth.  | 156.88 <sup>ef</sup>  | 176.44 <sup>efghi</sup> | 25876.17 <sup>efg</sup> | 583.86 <sup>ef</sup>  | 3.00 <sup>i</sup>  |
| 7.     | <i>Alstonia scholaris</i> (Linn.) R. Br.       | 128.70 <sup>hi</sup>  | 144.51 <sup>jkl</sup>   | 15452.69 <sup>hij</sup> | 461.44 <sup>ij</sup>  | 13.00 <sup>c</sup> |
| 8.     | <i>Ailanthus triphysa</i> (Dennst) Alston      | 187.99 <sup>c</sup>   | 222.10 <sup>cd</sup>    | 28243.61 <sup>ef</sup>  | 631.03 <sup>de</sup>  | 4.00 <sup>hi</sup> |
| 9.     | <i>Bombax ceiba</i> Linn.                      | 232.11 <sup>b</sup>   | 275.65 <sup>a</sup>     | 51029.40 <sup>a</sup>   | 821.71 <sup>a</sup>   | 5.00 <sup>gh</sup> |
| 10.    | <i>Bridelia retusa</i> (L.) A. Juss.           | 149.29 <sup>efg</sup> | 150.04 <sup>jk</sup>    | 20610.95 <sup>ghi</sup> | 531.28 <sup>fgh</sup> | 24.00 <sup>b</sup> |

|     |                                                  |                       |                        |                         |                        |                    |
|-----|--------------------------------------------------|-----------------------|------------------------|-------------------------|------------------------|--------------------|
| 11. | <i>Casuarina equisetifolia</i> J. R. & G. Forst. | 99.11 <sup>j</sup>    | 135.93 <sup>klm</sup>  | 11010.59 <sup>j</sup>   | 383.06 <sup>k</sup>    | 14.00 <sup>c</sup> |
| 12. | <i>Cassia fistula</i> Linn.                      | 165.85 <sup>de</sup>  | 154.05 <sup>ijk</sup>  | 20254.26 <sup>ghi</sup> | 524.45 <sup>fghi</sup> | 5.00 <sup>gh</sup> |
| 13. | <i>Ceiba pentandra</i> L. Gaertn                 | 258.38 <sup>a</sup>   | 237.76 <sup>bc</sup>   | 45694.11 <sup>ab</sup>  | 780.38 <sup>ab</sup>   | 6.00 <sup>fg</sup> |
| 14. | <i>Canarium strictum</i> Roxb.                   | 188.96 <sup>c</sup>   | 226.68 <sup>bc</sup>   | 25200.29 <sup>fg</sup>  | 574.84 <sup>ef</sup>   | 6.00 <sup>fg</sup> |
| 15. | <i>Hopea parviflora</i> Bedd.                    | 136.80 <sup>ghi</sup> | 187.45 <sup>ef</sup>   | 19948.68 <sup>ghi</sup> | 490.73 <sup>ghi</sup>  | 3.00 <sup>i</sup>  |
| 16. | <i>Lagerstroemia lanceolata</i> Wight.           | 177.81 <sup>cd</sup>  | 199.02 <sup>de</sup>   | 34674.07 <sup>cd</sup>  | 674.96 <sup>cd</sup>   | 3.00 <sup>i</sup>  |
| 17. | <i>Melia dubia</i> Cav.                          | 133.35 <sup>ghi</sup> | 158.57 <sup>hijk</sup> | 16161.98 <sup>hij</sup> | 471.80 <sup>hij</sup>  | 7.00 <sup>ef</sup> |
| 18. | <i>Mangifera indica</i> Linn.                    | 188.93 <sup>c</sup>   | 248.25 <sup>b</sup>    | 31955.31 <sup>de</sup>  | 658.34 <sup>d</sup>    | 4.00 <sup>hi</sup> |
| 19. | <i>Neolamarkiana cadamba</i> Roxb.               | 165.52 <sup>de</sup>  | 186.44 <sup>efg</sup>  | 21172.97 <sup>gh</sup>  | 547.05 <sup>fg</sup>   | 11.00 <sup>d</sup> |
| 20. | <i>Thespesia populnea</i> (L.) Soland. ex Correa | 91.25 <sup>j</sup>    | 124.16 <sup>lm</sup>   | 10830.88 <sup>j</sup>   | 384.21 <sup>k</sup>    | 6.00 <sup>fg</sup> |
|     | <b>CD VALUE</b>                                  | <b>19.06</b>          | <b>24.33</b>           | <b>6130.43</b>          | <b>69.57</b>           | <b>1.15</b>        |

VTD- Vessel Tangential Diameter; VCD- Vessel Cross Diameter; VA- Vessel Area; VP- Vessel Perimeter; VF - Vessel Frequency

The statistical analysis revealed that all the vessel parameters studied, significantly differed for each species (Table 2). Vessel Tangential Diameter (VTD) was found to be the maximum in *Ceiba pentandra* with 258.38  $\mu\text{m}$  followed by *Bombax ceiba* with 232.11  $\mu\text{m}$  and *Acrocarpus fraxinifolius* with 224.34  $\mu\text{m}$ . The minimum vessel tangential diameter was recorded for *Aegle marmelos* with 93.82  $\mu\text{m}$  and *Casuarina equisetifolia* with 99.11  $\mu\text{m}$ . Vessel Cross Diameter (VCD) was found to be the maximum *Bombax ceiba* with 275.65  $\mu\text{m}$  followed by *Acrocarpus fraxinifolius* with 249.70  $\mu\text{m}$  and *Mangifera indica* with 248.25  $\mu\text{m}$ . The minimum vessel cross diameter was recorded for *Aegle marmelos* with 119.03  $\mu\text{m}$  followed by *Thespesia populnea* with 124.16  $\mu\text{m}$  and *Casuarina equisetifolia* with 135.93  $\mu\text{m}$ .

Vessel Area (VA) was found to be the maximum in *Bombax ceiba* with 51029.40  $\mu\text{m}^2$  followed by *Ceiba pentandra* with 45694.11  $\mu\text{m}^2$ . The minimum vessel area was recorded for *Aegle marmelos* with 10132.23  $\mu\text{m}^2$  followed by *Thespesia populnea* with 10830.88  $\mu\text{m}^2$ . Vessel Perimeter (VP) was found to be the maximum in *Bombax ceiba* with 821.71  $\mu\text{m}$  followed by *Ceiba pentandra* with 780.38  $\mu\text{m}$  but they are statistically on par with each other. Vessel Frequency (VF) was found to be the maximum in *Aegle marmelos* (37 per  $\text{mm}^2$ ) followed by *Bridelia retusa* (24 per  $\text{mm}^2$ ), *Casuarina equisetifolia* (14 per  $\text{mm}^2$ ) and *Neolamarkiana cadamba* (11 per  $\text{mm}^2$ ) and they differed significantly from each other. The lowest vessel frequency was recorded in *Acacia nilotica*, *Albizia odoratissima*, *Hopea parviflora* and *Lagerstroemia lanceolata* with a value of 3 per  $\text{mm}^2$ .

#### 4.2.1.2. Ray parameters

Ray parameters like Ray Height (RH), Ray Width (RW) and Ray Frequency (RH) were studied.

**Table 3: Analysis Of Variance (ANOVA) table for Ray parameters**

| S. no. | Species                                          | RW                   | RH                     | RF                  |
|--------|--------------------------------------------------|----------------------|------------------------|---------------------|
| 1.     | <i>Acrocarpus fraxinifolius</i> Arn.             | 38.84 <sup>gh</sup>  | 306.06 <sup>efgh</sup> | 8.00 <sup>fg</sup>  |
| 2.     | <i>Artocarpus hirsutus</i> Lam.                  | 33.47 <sup>gh</sup>  | 1343.40 <sup>ab</sup>  | 9.00 <sup>ef</sup>  |
| 3.     | <i>Azadirachta indica</i> A. Juss.               | 61.95 <sup>c</sup>   | 313.98 <sup>efgh</sup> | 12.00 <sup>bc</sup> |
| 4.     | <i>Aegle marmelos</i> L. Correa                  | 34.12 <sup>gh</sup>  | 287.05 <sup>efgh</sup> | 10.00 <sup>de</sup> |
| 5.     | <i>Acacia nilotica</i> (Linn.) Wild. Ex Delile   | 46.87 <sup>ef</sup>  | 1146.87 <sup>b</sup>   | 7.00 <sup>gh</sup>  |
| 6.     | <i>Albizia odoratissima</i> (Linn. f.) Benth.    | 33.70 <sup>gh</sup>  | 239.14 <sup>fgh</sup>  | 7.00 <sup>gh</sup>  |
| 7.     | <i>Alstonia scholaris</i> (Linn.) R. Br.         | 54.52 <sup>cde</sup> | 277.76 <sup>efgh</sup> | 7.00 <sup>gh</sup>  |
| 8.     | <i>Ailanthus triphysa</i> (Dennst) Alston        | 133.49 <sup>a</sup>  | 604.14 <sup>d</sup>    | 6.00 <sup>hi</sup>  |
| 9.     | <i>Bombax ceiba</i> Linn.                        | 138.88 <sup>a</sup>  | 1253.84 <sup>b</sup>   | 5.00 <sup>ij</sup>  |
| 10.    | <i>Bridelia retusa</i> (L.) A. Juss.             | 53.31 <sup>de</sup>  | 1501.97 <sup>a</sup>   | 6.00 <sup>hi</sup>  |
| 11.    | <i>Casuarina equisetifolia</i> J. R. & G. Forst. | 20.04 <sup>i</sup>   | 221.28 <sup>gh</sup>   | 15.00 <sup>a</sup>  |
| 12.    | <i>Cassia fistula</i> Linn.                      | 23.78 <sup>i</sup>   | 214.69 <sup>gh</sup>   | 13.00 <sup>b</sup>  |
| 13.    | <i>Ceiba pentandra</i> L. Gaertn                 | 93.91 <sup>b</sup>   | 844.58 <sup>c</sup>    | 4.00 <sup>j</sup>   |
| 14.    | <i>Canarium strictum</i> Roxb.                   | 31.83 <sup>h</sup>   | 385.80 <sup>efg</sup>  | 7.00 <sup>gh</sup>  |
| 15.    | <i>Hopea parviflora</i> Bedd.                    | 58.50 <sup>cd</sup>  | 485.41 <sup>de</sup>   | 7.00 <sup>gh</sup>  |
| 16.    | <i>Lagerstroemia lanceolata</i> Wight.           | 18.90 <sup>i</sup>   | 444.35 <sup>def</sup>  | 10.00 <sup>de</sup> |
| 17.    | <i>Melia dubia</i> Cav.                          | 47.66 <sup>ef</sup>  | 289.93 <sup>efgh</sup> | 5.00 <sup>ij</sup>  |

|     |                                                  |                     |                       |                     |
|-----|--------------------------------------------------|---------------------|-----------------------|---------------------|
| 18. | <i>Mangifera indica</i> Linn.                    | 20.05 <sup>i</sup>  | 104.41 <sup>h</sup>   | 11.00 <sup>cd</sup> |
| 19. | <i>Neolamarkiana cadamba</i> Roxb.               | 40.37 <sup>fg</sup> | 602.40 <sup>d</sup>   | 13.00 <sup>b</sup>  |
| 20. | <i>Thespesia populnea</i> (L.) Soland. ex Correa | 38.74 <sup>gh</sup> | 248.19 <sup>fgh</sup> | 8.00 <sup>fg</sup>  |
|     | <b>CD VALUE</b>                                  | <b>7.70</b>         | <b>211.32</b>         | <b>1.24</b>         |

RW- Ray Width; RH- Ray Height; RF- Ray Frequency

The statistical analysis revealed that all the ray parameters studied, significantly differed for each species (Table 3). Ray frequency (RF) was found to be the highest in *Casuarina equisetifolia* (15 per mm) followed by *Cassia fistula* (13 per mm) and *Neolamarkiana cadamba* (13 per mm) and the lowest was recorded in *Ceiba pentandra* (4 per mm) followed by *Bombax ceiba* (5 per mm) and *Melia dubia* (5 per mm). Ray height (RH) was found to be maximum in *Bridelia retusa* with a height of 1.50 mm followed by *Bombax ceiba* with a height of 1.25 mm and the lowest was recorded in *Cassia fistula* with a height of 0.21 mm followed by *Casuarina equisetifolia* with a height of 0.22 mm. Ray width (RW) was found to be the highest in *Bombax ceiba* and *Ailanthus triphysa* with 138.88  $\mu$ m and 133.49  $\mu$ m respectively. The minimum width was observed in *Lagerstroemia lanceolata* (18.90  $\mu$ m), *Mangifera indica* (20.05  $\mu$ m), *Casuarina equisetifolia* (20.04  $\mu$ m) and *Cassia fistula* (23.78  $\mu$ m).

#### 4.2.1.3. Fibre parameters

Fibre parameters like Fibre Length (FL), Fibre Total Diameter (FTD), Fibre Lumen Diameter (FLD) and Fibre Wall Thickness (FWT) were studied.

**Table 4: Analysis Of Variance (ANOVA) table for Fibre parameters**

| S. no. | Species                                           | FL                     | FTD                  | FLD                 | FWT                   |
|--------|---------------------------------------------------|------------------------|----------------------|---------------------|-----------------------|
| 1.     | <i>Albizia odoratissima</i> (Linn. f.)<br>Benth.  | 1011.47 <sup>efg</sup> | 19.11 <sup>fg</sup>  | 11.65 <sup>f</sup>  | 7.63 <sup>de</sup>    |
| 2.     | <i>Acacia nilotica</i> (Linn.) Wild. Ex<br>Delile | 1066.77 <sup>de</sup>  | 15.06 <sup>hi</sup>  | 9.84 <sup>g</sup>   | 5.37 <sup>mn</sup>    |
| 3.     | <i>Acrocarpus fraxinifolius</i> Arn.              | 798.49 <sup>i</sup>    | 19.48 <sup>efg</sup> | 13.77 <sup>e</sup>  | 5.71 <sup>klmn</sup>  |
| 4.     | <i>Aegle marmelos</i> L. Correa                   | 904.91 <sup>h</sup>    | 29.00 <sup>b</sup>   | 20.88 <sup>a</sup>  | 8.19 <sup>d</sup>     |
| 5.     | <i>Ailanthus triphysa</i> (Dennst) Alston         | 1180.57 <sup>c</sup>   | 25.64 <sup>c</sup>   | 15.66 <sup>d</sup>  | 9.93 <sup>c</sup>     |
| 6.     | <i>Alstonia scholaris</i> (Linn.) R. Br.          | 1126.69 <sup>cd</sup>  | 26.06 <sup>c</sup>   | 18.85 <sup>bc</sup> | 6.51 <sup>ghijk</sup> |

|     |                                                         |                        |                      |                     |                       |
|-----|---------------------------------------------------------|------------------------|----------------------|---------------------|-----------------------|
| 7.  | <i>Artocarpus hirsutus</i> Lam.                         | 1058.19 <sup>def</sup> | 24.41 <sup>cd</sup>  | 17.62 <sup>c</sup>  | 6.72 <sup>fghij</sup> |
| 8.  | <i>Azadirachta indica</i> A. Juss.                      | 960.75 <sup>fgh</sup>  | 13.60 <sup>i</sup>   | 8.78 <sup>gh</sup>  | 5.08 <sup>n</sup>     |
| 9.  | <i>Bombax ceiba</i> Linn.                               | 1146.76 <sup>cd</sup>  | 25.09 <sup>c</sup>   | 18.47 <sup>c</sup>  | 7.37 <sup>defg</sup>  |
| 10. | <i>Bridelia retusa</i> (L.) A. Juss.                    | 920.10 <sup>gh</sup>   | 14.34 <sup>i</sup>   | 8.86 <sup>gh</sup>  | 5.53 <sup>lmn</sup>   |
| 11. | <i>Canarium strictum</i> Roxb.                          | 921.56 <sup>gh</sup>   | 25.80 <sup>c</sup>   | 18.81 <sup>bc</sup> | 7.15 <sup>efgh</sup>  |
| 12. | <i>Cassia fistula</i> Linn.                             | 923.98 <sup>gh</sup>   | 17.58 <sup>gh</sup>  | 9.74 <sup>gh</sup>  | 7.51 <sup>def</sup>   |
| 13. | <i>Casuarina equisetifolia</i> J. R. & amp;<br>G.Forst. | 920.69 <sup>gh</sup>   | 12.75 <sup>i</sup>   | 6.39 <sup>i</sup>   | 6.38 <sup>hijkl</sup> |
| 14. | <i>Ceiba pentandra</i> L. Gaertn                        | 1610.99 <sup>b</sup>   | 19.69 <sup>efg</sup> | 12.98 <sup>ef</sup> | 6.17 <sup>ijklm</sup> |
| 15. | <i>Cocos nucifera</i> Linn.                             | 1760.12 <sup>a</sup>   | 45.60 <sup>a</sup>   | 8.11 <sup>h</sup>   | 36.63 <sup>a</sup>    |
| 16. | <i>Hopea parviflora</i> Bedd.                           | 991.47 <sup>efgh</sup> | 25.89 <sup>c</sup>   | 14.03 <sup>de</sup> | 12.38 <sup>b</sup>    |
| 17. | <i>Lagerstroemia lanceolata</i> Wight.                  | 791.08 <sup>i</sup>    | 20.31 <sup>ef</sup>  | 13.46 <sup>e</sup>  | 5.47 <sup>mn</sup>    |
| 18. | <i>Mangifera indica</i> Linn.                           | 954.93 <sup>fgh</sup>  | 13.93 <sup>i</sup>   | 8.79 <sup>gh</sup>  | 5.11 <sup>n</sup>     |
| 19. | <i>Melia dubia</i> Cav.                                 | 605.43 <sup>j</sup>    | 21.86 <sup>de</sup>  | 15.50 <sup>d</sup>  | 6.87 <sup>efghi</sup> |
| 20. | <i>Neolamarkiana cadamba</i> Roxb.                      | 1188.29 <sup>c</sup>   | 26.04 <sup>c</sup>   | 20.29 <sup>ab</sup> | 6.00 <sup>ijklm</sup> |
| 21. | <i>Thespesia populnea</i> (L.) Soland. ex<br>Correa     | 984.79 <sup>efgh</sup> | 25.78 <sup>c</sup>   | 18.66 <sup>bc</sup> | 8.17 <sup>d</sup>     |
|     | <b>CD VALUE</b>                                         | <b>103.33</b>          | <b>2.60</b>          | <b>1.72</b>         | <b>0.86</b>           |

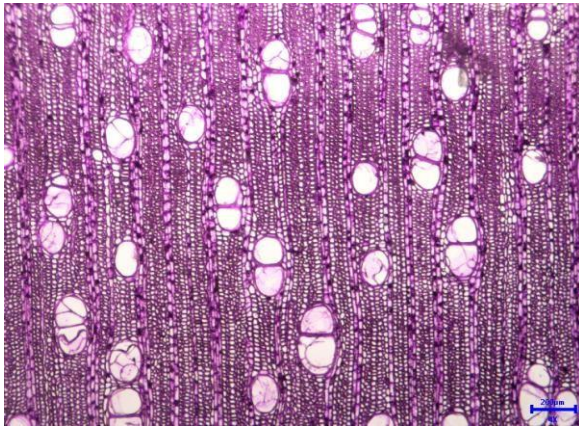
FL- Fibre length; FTD- Fibre Total Diameter; FLD- Fibre Lumen Diameter; FWT- Fibre Wall Thickness

The statistical analysis revealed that all the ray parameters studied, significantly differed for each species (Table 4). In the present study, maximum fibre length was observed in *Cocos nucifera* with a value of 1760.12  $\mu\text{m}$  followed by *Ceiba pentandra* with a value of 1610.99  $\mu\text{m}$  and the minimum was observed in *Melia dubia* which recorded 605.43  $\mu\text{m}$ . Fibre Total Diameter (FTD) observed a peak for *Cocos nucifera* with a value of 45.60  $\mu\text{m}$  followed by *Aegle marmelos* with a value of 29.00  $\mu\text{m}$  and the minimum value was observed in *Casuarina equisetifolia* a value of 12.75  $\mu\text{m}$  followed by *Azadirachta indica* (13.60  $\mu\text{m}$ )  $\mu\text{m}$ , *Mangifera indica* (13.93  $\mu\text{m}$ ) and *Bridelia retusa* (14.34  $\mu\text{m}$ ).

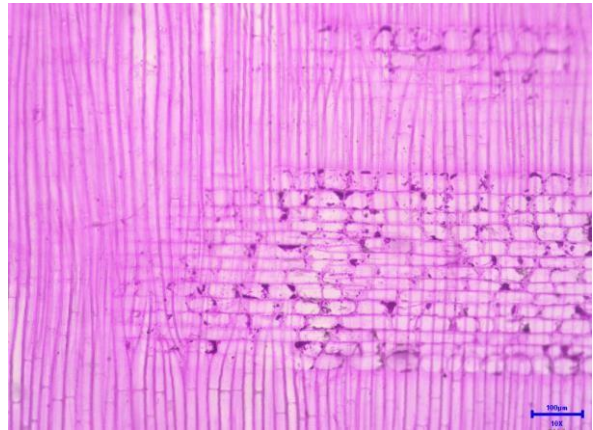
Fibre Lumen Diameter (FLD) was found to be the highest in *Aegle marmelos* (20.88  $\mu\text{m}$ ) and *Neolamarkiana cadamba* (20.29  $\mu\text{m}$ ) and the lowest was recorded in *Casuarina equisetifolia* (6.39  $\mu\text{m}$ ). Fibre Wall Thickness (FWT) was found to be the highest in *Cocos nucifera* with a value of 36.63  $\mu\text{m}$  followed by *Hopea parviflora* with a value of 12.38  $\mu\text{m}$  and the lowest was recorded in *Mangifera indica* with a value of 5.11  $\mu\text{m}$ .

## Plate 2: Microscopic images of wood anatomical sections

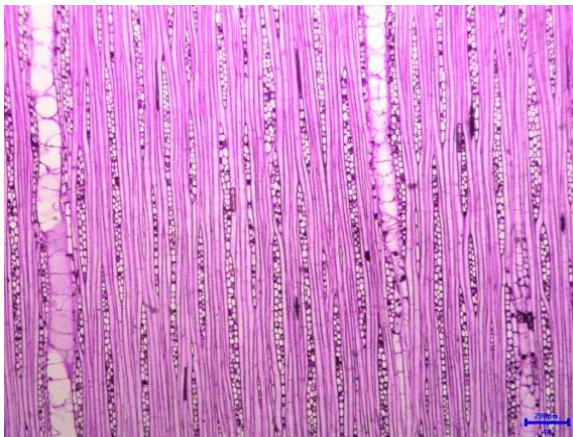
### 2.1. *Acacia nilotica* (Linn.) Wild. Ex Delile



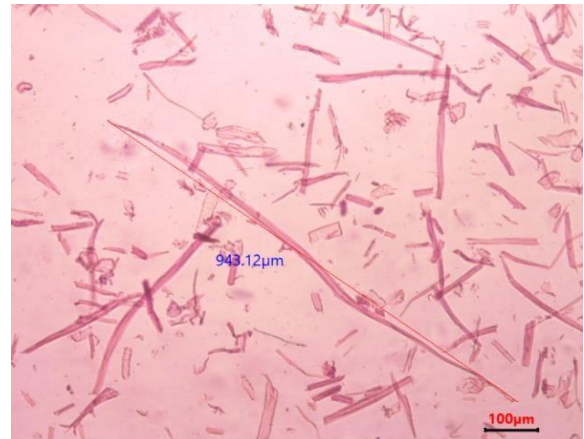
*Acacia nilotica* CS 4X



*Acacia nilotica* RS 10X



*Acacia nilotica* TS 4X



*Acacia nilotica* Fibre

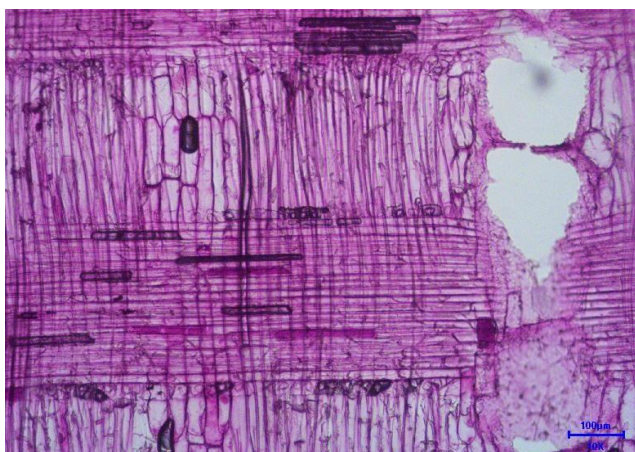
### 2.2. *Acrocarpus fraxinifolius* Arn.



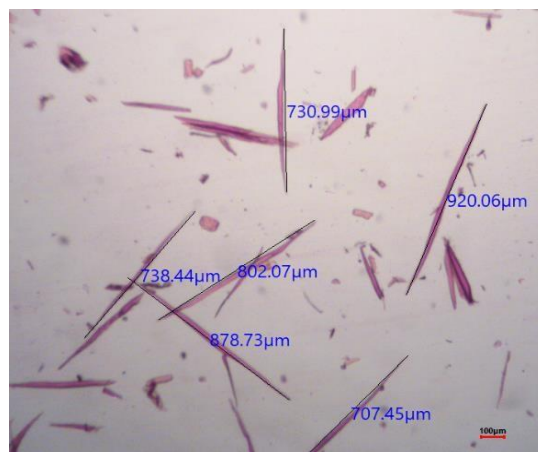
*Acrocarpus fraxinifolius* CS 4X



*Acrocarpus fraxinifolius* TS 10X

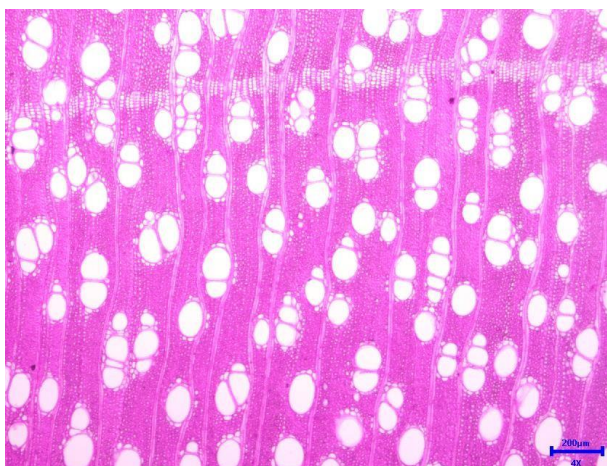


*Acrocarpus fraxinifolius* RS 10X

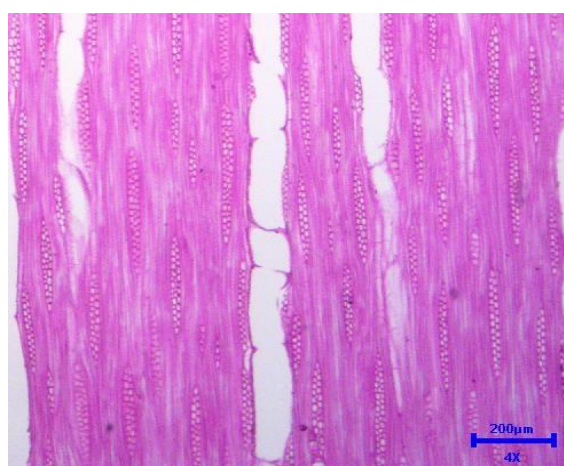


*Acrocarpus fraxinifolius* Fibre

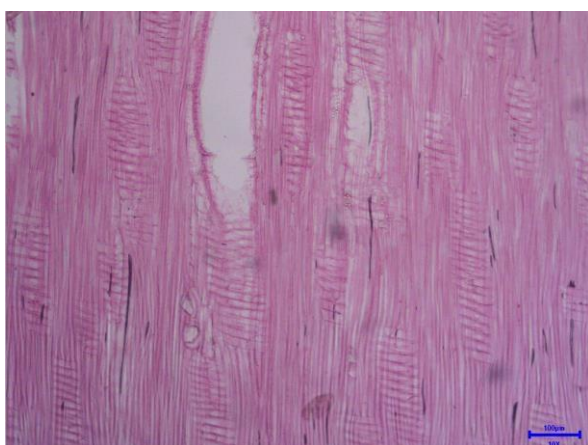
### 2.3. *Aegle marmelos* L. Correa



*Aegle marmelos* CS 4X



*Aegle marmelos* TS 4X

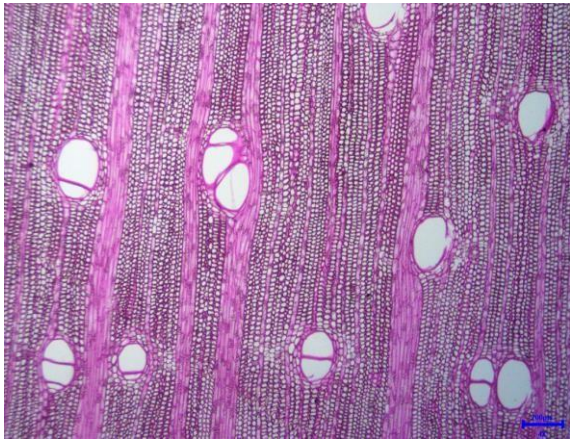


*Aegle marmelos* RS 10X

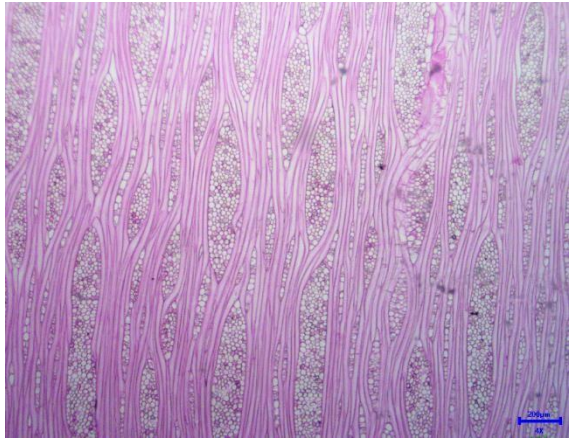


*Aegle marmelos* Fibre

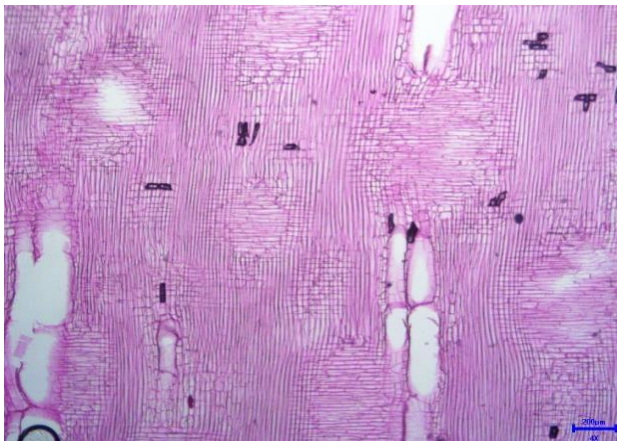
#### 2.4. *Ailanthus triphysa* (Dennst) Alston



*Ailanthus triphysa* CS 4X



*Ailanthus triphysa* TS 4X

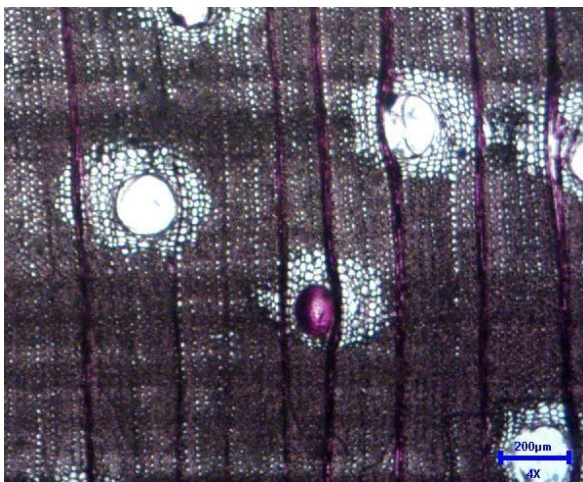


*Ailanthus triphysa* RS 4X

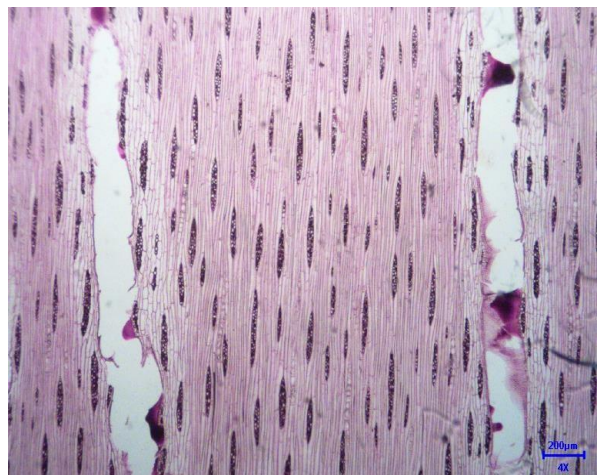


*Ailanthus triphysa* Fibre

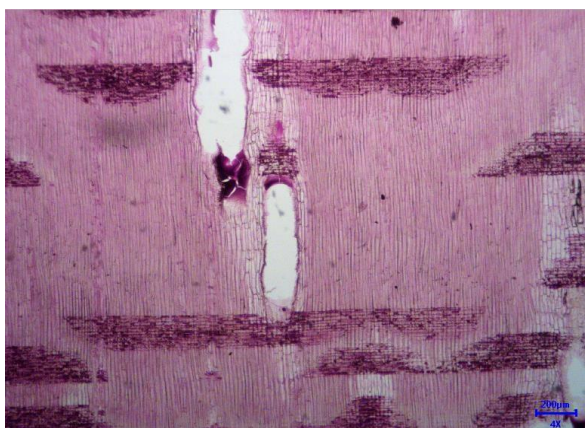
#### 2.5. *Albizia odoratissima* (Linn. f.) Benth.



*Albizia odoratissima* CS 4X



*Albizia odoratissima* TS 4X

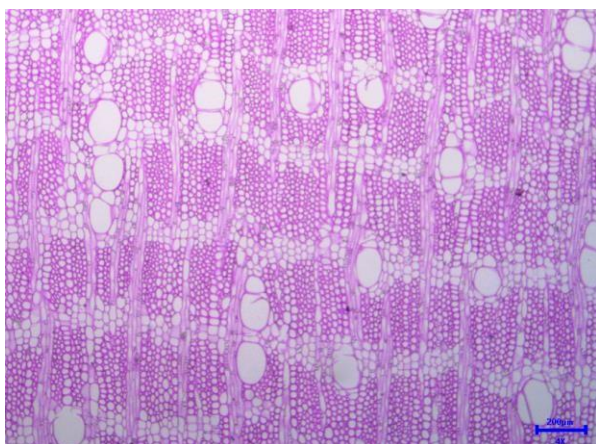


*Albizia odoratissima* RS 4X

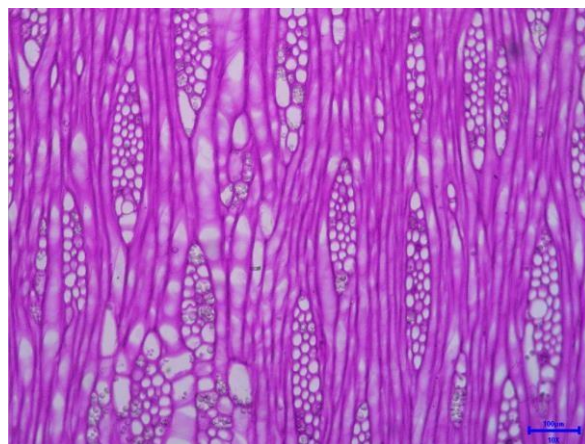


*Albizia odoratissima* Fibre

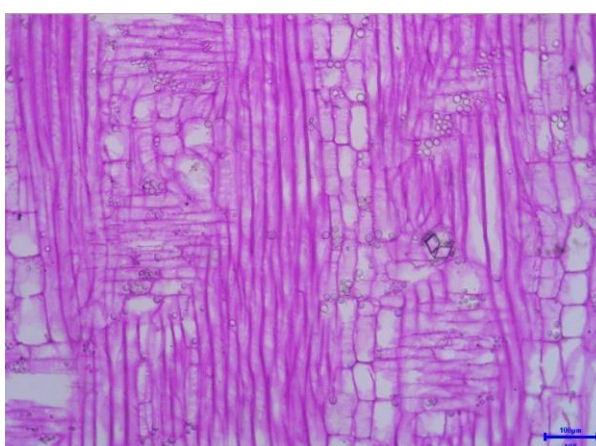
## 2.6. *Alstonia scholaris* (Linn.) R. Br.



*Alstonia scholaris* CS 4X



*Alstonia scholaris* TS 10X



*Alstonia scholaris* RS 10X



*Alstonia scholaris* Fibre

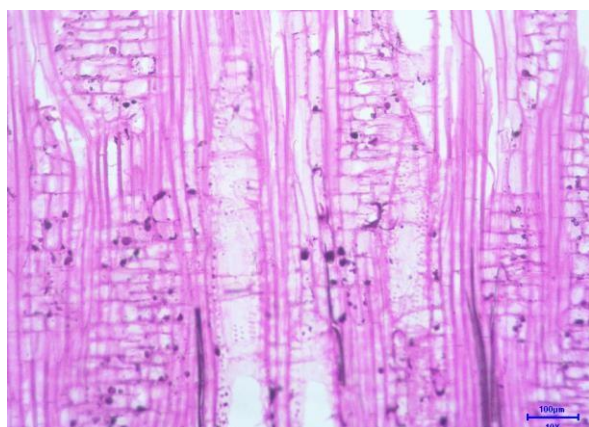
## 2.7. *Artocarpus hirsutus* Lam.



*Artocarpus hirsutus* CS 4X



*Artocarpus hirsutus* TS 4X

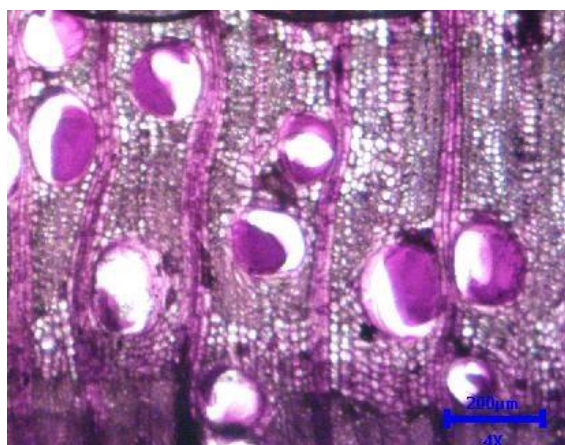


*Artocarpus hirsutus* RS 10X

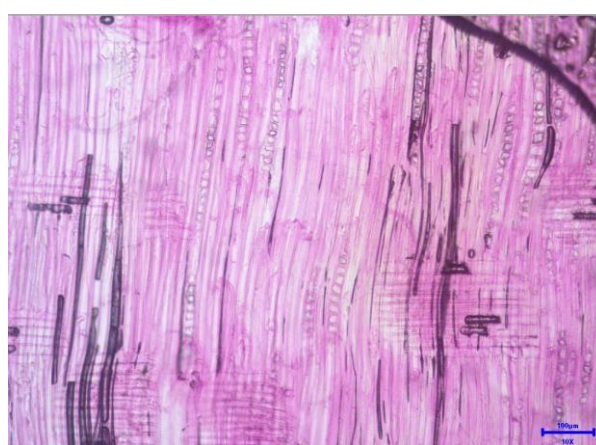


*Artocarpus hirsutus* Fibre

## 2.8. *Azadirachta indica* A. Juss.



*Azadirachta indica* CS 4X



*Azadirachta indica* RS 4X



*Azadirachta indica* TS 10X



*Azadirachta indica* Fibre

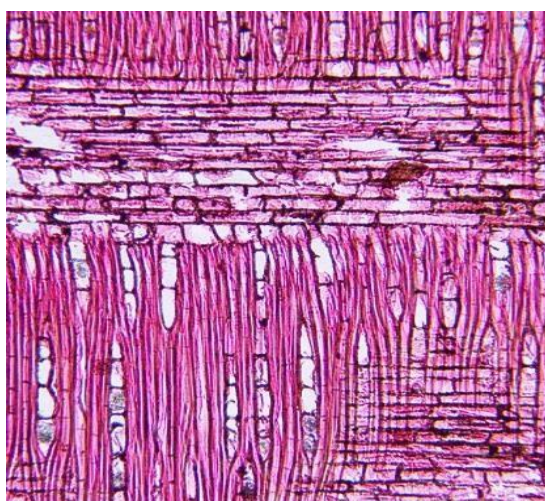
## 2.9. *Bombax ceiba* Linn.



*Bombax ceiba* CS 4X



*Bombax ceiba* TS 4X

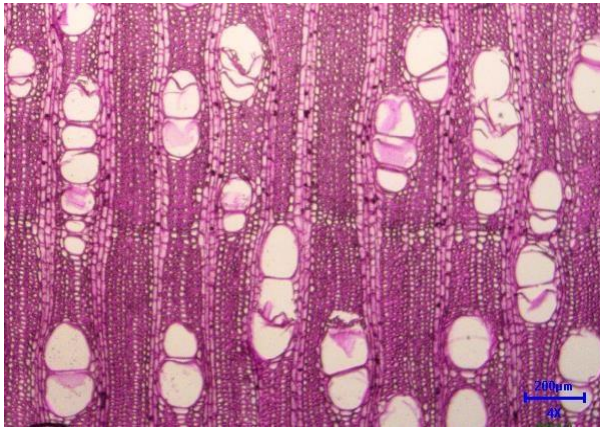


*Bombax ceiba* RS 10X

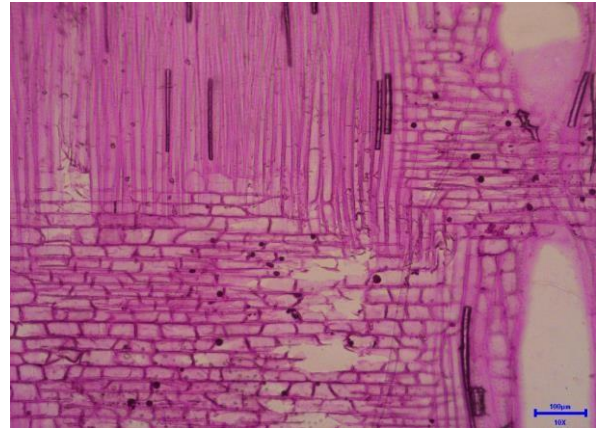


*Bombax ceiba* Fibre

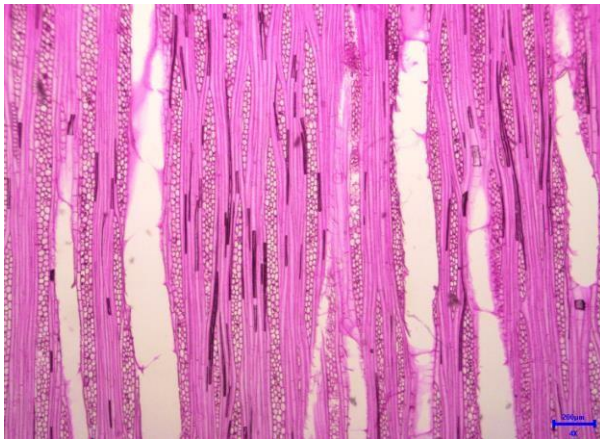
**2.10. *Bridelia retusa* (L.) A. Juss.**



*Bridelia retusa* CS 4X



*Bridelia retusa* RS 10X

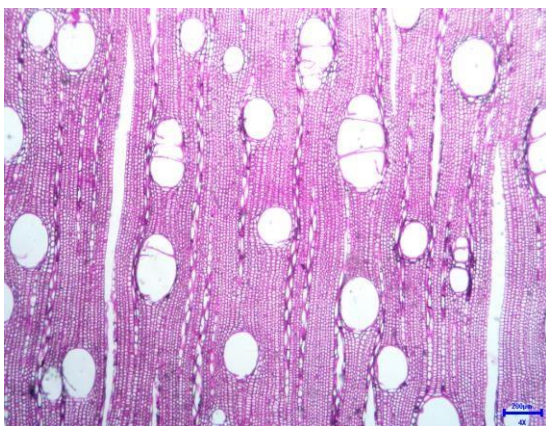


*Bridelia retusa* TS 4X

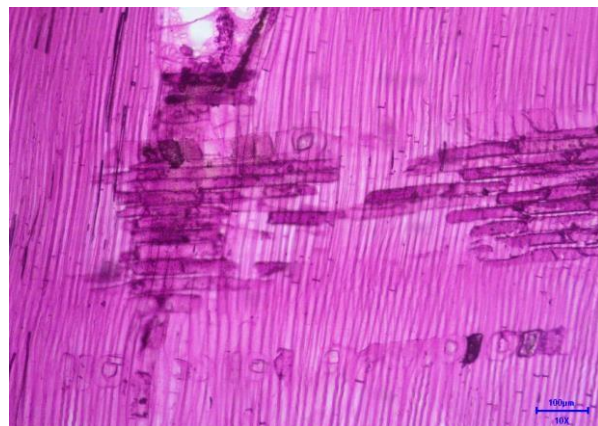


*Bridelia retusa* Fibre

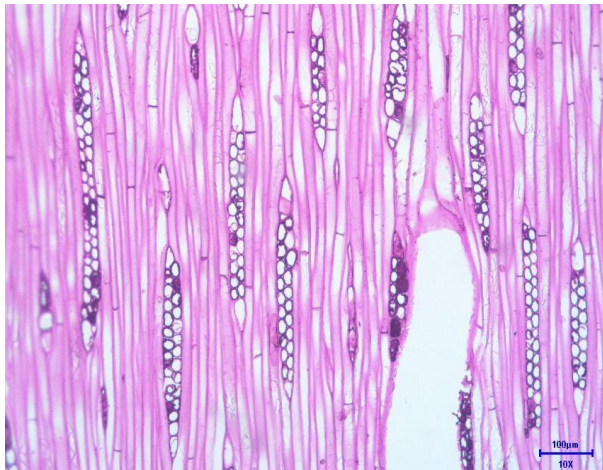
**2.11. *Canarium strictum* Roxb.**



*Canarium strictum* CS 4X



*Canarium strictum* RS 10X

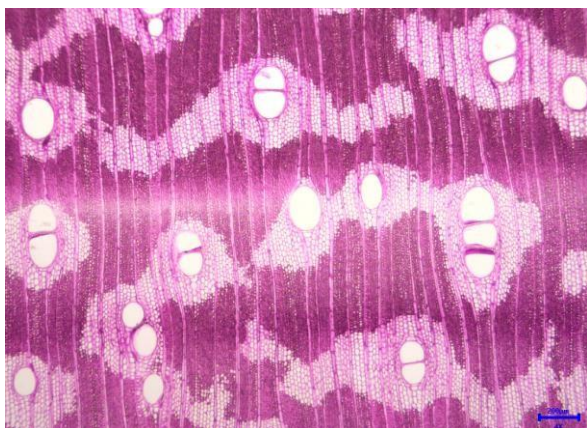


*Canarium strictum* TS 10X

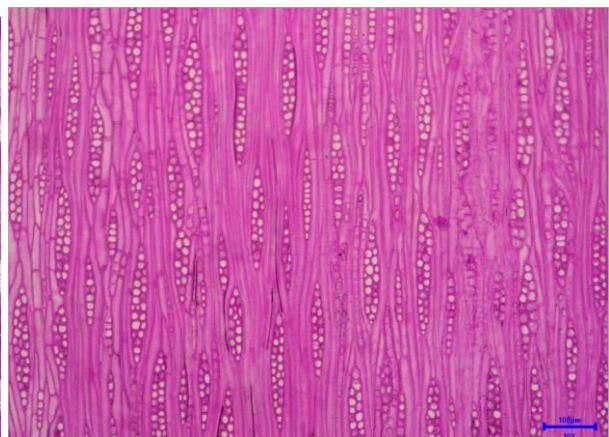


*Canarium strictum* Fibre

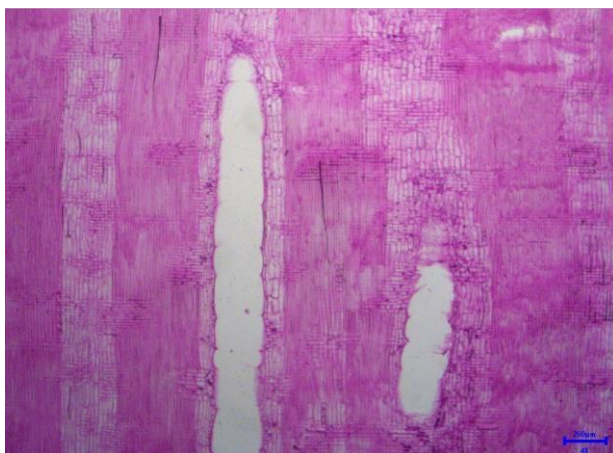
## 2.12. *Cassia fistula* Linn.



*Cassia fistula* CS 4X



*Cassia fistula* TS 10X

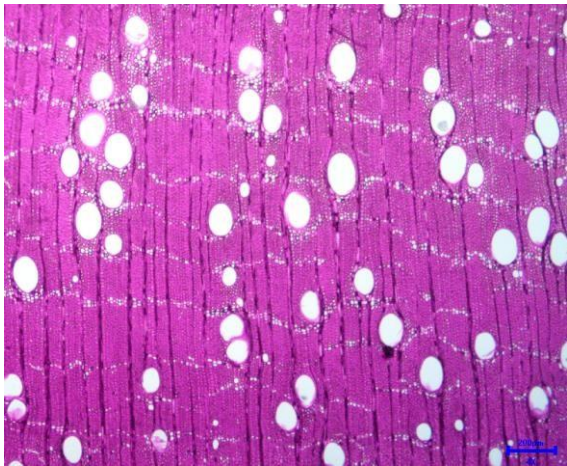


*Cassia fistula* RS 4X

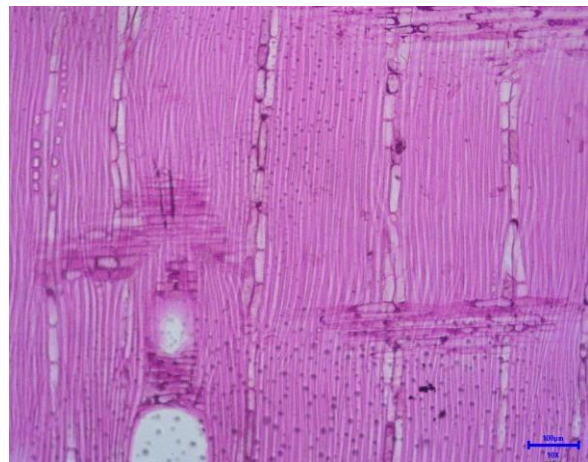


*Cassia fistula* Fibre

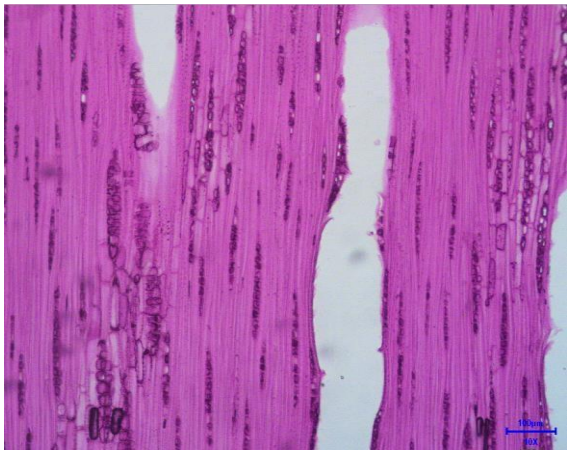
**2.13. *Casuarina equisetifolia* J. R. & G. Forst.**



*Casuarina equisetifolia* CS 4X



*Casuarina equisetifolia* RS 10X

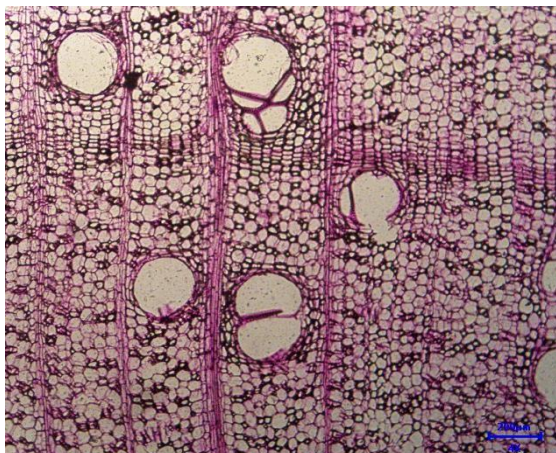


*Casuarina equisetifolia* TS 10X

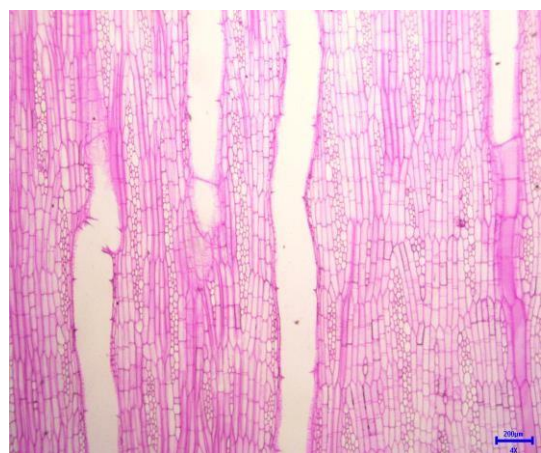


*Casuarina equisetifolia*  
Fibre

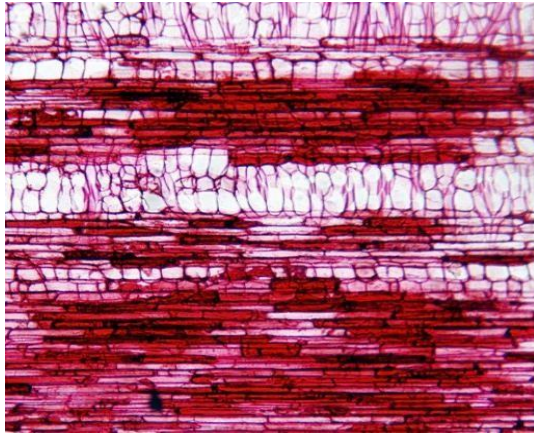
**2.14. *Ceiba pentandra* L. Gaertn**



*Ceiba pentandra* CS 4X



*Ceiba pentandra* TS 4X

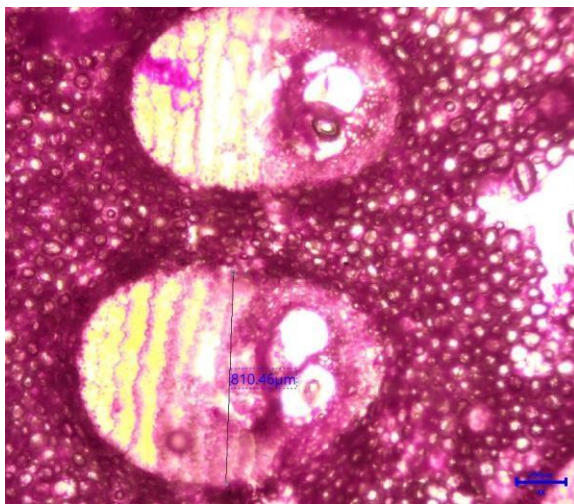


*Ceiba pentandra* RS 10X

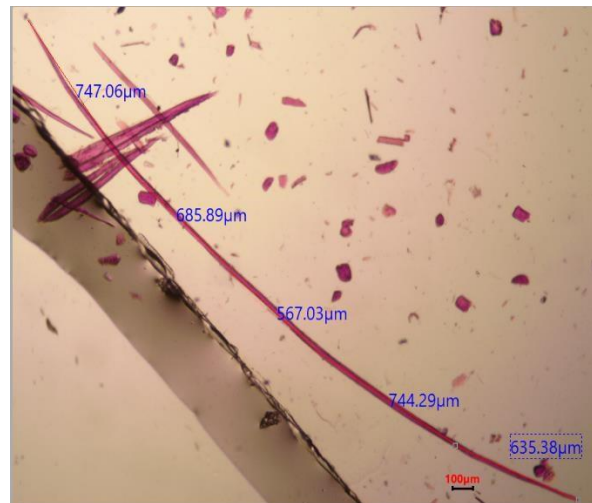


*Ceiba pentandra* Fibre

### 2.15. *Cocos nucifera* Linn

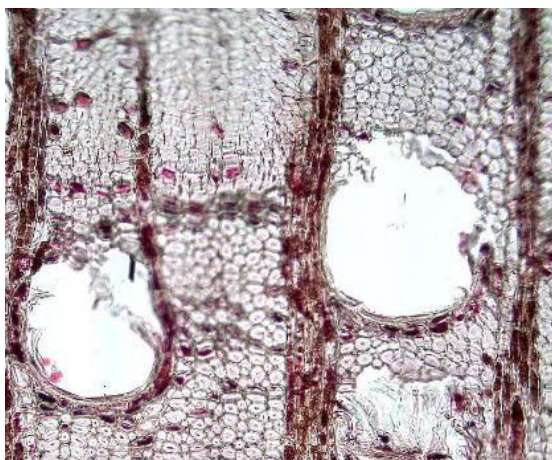


*Cocos nucifera* CS 4X

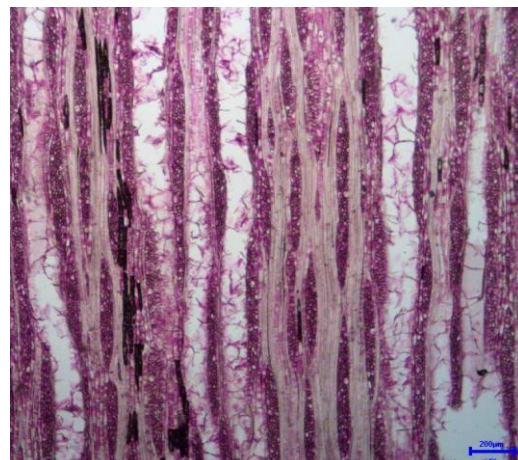


*Cocos nucifera* Fibre

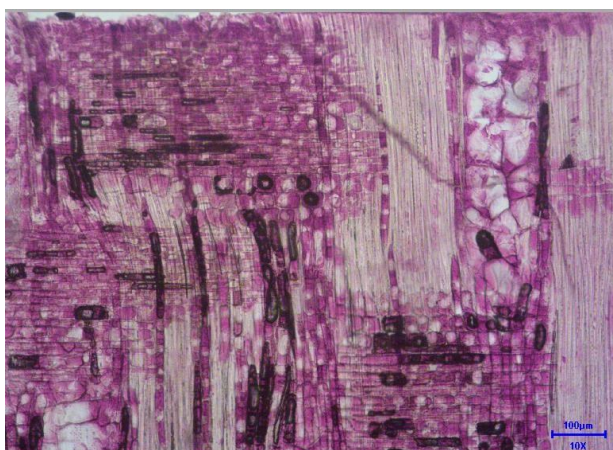
### 2.16. *Hopea parviflora* Bedd.



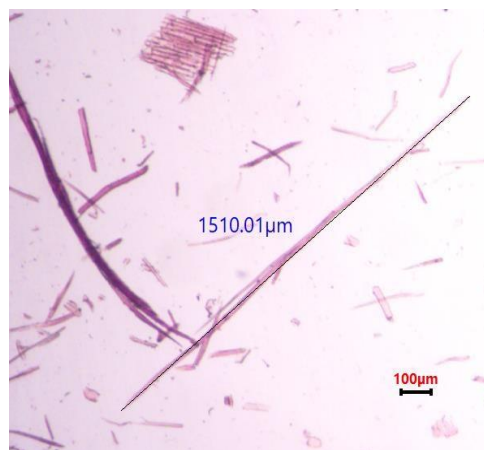
*Hopea parviflora* CS 10X



*Hopea parviflora* TS 4X

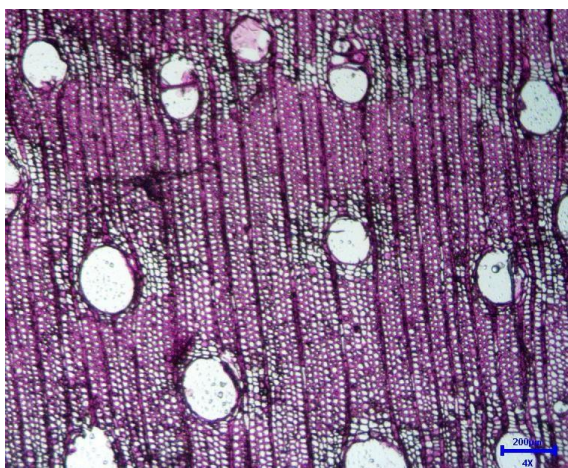


*Hopea parviflora* RS 10X

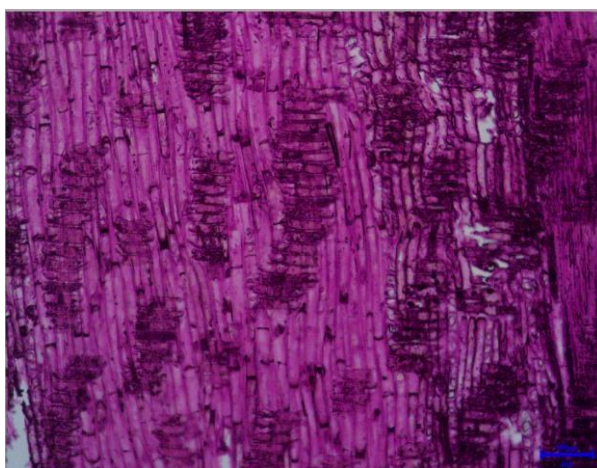


*Hopea parviflora* Fibre

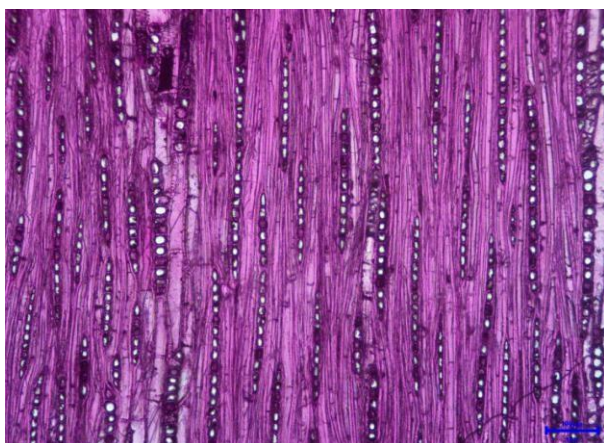
### 2.17. *Lagerstroemia lanceolata* Wight.



*Lagerstroemia lanceolata* CS 4X



*Lagerstroemia lanceolata* RS 10X

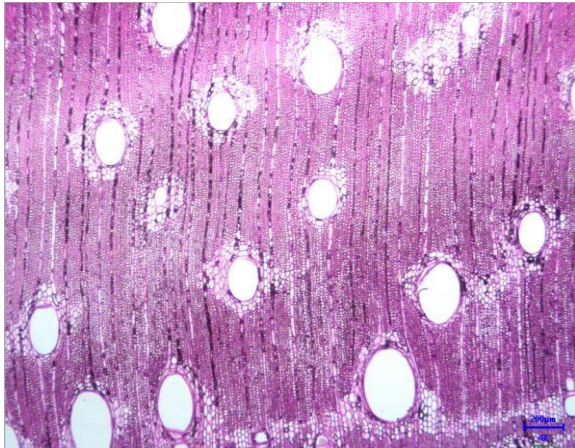


*Lagerstroemia lanceolata* TS 10X



*Lagerstroemia lanceolata* Fibre

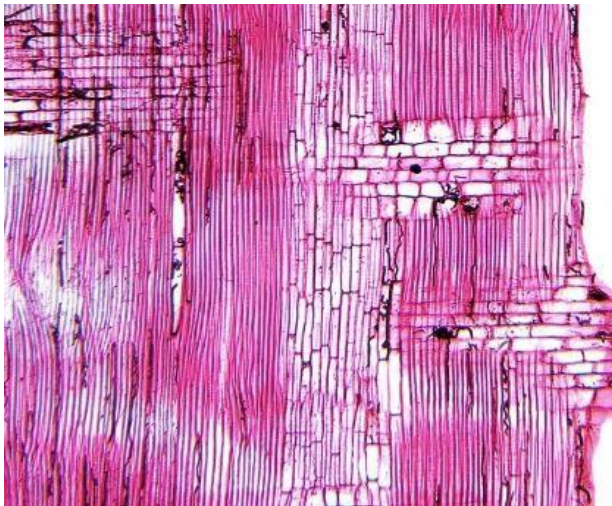
### 2.18. *Mangifera indica* Linn.



*Mangifera indica* CS 4X



*Mangifera indica* TS 4X

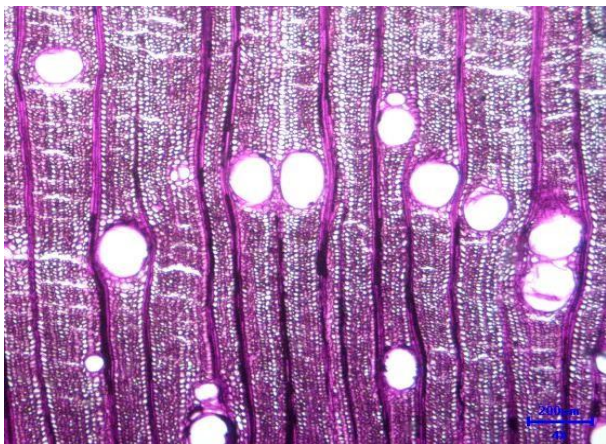


*Mangifera indica* RS 4X

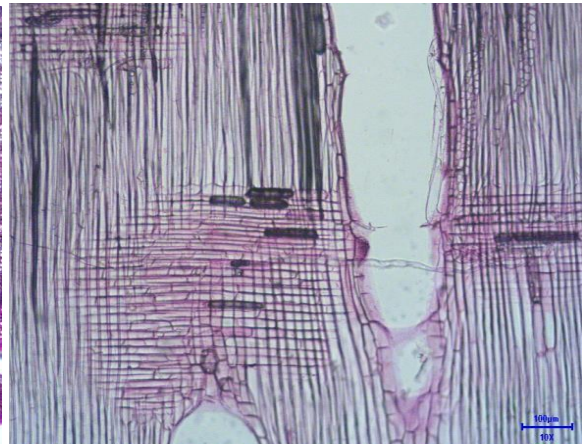


*Mangifera indica* Fibre

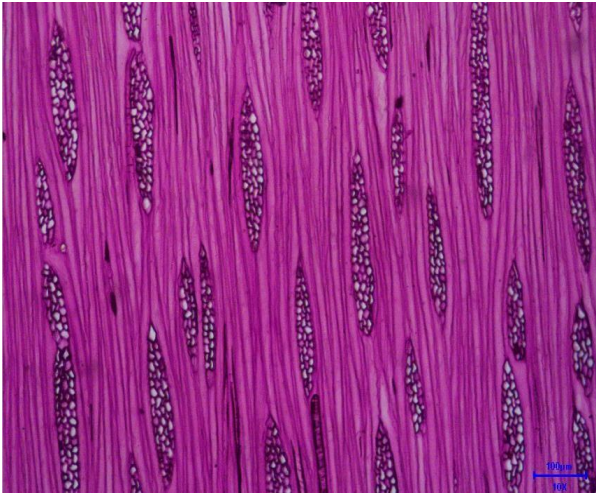
### 2.19. *Melia dubia* Cav.



*Melia dubia* CS 4X



*Melia dubia* RS 10X

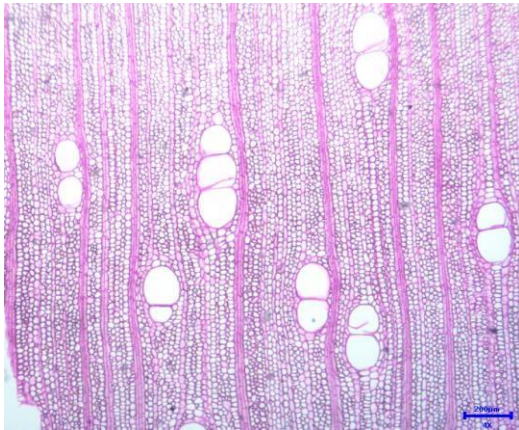


*Melia dubia* TS 10X

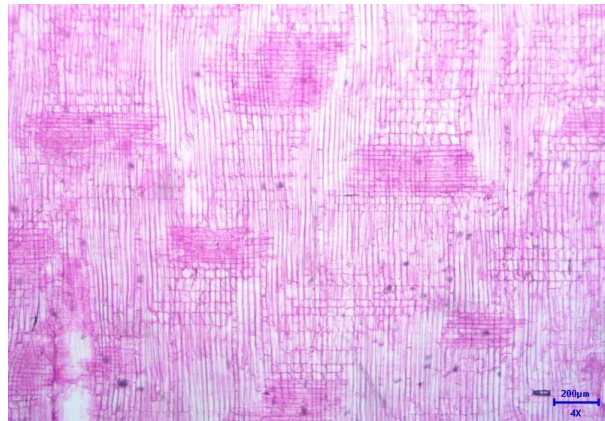


*Melia dubia* Fibre

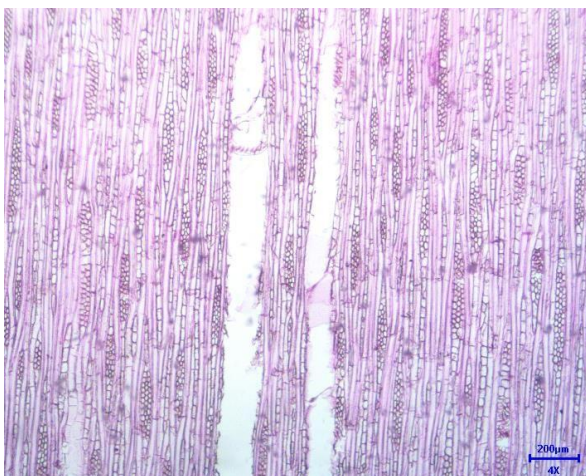
## 2.20. *Neolamarkiana cadamba*



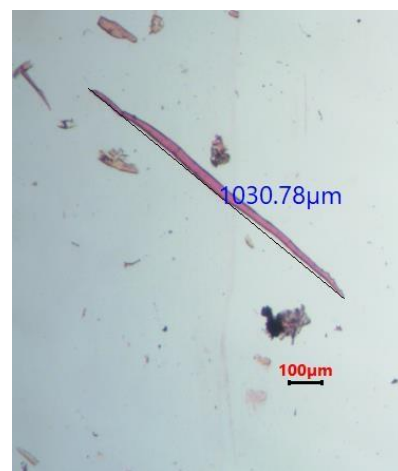
*Neolamarkiana cadamba* CS 4X



*Neolamarkiana cadamba* RS 4X



*Neolamarkiana cadamba* TS 4X

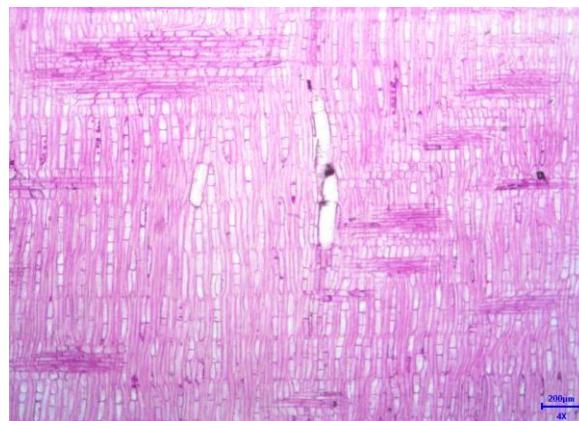


*Neolamarkiana cadamba* Fibre

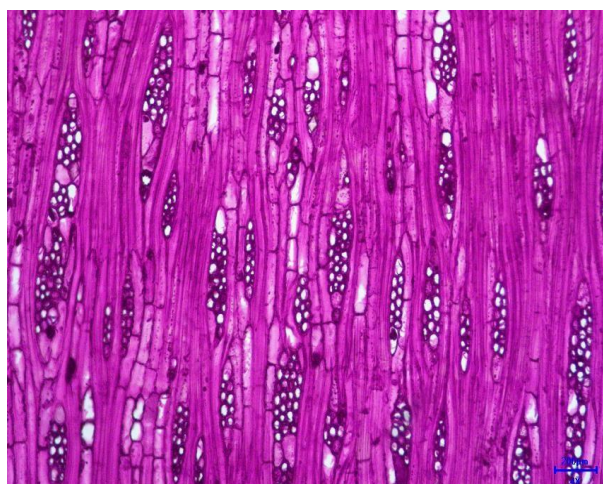
2.21. *Thespesia populnea* (L.) Soland. ex Correa



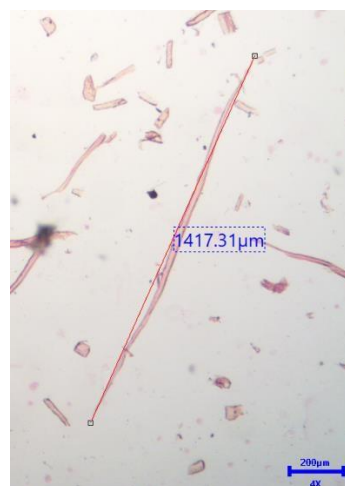
*Thespesia populnea* CS 4X



*Thespesia populnea* RS 4X



*Thespesia populnea* TS 10X



*Thespesia populnea* Fibre

## **DISCUSSION**

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## 5. DISCUSSION

### 5.1. PHYSICAL PROPERTIES

#### 5.1.1. Specific Gravity

Specific gravity is considered as a single vital property which determines the end use of the wood. Its impact on the yield and quality of both fibrous and solid wood products makes it a critical wood property (Haslett and Young, 1990). It is the most extensively researched characteristic of wood and depends on the ratio of cell wall components to cellular voids. As a result, specific gravity is frequently used as an indicator for the quality of wood (Zobel and Buitjenen, 1989; Woodcock and Shier, 2002; Perera *et al.*, 2012).

The present study revealed that the wood specific gravity (Oven-dry condition) differed significantly between species. The highest specific gravity was found in *Hopea parviflora* (0.86) and *Cocos nucifera* (0.83). The lowest specific gravity was for the *Ceiba pentandra* (0.25), *Ailanthus triphysa* (0.3), *Alstonia scholaris* (0.35) and *Bombax ceiba* (0.39).

According to Sarker *et al.* (2021) the specific gravity of *Albizia odoratissima*, a moderately heavy timber is 0.60. While in another study by Chowdhury and Ghosh (1958) reported the specific gravity of the aforementioned to be 0.85. In the current study the specific gravity was observed to be 0.79 and it is in line with the other studies.

While examining various species for analysing the wood specific gravity of trees in hot semi-arid zone, of India, Gupta *et al.* (2017) examined the specific gravity of *Acacia nilotica* and reported it to be  $0.71 \pm 0.02$ . The specific gravity of *Acacia nilotica* wood ranged from 0.67-0.68 and it is regarded as a weighty wood (Nair and Latt, 1997). Chowdhury and Ghosh (1958) reported it to be 0.64. Meghwal *et al.*, (2020) analysed several hardwood species which differed greatly with respect to different wood quality parameters. In his study the specific gravity of *Acacia nilotica* was observed as 0.66 and *Ailanthus excelsa* as 0.44. But in the present study, the specific gravity of *Acacia nilotica* was observed to be 0.73 and *Ailanthus triphysa* as 0.3 which are on par with the other studies.

The specific gravity of *Mangifera indica* was reported to be 0.75 by Sheikh *et al.* (2011); 0.59 by Chowdhury and Ghosh (1958) and  $0.703 \pm 0.076$  by Sundarapandian *et al.* (2014). In the current study, the specific gravity of *Mangifera indica* was observed to be 0.67.

Ashwath *et al.*, (2021) observed that in *Acrocarpus fraxinifolius* the specific gravity ranged from 0.37 to 0.58. Ranot and Sharma (2013) reported it to be 0.79. Sanjeev *et al.* (2009)

observed it to be 0.51, while in this study it was observed to be 0.53. The specific gravity of *Bombax ceiba* was reported as 0.26 by Sanjeev *et al.* (2009), 0.34 by Simpson (1991) and 0.42 by Chauhan and Sharma (2016). In this study it was observed to be 0.39.

Simpson (1991) studied the specific gravity and other parameters of various tree species. It was found that the specific gravity of *Melia dubia* was 0.41; *Ceia pentandra* was reported to have a specific gravity of 0.23 (Simpson 1991); while in another study, *Ceia pentandra* was reported to have 0.28 (Hegde *et al.*, 2014). The specific gravity of *Thespesia populnea* was reported to be 0.523 and that of *Neolamarkia cadamba* was 0.53. Sanjeev *et al.* (2009) however, reported it to be 0.44, *Alstonia scholaris* was found to have a specific gravity of 0.36, while Muller-Landau (2004) reported it to be 0.41 under air dry conditions. *Casuarina equisetifolia* was reported to be 0.84, while Sundarapandian *et al.* (2014) found it to be in the range  $0.795 \pm 0.057$ . In the current study, the specific gravity of *Melia dubia* was 0.43, *Ceia pentandra* was 0.25, *Thespesia populnea* was 0.70, *Neolamarkia cadamba* was 0.38, *Alstonia scholaris* was 0.35 and *Casuarina equisetifolia* was 0.79.

Hegde *et al.* (2014) found that the specific gravity of *Bridelia retusa* as 0.76. In the present study, it was observed to be 0.78. In case of *Cocos nucifera* the reported specific gravity by Sundarapandian *et al.* (2014) was  $0.705 \pm 0.033$ . But, in this study it was observed to be 0.83, this variation was recorded as the samples collected belonged to the high-density category. Sheikh *et al.* (2011) observed the specific gravity of *Aegle marmelos* to be  $0.85 \pm 0.03$  but, Chowdhury and Ghosh (1958) reported it to be 0.75 and Sundarapandian *et al.* (2014) reported it as  $0.747 \pm 0.004$ . In the present study, it was observed to be 0.76. The specific gravity of *Cassia fistula* was reported to be 0.812, 0.74, 0.71 respectively (Sheikh *et al.*, 2011; Purkayastha, 1982; Simpson, 1991). The present study found the specific gravity to be 0.76.

According to Anoop *et al.* (2011) *Artocarpus hirsutus* is a moderately heavy timber and the specific gravity is  $0.48 \pm 0.12$  and in this study, it was found that the specific gravity of the above species as 0.57. Nazma *et al.*, (1981) also reported that the species is moderately heavy, and its specific gravity was 0.59.

### **5.1.2. Other Physical Properties**

#### **5.1.2.1. Colour**

Physical properties like colour, odour, lustre and texture are the preliminary characters observed which enables in general categorization of the wood. Colour enables us to get a

primary idea of the wood, regarding its identity using range of hues, tints, and combinations that exist.

In the present study, distinctive heartwood colour of wood samples can be classified into 3 groups- whitish to pale yellow coloured wood, yellow to light brown woods and brown to dark coloured woods. *Casuarina equisetifolia* had a distinctive purplish hue in the heartwood. Whitish to pale yellow coloured wood were *Ailanthus triphysa*, *Alstonia scholaris*, *Bombax ceiba*, *Ceiba pentandra* and *Neolamarkiana cadamba*. Yellow to light brown woods were *Aegle marmelos*, *Canarium strictum*, *Cassia fistula*, *Mangifera indica*, *Melia dubia*, *Azadirachta indica*. Brown to dark coloured woods were *Albizia odoratissima*, *Acacia nilotica*, *Acrocarpus fraxinifolius*, *Artocarpus hirsutus*, *Bridelia retusa*, *Casuarina equisetifolia*, *Cocos nucifera*, *Hopea parviflora*, *Lagerstroemia lanceolata* and *Thespesia populnea*.

#### 5.1.2.2. Odour and texture

Odour is a distinctive smell. Every wood has odour which is the direct result of the compounds formed within the wood (Schreiner *et al.*, 2018; Tissandié *et al.*, 2018; Amaral *et al.*, 2019). In the current study *Azadirachta indica* had a characteristic odour.

Texture of wood is a wood grain visible on the section of wood and it is created by its structure e.g. annual rings, pith rays, arrangement of wood fibres etc (Pivarciova and Cernecky, 2011). Bijalwan *et al.* (2014) observed that the wood of *A. cadamba* wood has straight grain with fine to medium texture and low lusture.

In the present study, the woods were categorised into 3 main groups based on texture. Fine, Medium and Coarse. *Aegle marmelos*, *Alstonia scholaris*, *Neolamarkiana cadamba* and *Thespesia populnea* can be categorised into fine textural class. *Acacia nilotica*, *Artocarpus hirsutus*, *Casuarina equisetifolia*, *Lagerstroemia lanceolata* and *Mangifera indica* can be categorised into medium textural class, while *Acrocarpus fraxinifolius*, *Ailanthus triphysa*, *Albizia odoratissima*, *Azadirachta indica*, *Bombax ceiba*, *Bridelia retusa*, *Canarium strictum*, *Cassia fistula*, *Ceiba pentandra*, *Cocos nucifera*, *Hopea parviflora* and *Melia dubia* can be categorised into Coarse textural class.

### 5.2. Anatomical Properties

Wood anatomy forms the strong basis for identification of species. It is found that transverse section of wood under magnification will serve in most cases a sure means of identification (Bailey and Howard, 1941).

### 5.2.1. Vessel Morphology

Vessel characteristics are the most studied feature in wood anatomical studies. A significant amount of information can be extracted from observing the vessel and the associated parenchyma (Pourtahmasi *et al.*, 2011). Vessel morphology includes, measurements of vessel diameter, vessel area and vessel frequency characteristics of the wood sample under study. Vessel diameter is usually measured as tangential diameter. In the current study, the maximum vessel diameter was observed for *Ceiba pentandra* with 258.38  $\mu\text{m}$  followed by *Bombax ceiba* with 232.11  $\mu\text{m}$  and *Acrocarpus fraxinifolius* with 224.34  $\mu\text{m}$ . The minimum vessel diameter was recorded for *Aegle marmelos* with 93.82  $\mu\text{m}$  and *Casuarina equisetifolia* with 99.11  $\mu\text{m}$ . For all the other species, the values were on par with other databases. From this study it can be concluded that vessel diameter is an important parameter for the identification purpose as it varies significantly among different species.

**Table 5: The comparison of vessel frequency between the current study and the Insidewood database**

| S.no. | Species name                                      | Measurements from the current study ( $\mu\text{m}$ ) | Measurements from the Insidewood database ( $\mu\text{m}$ ) |
|-------|---------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------------|
| 1     | <i>Acrocarpus fraxinifolius</i> Arn.              | 224.34                                                | $\geq 200$                                                  |
| 2     | <i>Artocarpus hirsutus</i> Lam.                   | 123.92                                                | 100 -200                                                    |
| 3     | <i>Azadirachta indica</i> A. Juss.                | 140.86                                                | 100 -200                                                    |
| 4     | <i>Aegle marmelos</i> L. Correa                   | 93.82                                                 | 50 – 100                                                    |
| 5     | <i>Acacia nilotica</i> (Linn.) Wild.<br>Ex Delile | 120.51                                                | 100 – 200                                                   |
| 6     | <i>Albizia odoratissima</i> (Linn. f.)<br>Benth.  | 156.88                                                | 100 – 200                                                   |
| 7     | <i>Alstonia scholaris</i> (Linn.) R.<br>Br.       | 128.70                                                | 50 - 100                                                    |

|    |                                                         |        |           |
|----|---------------------------------------------------------|--------|-----------|
| 8  | <i>Ailanthus triphysa</i> (Dennst)<br>Alston            | 187.99 | 100 – 200 |
| 9  | <i>Bombax ceiba</i> Linn.                               | 232.11 | >= 200    |
| 10 | <i>Bridelia retusa</i> (L.) A. Juss.                    | 149.29 | 100 – 200 |
| 11 | <i>Casuarina equisetifolia</i> J. R. &<br>amp; G.Forst. | 99.11  | 50 - 100  |
| 12 | <i>Cassia fistula</i> Linn.                             | 165.85 | 100 – 200 |
| 13 | <i>Ceiba pentandra</i> L. Gaertn                        | 258.38 | >= 200    |
| 14 | <i>Canarium strictum</i> Roxb.                          | 188.96 | 100 – 200 |
| 15 | <i>Hopea parviflora</i> Bedd.                           | 136.80 | -         |
| 16 | <i>Lagerstroemia lanceolata</i><br>Wight.               | 177.81 | 100 – 200 |
| 17 | <i>Melia dubia</i> Cav.                                 | 133.35 | 100 – 200 |
| 18 | <i>Mangifera indica</i> Linn.                           | 188.93 | 100 – 200 |
| 19 | <i>Neolamarkiana cadamba</i><br>Roxb.                   | 165.52 | 100 – 200 |
| 20 | <i>Thespesia populnea</i> (L.)<br>Soland. ex Correa     | 109.25 | 100 – 200 |

The species under the current study was compared to the inside wood database and it was observed that the values did not differ between the recorded vessel diameter values and the values reported in the database.

Vessel frequency was analysed in the present study and it was observed that the highest vessel frequency was recorded in *Aegle marmelos* (37 per mm<sup>2</sup>) followed by *Bridelia retusa* (24 per mm<sup>2</sup>), *Casuarina equisetifolia* (14 per mm<sup>2</sup>) and *Neolamarkiana cadamba* (11 per mm<sup>2</sup>) and the lowest was recorded in *Acacia nilotica*, *Albizia odoratissima*, *Hopea parviflora* and *Lagerstroemia lanceolata* with a value of 3 per mm<sup>2</sup>. From the present study, we can conclude that vessel frequency shows much variation among different species it can be used as a feature for identification.

**Table 6: The comparison of vessel frequency between the current study and the Insidewood database**

| S.no. | Species name                                    | Measurements from the current study (no/mm <sup>2</sup> ) | Measurements from the Insidewood database (no/mm <sup>2</sup> ) |
|-------|-------------------------------------------------|-----------------------------------------------------------|-----------------------------------------------------------------|
| 1     | <i>Acrocarpus fraxinifolius</i> Arn.            | 5                                                         | <=5                                                             |
| 2     | <i>Artocarpus hirsutus</i> Lam.                 | 14                                                        | 5 - 20                                                          |
| 3     | <i>Azadirachta indica</i> A. Juss.              | 8                                                         | 5 - 20                                                          |
| 4     | <i>Aegle marmelos</i> L. Correa                 | 37                                                        | 5 - 20                                                          |
| 5     | <i>Acacia nilotica</i> (Linn.) Wild. Ex Delile  | 3                                                         | 5 - 20                                                          |
| 6     | <i>Albizia odoratissima</i> (Linn. f.) Benth.   | 3                                                         | <=5                                                             |
| 7     | <i>Alstonia scholaris</i> (Linn.) R. Br.        | 13                                                        | 20 - 40                                                         |
| 8     | <i>Ailanthus triphysa</i> (Dennst) Alston       | 4                                                         | <=5                                                             |
| 9     | <i>Bombax ceiba</i> Linn.                       | 5                                                         | <=5                                                             |
| 10    | <i>Bridelia retusa</i> (L.) A. Juss.            | 24                                                        | 5 - 20                                                          |
| 11    | <i>Casuarina equisetifolia</i> J. R. & G.Forst. | 14                                                        | 5 - 20                                                          |
| 12    | <i>Cassia fistula</i> Linn.                     | 5                                                         | 5 - 20                                                          |
| 13    | <i>Ceiba pentandra</i> L. Gaertn                | 6                                                         | 5 - 20                                                          |
| 14    | <i>Canarium strictum</i> Roxb.                  | 6                                                         | <=5                                                             |
| 15    | <i>Hopea parviflora</i> Bedd.                   | 3                                                         | -                                                               |
| 16    | <i>Lagerstroemia lanceolata</i> Wight.          | 3                                                         | <=5                                                             |
| 17    | <i>Melia dubia</i> Cav.                         | 7                                                         | -                                                               |
| 18    | <i>Mangifera indica</i> Linn.                   | 4                                                         | <=5                                                             |

|    |                                                  |    |        |
|----|--------------------------------------------------|----|--------|
| 19 | <i>Neolamarkiana cadamba</i> Roxb.               | 11 | 5 - 20 |
| 20 | <i>Thespesia populnea</i> (L.) Soland. ex Correa | 6  | 5 - 20 |

The species under the current study was compared to the inside wood database and it was observed that there is no significant difference between the recorded vessel frequency values and the database values.

### 5.2.2. Ray Morphology

Ray characteristics are used to evaluate the suitability of a wood for a particular application. Differences in ray properties are observed between species, sites, trees, and within the tree. On an average, ray tissue constitutes 17% of hardwood xylem, and sometimes it may reach more than 30% (Haygreen and Bower, 1982). Various studies have shown that in conditions of rising environmental stress, there were much more rays and they were shorter in height. (Schneider and Halbwachs, 1989). Higher number of rays were observed in species of more mesic habitat and a trend towards lower number of rays was observed in species of drier regions (Lens *et al.*, 2011).

Ray morphology includes the ray height, ray width and ray frequency characteristics of the wood sample under study. Ray height was analysed in the present study and it was observed that maximum height of ray was observed in *Bombax ceiba* with a height of 1.25 mm followed by *Bridelia retusa* with a height of 1.50 mm and the lowest was recorded in *Cassia fistula* with a height of 0.21 mm followed by *Casuarina equisetifolia* with a height of 0.22 mm. The present study showed much variation among different species and can be used as a feature for identification.

**Table 7: The comparison of ray height between the current study and the Insidewood database**

| S.no. | Species name                                         | Measurements from the current study (mm) | Measurements from the Insidewood database (mm) |
|-------|------------------------------------------------------|------------------------------------------|------------------------------------------------|
| 1     | <i>Acrocarpus fraxinifolius</i> Arn.                 | 0.31                                     | < 1                                            |
| 2     | <i>Artocarpus hirsutus</i> Lam.                      | 0.82                                     | < 1                                            |
| 3     | <i>Azadirachta indica</i> A. Juss.                   | 0.31                                     | < 1                                            |
| 4     | <i>Aegle marmelos</i> L. Correa                      | 0.29                                     | < 1                                            |
| 5     | <i>Acacia nilotica</i> (Linn.) Wild. Ex Delile       | 0.70                                     | < 1                                            |
| 6     | <i>Albizia odoratissima</i> (Linn. f.) Benth.        | 0.24                                     | < 1                                            |
| 7     | <i>Alstonia scholaris</i> (Linn.) R. Br.             | 0.28                                     | < 1                                            |
| 8     | <i>Ailanthus triphysa</i> (Dennst) Alston            | 0.60                                     | < 1                                            |
| 9     | <i>Bombax ceiba</i> Linn.                            | 1.25                                     | > 1                                            |
| 10    | <i>Bridelia retusa</i> (L.) A. Juss.                 | 1.50                                     | > 1                                            |
| 11    | <i>Casuarina equisetifolia</i> J. R. & amp; G.Forst. | 0.22                                     | < 1                                            |
| 12    | <i>Cassia fistula</i> Linn.                          | 0.21                                     | < 1                                            |
| 13    | <i>Ceiba pentandra</i> L. Gaertn                     | 1.10                                     | > 1                                            |
| 14    | <i>Canarium strictum</i> Roxb.                       | 0.39                                     | < 1                                            |
| 15    | <i>Hopea parviflora</i> Bedd.                        | 0.49                                     | -                                              |
| 16    | <i>Lagerstroemia lanceolata</i> Wight.               | 0.44                                     | < 1                                            |
| 17    | <i>Melia dubia</i> Cav.                              | 0.29                                     | < 1                                            |
| 18    | <i>Mangifera indica</i> Linn.                        | 1.04                                     | < 1                                            |

|    |                                                  |      |     |
|----|--------------------------------------------------|------|-----|
| 19 | <i>Neolamarkiana cadamba</i> Roxb.               | 0.60 | < 1 |
| 20 | <i>Thespesia populnea</i> (L.) Soland. ex Correa | 0.25 | < 1 |

The species in the current study was compared to the inside wood database and it was observed that there was not much variation between the recorded ray height values and the database values.

Ray frequency was analysed in the present study and it was observed that the highest ray frequency was recorded in *Casuarina equisetifolia* (15 per mm) *Cassia fistula* (13 per mm) and *Neolamarkiana cadamba* (13 per mm) and the lowest was recorded in *Ceiba pentandra* (4 per mm) followed by *Bombax ceiba* (5 per mm) and *Melia dubia* (5 per mm). From the present study we can conclude that ray frequency shows much variation among different species it can be used as a feature for identification.

**Table 8: The comparison of ray frequency between the current study and the Insidewood database**

| S.no. | Species name                                   | Measurements from the current study (no./mm) | Measurements from the Insidewood database (no./mm) |
|-------|------------------------------------------------|----------------------------------------------|----------------------------------------------------|
| 1     | <i>Acrocarpus fraxinifolius</i> Arn.           | 8                                            | 4-12                                               |
| 2     | <i>Artocarpus hirsutus</i> Lam.                | 9                                            | 4-12                                               |
| 3     | <i>Azadirachta indica</i> A. Juss.             | 12                                           | 4-12                                               |
| 4     | <i>Aegle marmelos</i> L. Correa                | 10                                           | 4-12                                               |
| 5     | <i>Acacia nilotica</i> (Linn.) Wild. Ex Delile | 7                                            | 4-12                                               |
| 6     | <i>Albizia odoratissima</i> (Linn. f.) Benth.  | 7                                            | 4-12                                               |
| 7     | <i>Alstonia scholaris</i> (Linn.) R. Br.       | 7                                            | 4-12                                               |

|    |                                                         |    |       |
|----|---------------------------------------------------------|----|-------|
| 8  | <i>Ailanthus triphysa</i> (Dennst)<br>Alston            | 6  | <= 4  |
| 9  | <i>Bombax ceiba</i> Linn.                               | 5  | 4-12  |
| 10 | <i>Bridelia retusa</i> (L.) A. Juss.                    | 6  | 4-12  |
| 11 | <i>Casuarina equisetifolia</i> J. R. &<br>amp; G.Forst. | 15 | >= 12 |
| 12 | <i>Cassia fistula</i> Linn.                             | 13 | 4-12  |
| 13 | <i>Ceiba pentandra</i> L. Gaertn                        | 4  | 4-12  |
| 14 | <i>Canarium strictum</i> Roxb.                          | 7  | 4-12  |
| 15 | <i>Hopea parviflora</i> Bedd.                           | 7  | -     |
| 16 | <i>Lagerstroemia lanceolata</i> Wight.                  | 10 | 4-12  |
| 17 | <i>Melia dubia</i> Cav.                                 | 5  | 4-12  |
| 18 | <i>Mangifera indica</i> Linn.                           | 11 | 4-12  |
| 19 | <i>Neolamarkiana cadamba</i> Roxb.                      | 13 | >= 12 |
| 20 | <i>Thespesia populnea</i> (L.) Soland.<br>ex Correa     | 8  | 4-12  |

The species in the current study was compared to the inside wood database and it was observed that there was no significant difference between the recorded ray frequency values and the database values.

### 5.2.3. Fibre Morphology

Fibre morphology includes fibre length, fibre diameter fibre lumen diameter and fibre wall thickness characteristics of the wood sample under study. Fibre length and width of both woody and non-woody species vary depending on plant species (Marja-Sisko and Illvessalo-Pfaffli, 1995). In the current study, maximum fibre length was observed in *Cocos nucifera* with a value of 1760.12  $\mu\text{m}$  followed by *Ceiba pentandra* with a value of 1610.99  $\mu\text{m}$  and the minimum was observed in *Melia dubia* which recorded 605.43  $\mu\text{m}$ . Bhat *et al.* (1990) reported that there are variations in fibre wall thickness from tree to tree and within individual trees which are similar to the patterns of variation in density and hence there is a close relationship between these two wood properties.

**Table 9: The comparison of fibre length between the current study and the Insidewood database**

| S.no. | Species name                                         | Measurements from the current study (µm) | Measurements from the Insidewood database (µm) |
|-------|------------------------------------------------------|------------------------------------------|------------------------------------------------|
| 1     | <i>Acrocarpus fraxinifolius</i> Arn.                 | 998.49                                   | 900-1600                                       |
| 2     | <i>Artocarpus hirsutus</i> Lam.                      | 1058.19                                  | 900-1600                                       |
| 3     | <i>Azadirachta indica</i> A. Juss.                   | 960.75                                   | 900-1600                                       |
| 4     | <i>Aegle marmelos</i> L. Correa                      | 904.91                                   | <= 900                                         |
| 5     | <i>Acacia nilotica</i> (Linn.) Wild. Ex Delile       | 1066.77                                  | 900-1600                                       |
| 6     | <i>Albizia odoratissima</i> (Linn. f.) Benth.        | 1011.47                                  | 900-1600                                       |
| 7     | <i>Alstonia scholaris</i> (Linn.) R. Br.             | 1126.69                                  | 900-1600                                       |
| 8     | <i>Ailanthus triphysa</i> (Dennst) Alston            | 1180.57                                  | 900-1600                                       |
| 9     | <i>Bombax ceiba</i> Linn.                            | 1146.76                                  | 900-1600                                       |
| 10    | <i>Bridelia retusa</i> (L.) A. Juss.                 | 920.10                                   | 900-1600                                       |
| 11    | <i>Casuarina equisetifolia</i> J. R. & amp; G.Forst. | 920.69                                   | 900-1600                                       |
| 12    | <i>Cassia fistula</i> Linn.                          | 923.98                                   | 900-1600                                       |
| 13    | <i>Ceiba pentandra</i> L. Gaertn                     | 1610.99                                  | 900-1600                                       |
| 14    | <i>Canarium strictum</i> Roxb.                       | 921.56                                   | 900-1600                                       |
| 15    | <i>Cocos nucifera</i>                                | 1760.12                                  | -                                              |
| 16    | <i>Hopea parviflora</i> Bedd.                        | 991.47                                   | -                                              |

|    |                                                     |         |          |
|----|-----------------------------------------------------|---------|----------|
| 17 | <i>Lagerstroemia lanceolata</i> Wight.              | 791.08  | <= 900   |
| 18 | <i>Melia dubia</i> Cav.                             | 605.43  | 900-1600 |
| 19 | <i>Mangifera indica</i> Linn.                       | 954.93  | <= 900   |
| 20 | <i>Neolamarkiana cadamba</i> Roxb.                  | 1188.29 | 900-1600 |
| 21 | <i>Thespesia populnea</i> (L.) Soland.<br>ex Correa | 984.79  | 900-1600 |

A comparison with the Insidewood database showed that there is significant difference in fibre length between *Mangifera indica*, *Aegle marmelos* and *Melia dubia*. In *Mangifera indica* and *Aegle marmelos* a slight increase was observed whereas in *Melia dubia* there was a significant reduction in the fibre length. The decrease in fibre length of *Melia dubia* may be due to the difference in site conditions from which the sample was collected. Thus, fibre length can be included as a feature for identification as there is significant difference between the species.

### 5.3. Dichotomous key for the identification of timbers in the present study.

1. Monocot ..... *Cocos nucifera*
1. Dicot ..... 2.
  2. Growth ring present ..... *Bridelia retusa*
  2. Growth ring absent ..... 3.
    3. Deposits present in heartwood ..... 4.
    3. Deposits absent in heartwood ..... 6.
      4. Red coloured deposits present ..... *Thespesia populnea*
      4. Light coloured deposits present ..... 5.
  5. Yellow deposits present ..... *Cassia fistula*
  5. White chalky deposits present ..... *Artocarpus hirsutus*
  6. Vessels exclusively solitary ..... *Casuarina equisetifolia*
  6. Combination of solitary and radial multiple vessels ..... 7.

|                                               |                                 |
|-----------------------------------------------|---------------------------------|
| 7. Helical thickenings in vessel elements     |                                 |
| present                                       | 8.                              |
| 7. Helical thickenings in vessel elements     |                                 |
| absent                                        | 9.                              |
| 8. Helical thickenings present only in        |                                 |
| narrow vessel elements                        | <i>Melia dubia</i>              |
| 8. Helical thickenings present throughout     |                                 |
| narrow vessel elements                        | <i>Azadirachta indica</i>       |
| 9. Septate fibre present                      | 10.                             |
| 9. Septate fibre absent                       | 12.                             |
| 10. Prismatic crystals present                | 11.                             |
| 10. Prismatic crystals absent                 | <i>Acrocarpus fraxinifolius</i> |
| 11. Prismatic crystals present in fibres      | <i>Lagerstroemia lanceolata</i> |
| 11. Prismatic crystals absent in fibres       | <i>Canarium strictum</i>        |
| 12. Axial parenchyma apotracheal              | 13.                             |
| 12. Axial parenchyma paratracheal             | 14.                             |
| 13. Sheath cells present                      | <i>Ceiba pentandra</i>          |
| 13. Sheath cells absent                       | <i>Bombax ceiba</i>             |
| 14. Vessel outline angular                    | <i>Alstonia scholaris</i>       |
| 14. Vessel outline not angular                | 15.                             |
| 15. Canals present                            | 16.                             |
| 15. Canals absent                             | 17.                             |
| 16. Axial canals in tangential lines          | <i>Hopea parviflora</i>         |
| 16. Intercellular canals of traumatic         | <i>Ailanthus triphysa</i>       |
| 17. Included phloem present                   | <i>Neolamarkiana cadamba</i>    |
| 17. Included phloem absent                    | 18.                             |
| 18. Heartwood fluorescent                     | 19.                             |
| 18. Heartwood non-fluorescent                 | <i>Aegle marmelos</i>           |
| 19. Strong yellow colour fluorescence present | 20.                             |
| 19. Weak yellow colour fluorescence present   | <i>Mangifera indica</i>         |
| 20. Very thick-walled fibres                  | <i>Albizia odoratissima</i>     |
| 20. Thin to thick-walled fibres               | <i>Acacia nilotica</i>          |

#### 5.4. List of macroscopic card key features (IAWA) for identification of the timber species.

1. ***Albizia odoratissima* (Linn. f.) Benth.** – 2p 5p 13p 22p 23p 26p 27p 29p 30p 42p 43p 46p 47v 52p 53p 58p 61p 65p 66p 70p 72p 79p 80p 81p 83p 89p 91p 92p 104p 115p 136p 142p 168p 169p 170p 189p 192p 194p 195p 196p 197p 204p
2. ***Acacia nilotica* (Linn.) Wild. Ex Delile-** 2p 5p 13p 22p 23p 26p 29p 30p 42p 46p 47p 52p 53v 58p 61p 66p 69p 72p 79p 80v 81v 83v 89v 91p 92p 98p 104p 115p 136p 142p 164p 166p 168p 169p 178p 179p 181p 189p 192p 194p 195p 196p 197p 204p
3. ***Acrocarpus fraxinifolius* Arn.**-2p 5p 12p 13p 22p 26p 27p 29p 30p 43p 46p 47p 53p 61p 65v 66p 69p 72p 79p 80p 81p 82v 83v 89p 92p 93p 98p 104p 106p 110v 114p 115p 122p 136p 137p 138p 140v 141v 142p 154p 168p 169p 170p 189p 192p 194p 196p 197p 199p 204p
4. ***Aegle marmelos* L. Correa-** 2p 5p 12v 13p 22p 24v 25p 30p 41p 47p 48p 52p 53v 58p 61p 66p 69p 71p 78p 79v 89p 91p 92p 97p 104p 115p 136p 142p 168p 169p 170p 171p 172p 189p 192v 195p 199p 200p 203p
5. ***Ailanthus triphysa* (Dennst) Alston-** 2p 5p 13p 22p 23p 25p 30p 42p 43p 46p 61p 66p 68p 72p 80p 82p 83p 85v 86p 91p 92p 93p 98p 106p 107v 114p 131p 136v 137v 141v 168p 169p 170p 171p 172p 173p 175p 176p 177p 189p 192p 193p 194p 197p 199p 200p
6. ***Alstonia scholaris* (Linn.) R. Br.**- 2pp 5p 10p 13p 22p 24p 25p 29p 30p 41p 48p 49p 53p 54p 62p 66p 69p 70v 72p 76p 77p 92p 93p 94p 97p 107p 108p 115p 136v 137p 142p 171p 173p 189p 204v
7. ***Artocarpus hirsutus* Lam.**- 2p 5p 13p 22p 23p 26p 27p 31p 42p 43p 46p 47v 52p 53p 56p 58p 61p 66p 69p 71p 72p 79p 80p 81p 82v 83v 91p 92p 98p 103v 106p 107p 114p 115p 168p 169p 170p 171p 172p 189p 192p 194p 196p 197p 199p
8. ***Azadirachta indica* A. Juss.**- 1v 2v 5p 6v 11v 13p 22p 24v 25p 30p 36p 37p 42p 45v 46v 47p 52p 53v 58p 61p 66p 69p 71p 72p 79p 85p 89v 92p 93p 94p 97v 98v 104v 106v 115p 131v 136p 141p 142p 168p 169p 171p 172p 173p 178p 179p 189p 192p 194p 196p 197p 198p

9. ***Bombax ceiba* Linn.**- 2p 5p 13p 22p 27p 30p 31v 43p 46p 47v 53p 56p 61p 66p 69p 72p 73p 77p 79v 86v 92p 93p 98p 106p 107v 115p 119v 120p 122p 136v 137v 141v 183p 184p 186p 189p 192p 193v 194p 196p 197v 198p
10. ***Bridelia retusa* (L.) A. Juss.**- 1p 5p 13p 22p 25p 31p 32p 41v 42p 47p 48p 49v 52p 56p 61p 65p 69p 72p 78p 89p 92p 93p 98p 102p 109p 112p 115p 136p 137p 138p 142p 168p 169p 170p 171p 172p 173p 189p 192p 194p 196p 198p
11. ***Canarium strictum* Roxb.**-2p 5p 13p 22p 23v 26p 27p 31p 32p 42 43v 46p 47p 53p 61p 65p 69p 72p 75p 78p 97p 106p 107p 115p 128p 136p 137p 168p 169p 189p 194p 200p
12. ***Cassia fistula* Linn.** – 2p 5p 13p 22p 26p 29p 30p 42p 46p 47p 52p 58p 61p 65p 66p 70p 71p 72p 79v 80p 81p 82p 83p 89p 91p 92p 97p 104p 115p 136p 142p 168p 169p 189p 192p 195p 196p 198p
13. ***Casuarina equisetifolia* J. R. & amp;G.Forst.**- 2p 5p 7v 9p 13p 14v 15v 22p 24p 25p 30p 41p 42p 45v 47p 53p 58p 60p 62p 63p 66p 70p 72p 76p 77p 86p 87v 92v 93p 94v 97p 104p 116p 136p 138v 139v 142p 168p 170p 171p 172p 173p 174p 175p 176p 189p 192p 195p 196p 197p 198p
14. ***Ceiba pentandra* L. Gaertn**- 1v 2p 5p 13p 22p 23v 26p 27p 31p 32v 35p 43p 46p 47v 53p 56p 61p 66p 68v 69p 72p 73p 77p 79p 86v 89v 91v 92p 93v 98p 99v 102p 106p 107p 110p 114p 115v 120p 136p 137p 138p 141p 183p 184p 186p 187p 189p 192p 193p 197v 198v 200p 201p
15. ***Hopea parviflora* Bedd.**- 2p 5p 13p 22p 29p 31p 32v 42p 47p 60p 61p 66p 69p 71p 79p 80p 82p 83p 92p 93p 97v 98v 102v 106p 107p 115p 122p 127p 128p 136p 137p 138p 139p 140v 142p 168p 170p 171p 172p 173p 189 p192p 194p 196p 197p 199p
16. ***Lagerstroemia lanceolata* Wight.**- 2p 5p 13p 22p 23p 26p 27p 29p 30p 31p 42p 43p 46p 47p 53p 56p 58p 61p 65p 69p 73p 80p 82p 83p 92p 93p 96p 104p 115v 116p 136p 142p 143p 154p 168p 169p 189p 192p 194p 196v 197p 198v
17. ***Mangifera indica* Linn.**- 1v 2v 5p 13p 22p 23p 26p 27p 31p 32p 42p 46p 47p 53p 56p 58v 61p 66p 69p 71p 79p 80p 81v 82v 83v 89p 92p 97p 104v 106p 115p 136p 137p 138p 141v 168p 169p 170p 171p 172p 173p 189p 192p 194p 196v 197p 198v 199v 204v

18. ***Melia dubia* Cav.-** 1p 2p 5p 13p 22p 25p 26p 30p 36p 37p 39p 42p 43p 52p 58p 61p  
66p 68p 69p 72p 78p 79p 89v 98p 104p 106p 114p 115p 168p 169p 189p 192p 193p  
196p 197p
19. ***Neolamarkiana cadamba* Roxb.-** 2p 5p 13p 22p 23v 25p 26p 29p 30p 42p 46p 47p  
53p 54p 62p 63v 66p 68p 69p 72p 73p 76p 77p 78p 93p 94p 97v 98v 103v 107p 108p  
113p 116p 153v 168p 169p 170p 171p 172p 173p 189p 192v 193p 194p 199p 200p
20. ***Thespesia populnea* (L.) Soland. ex Correa-** 2p 5p 11v 13p 22p 23p 24p 25v 30p 41p  
42p 45p 47p 58p 61p 63p 66p 68p 69p 76p 77p 79p 86p 89p 90p 91p 92p 97p 98p 106p  
107p 110p 115p 118p 119p 120p 171p 173p 189p 192v 194p 196p 197p 198p

## **SUMMARY**

## 6. SUMMARY

The present research involved an intensive examination of the wood physical and anatomical characteristics of selected timber species of South India. Wood samples of 21 tree species were collected from different timber markets and saw mills across Kerala to conduct the study. The anatomical properties like vessel diameter, vessel area, vessel frequency, ray height, ray width, ray frequency, fibre length, fibre width and fibre wall thickness were analysed in this study. The general features like colour, weight, texture etc. were also considered in the procedure of identification.

Both IAWA key and Dichotomous key was developed for enriching the database, which would further assist in identification of unknown samples and can be used for future reference for studying the anatomical features. This would ease in accurate identification of the species from other similar species on a microscopic level. The information collected about the timber species will be useful for the research in the field of identification and anatomical studies. The results of the investigations are given below.

1. Between species, wood specific gravity differed significantly. The highest specific gravity was found in *Hopea parviflora* and *Cocos nucifera*. While the lowest specific gravity was observed in *Ceiba pentandra*.
2. All the species studied was categorised to the diffuse porous.
3. Small vessels were found in *Aegle marmelos* and comparatively larger vessels were observed in *Ceiba pentandra*. So, the evolutionary trend of vessel area showed that the primitive species among the studied samples, will be *Aegle marmelos* and the advanced one will be *Ceiba pentandra*.
4. Vessels were solitary and in radial multiples of 2-3 in most of the studied species, except *Casuarina equisetifolia* where vessels are exclusively solitary and *Alstonia scholaris* are in radial multiples of 4-8.
5. The maximum vessel diameter was observed for *Ceiba pentandra* with 258.38  $\mu\text{m}$  followed by *Bombax ceiba* with 232.11  $\mu\text{m}$  and *Acrocarpus fraxinifolius* with 224.34  $\mu\text{m}$ . The minimum vessel diameter was recorded for *Aegle marmelos* with 93.82  $\mu\text{m}$  and *Casuarina equisetifolia* with 99.11  $\mu\text{m}$ .
6. Vessel frequency was observed to be highest in *Aegle marmelos* (37 per  $\text{mm}^2$ ) followed by *Bridelia retusa* (24 per  $\text{mm}^2$ ), *Casuarina equisetifolia* (14 per  $\text{mm}^2$ ) and *Neolamarkiana cadamba* (11 per  $\text{mm}^2$ ) and the lowest was recorded in *Acacia nilotica*,

*Albizia odoratissima*, *Hopea parviflora* and *Lagerstroemia lanceolata* with a value of 3 per mm<sup>2</sup>.

7. Rays are variable, which possess a mixture of homocellular and heterocellular to exclusively homocellular rays. In *Aegle marmelos*, *Albizia odoratissima* and *Cassia fistula* only procumbent rays were observed.
8. Ray frequency was analysed in the present study and it was observed that the highest ray frequency was recorded in *Casuarina equisetifolia* (15 per mm) *Cassia fistula* (13 per mm) and *Neolamarkiana cadamba* (13 per mm) and the lowest was recorded in *Ceiba pentandra* (4 per mm) followed by *Bombax ceiba* (5 per mm) and *Melia dubia* (5 per mm).
9. Ray height was analysed in the present study and it was observed that the maximum height of ray was observed in *Bombax ceiba* with a height of 1.253 mm followed by *Bridelia retusa* with a height of 1.50 mm and the lowest was recorded in *Cassia fistula* with a height of 0.21 mm followed by *Casuarina equisetifolia* with a height of 0.22 mm
10. Paratracheal parenchyma is an advanced character was observed in most of the species.
11. Angular vessel outline was observed only in *Alstonia scholaris*.
12. Chalky deposits present in *Artocarpus hirsutus* were found as one of the distinguishable characters of that species.
13. Red coloured deposits present in *Thespesia populnea* were found as one of the distinguishable characters of that species.
14. In majority of the species, prismatic crystals were observed. But only in *Lagerstroemia lanceolata* prismatic crystals were present in fibres.
15. In *Hopea parviflora*, majority of the vessels were filled with tyloses and presence of resin canals was observed.
16. In *Ceiba pentandra*, the absence of sheath cells helped in distinguishing it from a related and similar species- *Bombax ceiba*.
17. In *Neolamarkiana cadamba*, included phloem was present.
18. The specific odour *Azadirachta indica* could also aid in identification of the species.
19. By utilizing all these information obtained from the anatomical studies a dichotomous key and an IAWA key was prepared for the 21 selected timbers.
20. Dichotomous key helps to look for key features that will be useful for distinguishing tree species. A well-constructed dichotomous key can quickly lead to identification.
21. Very little variations in tissue characteristics were observed when the observed results are compared with the existing database.

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**Characterization of wood physical and anatomical features for  
the development of identification keys for twenty tree species of  
South India**

**By**

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**ABSTRACT**

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**MASTER'S THESIS SEMINAR**

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**ABSTRACT**

Wood has played a vital role in the history of human civilisation. Mankind have been using it as a building material, for making furniture, paper and fuelwood since time immemorial. The demand for wood continues to increase annually, even today. The rapidly expanding global population has created consumer demand for wood and wood products. This has led to unsustainable exploitation of forests globally, paving the way for illegal logging and resultant timber adulteration (UNODC, 2020). Illegal logging and global trade of such timber accounts for 51-152 billion U.S. dollars annually (INTERPOL, 2019). Accurate identification of timbers is therefore a need of the hour. Identifying the timber is also a necessity, even to determine its general end-use. In this backdrop, the present study was conducted to characterise the physical and anatomical features of 21 timber species and to develop a dichotomous Key and an IAWA (International Association of Wood Anatomists) Key for the accurate identification of the selected species.

A survey was conducted, and wood samples were collected from different parts of Kerala. The procured samples were cut to the required dimensions (1x1x1 cm<sup>3</sup>). Gross features were recorded, and sections were prepared using a sliding microtome (Leica SM 2000R). Permanent slides were then prepared. The photomicrography of Transverse Sections (TS), Tangential Longitudinal Sections (TLS), and Radial Longitudinal Sections (RLS) were taken using a Catymage® image analyzer using a Catcam 500E series microscope camera, mounted on a Motic BA210 trinocular microscope.

Physical properties like colour, odour, lustre, texture, basic density etc. and micro-anatomical properties like vessel, ray and fibre morphology were studied. All the quantifiable parameters differed significantly between the species and characteristic features were identified.

Wood specific gravity differed significantly. Highest specific gravity was observed in *Hopea parviflora* and *Cocos nucifera*, while the lowest specific gravity was observed in *Ceiba pentandra*. All the species studied (except *Cocos nucifera*) were categorised as diffuse porous. Small vessels were found in *Aegle marmelos* and comparatively larger vessels were observed in *Ceiba pentandra*. Vessels were solitary and in radial multiples of 2-3 in most of the species studied, except *Casuarina equisetifolia* which were exclusively solitary and in *Alstonia scholaris* they were in radial multiples of 4-8. Maximum vessel diameter was observed for *Ceiba pentandra* with 258.38  $\mu\text{m}$  followed by *Bombax ceiba* with 232.11  $\mu\text{m}$  and *Acrocarpus fraxinifolius* with 224.34  $\mu\text{m}$ . The lowest vessel diameter was recorded in *Aegle marmelos* (93.82  $\mu\text{m}$ ) and *Casuarina equisetifolia* (99.11  $\mu\text{m}$ ).

Vessel frequency was found to be highest in *Aegle marmelos* (37 per  $\text{mm}^2$ ) followed by *Bridelia retusa* (24 per  $\text{mm}^2$ ) and the lowest was recorded in *Acacia nilotica*, *Albizia odoratissima*, *Hopea parviflora* and *Lagerstroemia lanceolata* with a value of 3 per  $\text{mm}^2$ . Rays were observed to be variable, with a mixture of homocellular and heterocellular rays to exclusively homocellular rays. In *Aegle marmelos*, *Albizia odoratissima* and *Cassia fistula*, only procumbent rays were observed. Ray frequency was analysed in the present study and it was found that the highest ray frequency was found in *Casuarina equisetifolia* (15 per mm) *Cassia fistula* (13 per mm) and *Neolamarkiana cadamba* (13 per mm) and the lowest was recorded in *Ceiba pentandra* (4 per mm), followed by *Bombax ceiba* (5 per mm) and *Melia dubia* (5 per mm).

Ray height was highest in *Bombax ceiba* (1.25 mm), followed by *Bridelia retusa* (1.50 mm) and the lowest was recorded in *Cassia fistula* (0.21 mm ) followed by *Casuarina equisetifolia* (0.22 mm). Paratracheal parenchyma is an advanced character and was observed in most of the species. Angular vessel outline was observed only in *Alstonia scholaris*. Utilizing all the physical and anatomical information obtained from the study, a dichotomous key and an IAWA key was prepared for the selected timbers species.