DEVELOPMENT OF ANATOMICAL KEY FOR THE IDENTIFICATION OF SELECTED TIMBERS OF KERALA

By

NIMMI SATHISH

(2018-17-002)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Forestry

Faculty of Forestry

Kerala Agricultural University

DEPARTMENT OF FOREST PRODUCTS AND UTILIZATION
COLLEGE OF FORESTRY
VELLANIKKARA, THRISSUR – 680656
KERALA, INDIA

2020

DECLARATION

I hereby declare that the thesis entitled **"Development of anatomical key for the identification of selected timbers of Kerala"** 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.

Nimmi

Vellanikkara | Nimmi Sathish

Date: | (2018-17-009)

CERTIFICATE

Certified that the thesis, entitled "Development of anatomical key for the identification of selected timbers of Kerala" is a record of research work done independently by **Nimmi Sathish (2018-17-002)** 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.

Vellanikkara

Dr. E.V. Anoop

(Major Advisor, Advisory Committee)

Professor and Head
Department of Forest Products and Utilization
College of Forestry, Kerala Agricultural University
Vellanikkara, Thrissur, Kerala.

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Nimmi Sathish, a candidate for the degree of Master of Science in Forestry with major in Forest Products and Utilization, agree that the thesis entitled "Development of anatomical key for the identification of selected timbers of Kerala" may be submitted by Nimmi Sathish, in partial fulfilment of the requirement for the degree.

Dr. E. V. Anoop
(Chairman, Advisory Committee)
Professor and Head
Dept. of Forest Products and Utilization
College of Forestry
KAU, Vellanikkara

Dr. A. V. Santhoshkumar
(Member, Advisory Committee)
Professor and Head
Dept. of Forest Biology and Tree Improvement
College of Forestry
KAU, Vellanikkara

Dr. T. K. Kunhamu
(Member, Advisory Committee)
Professor and Head
Dept. of Silvicuture and Agroforestry
College of Forestry
KAU, Vellanikkara

Dr. Jijeesh. C. M
(Member, Advisory Committee)
Professor
Dept. of Silvicuture and Agroforestry
College of Forestry
KAU, Vellanikkara

Acknowledgment

It is with the utmost respect and great devotion, I place on record my deep sense of gratitude and indebtedness to my major advisor ***Dr. E.V. Anoop****, Professor and Head, Department of Forest Products and Utilization, College of Forestry whose pragmatic suggestions, erudite guidance and support throughout the study period made my thesis work an easy task.*

I express my deep sense of gratitude to Kerala Agricultural University for the financial and technical support for the pursuance of my research. I would like to thank the academic and technical support provided by my Institution, College of Forestry in the successful completion of my thesis. I take this opportunity to recognize ***Dr. K. Vidyasagaran****, Dean, College of Forestry for his support during the study.*

I extend my cordial thanks to ***Mr. Anish. M. C.*** *Assistant professor, Department of Forest products and utilisation, for his guidance and encouragement he provided throughout my study period. I would also like to thank the experts in the advisory committee,* ***Dr. T. K. Kunhamu,*** *Professor and Head, Department of silviculture and agroforestry, College of Forestry, Kerala Agricultural University,* ***Dr. A.V. Santhosh Kumar,*** *Professor and Head, Department of Forest Biology and Tree Improvement, College of Forestry, Kerala Agricultural University, and* ***Mr. Jijeesh C. M,*** *Assistant Professor, Department of silviculture and agroforestry, College of Forestry, Kerala Agricultural University, for their constant encouragement and constructive suggestions throughout the study period.*

I wish to express my sincere thanks to my seniors, ***Dr. Pavin Praize Sunny Sharmista. N****, Department of Forest products and utilisation, for their valuable suggestions and guidance in conducting the extensive lab work.*

Words are not enough to thank my friend ***Aishwarya. M,*** *MSc. Graduate from Providence College, Thrissur for assisting me in completing the work successfully. I express my sincere gratitude to* ***Mr. Midhun Murali****,* ***Deepak Ranjan Sahoo, Arjun M. S, Gayathri Mukhundan, Jobin Kuriakose*** *and* ***Shibhu C****, Department of Forest products and utilisation for his valuable assistance throughout the study**.** I wish to express thanks to my batch mates*

Azhar Ali *and* ***Prabhu P*** *for their continuous mental support throughout the study period.*

I place on record my sense of gratitude to my batchmates and friends including ***Anjana, Abhirami, Ajishma, Aleena, Anjali, Abin, Arshad, Jes and Subhasmita*** *who have constantly helped and provided me with unfailing support.*

Finally, I must express my very profound gratitude to my parents for the continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Nimmi

NIMMI SATHISH

CONTENTS

LIST OF TABLES

LIST OF PLATES

INTRODUCTION

1. INTRODUCTION

Deforestation poses a massive threat to global biodiversity with illegal logging and the associated trade in illegally sourced wood products. This can act as a significant contributor to the continuation of unsustainable deforestation rates. Reputed timber traders are also struggling to trigger their own supply chains and comply with the growing requirement for due diligence with respect to timber origin and legality. A range of scientific methods have been developed independently with the potential to provide the required identification information. The demand for practical methods of identifying and investigating the physical properties of commercial timbers has stimulated the study of anatomy. The study of wood anatomy, with special reference to the production and utilization of timber is a highly specialised discipline which is used in combination with various technologies in forensic timber identification. Wood anatomical features are generally considered not prone to changes under normal circumstances and therefore it forms the basis of wood identification. Timber identification has traditionally been provided by wood anatomists through the examination of the internal structure of wood (Carlquist, 2001). As anatomical characters can be influenced by both genetic and environmental factors, combination of characters can be used to differentiate taxa. Analysis can be undertaken at both the macroscopic and microscopic scale, but microscopic examination is usually required to achieve a diagnostic identification. This has naturally been carried out more with reference to the important timbers of certain geographical regions than with botanical groups.

Study on wood anatomical variation is quite useful as the internal structure of wood profoundly influences the properties of wood (Dadswell, 1957; 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; Rao and Rao, 1978; Pande *et al.*, 1995).

The timber supply chain has responded to nature's variability and now provides repeatable product supply from managed forests. There are thousands of species of trees from which timber can be obtained, each with different rates of growth, structural properties, and degrees of durability. The industry has also created grading processes to deliver reliable technical performance (grades) for these products. Some timbers are highly decorative, some are very strong, some have good resistance to rot (whereas some behave very badly when they get wet) - in fact almost every species of wood has features that can be good in some uses, but not so good in others. Therefore, knowing what type of wood you have in front of you can be extremely important, either because you may have paid a lot of money for something you didn't actually get, or maybe because the wood you've got is unsuitable for the job you have in mind for it. Timber identification is a skill that must be gained with practice and with a bit of extra help from a skilled wood scientist.

The IAWA (International Association of Wood Anatomists) List of Microscopic Features for Hardwood Identification (Wheeler *et al*., 1989) is an important standardized list of characters and terminology that can be used in descriptive wood anatomical studies and identification obtained through comparison to reference materials.. The commonly used keys for wood identification are the dichotomous key, perforated card key and the computer aided identification key. Dichotomous keys are the most simple and easy to use keys. These types of keys have been used for over centuries in biological identification. The multiple entry perforated card type of key was introduced by the Forest Products Research Laboratory in 1936, when a key for the identification of hardwoods based on microscopic features was conducted (IAWA, 1989).

It is often sufficient to make a clean cut with a razor across the end grain for identifying wood from broadleaved trees and observe features such as the arrangements of vessels that transport water up the tree, the arrangements of rays, growth rings, colour, etc. Sometimes the tangential and radial surfaces must be cut for extra details. In certain advanced cases, thin sections must be cut for examination under a microscope. Hardwoods can often be identified simply by means of their larger 'diagnostic features' - using nothing more complicated than a X10 magnification hand lens; whereas Softwoods (with their simpler, but generally harder-to-see cell structure) can often only be identified by putting a thin slice of the wood under a microscope (Brazier, 1975). Either way, getting the right answer - about wood species - is often vital in making sure you have the right timber to do the right job. The aspects of variation in wood structure are of practical importance in the industrial sense (Jane, 1967). He collected opinion of wood anatomists engaged in wood quality study to look at the question of variability in wood structure. Wood anatomists in the field look at variation in three ways: the differences between species, genera and families; the variations observed within individuals of the same species and the variations occurring in the individual trees as they grow older, from the pith outwards and from the bottom upwards. The wood anatomists are concerned with wood quality and interested first of all in the general way in which structural features influence wood properties, processing and use of characteristics. The ways in which the structural features of the particular species determine their properties and their applications can be studied more precisely.

Hence, the preparation of anatomical key is very important in the field of wood industries for the identification of the suitable material or the tree. Anatomical keys of different timbers assist in a large way do away with the confusion in the identification of timbers. The anatomical variations of each species are very conspicuous in making the identification keys. An understanding of the variation and specific characters of the desirable timbers helps a lot in the field of wood sciences. The anatomical keys can also support the molecular studies like DNA bar coding, molecular markers etc. The anatomical studies are carried out according to the characters of the vessel, ray and the specific gravity of the wood. Wood anatomical analysis can generally only achieve identification to the genus level (Gasson, 2011). Automated wood anatomical analysis (‘machine vision’) using sophisticated image capture and processing algorithms is a new area of research showing much promise for timber identification (Hermanson and Wiedenhoeft, 2011), and could potentially facilitate identification to the species level. Wood anatomical analysis is the most frequently used method for taxonomic identification, both on the front-line for screening purposes, and in the laboratory for diagnostic identification. Wood anatomical data have diverse applications, including plant systematics and evolution.

In this study, 20 species of trees were considered in the preparation of anatomical keys for the identification of currently used timbers. The species of trees used for the study are *Acacia auriculiformis,* A. Cunn. Ex Benth. *, Acacia mangium* Willd. , *Albizzia lebbeck* (L.) Benth. , *Albizzia odoratissima* (L.f) Benth. , *Artocarpus heterophyllus Lamk.* , *Artocarpus hirsutus* Lamk. , *Dalbergia latifolia* Roxb. , *Dalbergia nigra* Fr. All. , *Hevea braziliensis* (H. B. K.) M.A, *Hopea parviflora* Bedd. , *Intsia bijuga* (Colebr.) O. Kuntze. , *Ocotea rodiaei* (Schomb) Mez. , *Peltogyne paniculata Benth.* , *Pterocarpus marsupium* Roxb. , *Pterocarpus dalbergioides* Roxb. Ex DC. , *Santalum album* Linn. , *Swietenia macrophylla* King. , *Tectona grandis* Linn. , *Xylia dolabriformis* Benth. , *Xylia xylocarpa* (Roxb.) Taub. So the present work aims at collection of the wood specimens from different timber markets across Kerala to prepare a wood anatomical key of currently used timbers.

In this backdrop, the objectives of the study were;

1. To study the anatomical and physical properties including vessel morphology, ray morphology, fibre morphology and other special characters of the currently used timbers of the state.
2. To identify the collected specimens of currently used timbers using the available databases and other referral sources.
3. To develop a dichotomous key and an IAWA key for the selected timbers.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

In the middle and late 1600s, the knowledge of plant anatomy progressed when Robert Hooke and Nehemiah Grew used microscope to illustrate plant structure. At the beginning of nineteenth century wood anatomy and wood technology started to take off. Two publications which were of great importance in influencing future work appeared in 1900. The first one was Systematic Anatomy of the Dicotyledons (Solereder, 1908) published in 1899, focusing on the anatomical part of the plant families and descriptions of plant parts. Later in 1950, Metcalfe and Chalk provided a re-write of the Anatomy of the Dicotyledons. Both editions are outstanding contributions to wood anatomy. When the first part of Micrography of Javanese Woods by Moll was published in 1906, it became a second milestone. These two publications togetherly established a pattern of research taking anatomy into a comparative phase beyond the fields of phylogeny and taxonomy. Comparative anatomy gave the basis for studies contributing to scientific classification and species grouping. Based on its anatomy, the author of the primary 'key' for the timber identification is a matter for literary research and the key is of dichotomous nature. These keys are convenient as the number of individuals requiring sorting is less and continual addition is not required. But a need is there for a universal key which helps for an indefinite increase in the number of entries, where the numbers are large. This was called as 'A Universal Index to Wood' (Swain, 1926). It composed a series of six schedules, and each consisted of a list of characteristics with each feature indicated by a distinctive number. In 1938, Clarke developed the most practical system, a card with marginal perforations corresponding to the structural characteristics and creating one or more cards as necessary for every timber. This was adopted by Chalk for recording information for the Anatomy of the Dicotyledons (Metcalfe and Chalk, 1950) and, first by Phillips for softwoods in 1941 and later by Brazier and Franklin (1961) for hardwoods, for the keys prepared at Risborough. New techniques often provide a noval view and better understanding of behavior of wood, but they usually complement and rarely replace previous techniques. Whether it is simple or sophisticated, they said the anatomist to look at wood and, to interpret sensibly what he sees, and this must be an essential prerequisite if the material needs to be processed and utilized efficiently. However, while new techniques often contribute to detailed knowledge of wood behavior, many of its significant technical aspects can be understood and anticipated from intelligent investigation of its gross structure, using the unaided eye or only simple technical aids.

2.1. Significance of wood anatomical studies

There is a rising awareness for the more effective utilization of the world's forest resource, mainly from the tropical areas. In South-East Asia and in West African territories, many of the commercially important timbers are well known, but in Central and South America, it needs to be found out. The pioneer requirement for their efficient use is the contribution of an experienced anatomist for technical sorting and classification of timbers. The second major development needed is an increased dependence on plantation forests. Selection of breeding stock is being made and this will lead to improved yields of timber of high quality in near future. It is important to investigate more about the wood heritability characteristics and calls for suitable growth of known genetic origin, controlled or of clonal pollination. The next significant area is to find out the relationships between its structure and performance. This is important as it can contribute to the more efficient selection and utilization of timber where such features are significant.

2.2. Identification studies of Indian timbers

In the early decades, there was a focus on comparative anatomy, normally as a contribution for developing the utilization of the tropical forest resource. Studies of the interaction between growth and wood structure have gained special interest in the post Second World War period. It has been created by an awareness in many countries for a need to depend increasingly on managed forests as a source of timber and to produce such timbers at minimum cost compatible with acceptable technical performance. Considering the future of wood anatomy, it has a fundamental role in developing and applying the wood technology for its efficient utilization. Mainly it has role in contributing to the utilization of many under-used timbers in the developing countries, as well as the effective generation of plantation timber.

In India, anatomical studies were conducted in different Indian species of Populus by Gamble (1922), Pearson and Brown (1932), Metcalf and Chalk (1950), Raturi *et al.*, (2001), Gautam (2010). Gamble (1922) described a small account of wood structure of *P. ciliata, P. euphratica* and *P. alba* in his classical work 'A manual of Indian timbers'. The common features of the wood of all three species were: wood was soft, even grained, annual rings marked by smaller and fewer pores, pores small, very numerous often subdivided or in short radial multiples, rays fine to very fine, numerous and regular. The colour differentiation in wood was: grey or brownish grey in *P. ciliata;*, sapwood white and heartwood red coloured and black near the pith in *P. euphratica* whereas wood white often with red or yellowish tinge in *P. alba*. Metcalfe and Chalk (1950) describe rays as uniseriate sometimes biseriate with less than one millimetre in height and homogeneous. Pearson and Brown (1932) made a complete anatomical description of these species. There not much difference was observed in wood structure of these three species. However, the colour of wood of *P. euphratica* was red to reddish brown with dark lines forming tortoise shell figure in flat sown board. Gautam (2010) described the structure of micro- and macro-propagated wood of L34 clone of *P. deltoides* as per IAWA feature list of microscopic features (IAWA, 1989).

The first record on the identification of Indian timbers is the publication by Troup (1909), a forest economist in the Forest Research Institute, Dehra Dun. He gathered information about 553 major commercially important timbers of India. The main objective of the publication was to assist the foresters and other users in timber identification based on their general features and to form decisions regarding the suitability of the timbers for specific purposes.

In 1832, Wallich, who was the Superintendent of the Botanic Garden at Calcutta, prepared the first 'List of Indian woods' composing of 457 species of Indian woods and their description. He was sent by the Governor-General of India on several botanical missions and expeditions, he collected specimens of the native woods, which were sent to London, and deposited at the India House. The description of each species mainly focuses on their conspicuous wood characters. Appended to the catalogue are two valuable tables of experiments on the strength of some of the most import ant kinds of Indian timber, made by

Mr. Kyd, at Calcutta, and by Major H. Campbell, in the gun-carriage manufactory at Cassipur, near Calcutta.

The gross anatomical features of the timbers of the Madras Presidency having the description of the timber species in this region as well as information of commonly imported timbers was described by Lushington (1919). A comparison study between the indigenous and imported timbers was also made in this publication. A clear account of the commercially important timbers of India is made by Gamble (1922). He included description about the common field identification features such as color, odour, hardness, weight, grain characters, etc., supported by photomicrographs of cross sections of wood.

The common commercially important timbers of India and their uses by Trotter (1929) I.F.S, forest economist of Forest Research Institute, Dehra Dun comprises description of common Indian woods of 86 species and includes about their seasoning, strength, sources of supply price etc.

The publication titled "Commercial timbers of India" by Pearson and Brown (1932) explains the anatomy of 320 commercially important species of timbers of 53 families. The book describes about the distribution, physical properties, supply, mechanical properties and uses of each timber along with minute anatomy. The description is supported with photomicrographs of cross sections of timbers and classification is done based on their end uses. A brief explanation on the gross structural features like growth ring characteristics, parenchyma types, pore arrangement and ray characteristics of 26 Burmese timbers like Teak and Andaman Padauk is described by Chowdhury (1945). Trotter (1959) gives information manual on 150 commercial timbers common to India. This includes data like species name, vernacular name, trade name, weight, strength, seasoning quality, durability, uses, and source of supply and price of timber along with description of the wood characters. He sorted the timbers according to their uses to assist the users to choose the timber species based on their requirement.

The "Indian Woods" - A comprehensive compilation series, was published by the Wood Anatomy Branch of FRI, Dehra Dun (Chowdhury and Ghosh, 1958; Rao, 1963; Rao and Purkayastha, 1972; Purkayastha, 1982;

Purkayastha, 1985). It deals with the structure, properties, identification, and uses of woods found in the India and Burma. In addition to description on trees, structure of shrubbery wood species has also been explained.

The minute anatomical characters and gross of twenty-five commercially important timbers of Madras were recorded by Harikrishnan (1960). It covers gross and general features of common wood species and directs the uses to where each species can be put to. Ghosh (1960) studied the significance of dichotomous keys in the identification of timber samples and explained how to use the key. Dissections under binocular microscope, hand sections and microtome sections of variable thickness of the fruit of different ages were obtained and stained by usual customary methods. Rao and Juneja (1971) made the identification key for fifty commercially important India timbers. Purkayastha *et al.* (1976) created the anatomical description of commercially important timbers of the Andamans. It provides detailed explanation of 36 timbers, including their general characters, gross features, micro anatomy, their supply, and utilization. This manual is supposed to ease the identification of commercially important timbers of the Andamans both in the laboratory and field.

Nazma *et al*. (1981) published a handbook of 162 commercially valuable timbers common to Kerala. It deals with general features and gross anatomy of timber that can assist in the identification of timbers. In addition to the identification characters, the trade name, local name, strength, distribution, tree characteristics, working properties and utilization of these timbers are provided.

The characteristics of 21 lesser-known timber species of Kerala forests were studied by Bhat (1994). The features examined includes physical properties of wood like grain, colour, texture, heartwood content, shrinkage, and basic density along with the anatomical woood structure. Most of the timbers they investigated are having density comparable to commonly utilized structural and joinery timbers. His study reveals that a high proportion of the less-known native hardwoods have timber value which can be exploited for gaining optimum use of the resource.

Bhat *et al.* (2007) published The Handbook of lesser-known timbers is a good reference for timber users to understand more about the lesser known timbers of the timber market particularly in Kerala. The characteristics and uses of 77 timbers are given in the handbook, of which 52 species are imported.

Saxena and Gupta (2011) studied the wood anatomy of salvadoraceae family from the Indian subcontinent giving special reference to the ultra structure of the vessel wall. Their study explains the microstructure of the members of family Salvadoraceae like *Azima tetracantha, Salvadora oleoides, and S. persica,* represented in the Indian Subcontinent. Based on the wood anatomical features, identification has been developed for the separation of the species. SEM studies marked the presence of vesturing in inter-vessel pits of some species of Salvadora.

Wood anatomical variations in some species of Quercus of Meghalaya were investigated by Sharma *et al.* (2011). They found that vessels are solitary or radial multiple of two seen in radial or diagonal pattern. They evaluated that the species of Quercus show the presence of vasicentric tracheids and scalariform perforation plates. They also found that aggregate rays are found only in *Q. acutissima* where as *Q. semiserrata* and *Q. lanceofolia* have presence of multiseriate rays and both heterocellular and homocellular rays are found in Quercus species except *Q. fenestrata* and *Q. acutissima* that have only heterocellular rays. Axial parenchyma is found as apotracheal diffuse type in all species except *Q. acutissima* that shows diffuse in aggregate, unilateral and banded paratracheal parenchyma along with apotracheal diffuse.

Pande (2012) discussed the Status of Anatomy and Physical Properties of Wood in Poplars. He found that the anatomical structure of *P. ciliata, P. alba, P. euphratica and P. deltoides* is similar, however, the colour differentiation in wood was reported; grey or brownish grey in *P. ciliata*, sapwood white and heartwood red coloured and black near the pith in *P. euphratica*, whereas white often with red or yellowish tinge in *P. alba* white to offwhite in *P. deltoides.*

Singh *et al.* (2013) studied about the variations in wood anatomical features of some Terminalia species of Assam. Their investigation was carried out on four species of Terminalia namely *T. arjuna, T. bellerica, T. chebula* and *T.*

myriocarpa to study variations in their wood elements. It was observed that all species of Terminalia had diffuse porous wood with indistinct growth rings in T. *arjuna* and T. *chebula* and distinct growth rings in *T. bellerica* and *T. myriocarpa*. Minimum and maximum vessel frequency were observed as 2 per mm^2 (T. *myriocarpa*) and 14 per mm^2 (*T. chebula*), while minimum and maximum rays per mm were observed as 8 per mm and 16 per mm in all selected species of Terminalia except *T. myriocarpa*. Tyloses were observed only in *T. myriocarpa*. Analysis of variance showed that significant differences exist among wood element dimension of all selected species. Fiber length showed positive and significant correlation with vessel length and wood density and negative and significant correlation with fiber diameter but a non-significant and negative correlation with fiber wall thickness.

A study on wood physical, mechanical, and anatomical properties of *Swietenia macrophylla* Roxb, a potential exotic species for South India was made by Anoop *et al.* (2014). This study focuses on the evaluation of physical, mechanical, and anatomical properties of *S. macrophylla* and interrelationship of these properties. They also focus on the variation found in the timber quality of the above species when they are grown outside their natural home range. Growth measurements comparing with the information on wood quality parameters will assist in taking judicious management decisions for raising and management of these species.

Gupta (2016) made study on the variations in wood anatomy of hardwood species collected from the coal mines of Jharkhand. The proposed investigation envisages detailed anatomical studies besides certain physical properties of 19 hardwood species collected from the biggest coal mine areas of India. This study brings out various facets of wood anatomy in relation to mining stress by testing the hypotheses statistically.

Vessel morphological parameters viz., vessel frequency, vessel diameter, vessel area and vessel length of *Artocarpus hirsutus* wood collected from trees grown in three agro-climatic zones of Thrissur district, Kerala were studied by Anoop *et al.* (2017). Significant variation was found only among agro-climatic zones for vessel length and not between girth classes within zones. In this study vessel area, vessel frequency and vessel diameter did not show any significant variation between three zones as well as between girth classes. Eco anatomical properties like vulnerability and vessel mesomorphy were also calculated and vulnerability showed significant difference between the three zones. Vessel mesomorphy values of anjily wood indicated that the species is mesic in nature. As information on wood properties of *Artocarpus hirsutus* is very scarce, this study can provide important details regarding wood properties of this species.

2.3. Identification studies of imported timbers

In our country, the demand and supply of timber was immensely affected by large scale industrialization and urbanization. All types of felling from natural forests have been banned and this also contributed to the shortage of timber. For mitigating the acute shortage, timber industry focussed on import of timbers from outside the country on a large scale. As a result, many timbers are imported into our timber market, mainly for construction activities. It includes teak (*Tectona grandis* L.f), meranti (*Shorea sp*.), greenheart (*Ocotea rodiaei),* pyinkado (*Xylia dolabriformis Benth.*), (Schomb) Mez.), kempas (*Koompassia malaccensis* Maing.), kusia (*Nauclea diderrichii* Kuntze), Malaysian padauk (*Pterocarpus sp.*). and Brazilian rosewood (*Dalbergia nigra* Fr. All.) However, no detailed work has been carried out on the identification of these timbers, which are imported into the country. Information present about these timbers from the studies carried out in their native states is also fragmentary and much scattered.

Bond developed the book, 'Wood Identification for Hardwood and Softwood Species Native to Tennessee' in 1914. It gives information on wood identification of many species common to Tennessee with the help of a hand-magnifying lens. Photomicrographs of timber species are much valuable for the identification of any timber species. Howard (1941) gave data of 504 hardwood and softwood timbers of the world along with its photomicrographs. He stated that the minute anatomical photos help in nullifying confusion regarding the identity of a wood sample and can even be used as a witness before legal courts. More recently, Miles (1978) has brought out a book on photomicrographs of important world woods.

The wood anatomy of commercial timbers was described by Menon (1955, 1959, 1971) in Malaysia. In the next publication the anatomical distinction between some of the confusing groups of timbers *viz*. , dark red, light red, yellow and white Meranti was done. Titmuss (1971) investigated macroscopic features for identification of commercially important timbers of the world, among which some of the timbers are coming under the presently used imported timbers of Kerala. Features like, growth ring, porosity, parenchyma arrangement, pore distribution, odour, colour, presence or absence of gum ducts, along with tree distribution and characteristics are explained in detail. Farmer (1972) provides complete description of 117 commercial hardwoods which composes of the meranti group of timbers, teak, kusia, greenheart, kempas, etc. The objective is to provide information that will aid timber users to select the timber best suited for their purposes and to process them in the most satisfactory manner, having regard to the individual features of timbers like grain, colour, strength properties, and weight, working properties, bending nature, natural durability, and preservation.

In 1970, a comprehensive three volume work on major timbers of the world was compiled by Rendle. More than 200 of the well-known world timbers are illustrated with detailed description of each species. This is done to enable the industrialists and architects to select timbers based on their characteristics and uses. The third volume is dealing with timbers from Australia, Asia, and New Zealand. Titmuss (1971) has provided data of 252 commercially important timbers of the world about their distribution and macroscopic features which assist in the field identification of timbers. This manual will aid in the field identification of some of the commercially utilized timbers of the Indian market. The significance of general and anatomical features for identification was highlighted by Edlin (1977). He provided description of 40 timbers that are commonly used in the world along with a collection of the actual wood samples.

The Morphological and Anatomical Characteristics of 25 Commercial Burmese Timbers was done by Kywe and Soe (1983). This work, which aid in the understanding and identification of Burmese Commercial timbers. In this work a brief and concise description of the plant, the important characteristics of the wood, and its uses of (25) commercially important Burmese Timbers have been given with simple illustrations. Although Pearson and Brown (1932), in their " Commercial Timbers of India" have included some of the Burmese timbers along with those of the Indian ones, have dealt only with the selected and limited species of Burmese timbers.

In 1984, Martin Chudnoff, a forest products technologist made a study on the tropical trees of the world. It contains descriptions of 370 species or generic groupings of tropical trees and their timbers grouped by regional origin: Africa, Tropical America, and Southeast Asia and Oceania. Standardized descriptions emphasize physical and mechanical properties, processing characteristics, and uses. Chong *et al.* (1992) investigated the wood properties of lesser-known species like *Koompassia malaccensis* (kempas) grown in Indonesia. Schmid *et al.* (1997) studied about Dipterocarpaceae members of all timber size found in the rainforests of Malaysia. This manual composes dichotomous keys based on information on silviculture, forest characters, wood anatomy and its uses.

Currently, Richter and Trockenbrodt (1993, 1996) formed the IAWA feature list for use with DELTA; option INTKEY (interactive wood identification). A database with more than 200 trade timbers (entries) is currently present, and as time allows, new entries are added. While using key, illustrations and explanatory notes can be accessed, and is available in German and English versions.

Liang *et al.* (1993) described the anatomy of five genera of Magnoliaceae (fifty nine native species, two introduced species) of China. Magnoliaceae wood from China is characterised by scalariform to opposite vessel wall pitting, diffuse-porosity, scalariform perforations with some bars or in some Magnolia species ground tissue fibers with distinctly to minutely bordered pits, simple perforations, heterocellular rays with one marginal row of upright/square cells and marginal parenchyma. Their study reveals that wood anatomical features between Manglietia and Magnolia more or less overlap and these genera can be distinguished by wood anatomical means. They also found that the wood anatomy is similar in the evergreen species of Michelia and Magnolia. The only genus in which crystals were found is Kmeria.

For Argentinian woods, Monteoliva and Olivera (1994) developed a system of identification with the IAWA feature list as a base, along with the using additional features suitable for local woods. By gathering new data as well as by comparing the literature, they have found discrepancies between their own observations and literature descriptions. This shows that while existing wood anatomical data are useful, it is important to continue to add to and refine the existing data.

An interactive computer key based on the macroscopic features of 115 major Guyanese tree species was prepared by Brunner *et al.* (1994). The key is intended for use by forest products industry personnel and is accompanied by a synoptic key and information on the appearance distribution, wood structure and properties of these species. Other computer-assisted wood identification projects include ones for Japanese woods (Kuroda, 1987; Izumoto and Hayashi, 1990), tropical woods (Tochigi *et al.*, 1984), and Chinese woods (Yang and Cheng, 1990; Zhang *et al.*, 1986). A program and database for South African woods is used in teaching wood anatomy and identification at the University of Stellenbosch (Wheeler and Baas, 1998).

Miller and Pierre (2001) studied the Wood anatomical characteristics of approximately l00 Guyanese timbers. Their work provides complete anatomical descriptions and a dichotomous key of approximately I00 Guyanese timbers to enable users to accurately identify the various species. All characters and their interpretations follow the IAWA List of Microscopic Features for Hardwood Identification.

Global variations in dicot wood anatomy based on the Inside wood Database was made by Wheeler *et al*. (2007). The Inside Wood database is a resource for further studies including detailed information on the ecologic and geographic range of each species and on vessel diameter, density, and cell lengths would help advance the use of wood anatomical features as proxies for macroclimate and ecology. It is also significant in interpreting fossil wood assemblages and tracing the eco physiological history of woody dicots. The database also can be used to investigate how wood anatomical patterns vary within families and orders.

In the study of use of wood characters in the identification of selected timber species in Nigeria, Ten popular timber species belonging to seven families were identified in the Herbarium by Jayeola *et al.* (2009). Wood samples of each species were studied anatomically in search of stable taxonomic micro morphological attributes. Characters of the tracheary elements the vessel; fibre and ray structure; intercellular canal and phloem parenchyma are diagnostic among the species. The grains of the all the ten woods studied vary from coarse or rough to smooth with lustrous or glossy surface. Four species, *Afzelia toxicana, Var africana, Cordia millenii*, of the 10 species studied, three possess hard texture, five hard while two are soft. *Terminalia ivorense* and *Triplochyton scleroxylon* are coarse grained while *Antiaris toxicana, Khaya ivoremse, Mansonia altissima, Milicia excelsa* and *Tectona grandis* are smooth grained and lustrous.

Esteban and Palacios (2009) compared the wood anatomy of Abietoideae (Pinaceae). This study assesses the systematic significance of the wood structure in this group. In particular, the presence of normal and traumatic resin canals, the ray structure and the axial parenchyma constitute phylogenetically informative features.

Wood identification of *Dalbergia nigra* using quantitative wood anatomy, principal components analysis and naive Bayes classification was done by Gasson *et al.* (2010). The Brazilian species *Dalbergia nigra*, commonly known as Brazilian rosewood, has been traded for over 300 years. They used a combination of qualitative and quantitative wood anatomy and statistical analysis to establish one set of characters that could be used to distinguish *D. nigra* from similar species in the genus. In addition, six Latin American Dalbergia species were studied because of its commercial importance and are similar enough to *D. nigra* in terms of overall appearance and/or anatomy, to be mistaken for it. This study confirms that *D. cearensis* can be distinguished from *D. nigra* and the other species in this study by its small, numerous vessels, with any specimen with a vessel frequency more than 10 vessels mm^2 being *D. cearensis*. Specimens with a high ray frequency, over 100 rays 10 mm^2, and a high number of axially fused rays are likely to be *D. miscolobium*. However, in a naive Bayes classification using the four characters - minimum vessel diameter, frequency of solitary vessels, mean ray width, and frequency of axially fused rays– unidentified specimens can be determined as ‘not nigra’ with no false negatives. Specimens determined as ‘nigra’ are twice as likely to be genuine *D. nigra* as not. This suggests that whilst wood anatomy alone is unlikely to provide the level of identification certainty needed by legislation such as CITES, it can be used as a relatively inexpensive and straightforward way of reducing the number of specimens that would need more comprehensive study.

The wood anatomy of all currently CITES-listed angiosperm and conifer tree taxa is illustrated with low to high power magnification light micrographs by Gasson (2011). He made anatomical studies on the CITES-listed tree species. Their diagnostic wood features are presented in numerical codes taken from the IAWA Hardwood (Wheeler *et al.,* 1989) and Softwood (Richter *et al*., 2004) Lists of microscopic features for wood identification. Features used are summarized in two appendices. These descriptions and illustrations can be used for genus identification when carefully compared with look-alike non-CITES-listed timbers illustrated and described in the Inside Wood web-database or present in reference wood collections.

Wood anatomical variables in tropical trees and their relation to site conditions and individual tree morphology were studied by Esther Fichtler and Martin Worbes (2012). The sample set of this study consisted of 139 stem discs from 35 angiosperm families, including 83 genera and 111 species. All samples originated from the tropical stem-disc collection of the Department of Crop Sciences, Agronomy in the Tropics, University of Gottingen, Germany, and have been subject to earlier tree-ring studies. They observed about relationships between wood anatomical variables, Relationships between wood anatomical variables with individual tree morphology and tree age, Relationships between wood anatomical traits and tree growth to climate variables, Variation in wood anatomical variables within and between families and sites, Relation of wood variables to phylogenetic background etc. The variable ‘vessel diameter’ showed the strongest and most significant correlations to other wood anatomical variables, but also to climate parameters and tree morphology.

Thereby tree size (DBH & height) and crown exposure to light had the strongest impact on vessel size and consequently on hydraulic stem architecture.

The Variation in wood density and anatomy in a widespread mangrove species of New Zealand and Australia was studied by Santini *et al.* (2012). They found that at the cellular level, high wood density was associated with large xylem vessels and thick fibre wall. Additionally, wood density increased with decreasing proportions of phloem per growth layer of wood. According to their observations tree growth rates were positively correlated with xylem vessel size and wood density.

Maiti *et al.* (2016) made the study on A Comparative Wood Anatomy of 15 Woody Species in North-eastern Mexico. They stated that there existed large variation in various wood anatomical traits as well their hydraulic architecture which can be related in the species identification and quality determinations of the species. There is also large variability in the morphology, length, wall lignification of fiber cell in the woods among species. The intensity of lignification contribute to the strength and high quality timber for furniture, soft wood containing high amount of parenchymatous tissue and thin walled fibre cells for fabrication soft furniture, fences. Woods having fibre cells with broad lumen and thin wall could be suitable for the manufacture of paper.

Comparison of the wood anatomical characteristics of local tree species in Moluccas, Indonesia was made by Hidayat *et al.* (2017). The tree species under observation were Moluccan ironwood (*Intsia bijuga*), linggua (*Pterocarpus indicus*), red meranti *(Shorea parvifolia*), and gofasa (*Vitex cofassus*). Qualitative evaluation was conducted by observing the anatomical structure in cross, radial, and tangential sections of each sample. For the quantitative evaluation, the dimensions of vessels, rays, and fibers were measured. Qualitative evaluation showed that crystals were observed in Moluccan ironwood, linggua, and gofasa, while resin canals were only observed in red meranti. Tyloses were frequently observed in gofasa but infrequently observed in linggua and red meranti. Quantitative evaluation showed that Moluccan ironwood with the higher density had thicker fiber wall, higher quantity of ray number, and wider rays than the other species. Red meranti had higher values of ray height and fiber length than the other three species.

2.4. Wood anatomical studies in relation with ecology and evolution

The development of anatomical concepts opened new vistas to the study of fossil angiosperm woods. The identification and the systematic assignment of fossil woods and study of salient trends of their structural modification are of great service in the study and interpretation of fossil woods. The Role of Wood Anatomy in Phylogeny was first studied by Tippo (1946).

Further Concepts in Ecological Wood Anatomy, with Comments on Recent Work in Wood Anatomy and Evolution was studied by Carlquist (1980). He made Comments on the problems of quantification and statistical significance in ecological wood anatomy. A resume of recent views on the vessel element as an adaptive structure, with an attempt to delineate what should and should not be inferred in describing the major trends of wood evolution as irreversible is discussed in this study.

Wood anatomy is considered as a source of independent data that can be used to assess evolutionary relationships among angiosperms. A study on 'Angiosperm Wood Evolution and the Potential Contribution of Paleontological Data' was made by Herendeen *et al.* (1999). Paleobotanical data summarized by Wheeler and Baas (1993) provide broad chronological corroboration of some wood anatomical trends, such as evolution from scalariform to simple perforation plates and long to short vessel elements.

Herendeen and Miller (2000) analyzed the utility of wood anatomical charaters in cladistics analysis. They have discussed the standard IAWA List of wood anatomical characters, which are defined primarily for identification, and recast them in a format that is more appropriate for cladistic analysis.

Wimmer (2002) studied about the wood anatomical features in tree-rings as indicators of environmental change. They provided new insights to processes going on in trees with structural features that have shown connections to environmental parameters, not given by other parameters. This review emphasizes work done primarily on continuous and non-continuous wood anatomical features measured in dated tree-rings, reflecting internal and external conditions and processes. It is shown how environmental changes have caused modifications or adaptations of structural features in dated tree-rings. They conclude that overall, wood anatomy indicates that growth and development of trees are dynamic processes. They found that, wood anatomy features may be either observed continuously in every ring, or discontinuously in some rings.

A study was undertaken on structural heartwood characteristics of *Prosopis laevigata* by Carrillo *et al.* (2008), using light microscopy coupled with a digitized image analysis system. Average fibre length is 975 µm, the fibres are thick-walled with a single cell wall thickness of 13 µm on average. Average diameter of the vessels which are arranged in non-specific patterns differs significantly between earlywood (116 µm) and latewood (44 µm). The chemical distribution of lignin and phenolic deposits in the tissue was investigated by means of scanning UV microspectrophotometry (UMSP). Monosaccharides were qualitatively and quantitatively determined by borate complex anion exchange chromatography. Holocellulose content ranged between 61.5 and 64.7% and Klason lignin content between 29.8 and 31.4%.

Micco *et al.* (2008) studied wood anatomy and hydraulic architecture of stems and twigs of some Mediterranean trees and shrubs along a mesic-xeric gradient. This study focuses on the anatomy of juvenile and mature wood of some species representative of continuous sequences of Mediterranean vegetation formations according to gradients of water availability, from xeric to relatively mesic: Although some attributes (i.e. porosity and type of imperforate tracheary elements) were similar in young twigs and older rings, other traits (i.e. vessel frequency and size) evidenced the different hydraulic properties of twig and stem wood. The difference between juvenile and mature structures was large in the species of the mesic end of the gradient while it was relatively small in those more xeric. The species showed large variations in wood anatomical traits, most of them are diffuse porous, few semi to ring porous, vessels are narrow resistant to cavitation during drought and freezing.

Kleeberg (1885) studied in some species of Abies, by using ray height as the parameter to distinguish between species recording the following heights: *A. cephalonica* Loudon 24 cells, *A. alba* 26, *A. religiosa* (Kunth) Schltdl. and Cham. 6, *A. pinsapo* 14, *A. nordmanniana* Spach 20, *A. grandis* 16, *A. equi-trojani* (Asch. & Sint. ex Boiss.) Mattf. 20 and *A. balsamea* 15, whereas Wiesehuegel (1932) regarded the low ray height of *A. lasiocarpa* (Hook.) Nutt. and *A. arizonica* Merriam (< 15 cells) as sufficient grounds to distinguish these two species from the others.

Later, a study was undertaken on wood anatomy and ultrastructure of the 3 species of wood of Prosopis growing in heterogeneous forest dry Chaqueno Park. The species studied were: *Prosopis vinalillo, P. alba* and *P. nigra*. The results show that the 3 species are very similar and consistent with the structural features of the subfamily Mimosoideae. However, the number of vessels/ mm2 was quite variable between species and between individuals of the same species. Samples observed under scanning electron microscope showed displaying ornamentations in pits and striations on the vessel's walls. These striations were shown to be characteristics of the three Prosopis species. (Muniz *et al.,* 2010).

A case study was made by Pace and Angyalossy (2013) in the wood anatomy and evolution in the family bignoniaceae. They studied important aspects in classical wood anatomy and evolution and test hypotheses regarding patterns of wood evolution using the Bignoniaceae as a model. They found that vessels increase in diameter in the lianoid lineages but decrease in trees and shrubs during evolution. This showed that the rays in trees have evolved from a mixture of homo- and heterocellular to exclusively homocellular and storied in some lineages, while in the lianas the opposite pattern was recorded. Other patterns are consistent with more general phylogenetic trends. The parenchyma increases in abundance from the most basal to the most derived nodes of the phylogeny. Other characters in the family that are delimited and discussed include growth rings, porosity, perforation plates, ray width, and height. This work provides evidence that wood evolution is rather labile and that the evolution of new habits and the occupation of new habitats greatly influence wood evolution.

A study done on the anatomical heartwood characteristics viz., fibre length (μm), diameter of vessels (μm), and the area of the vessels (μm^2 revealed that in the locality Linares, Nuevo Leon, Mexico, with higher precipitation and lower temperature the wood showed higher fibre length and higher diameter of the vessels than China, Nuevo Leon (Carrillo-Parra *et al*., 2013).

Aiming at optimally involving wood research in trait-based ecology, some trait concepts are analysed by Beeckman (2016). He made a study on the relation of wood anatomy and ecology. The time dimension is highlighted in this study and also the foundations for understanding bio-hydraulics, bio-mechanics and metabolism of wood and relevant traits. He discussed about the ecological wood anatomy and dendrochronology and also about Vessels, tracheids and biohydraulics and Fibers, tracheids and biomechanics. They also provide guidelines for implementing wood anatomy in trait-based ecology.

2.5. Literature on vessels

The increasing trend of vessel element's dimensions from pith to outward was reported on different clones of P. deltoides by Chauhan *et al.* (2001). Significant variation in vessel element diameter with pith to outwards increasing trend and non-significant variation of vessel element length was reported by Pande and Dhiman (2011) in some P. deltoides clones. Xeric conditions apparently favoured selection for short elements with simple perforation plate while scalariform ones remained generally restricted to plant taxa with a mesic or alpine ecology (Carlquist, 1975). Xeromorphic woods are generally characterised by an increased number of narrow vessels (Carlquist, 1975; Baas *et al.,* 1983). Conductivity being proportional to the fourth power of vessel radius (Zimmermann, 1983) narrow vessels only allow slow water flow rate however, they are valuable for safety since they guarantee water transport also when large vessels are embolised (Rouffa and Carlquist, 1976).

In arid and semi-arid environments vessel size may be limited also by the need to reduce inter vessel pitting and embolism by air seeding which is a phenomenon described as gas being drawn through pit membrane pores (Wheeler *et al*., 2005; Sperry *et al.,* 2006).

The porosity of pit membranes between adjacent vessels might be designed to solve the conflict between the functional requirements to minimize vascular resistance, which favours thin, porous membranes, and to limit embolism spreading which requires robust membranes and smaller pores. Indeed, a decrease in the total pit area per vessel causes a decrease in the average size of membrane pore and hence an increase in safety from cavitations (Wheeler *et al*., 2005).

Vessel grouping is another phenomena favouring safety, common in arid desert and Mediterranean (Carlquist, 1989). Lens *et al.* (2011) has reported a positive correlation between vessel grouping and cavitations resistance that if a particular vessel in a group embolises, the surrounding active vessels maintain the 3D conductive pathway. In xeric environments, increase in mechanical strength can be guaranteed by the presence of vessels and imperforate tracheary elements with very thick walls and narrow lumen (Sperry, 2003). Larger diameter vessels are more efficient and not so safe, while opposite is true for vessels with small diameter (Alves and Angyalossy, 2002). Vessel diameter should not be linked with sap transport only; since it is also related to the woods with higher or lower mechanical resistance. Therefore, large diameter vessels can lead to weaker woods when compared to woods with smaller diameter vessels. However, it is possible to keep high conductivity and mechanical resistance by combining large vessel diameter with fibres whose walls provide the resistance required of the tissue as a whole (Tyree *et al.*, 1994). A central hypothesis of vascular transport is that xylem safety from water stress induced failure (cavitation resistance) comes at the cost of reduced efficiency of the hydraulic transport system. In many instances plants appear to have efficient xylem vessels suggesting that there is selection against inefficient combination of traits. Xylem traits may reflect specific environmental or ecological/ selected relationships (Hacke *et al.*, 2009).

Trees growing at stressed sites are required to shift towards safety in the water conducting system (Tyree *et al*., 1994) leading to smaller vessel diameter. Survival and competitiveness of tree species depend on their general stress avoidance strategy but also on their ability to adjust and optimize their hydraulic architecture by differences in vessel size and frequency to varying environmental condition from year to year (Fonti *et al.*, 2010). The high variation of vessel diameter with these sites can be attributed to different plant strategies and strong impact of individual tree morphology (Fitchler and Worbes, 2012).

Dickison (2000) mentions in addition to vessel diameter, the danger of embolism is mainly related to the pit features. The small pits (Baas *et al.*, 1983) with small size apertures (Tyree *et al*., 1994; Sperry and Hacke, 2004) offer a strategy to reduce the occurrence of cavitation regardless of vessel size. High vulnerability index is more efficient in transport of water, but more vulnerable to embolism. Studies emphasize the importance of variation in diameter and frequency and vessel grouping to adjust water transport under diverse environmental conditions (Longui *et al*., 2012) Xylem development is suspended growing under pollution stress (Rajput *et al*., 2008).

2.6. Literature on rays

Rays are largely investigated in wood ecological studies (Alves and Angyalossy, 2002). Carlquist (1988) mentioned that more studies comparing the frequency of rays with environmental condition are necessary. 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)**.** Ray height and ray width is greater than in normal wood than in wound altered wood of Aspidosperma quebracho-blanco (Bravo, 2010). Chimelo and Mattos (1988) studied on Brazilian timbers and found broader rays in Brazilian Caatinga and Cerrado vegetation (xeric conditions) species than in more mesic forest species. Studies showed higher rays in species of more xeric habits and environmental stresses in Brazilian species (Halbwachs and Kisser, 1967; Eckstein *et al.*, 1974; Grill *et al*., 1979; Kartusch and Halbwachs, 1985; Luchi *et al*., 2005).

The investment in parenchyma at stressed sites guarantees a better and faster supply with reserves promoting a fast flushing and production of early wood (Dunisch and Puls, 2003) which means that the investment in parenchyma is not random but clearly reflects the mechanisms of carbohydrate storage and mobilization as a function of specific phenological behavior triggered by the dominating and limiting external growth factor. In addition, a higher amount of parenchyma cells may be important in refilling mechanisms of cavitated vessels (Brodersen *et al*., 2010). Trees at less stressed sites seem to be able to invest more carbon in fibre cell structure that promise protection against mechanical and chemical forces while stressed sites require more investment in parenchyma structure to ensure better growth (Poorter *et al*., 2009).

During the second half of 1970's, the ray height curve of the heavily stressed site increased slightly which is similar to the conclusions by Kisser and Halbwachs (1967). Various patterns of discussed trends lead to the inference that a pulse type disturbance on the heavily stressed site has altered growth of tree stem as well as the structure of wood (Fichtler and Worbes, 2012). Novruzova (1972) claims a higher percentage of ray tissue in xerophytic species when compared with those in mesic sites and Chalk (1955) mentioned that wood specimens with narrow rays (eg. Uniseriate rays) have a lower proportion of the wood belonging to ray tissue whereas samples with wider rays have greater proportion of wood found as ray tissue.

2.7. Literature on fibres

The analysis of fibre morphological variations of the Nigerian guinea savannah timber species reveals that there were significant differences in the fibre diameter, fibre length, cell wall thickness and the lumen width of the timber species. Pande (2012) reported an increase in fibre length from base to top in *Populus deltoides*. Fibre length was lesser at the bottom and higher in mid of the Populus species (Kauubaa *et al*., 1998). Yang and Cheng (1990) reported a pattern of increased fibre length from base to top. Fibre length has been defined by Dinwoodie (1965) as one of the major factors influencing the strength properties of paper. It is one among the quality parameters for pulpwood, and it has been investigated extensively in relation to within-tree position and its tree age (Jorge *et al*., 2000). Giving focus on non-wood pulping, it is significant to know the fibre length for interpreting variability also (Han *et al*., 1999). Variations in fibre wall thickness from tree to tree and within individual trees are similar to the patterns of variation in density as a result of the close relationship between these two wood properties (Bhat *el al.*, 1990).

2.8. Literature on dichotomous keys

Diagnostic keys are the most simple and ready to use keys that have been used since earlier times in biological identification (Pankhurst, 1978). Pearson and Brown (1932) published the family-wise dichotomous keys for the identification of major timbers of India belonging to 53 families. Dichotomous keys contain a series of paired contrasting choices, with one or more features used at each dichotomy / couplet. At each couplet, one of the two statements is chosen and is applied to the unknown. The key user is directed to another couplet, and this technique is continued until reaching a name finally (which for wood could be a species, species group, genus, group of genera / family). The author of the dichotomous key will predetermine the starting point and sequence in which the features are used. The unknown sample must match every feature of the taxon as defined in the key and there is normally only one path to one identity.

Computer programs assist in developing keys by estimating the information content of wood characters, and how to use the characters for dividing species into groups (Dallwitz and Paine, 1986). The anatomical key for identification of 26 timber species of Burma was given by Chowdhury (1945). Ghosh (1960) studied the significance of the dichotomous key in the wood sample identification of and explained the way in which how we can use the key. Rao and Juneja (1971) formed the identification key for fifty common commercially important timbers of Indian subcontinent. The manual on "Indian Woods" published by Forest Research Institute (FRI), Dehradun provides dichotomous keys for the identification of major timber species of the Indian sub-continent and Burma.

Dichotomous keys direct the user to look for the characteristics the key constructor considered as necessary in distinguishing characters. Also, a well constructed dichotomous key can quickly help in timber identification. Dichotomous keys are helpful for unknown sample identification, where the possible matches are small in number and for samples without missing characteristics. The longer the key, the more likely there will be an error in choosing the correct descriptor at any one couplet; keys with over 200 taxa are unwieldy (Pankhurst, 1978, 1991). Dichotomous keys are significant, for commercially important woods, in regional works and for woods belonging to a particular genus/family. Some anatomists can recognize that a wood belongs to a particular genus/family, and so can instantly refer to these keys. Otherwise, for determining the genus/family of the unknown sample, it will be significant in using a key (e.g., CSIRO family key) by using lists giving by family occurrence of features (Metcalfe and Chalk, 1950, 1983) or by reading the short, generalized family descriptions in 'Anatomy of the Dicotyledons' (Metcalfe and Chalk, 1950). There is an importance for a family key that can indicate in which family's particular combinations of characters occur, and for that key to be linked to specific publications and keys for genera and families.

The information and data on the anatomical properties in this research is more or less adequate. Although the properties and gross structure of a species can be accepted, in finer details, there can be variation not only between localities, but also within a locality and even within a tree.

MATERIAL AND METHODS

3. MATERIALS AND METHODS

The primary focus is on examination of the shape, size, arrangement and contents of the various cell and tissue types found in wood. Determinations are based on a large set of wood anatomical characters. Each anatomical character has a relative degree of environmental and genetic influence, and as such, specific combinations of characters can serve as diagnostic identifiers of certain taxonomic groups.

Macroscopic examination can be undertaken with the naked eye, or with the aid of a small magnifying hand lens. Microscopic identification requires sectioning a sample, the staining of those sections where required and observation under a light microscope.

The wood samples of 20 tree species were collected from various sawmills across Kerala and from KFRI (Kerala Forest Research Institute). The project aims at studying the physical properties as well as the gross and minute anatomical properties of the currently used (commercially valuable) timbers of Kerala. Heart wood samples of timber species used for the study are described in the Table 1.

Table 1. Samples of the timber species used in the study

Sl. No:	Scientific Name	Trade name	Local name	Family
1	*Acacia auriculiformis* A. Cunn. Ex Benth.	Acacia	Kasia (India) Black wattle	Leguminosae (Fabaceae)
2	*Acacia mangium* Willd.	Mangium	Brown salwood	Leguminosae (Fabaceae)
3	*Albizzia lebbeck* (L.) Benth.	Kokko	Vaga, Lebbek Tree,	Mimosaceae

4	*Albizzia odoratissima* (L.f) Benth.	Kala siris	Kunnivaka, Pulivaka	Leguminosae (Fabaceae)
5	*Artocarpus heterophyllus* Lamk.	Plavu	Jack wood	Moraceae
6	*Artocarpus hirsutus* Lamk.	Ayani	Anjili , Ayani	Moraceae
7	*Dalbergia latifolia* Roxb.	Indian rose wood	Veeti, Eeti, Kariveeti	Leguminosae
8	*Dalbergia nigra* Fr. All.	Brazilian Rosewood	Violet (Kerala)	Leguminosae
9	*Hevea braziliensis* (H. B. K.) M. A	Rubber	Rubber tree	Euphorbiaceae
10	*Hopea parviflora* Bedd.	Malabar ironwood	Thambakam	Dipterocarpaceae
11	*Intsia bijuga* (Colebr.) O. Kuntze.	Merbau	Kwola	Leguminosae
12	*Ocotea rodiaei* (Schomb) Mez.	Green- heart	Cogwood	Lauraceae
13	*Peltogyne paniculata* Benth.	Purpleheart	Violet wood	Leguminosae
14	*Pterocarpus marsupium* Roxb.	Bijasal	Venga	Leguminosae
15	*Pterocarpus dalbergioides* Roxb. ex DC.	Andaman padauk	East-Indian mahogany	Leguminosae
16	*Santalum album* Linn.	Sandal wood	Chandanam (Mal.)	Santalaceae
17	*Swietenia macrophylla* King.	Mahagony	Mahagony	Meliaceae

18	*Tectona grandis* Linn.	Teak	Thekku	Verbenaceae
19	*Xylia dolabriformis* Benth.	Pynkado	Burmese irul (India),	Leguminosae
20	*Xylia xylocarpa* (Roxb.) Taub.	Pynkado	Irul	Fabaceae

The features which were used in the identification studies include:

(a) General features:

These include features which can be directly observed without the aid of a microscope. The major features which studied include:

1. Color
2. Weight
3. Odor
4. Texture
5. Luster

(b) Anatomical features:

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

A. Fiber morphology

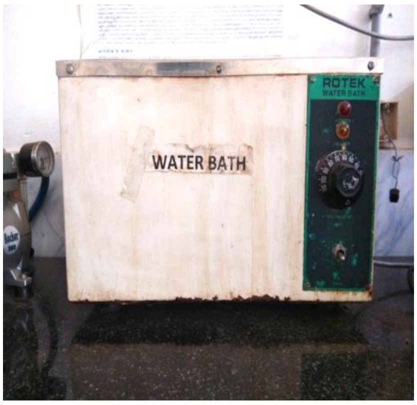
B. Vessel morphology

C. Ray morphology

(C) Physical properties

1. Specific gravity

Plate 1 Materials and equipments used in the study

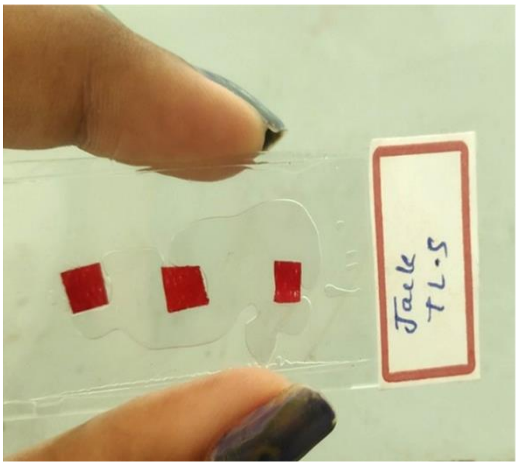


Rotek waterbath

Small block of 1x1x1 cm

Leica Sledge Microtome
(Leica SM 2000R)

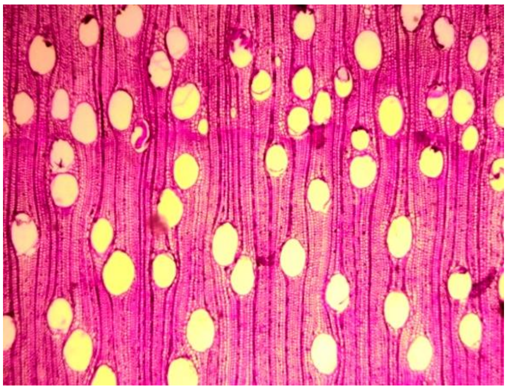
Sectioning using microtome.



TLS of *Artocarpus heterophyllus*

Microslide cabinet

Catcam 500E microscope camera on a Motic BA210 trinocular microscope



Slides under image analyzer

3.1. TECHNICAL PROCEDURES

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

3.1.1. Sectioning (Microtomy)

Blocks of size 1 cm^3 were taken using an electric wood cutter and were soaked in hot water using a Rotek water bath at 70^{o}C for 24 hours. Then small blocks of 1x1x1cm were first chiseled out from the soaked sample for the sectioning. The blocks are then subjected to microtomy. Transverse sections (TS), tangential longitudinal section (TLS), radial longitudinal section (RLS) of 15 - 20 µm thickness were prepared using a Leica Sledge Microtome (Leica SM 2000R).

3.1.2. Staining

Twenty-micron thick transverse, radial and tangential sections were differentially stained using saffranin. The best sections were selected and passed through the alcohol series of 70%, 90%, and 95% for 5 minutes each. These stained sections were passed through acetone for 3 minutes and air dried using a tissue paper to ensure complete dehydration. Then it is kept in 100% xylene for 3 hours. The slides were kept drying for one day. Now the sections are ready to mount in a clean slide using DPX. Finally, they were mounted in DPX mountant to prepare the permanent slides (size 75mm X 25mm, thickness 1mm) and covered by cover slips.

3.1.3. Microscopy

For microscopic examination, 20 µm thick cross, radial, and tangential, microtome sections were used, and observations were taken. Tissue proportion, vessel frequency and tangential diameter were taken from the cross section of wood. Cross, tangential, and radial sections were used to describe the structure of the wood.

3.1.4. Maceration

Small radial chips from the sample blocks were macerated to determine vessel element length, fiber length, and fiber diameter and wall thickness as per Schultz's method (50% Nitric acid and a pinch of Potassium chlorate). The macerated chips were kept in sunlight for two to four days till the chips turns to milky white. The chips were then washed with two to three times water and shake and few drops of saffranin were added. The macerated wood elements were thoroughly mixed and were spread on a glass slide and observations were taken under a compound microscope for vessel element length and fiber length, diameter, wall thickness.

3.1.5. Observations

From the macerated material, observations for fiber length, fiber diameter, wall thickness and vessel element length were taken. Tissue proportions like fibers, vessels, parenchyma, and rays were determined in cross section. The total score of each cell type was obtained by moving the slide from one end to the other both in tangential and radial direction.

3.1.6. Image analysis

Analysis of permanent slides is done with the help of Catcam 500E microscope camera, mounted on a Motic BA210 trinocular microscope. The photomicrography of the transverse, radial and tangential sections and the measurements of the vessels and rays were taken using the software called Catymage image analyzer. The anatomical features covered includes the arrangement, distribution, frequency and size of the various cell elements *viz*; vessel, axial parenchyma and ray parenchyma in the wood. These characters included both microscopic and macroscopic characters. For explaining macroscopic features, terminologies used by Rao and Juneja (1971) were made use of and for describing microscopic features, the IAWA list of microscopic features for hardwood identification (IAWA, 1989) and The timbers of Kerala, an open site of KAU was made use of. The help of highly expertise wood anatomists were also made for the final identification of the wood.

3.2. DATA COLLECTION

3.2.1. Measurement of vessel and ray dimensions

Observations like vessel diameter, vessel frequency from the transverse sections (TS) and ray width, ray height, ray frequency from the longitudinal sections (TLS) were calculated using the image analysis software from the permanent slides prepared. The area of vessel is measured using the polygon tool. The diameter of the vessels, the width and height of the rays were calculated using the line tool. The frequency of the vessel is calculated by counting randomly selected area per field and using the equation; Vessel frequency = number of vessels x 10^6/area in μm^2. The ray frequency is calculated using the line tool. The number of rays covering one-meter straight line gives the frequency of ray per µm.

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 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 centered on the pore. It should be noted that vasicentric parenchyma isn't always visible with a hand lens. If 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 neighboring 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 semicircular 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, colored deposits and other special features were also analyzed.

3.2.3. Analysis of physical properties

Physical properties like moisture content (MC), specific gravity (SPG) and shrinkage (radial and tangential) was analyzed in the wood anatomical studies. In this study the specific gravity of the wood specimens was determined. 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 3x3x3cm 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: Specific gravity = oven dry weight / green volume. Volume of water displaced by water-soaked wood Specific gravity is density of water at normal room temperature which is 1g/cc.

3.3. IDENTIFICATION PROCEDURES

One of the major tasks about doing wood identification is knowing to what level (family, genus, species group, or species) a wood can be identified and when to be satisfied with an identification. Isolated pieces of wood usually cannot be identified to species, and often not to a single genus. There are no all purpose rules. The level to which identification can be done varies within and between families. Identification by comparison is one of the most frequently used methods of identification and is the basis of most natural history field guides (Pankhurst, 1978). Wood anatomical atlases are the equivalent of such field guides. A particularly valuable atlas is the CSIRO Hardwood Atlas (Ilie, 1991) that has photographs without text descriptions of some 1800 species (cross, radial, and tangential sections are illustrated) and were intended to be a portable wood anatomical slide collection.

3.3.1. Comparison

Identification by comparison is one of the most frequently used methods of identification and is the basis of most natural history field guides (Pankhurst, 1978). Data in tabular form are particularly valuable for showing which combinations of features are useful for distinguishing between small groups of closely related woods or woods of similar appearance. Brazier and Franklin (1961) provided tables useful for distinguishing related species of some genera, related genera, and unrelated woods that appear similar.

3.3.2. Dichotomous key

Dichotomous keys present a series of paired contrasting choices, with one or more features used at each dichotomy / couplet. At each couplet, one of the two statements is chosen as applying to the unknown. The key user is directed to another couplet, and this process is continued until finally reaching a name (which for wood could be a species, species group, and genus, group of genera or family). The starting point and sequence in which features are used are predetermined by the author of the dichotomous key. The unknown must match every characteristic of the taxon as defined in the key and there is usually only one path to one's identity.

Dichotomous keys direct the observer to look for the features the key constructor considered, useful for distinguishing features; a well-constructed dichotomous key can quickly lead to identification. Dichotomous keys are useful for unknown species for which there is a small number of possible matches and for material with all features. They are particularly useful as regional works, and for commercially important woods, and for woods of a particular family or genus.

3.3.3. Multiple entry keys

The simplest multiple entry key is the called synoptical key, which lists for each diagnostic, feature the taxa that have that feature. These keys have the advantage that the sequence of characters used in an identification procedure is inspired by the unknown wood sample, not by the author of the key. Apparently, the first application of multiple entry card keys was for wood identification (Clarke, 1938; Pankhurst, 1991). In such card keys, there is one card per taxon.

Cards have perforated edges, the perforations are numbered sequentially, and each numbered perforation represents one feature. Usually, if some wood has a particular feature the edge of the card will be notched to indicate presence of that particular feature. To identify an unknown, 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. The cards with feature present fall out. The sorting process is repeated until a single or only a few cards remain.

3.3.4. Computer-aided wood identification

Many of the identifications done in an institution are of woods from nearby, so that it is sensible to ensure that there is a comprehensive database for that region, and a quick, easy, and reliable means of identifying the woods of a particular region. Data collected at one institution can be shared with others, with the data transmitted on paper, on diskette, or electronically via the internet. In this study, major two websites were approached for the identification processes. They were “Inside wood” (http://insidewood.lib.ncsu.edu/search) and “Timbers of Kerala” (http://trees.kau.edu/index.php). For describing microscopic features, the IAWA list of microscopic features for hardwood identification was made of. A ‘handbook of lesser-known timbers’ by Bhat *et al*. (2007) was also referred. The number of features in the IAWA list (163 anatomical and 58 miscellaneous features) exceeds the number that could be accommodated on marginally perforated cards, and allows more complete description of woods, which enables to distinguish a greater number of species.

So, using the above materials and methods an anatomical key for the species under this study were prepared which will be useful for the identification of the currently used timbers. This study provides detailed information about the general features and gross anatomical properties, which are useful in the identification and efficient utilization of 10 commercially important timbers currently used in Kerala. A dichotomous field key based on general features and gross anatomical features is also provided.

RESULTS

4. RESULTS

Twenty different timber species of economic importance collected from various timber markets across Kerala were studied in this work. Microscopic characteristics of the wood such as abundance and pattern of parenchyma, resin canals and tyloses (as seen in 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 anatomy

4.1.1. *Acacia auriculiformis A. Cunn. ex Benth*

Trade Name: Acacia

Local: Akasia (Indonesia): Australian Babul, Australian wattle, Acacia, Kasia (India)

Family: Leguminosae (Fabaceae)

Tree: A medium-sized tree reaching about 20m in height and 90cm in diameter. The species has become naturalized in many parts of India including Kerala. Origin (Distribution): An exotic tree. Native to Papua New Guinea (PNG), Australia and Solomon Islands; introduced into many tropical countries as a fast-growing species for pulp wood.

General features:

Colour: Heartwood is light brown to dark red; clearly demarcated from the yellowish white sapwood.

Weight: Moderately heavy (Air-dry specific gravity 0.60-0.75 with average values of 0.72)

Grain: Straight or wavy

Texture: Fine

Strength: Strong

Drying and Shrinkage: Dries easily; shrinkage (Green)-radial (2.66%), tangential (5.34%), volumetric (7.84 %).

Durability: Moderately durable

Treatability: Moderately resistant to treatment.

Working Properties: Planning-easy; boring-easy; turning-easy; nailing-satisfactory; finish-good.

Gross features:

Growth rings: Fairly distinct.

Wood structure: Diffuse porous wood.

Vessels - solitary and in radial multiples of two to three, diameter - 100 - 200 µm, frequency 5-20, length - <= 350 or 350 –800µm. Intervessel pits alternate, polygonal.

Fibres - non-septate, thin- to thick-walled, with simple to minutely bordered pits, length – 900-1600 or >=1600µm.

Axial parenchyma ,vasicentric, confluent, fusiform, two cells per parenchyma strand. Ray procumbent, width 1 to 3 cells, frequency - 4-12/mm^2. Prismatic crystals present.

Uses:

Used for furniture making and construction purposes. Mainly used for pulp wood production. Suitable for door and window shutters, light construction, furniture, flooring, industrial and domestic wood ware, tool handles, turnery articles, carom coins, agricultural implements, charcoal etc.

4.1.2. *Acacia mangium* Willd.

Trade Name : Mangium

Local: Brown salwood, Black wattle, Hickory wattle (Aus.)

Family: Leguminosae (Fabaceae)

Origin (Distribution): An exotic, native to Australia, Papua New Guinea and Indonesia; widely cultivated in different parts of Kerala. Tree : A medium-sized tree, reaching a height of 10-18 m and a diameter of 60-70 cm.

General features:

Colour: Heartwood is yellowish brown and sapwood is creamy white in colour.

Weight: Moderately hard and moderately heavy (70 kg/m^3 at 12 % m. c)

Grain: Straight to interlocked

Texture: Medium to fine

Strength: Strong

Drying and Shrinkage: Dries slowly, kiln-dries fairly rapidly but marked collapse may occur during the early stages of seasoning; collapse may be remedied by reconditioning; shrinkage- tangential (6.1%), volumetric (8.3 %) and radial (2.2 %).

Durability: Moderately durable, inner heart wood is subjected to heart rot. The wood is liable to be attacked by termites on ground contact.

Treatability: Moderately resistant to treatment. Working Properties: A tough and hard timber easy to work with hand tools. Planing-easy; boring easy; turning-easy; nailing-easy; good finish.

Gross features:

Growth rings: Fairly distinct.

Wood structure: Diffuse porous wood.

Vessels: solitary and in radial multiples of two to three; large to medium-sized; moderately numerous (10-16 per mm^2). Soft tissue forming a sheath around vessels.

Rays: fine, numerous and closely spaced. Rays one to three-cell wide, homogeneous.

Parenchyma: paratracheal and vasicentric.

Uses:

Used for furniture making, agricultural implements and construction work. Mainly used for pulp wood production. Suitable for door and window frames, cabinet making, light structural work, moldings, boxes, crates, paneling and turnery, sports goods and charcoal. It is used as a component of composite wood products.

4.1.3. *Albizia lebbeck* (Linn.) Benth.

Trade Name: Kokko

Local: Vaga, Lebbek Tree, Flea Tree, Frywood, Koko, Woman's tongues tree

Family: Mimosaceae

Origin (Distribution): Indomalaya, New Guinea and Northern Australia

Tree : Medium to large, about 20m in height and 65 cm in diameter. Bark grey to dark brown, rough, irregularly cracked.

General features:

Colour: Sapwood whitish or yellowish-white, heartwood brown or chocolate color with dark streaks, fairly lustrous.

Weight: Moderately heavy, 640kg/m^3 at12% m.c. Specific gravity 0.40-0.75.

Grain: Straight to wavy or interlocked

Texture: Coarse

Drying and Shrinkage: Moderately refractory. Shrinkage green-oven dry: radial-2.9%, tangential 5.8%

Durability: Very durable. Treatability: Heartwood partially treatable. Working Properties:

Difficult to saw, machining not satisfactory, can be worked to a fine smooth surface and takes good polish.

Gross features :

Wood structure: Diffuse-porous.

Growth rings: distinct, indistinct or absent.

Vessels - diameter 100 – 200 or >=200µm. 0-20/mm^2, length 0 - 800µm. Gums and other deposits in heartwood vessels. Intervessel pits alternate, polygonal. Septate or non-septate, thin- to thick-walled fibres with simple to minutely bordered pits are present. Fibre length – 900-1600µm.Axial parenchyma diffuse, vasicentric, aliform, lozenge-aliform, confluent, in marginal or in seemingly marginal bands, 3 – 10 seriate.

Ray – procumbent, 4-12 /mm^2.

Prismatic crystals present.

Uses:

Used for making class I general purpose plywood, decorative panelling, tea chests, blockboards, door shutters, furniture and cabinets, construction paraquet, musical instuments, mathematical and drawing instuments, tool handles; shafts of carts, lorry body.

4.1.4. *Albizia odoratissima* (L.f.) Benth.

Trade Name: Kala siris

Local: Kunnivaka, Pulivaka

Family: Leguminosae

Origin (Distribution): Southern moist mixed deciduous, Southern dry mixed deciduous and West coast semi-evergreen forests.

Tree : Medium-sized tree, about 20 m in height and 100 cm in diameter.

General features:

Colour: Sapwood white or yellowish white. Heartwood brown to dark brown with darker streaks and lustrous.

Grain: straight to wavy or interlocked.

Texture: coarse textured.Strength: moderately hard to hard.

Drying and Shrinkage: Moderately refractory. Shrinkage-radial 3%, tangential 5.2%.

Durability: Very durable.

Treatability: Heartwood very resistant to treatment.

Working Properties: Difficult to saw, machining not satisfactory, can be brought to a fine smooth surface.

Gross features :

Growth rings distinct.

Wood structure: Diffuse porous wood.

Vessels: mostly solitary; rarely in radial multiples of two to three. Vessel outline circular and is filled with brownish gummy deposits. Vessel element length ranges from 240 to 660 µm with a mean of 390 µm. Tangential diameter of vessel element ranging between 210 and 300 µm with a mean of 260µm.

Perforation simple. Inter-vessel pitting alternate; pit outline polygonal. Pits are large (8 to 13 µm) and vestured. Vessel-ray pitting similar to inter-vessel pitting in size and shape.

Parenchyma: paratracheal and apotracheal; paratracheal parenchyma aliform with a tendency to be confluent or banded. Apotracheal parenchyma scattered and in terminal bands. Crystals in chambered axial parenchyma cells. 3-4 cells per parenchyma strand.

Rays: one to three seriate, homogeneous. Number of rays per mm 5-9, ray height ranges from 160 - 450 µm with a mean of 260 µm.

Fibres: thin walled and septate with minute simple pits on radial walls. Length of fibre ranges from 990 to 1880 µm with a mean of 1430 µm.

Uses:

Plywood manufacturing, furniture and cabinets; building and bridge construction, railway sleepers, mathematical and engineering instruments, carts and carriages.

4.1.5. *Artocarpus heterophyllus* Lam.Syn.

Trade Name : Jack wood

Local : Plavu, Pilavu

Family: Moraceae

Origin (Distribution): West coast tropical evergreen and southern hill-top tropical evergreen forests and Western Ghats commonly in Deccan, warmer parts of the countries like West Bengal, Bihar and Manipur; widely cultivated

Tree: A medium to large, evergreen tree reaching 18-25 m in height and 120 cm in diameter.

Bark thick and blackish, mottled with black and green, rough with warty excrescences.

General features:

Colour: Heartwood yellow to yellowish brown or pinkish brown with darker streaks, lustrous when first exposed. Sapwood is greyish or pale yellow.

Weight: Moderately hard and moderately heavy. 555 kg/m^3 at 12% m.c

Grain: Straight to interlocked.

Texture: Coarse to medium

Drying and Shrinkage: Seasons well when open stacked after conversion without trouble or degrade. The converted material stacked in open piles with good circulation of air through the stock, gives best results. Kiln-drying schedule III is recommended.

Shrinkage: Volumetric – 5.72% (green to oven dry).

Durability: Very durable.

Treatability: Heart wood is resistant to treatment.

Working Properties: Easy to saw and work, can be brought to a smooth finish and takes good polish.

Gross features :

Growth rings: Indistinct to distinct, when distinct, demarcated by slightly denser and darker coloured latewood fibrous tissues.

Wood structure: Wood diffuse porous.

Vessels: solitary and in radial multiples of two to three; large to medium-sized, clearly visible with a hand lens; few to moderately numerous (2-5 per mm^2), oval to round in outlines, often filled with white chalky deposits or tyloses.

Soft tissue forming light coloured halos around vessels often extending sideways joining similar extensions and sometimes forming bands. Parenchyma : paratracheal- vasicentric to aliform.

Rays: moderately broad to fine, few and widely spaced and uniformly distributed, forming inconspicuous flecks on the radial surface; clearly visible to the unaided eye.

Uses:

A multipurpose constructional timber also used for furniture and cabinets, carving, turnery, class II plywood and veneers, marine plywoods and concrete shuttering plywood, blockboard, flush doors, musical, mathematical, engineering and drawing instruments, lorry, bus bodies and brush ware. In boat building, they are recommentrials for hull planking, decking, ribs, stringers, flooring transom and dugouts.

4.1.6. *Artocarpus hirsutus* Lamk.

Trade name: Aini

Local: Anjili, anyani

Family: Moraceae

Tree: Large to very large, 25-45 m in height with a clear bole of 10-20 m and up to 130 cm in diameter.

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

General features:

Colour: Sapwood greyish or yellowish-white, heartwood golden yellow to yellowish- brown, lustrous when first exposed.

Hardness: Moderately hard.

Grain: Straight to interlocked; texture medium.

Natural durability and preservation: Durable

Gross features:

Gross structure: Diffuse- porous.

Growth rings: Indistinct

Vessels: Very large to large, few, solitary or in radial multiples of 2 or 3; often filled with tyloses or white chalky deposits. Vessel diameter ranges from 139 µm – 198 µm with a mean of 163 µm. Vessel area ranges from 13169 µm - 26953 µm with a mean of 19356 µm. Vessel frequency ranges from 2 no. /mm^2 – 4 no. /mm^2 with a mean of 4 no./mm^2.

Parenchyma: Paratracheal - vasicentric to aliform.

Rays: Moderately broad to fine, fairly wide spaced. Four to five seriate, heterogenous type-II showing tendency to homogeneity. Ray width ranges from 32 µm – 82 µm with a mean of 55 µm. Ray height ranges from 451 µm – 1173 µm with a mean of 884 µm. Ray frequency ranges from 4 no. /mm - 6 no./mm with a mean of 5 no./mm. Fiber length ranges from 1180 µm - 2420 µm with a mean of 1880 µm.

Uses:

Boat and shipbuilding; vehicle bodies; beams, rafters, window, door frames and ceiling boards; furniture and cabinets; turnery; piles; flush door shutters; Class I plywood and veneers; marine plywood; blackboards; tool handles; fence posts; textile mill accessories; cooperage; hurdles for sports; mathematical, engineering and drawing instruments; brush ware; carts and carriages.

4.1.7. *Dalbergia latifolia* Roxb.

Trade name: Rosewood

Local: Veeti

Family: Fabaceae (Papilionaceae)

Tree: Medium to large, 15-30 m in height and up to 130 cm in diameter Bark grey with cracks, peels off in thin flakes.

Distribution: West coast semi-evergreen moist teak bearing and Southern secondary moist mixed deciduous forests.

General features:

Colour: Sapwood pale yellowish-white with pinkish tinge and heartwood purplish-brown with black or red streaks, colour uniform.

Hardness: Hard

Grain: Straight to shallowly interlocked; texture medium.

Natural durability and preservation: Very durable, sapwood perishable but readily treatable with complete penetration.

Gross features:

Gross structure: Diffuse-porous, rarely with a tendency to semi- ring -porous.

Growth rings: Scarcely distinct.

Vessels: Large to small, few to moderately numerous, solitary or often in short radial multiples; occasionally filled with gummy deposits. Vessel diameter ranges from 189 µm - 233 µm with a mean of 213 µm. Vessel area ranges from 28029 µm – 55187 µm with a mean of 38328 µm. Vessel frequency ranges from 3 no./mm^2 – 4 no./mm^2 with a mean of 3 no./mm^2

Parenchyma: Paratracheal - aliform to confluent and banded, also fine or interrupted lines delimiting growth rings.

Rays: Fine to very fine, visible only under lens, numerous, closely spaced. One to three seriate, homogenous to nearly heterogenous type-III. Ray width ranges from 24 µm - 36 µm with a mean of 27 µm. Ray height ranges from 113 µm - 169 µm with a mean of 141 µm. Ray frequency ranges from 10 no./mm - 16 no./mm with a mean of 13 no./mm. Fiber length ranges from 1110µm - 1770 µm with a mean of 1385 µm.

Uses:

One of the best known Indian timber for high class furniture and cabinets; construction of buildings; flush door shutters; Class I plywood; decorative plywood; air- craft plywood; marine plywood for face veneers; tool handles; artificial limbs and rehabilitation aids; textile mill accessories; chess pieces, discus and carrom draughts; musical instruments; engineering instruments: bentwood articles; handicrafts.

4.1.8. Dalbergia nigra **Fr. All.**

Trade Name : Rosewood - Brazilian

Local: Jacaranda (Brazil), Violet (Kerala)

Family: Leguminosae

Origin (Distribution): Latin American countries like Brazil.

Tree : Sometimes attains a height of 38 m with short irregular bole, often buttressed, trunk diameter ranges from 90 to 120 cm.

General features:

Colour: Sapwood pale in colour and irregularly demarcated from heartwood. Heartwood violet or purplish in colour with dark streaks; a highly decorative wood.

Weight: Moderately heavy

Grain: Straight.

Texture: Coarse

Strength: Moderately hard to hard

Drying and Shrinkage: The timber needs to be dried slowly to prevent checking. Shrinkage: radial- 2.9%, tangential- 4.6%, volumetric- 8.5%, T/R ratio- 1.6. Durability: durable

Treatability: Extremely difficult to treat

Working Properties: Easy to work with both hand and machine tools, though it may have a slight blunting effect on cutting edges. Brazilian Rosewood turns, and finishes well, though it can sometimes be difficult to glue due to its high natural oil content.

Gross features:

Wood structure: Diffuse porous wood.

Growth rings: not distinct but sometimes demarcated by the presence of parenchyma band.

Vessels: solitary with circular vessel outline, filled with dark gummy deposits. Vessel element length ranges from 330 to 640 µm with an average of 410 µm.

Tangential diameter ranges from 210 to 380 µm with a mean of 260 µm. Perforation simple. Inter-vessel pitting alternate, individual pit outline polygonal. Pits medium to large (7 to 12 µm) and vestured. Vessel-ray pitting similar to inter-vessel pitting in size and shape.

Parenchyma: apotracheal and paratracheal; apotracheal parenchyma in three to five cell wide continuous bands and paratracheal as aliform lozenge type with a tendency to be confluent. Number of parenchyma cells per strand two to four. Chambered crystalliferous cells with rhomboidal crystals present.

Rays: broad to moderately broad, moderately numerous and widely spaced, 3-4 cells wide, homogeneous wholly made up of procumbent cells. 5-7 rays per mm. Ray height ranges from 530 to 840 µm with an average of 680 µm.

Fibres: thin to thick walled, both septate and non-septate. Fibre length ranges from 1120 to 1910 µm with an average of 1480 µm.

Uses:

Mainly used in furniture industry because of its attractive figure. Also used for making cabinets and decorative veneer.

4.1.9. *Hevea braziliensis* (HBK) Muell. Arg.

Trade Name : Rubber

Local: Rubber tree

Family: Euphorbiaceae

Origin (Distribution): Native of Brazil; raised extensively in plantations of Malaysia, Indonesia, Thailand, SriLanka and India for latex production.

Tree: Large tree reaching a height of 30m and diameter of 40-70 cm, bark greyish-black, smooth.

General features:

Heartwood and sapwood are not distinct.

Colour: Wood is white to creamy in colour when freshly cut, sometimes with a pinkish ting,turns to light brown or creamy white on exposure.

Weight: Light to moderately heavy; (525-610 kg/m³ at 12% m. c).

Grain: Straight

Texture: Even and medium textured

Strength: Moderately strong

Drying and Shrinkage: Dries easily; but care is needed to avoid seasoning defects such as cupping, twisting, bowing, checking and splitting; a conventional kiln seasoning (steamheated, forced-air drying system) is preferred in drying, shrinkage-radial (1.2%), tangential (1.8%), volumetric (3.0%)

Durability: Perishable, the wood has to be treated with preservatives soon after felling (preferably with for 48 hrs.) Liable to discolouration caused by sap stain fungiand attack by pinhole and powder post beetles.

Treatability: Easy. Simple dip treatment or vacuum pressure impregnation process with preservatives such as borax-boric acid and copper-chrome arsenate (CCA) with adequate retention will protect the wood from fungal and insect attack.

Working Properties: Planing-easy; boring-easy; Turning-easy; Nailing-good, but pre-boring necessary; Finish-good. Tension wood can lead to fuzzy grain when machined. Finger jointing is often applied to achieve larger dimensions. Rubber wood can be stream bent with good results. It can easily be stained to resemble teak, rosewood, walnut, cherry, oak or other woods, depending on consumer demand.

Gross features :

Growth ring boundaries indistinct or absent.

Wood structure: diffuse-porous.

Vessel: diameter 100-200 or >= 200μm, 0-20/mm^2, Length <= 350 or 350-800 or >= 800μm. Intervessel pits alternate, polygonal. Tyloses common.

Fibres: Non-septate, thin- to thick- walled, with simple to minutely bordered pits, length <=900 or 900-1600 or >= 1600μm.

Parenchyma: Axial parenchyma in narrow bands or lines up to three cells wide, reticulate, in marginal or in seemingly marginal bands, 5-8 or >=8 cells per parenchyma strand.

Ray: procumbent with mostly 2-4 or >=4 rows of upright and / or square marginal cells , 4 – 10 seriate, with multiseriate portion(s) as wide as uniseriate portions, width 1 to 3 cells,

Frequency 4-12/mm^2. Prismatic crystals present.

Uses:

Used for the manufacture of furniture (dining sets, bedroom sets, lounge sets, rocking chairs) and furniture parts, bentwood furniture, second grade door furniture, dunnage pallets, parquet and strip flooring, paneling, wood-based panels particle board, cement and gypsum bonded, medium-density fibre board, packing cases, match splints and boxes etc. Traditionally it is used for fuel wood and industrial brick burning.

4.1.10. *Hopea parviflora* Bedd.

Trade name: Hopea

Local: Kambagam , thambagam, irumbagam

Family: Dipterocarpaceae.

Tree: Large to very large, 25-40 m in height with a clear bole of 10-20 m and up to 130 cm in diameter; often buttressed Bark light brown, mottled with white, smooth in young trees, changes to rusty brown and rough as the tree grows old.

Distribution: West coast tropical evergreen, Southern hill-top tropical evergreen, west coast semi-evergreen 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, sap- wood and heartwood not distinct.

Hardness: Hard to very hard.

Grain: Broad, shallowly interlocked; texture fine.

Natural durability and preservation: Very durable. Heartwood is very refractory to treatment.

Gross features:

Gross structure: Diffuse-porous.

Growth rings: Scarcely distinct.

Vessels: Medium to small, moderately numerous, solitary or in radial multiples of 2-5 or in oblique grouping; often filled with tyloses and occasionally lemon yellow deposits. Vessel diameter ranges from 168 µm – 227 µm with a mean of 214 µm. Vessel area ranges from 22498 µm - 42333 µm with a mean of 36546 µm. Vessel frequency ranges from 5 no./mm^2 – 7 no./mm^2 with a mean of 5 no./mm^2.

Parenchyma: Predominently apotracheal and diffuse-in-aggregate; paratracheal-vasicentric, inconspicuously confluent, tangential bands embedding resin ducts.

Rays: Moderately broad to fine. Ray width ranges from 50 µm – 76 µm with a mean of 66 µm. Ray height ranges from 253 µm – 640 µm with a mean of 455 µm. Ray frequency ranges from 3 no./mm – 5 no./mm with a mean of 4 no./mm.

Uses:

Beams, rafters and trusses in building construction; planks for ship building; tool handles; poles and posts; railway sleepers; cart and carriages.

4.1.11. *Intsia bijuga*

Trade name: Merbau, Ipil

Local: Kwila (New Guinea), Ipil (Philippines), Merbau (Malaya)

Family: Fabaceae (Leguminosae)

Tree: A large tree often with a rather short, thick bole, sometimes to 50 ft, often fluted; trunk diameters to 5 ft above large spreading buttresses.

Distribution: Indo-Malayan region, Indonesia, Philippines, and many of the western Pacific islands as well as Australia. May be locally common in lowland forests, transition zones behind mangroves.

General features:

Colour: Heartwood yellowish to orange brown when freshly cut, turning brown or dark red brown on exposure; sapwood pale yellow to light buff, sharply demarcated from the heartwood.

Hardness: Moderately hard to hard.

Grain: straight to interlocked or wavy

Natural durability and preservation: Heartwood has an average service life of 6 years in Malayan stake tests but generally reputed to have good durability; highly resistant to termite attack. Sapwood prone to powder is useful for post beetle attack. Heartwood is impermeable, but sapwood is treatable.

Gross features:

Gross structure: Diffuse porous wood.

Growth rings: Distinctly demarcated by the fibre arrangement.

Vessels: Solitary and in radial multiples of two to three, vessel outline circular. Vessel diameter ranges from 188 µm – 411 µm with a mean of 312 µm. Vessel area ranges from 31270 µm – 138724 µm with a mean of 78873 µm. Vessel frequency ranges from 2 no./mm^2 – 5 no/mm^2 with a mean of 4 no./mm^2.

Parenchyma: Axial parenchyma apotracheal and paratracheal; apotracheal parenchyma appearing as narrow, inconspicuous bands demarcating growth rings. Paratracheal parenchyma aliform lozenge type, with a tendency to be confluent, three to four cells per parenchyma strand.

Rays: Two to three seriate, homogenous. Ray width ranges from 45 µm – 60 µm with a mean of 52 µm. Ray height ranges from 319 µm – 668 µm with a mean of 435 µm. Ray frequency ranges from 3 no. /mm - 4 no./mm with a mean of 4 no./mm. Fiber length ranges about 1245 µm.

Uses:

Flooring, furniture making, panelling, fine joinery, decorative turnery, cabinet making, musical instruments, specialty items. The wood is also a source of dye.

4.1.12. Ocotea rodiei (R.H. Schomb.) Mez

Trade Name: Green-heart

Local: Cogwood, Demerara greenheart

Family: Lauraceae

Origin: Northeastern South America

Tree: 23-30 m tall, 5- 6 m trunk diameter

General features:

Color: Heartwood tends to be a pale olive green color with darker streaks. Sapwood is poorly distinguishable from heartwood.

Weight: Average Dried Weight: 63 lbs/ft^3 (1,010 kg/m^3). Specific Gravity >= 0.75.

Grain: straight to interlocked.

Texture: fine to medium

Strength: Strong. Drying and Shrinkage: Dries very slowly with a tendency to check and end split.

Radial: 8.2%,

Tangential: 8.9%, Volumetric: 16.5%, T/R Ratio: 1.1. Durability: very durable

Working Properties: Generally somewhat difficult to work on account of its density, with a moderate to high blunting effect on cutters. Sections with interlocked grain should be machined with care to avoid grain tear out. Gluing can be difficult in some pieces, and precautions should be followed. Turns and finishes well. Responds moderately well to steam-bending.

Gross features:

Growth ring boundaries indistinct or absent.

Wood structure: Diffuse-porous wood.

Vessels: Solitary vessel outline angular. Simple perforation plates present. Intervessel pits alternate, polygonal, size -<= 7µm. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell or Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular. Vessel diameter 100 - 200 µm. Vessel frequency 5 - 40/mm^2. Vessel length 350 -800 µm. Sclerotic tyloses common. Gums and other deposits in heartwood vessels.

Septate and non-septate fibres with simple to minutely bordered pits and very thick walls present.

Fibre length 900-1600 µm. Paratracheal axial parenchyma vasicentric, aliform, lozenge-aliform and unilateral paratracheal. 3-8 cells per parenchyma strand.Ray width 1 to 3 cells. Body ray cells procumbent with one row of upright and / or square marginal cells. Ray frequency 4-12 / mm^2.

Uses:

Boatbuilding, docks, decking, posts, fishing rods, pool cues, and other turned wood items.

4.1.13. *Peltogyne paniculata*

Trade name: Purple heart (Brazil), Amaranth (USA).

Local: Violet wood

Family: Fabaceae

Tree: Semi-deciduous tree with a heavy, umbrella-shaped crown; it can grow up to 4 meters tall. The straight, cylindrical bole has thin buttresses up to 90 cm tall; it can be 90 cm in diameter, with a considerable taper, and can be clear for 18 - 21 meters.

Distribution: Central America and tropical South America from Mexico to southern Brazil.

General features:

Colour: Heartwood colour varies, deep purple-violet when freshly cut, changes to well-known purple, which on prolonged exposure turns to purple-brown, lustrous; clearly demarcated from the whitish or cream coloured sapwood.

Hardness: Moderately hard to hard.

Grain: Straight, sometimes wavy or interlocked.

Natural durability and preservation: Heartwood has an average service life of 6 years in Malayan stake tests but generally reputed to have good durability; highly resistant to termite attack. Sapwood prone to powder-post beetle attack, very durable, resistant to dry-wood termites.

Gross features:

Gross structure: Diffuse-porous

Growth rings: Rings indistinct or absent.

Vessels: Vessels solitary and in short (mostly 2-3) radial multiples. Vessel diameter ranges from 165 µm - µm with a mean of 228 µm. Vessel area ranges from 22040 µm – 38903 µm with a mean of 28588 µm. Vessel frequency ranges from 7 no./mm^2 – 11 no/mm^2 with a mean of 9 no./mm^2.

Parenchyma: Paratracheal parenchyma; aliform and unilateral paratracheal (sometimes confluent); aliform parenchyma is lozenge type. Marginal (or seemingly marginal) banded parenchyma present (bands 2-4 cells wide). Axial parenchyma 4 cells per parenchyma strand.

Rays: Homocellular, typically procumbent. Storied structure not observed. Ray height ranges from 325 µm – 763 µm with a mean of 548 µm. Ray frequency ranges from 4 no./mm – 5 no/mm with a mean of 5 no./mm. Ray width ranges from 47 µm - 65 µm with a mean of 56 µm.

Fiber length ranges from 946µm - 1790µm with a mean of 1348 µm.

Uses:

With high strength and very good durability, an excellent structural timber suitable for heavy outdoor constructional work such as bridges and harbor works, furniture, door and window frames, general carpentry. Suitable for chemical plant as filter-press plates and frames. Used for small turned articles and to a limited scale for decorative veneer inlays. Unsuitable for plywood because of its weight.

4.1.14. *Pterocarpus marsupium* Roxb.

Trade name: Bijasal

Local: Venga

Family: Fabaceae (Papilionaceae)

Tree: Medium to large, 15-30 m in height and up to 100 cm in diameter bark dark brown or grey with shallow cracks; exfoliating in thin flakes, on injury exudes a red gummy substance.

Distribution: Southern moist mixed deciduous, moist teak bearing, West coast semi-evergreen and Southern dry mixed deciduous forests.

General features:

Colour: Sapwood pale yellowish-white, heart- wood golden brown or reddish-brown on exposure. Aqueous extract of wood is characteristic yellowish-blue and fluorescent.

Hardness: Moderately hard to hard.

Grain: Interlocked; texture medium to coarse.

Natural durability and preservation: Very durable. Heartwood very refractory to treatment, however sapwood is treatable.

Gross features:

Gross structure: Diffuse-porous often shows tendency towards semi-ring-porous.

Growth rings: Scarcely distinct

Vessels: Large to medium, few to moderately few, solitary or in radial multiples of 2-4; often filled with gummy deposits. Vessel diameter ranges from 133 µm – 176 µm with a mean of 151 µm. Vessel area ranges from 13568µm – 22692 µm with a mean of 17293 µm. Vessel frequency ranges from 4 no./mm^2 - 6 no./mm^2 with a mean of 5 no./mm^2

Parenchyma: Paratracheal - wavy or straight tangential bands, touching or partially enclosing the pores, often aliform to aliform-confluent.

Rays: Very fine, numerous, closely spaced, one to two seriate, homogenous, made of procumbent cells. Ray width ranges from 19 µm – 29 µm with a mean of 22 µm. Ray height ranges from 78 µm – 154 µm with a mean of 124 µm. Ray frequency ranges from 12 no./mm – 14 no./mm with a mean of 13 no./mm

Fiber length ranges from 1040 µm - 1540 µm with a mean of1260 µm.

Uses:

Constructional purposes like beams, pillars, door and window frames; boatbuilding; bridge construction; tool handles; poles and posts; railway sleepers; jumping and vaulting stands; lorry bodies; spokes and felloes of cart wheels; cups and vessels for drinking water, as water extract of the wood is believed to be beneficial for diabetic treatment.

4.1.15. *Pterocarpus dalbergioides*

Trade name: Padauk

Local: Redwood

Family: Fabaceae

Tree: Reaches a height of 80 to 120 ft, boles straight and cylindrical, clear to 40 ft; trunk diameters 2 to 4 ft above the buttresses.

Distribution: Found only in the Andaman Islands; growing in deciduous and semi moist deciduous forests, usually on or near riverbanks.

General features:

Colour: Sapwood light yellowish brown to grey, narrow; heartwood bright yellowish red to dark brick-red often streaked with darker lines and moulted with brown, lustrous when exposed, ageing to dull yellowish brown; without distinct odour or taste, moderately heavy.

Hardness: Moderately hard to hard.

Grain: Rather coarse; grain generally interlocked

Natural durability and preservation: The heartwood is rated as very durable and also resistant to termite attack. Heartwood is reported to be moderately resistant to preservative treatments; sapwood probably permeable.

Gross features:

Gross structure: diffuse porous to semi ring porous.

Growth rings: distinct.

Vessels: solitary and in radial multiples of two to four, medium-sized and few in number, with deposits inside the vessel. Vessel diameter ranges from 259 µm – 424 µm with a mean of 311 µm. Vessel area ranges from 44922 µm - 91656 µm with a mean of 68629 µm. Vessel frequency ranges from 1 no./mm^2 – 4 no./mm^2 with a mean of 2 no./mm^2.

Parenchyma: Ranges through vasicentric, aliform, confluent and narrow banded (two to five cells wide).

Rays: fine, moderately numerous and closely spaced forming ripple marks on tangential surface. One to two seriate, homogenous wholly made up of procumbent cells; filled with gummy infiltrations. Ray width ranges from 28 µm - 36 µm with a mean of 33 µm. Ray height ranges from 172 µm - 266 µm with a mean of 224 µm. Ray frequency ranges from 10 no./mm - 12 no./mm with a mean of 12 no./mm.

Fiber length ranges from 740 µm - 1520µm with a mean of 1250 µm.

Uses:

Joinery, flooring, furniture, decorative veneers, panelling, parquet, cabinetwork.

4.1.16. *Santalam album* L.

Trade Name : Sandal wood

Local: Santanam (Tam.), Chandanam (Mal.)

Family: Santalaceae

Origin (Distribution): Occasional in Southern dry mixed deciduous forests in Marayur (Idukki district); also cultivated to limited extent.

Tree: Small,7-10m height and 15-25cm diameter, semi parasitic tree with slender branches.

General features:

Colour: Sap wood whitish or pale brown, heartwood light yellowish- brown to dark brown

Lustrous.

Weight: Heavy, 945kg/m^3 at 12%m.c.

Grain: Straight to slightly wavy. Texture: Fine

Drying and shrinkage: Shrinkage: radial-5.2-7.7%, tangential-7.3-11.3%. Once dried the wood often shows considerable movement in service seasons well.

Durability: Very durable

Treatability: Treatable, but complete penetration not always obtained.

Working Properties: Easy to saw, turns well to a fine smooth surface and takes good polish.

Gross features :

Growth rings: Distinct, indistinct or absent.

Wood structure: Diffuse-porous.

Vessels exclusively solitary. Intervessel pits alternate. Vessel - diameter 50 - 100 µm, length <= 350 µm, frequency 20 – 40/mm^2. Gums and other deposits in heartwood vessels. Non-septate, thin- to thick-walled fibres with distinctly bordered pits are present. Fibre length 920-1380µm.Axial parenchyma diffuse, diffuse-in-aggregates. 2-4 cells per parenchyma strand.

Rays : procumbent with one row of upright and / or square marginal cells, 1 to 3 cells width, Frequency 4-12 /mm^2. Prismatic crystals present.

Uses:

The scented heartwood is the most valuable portion of the Sandalwood, prized for the manufacture of small boxes, frames and other small nick-necks which are often beautifully carved; wood yields sandal wood oil on distillation which is used as scent in perfumery and cosmetics, also has medicinal value.

4.1.17. *Swietenia macrophylla* king.

Trade name: Mahogany

Local: Honduras mahogany, Guatemala mahogany, Brazilian mahogany, Mogno (Brazil), Zopilote, Chiculte (Mexico).

Family: Meliaceae

Tree: A medium sized tree reaching a height of 12-18 m and a diameter of 80-130 cm.

Distribution: Native to Central and South America, particularly Mexico and Honduras, and introduced to many tropical countries including India. It is widely cultivated as an avenue tree.

General features:

Colour: Heartwood colour varies from light reddish or yellowish brown to dark reddish brown, lustrous. Sapwood is yellowish white to pale brownish gray.

Hardness: moderately hard and heavy

Grain: Straight to interlock. Flat-sawn surface produce prominent growth ring figure.

Natural durability and preservation: Moderately durable and extremely resistant.

Gross features:

Gross structure: Wood is diffuse porous.

Growth rings: Growth rings distinct.

Vessels: Vessels solitary and in radial multiples of two to three, medium-sized, moderately numerous (10-15 per mm^2). Soft tissue banded and forms incomplete sheaths around vessels. Pores usually stained or discoloured, darker, are large and evenly spread through the wood. Vessel diameter ranges from 134 µm – 186 µm with a mean of 168 µm. Vessel area ranges from 13176 µm – 25112 µm with a mean of 19728 µm. Vessel frequency ranges from 7 no. /mm^2 – 10 no. /mm^2 with a mean of 8 no. /mm^2.

Parenchyma: Scanty para tracheal and banded with four to five cells wide bands. Five to eight cells per parenchyma strands.

Rays: Rays fine to moderately broad, few and widely spaced. Rays can be seen clearly on radial-cut surfaces as smooth plates which reflect the light. One to three seriate, heterogenous type-III. Ray width ranges from 125 µm – 165 µm with a mean of 143 µm. Ray height ranges from 143 µm – 472 µm with a mean of 324 µm. Ray frequency ranges from 5 no./mm - 7 no./mm with a mean of 6 no./mm.

Fibre: Thin walled, septate with minute pits on radial walls. Fibre length ranges from 1010 µm - 1640 µm with a mean of 1350µm.

Uses:

High class furniture and cabinet making, paneling and Interior joinery, boat interiors, musical instruments, show cases, counters and interior decoration, jewellery boxes, carvings, rotary cut logs for ply wood and sliced veneers for decorative work.

4.1.18. *Tectona grandis* Linn.

Trade name: Teak

Local: Kyun (Burma), Teck (French). Teca (Spanish).

Family: Lamiaceae

Tree: On favorable sites, may reach 130 to 150 ft in height with clear boles to 80 to 90 ft; trunk diameters usually 3 to 5 ft; older trees fluted and buttressed.

Distribution: Native to India, Burma, Thailand, Indochina, including Indonesia, particularly Java. Extensively cultivated in plantations within its natural range as well as in tropical areas of Africa and Latin America.

General features:

Colour: Heartwood dark golden yellow, turning a dark brown with exposure, often very variable in colour when freshly machined showing blotches and streaks of various shades; sapwood pale yellowish, sharply demarcated.

Hardness: Moderately hard and moderately heavy.

Grain: straight, sometimes wavy.

Natural durability and preservation: Heartwood is rated as very durable with respect to decay fungi and termites; not immune to marine borers. Heartwood is extremely resistant to preservative treatments. Sapwood also shows low permeability.

Gross features:

Gross structure: Wood is ring porous.

Growth rings: Growth rings are distinct, delimited with early wood vessels enclosed in parenchymatous tissues, less than 1-6/ cm.

Vessels: Vessels large in early wood, oval in out line, occasionally filled with tyloses and yellowish-white powdery deposits. Vessels are medium to small in late wood. Mostly solitary or in short radial multiples, round to oval in out line, vessel lines of the early wood zone conspicuous on longitudinal surfaces. Vessel diameter ranges from 107 µm – 169 µm with a mean of 141 µm. Vessel area ranges from 11816 µm – 202922 µm with a mean of 16224 µm. Vessel frequency ranges from 7 no./mm^2 - 10 no./mm^2 with a mean of 8 no./mm^2

Parenchyma: Parenchyma paratracheal- vasicentric and in broad bands, distinct under the hand lens but distinct to the eye in the early wood forming a continuous zone enclosing the vessel along with initial band of parenchyma delimiting growth rings.

Rays: Rays moderately broad, fairly wide spaced and uniformly distributed; visible to the eye, distinct under the lens. 3-4 cell wide. Homogenous, wholly made up of procumbent cells showing a tendency towards heterogeneity (type-I) with one or two marginal rows of square cells. Ray width ranges from 125 µm – 165 µm with a mean of 143 µm. Ray height ranges from 245 µm - 816 µm with a mean of 464 µm. Ray frequency ranges from 4 no./mm – 5 no./mm with a mean of 4 no./mm.

Fiber length ranges from 920 µm - 1800 µm with a mean of 1435 µm.

Uses:

Ship building, joinery, furniture, flooring, carving, cabinet work, panelling, turnery, tanks and vats, fixtures requiring high resistance to acids.

4.1.19. *Xylia dolabriformis* Benth.

Trade Name : Pyinkado

Local: Varavu irul, Burmese irul (India), Pyin, Pyinkado (Myanmar)

Family: Leguminosae

Origin (Distribution): Burma and north-eastern parts of India. But widely imported from South East Asian countries.

Tree : Tree grows to a height of 30-37 m with straight, cylindrical bole.

General features:

Colour: Sapwood pale pinkish and heartwood dark yellowish brown with darker streaks;

darkens on exposure.

Weight: heavy to moderately (Air-dry specific gravity approx. 1.0)

Grain: Straight, wavy or broadly interlocked.

Texture: medium coarse.

Strength: very strong and hard.

Drying and Shrinkage: Dries slowly; with thick material moisture removal is difficult from the centre of the planks; kiln- seasoning recommended; tendency to surface check and split and to distort. Shrinkage- radial (3.3%), tangential (6.7%), volumetric (10.0%)

Durability: Very durable, highly resistant to termite attack.

Treatability: Extremely resistant to treatment.

Working Properties: Difficult to saw when green; wavy and interlocked grain affects machining properties; contains varying amounts of resin which may affect staining and polishing; Blunting- severe; Planing- moderately easy; Boring - moderately easy; Turning- easy; Nailing- poor, preboring necessary; Finish- good

Gross features :

Wood structure: Diffuse porous.

Growth rings fairly distinct due to the presence of fibrous zone.

Vessels: solitary and in radial multiples of two to three, medium-sized and visible to the naked eye, scanty to moderately numerous (12-20 vessels per mm^2) often filled with abundant tyloses. Tangential diameter ranges from 210 to 280 µm with an average of 235 µm. Vessel element length ranges from 455 to 700 µm with an average of 550 µm. Perforation simple.

Inter-vessel pitting alternate, individual pit outline polygonal in shape. Pits medium to large in size, ranging from 8 to 12µm, vestured. Vessel-ray pitting similar to inter-vessel pitting in size and shape and occurs throughout the ray cell.

Parenchyma - scanty paratracheal, vasicentric to aliform and apotracheal parenchyma as diffuse in aggregates also present; three to four cells per strand. Chambered crystalliferous cells present. Soft tissue forming narrow bands indistinct even with hand lens and also forming a sheath around vessels.

Rays fine to moderately broad, rarely visible to the naked eye, moderately numerous, one to three cell wide, homogeneous wholly made up of procumbent cells. Number of rays 5 to 7/mm, individual ray height ranges from 190 to 840 µm with a mean of 480 µm. Fibres thick walled, non-septate, length ranges from 790 to 1745 µm with an average of 1260 µm.

Uses:

Suitable for heavy, structural work as in piling, bridges and harbour work. As a flooring timber it has high resistance to abrasion and makes a decorative floor suitable for public building. Also used for high quality furniture, posts, beams, railway sleepers, tool handles and boat building. Unsuitable for plywood because of its weight.

4.1.20. *Xylia xylocarpa* (Roxb.)Taub.

Trade name: Irul

Local name: kadamaram, Irul

Family: Fabaceae (Leguminosae).

Tree: Medium to large, 15-25 m in height and up to 70 cm in diameter. Bark is reddish-grey, exfoliating in thick irregular flakes.

Distribution: Southern moist mixed deciduous and west coast semi-wood evergreen forests. Occasional in west coast secondary evergreen dipterocarp forest.

General features:

Colour: Sapwood is pale brownish or pinkish-white, heartwood is light to dark reddish-brown, often with dark streaks.

Hardness: Hard to very hard.

Grain: Straight lo interlocked; texture medium to fine.

Natural durability and preservation: Very durable. Very refractory.

Gross features:

Gross structure: Diffuse-porous

Growth rings: Fairly distinct

Vessels: Medium to small, moderately few to moderately numerous, solitary or in short radial multiples of 2-3 or rarely more; filled with orange-brown or reddish-brown gummy deposits. Vessel diameter ranges from 153 µm - 182 µm with a mean of 166 µm. Vessel area ranges from 20155 µm - 24521 µm with a mean of 21415 µm. Vessel frequency ranges from 11 no. /mm^2-15 no./mm^2 with a mean of 13 no./mm^2.

Parenchyma: Apotracheal - diffuse; paratracheal - vasicentric, occasionally confluent and also as discontinuous lines delimiting growth rings.

Rays: Fine, closely spaced. One to two seriate, homogenous, wholly made up of procumbent cells. Ray width ranges from 30 µm - 46 µm with a mean of 34 µm. Ray height ranges from 182 µm – 573 µm with a mean of 379 µm. Ray frequency ranges from 7 no. /mm - 10 no. /mm with a mean of 10 no./mm. Fiber length ranges from 330 µm - 1520 µm with a mean of 1145 µm.

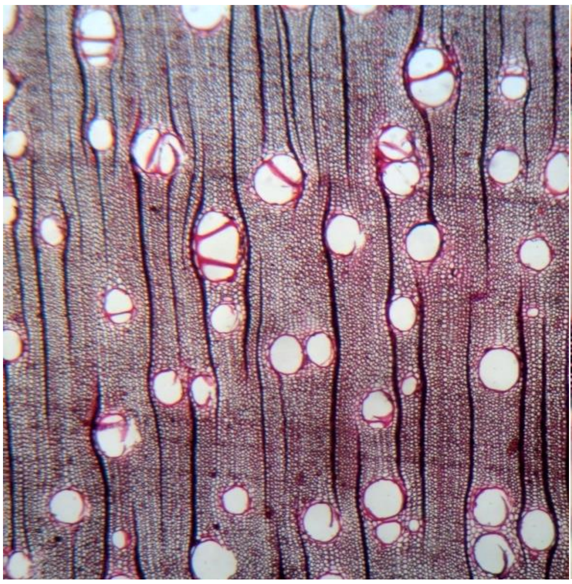
Uses:

Bridge and building construction, poles, cross arms, ballies and fence posts; railway sleepers; boat and ship building; textile mill accessories; agricultural implements.

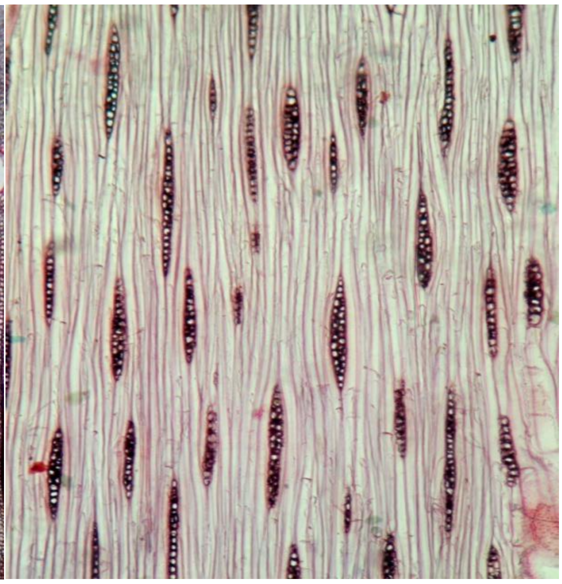
Plate 2 Microscopic images of wood anatomical sections

Acacia auriculiformis (TS 4X)

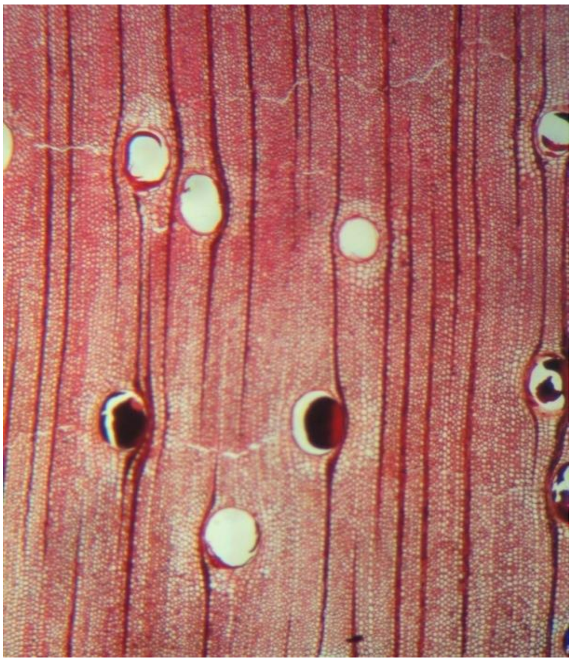
Acacia auriculiformis (TLS 4X)



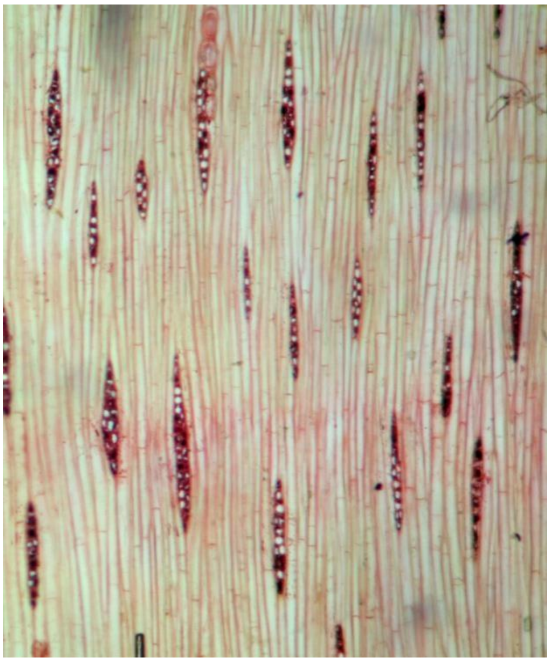
Acacia mangium (TS 4X)



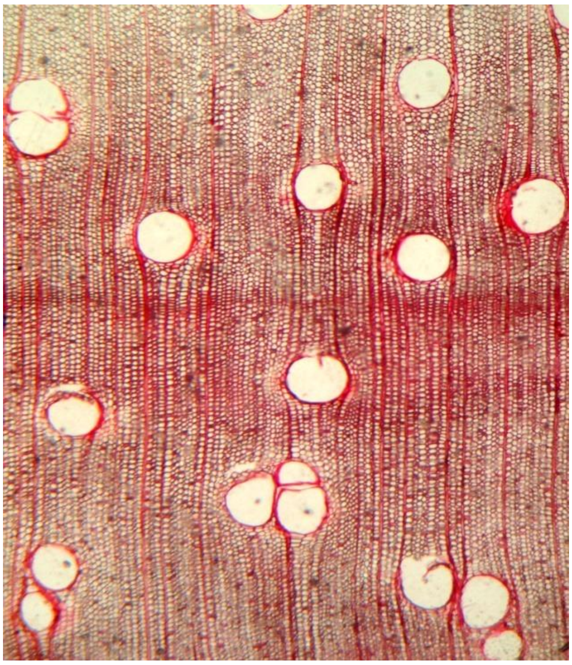
Acacia mangium (TLS 4X)



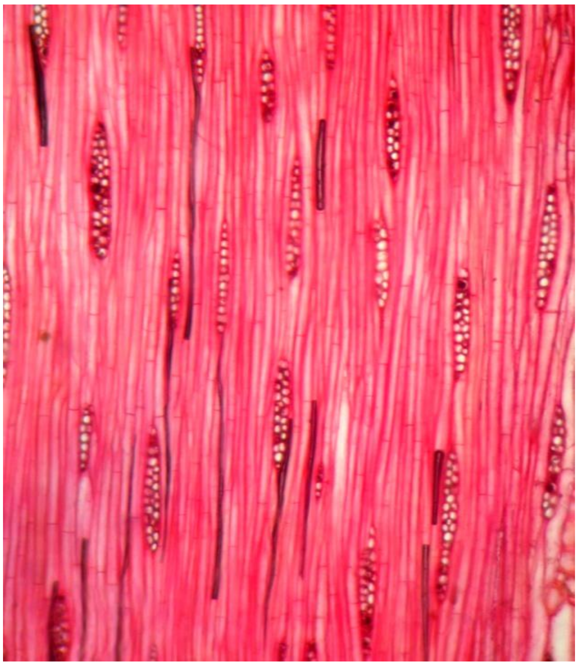
Albizzia lebbeck (TS 4X)



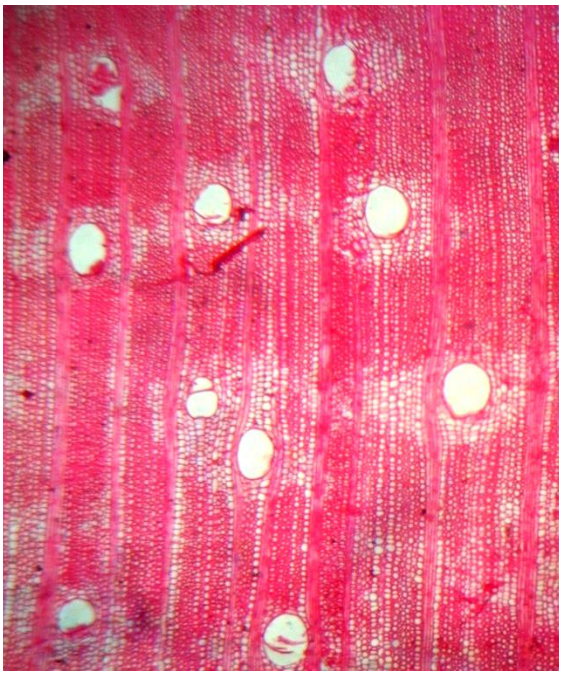
Albizzia lebbeck (TLS 4X)

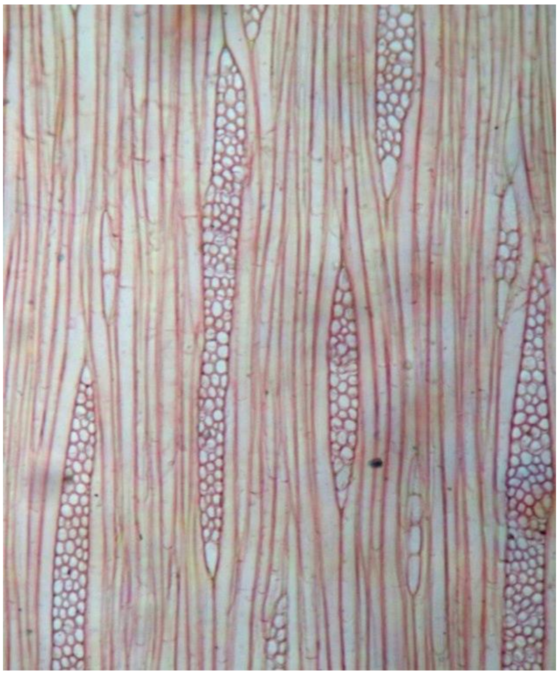


Albizzia odoratissima (TS)



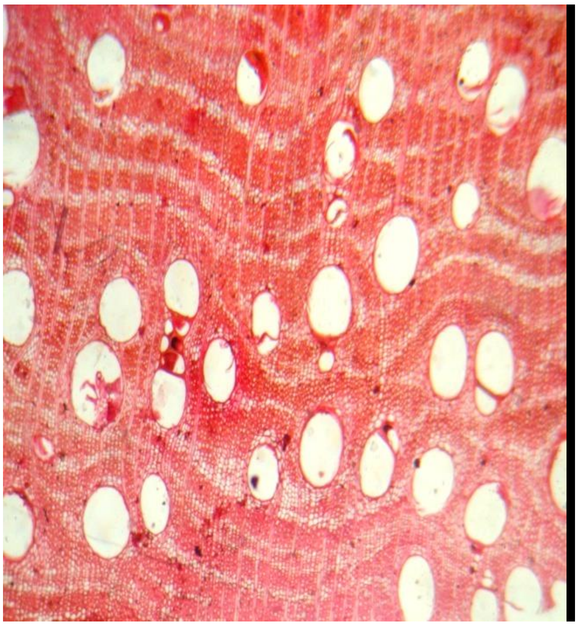
Albizzia odoratissima (TLS)





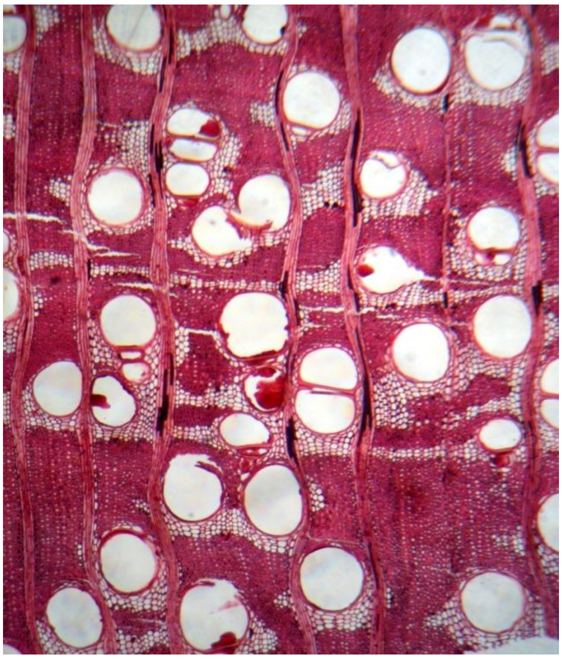
Artocarpus heterophyllus(TS 4X) *Artocarpus heterophyllus* (TLS 4X)

Artocarpus hirsutus (TS 4X) *Artocarpus hirsutus* (TLS 4X)

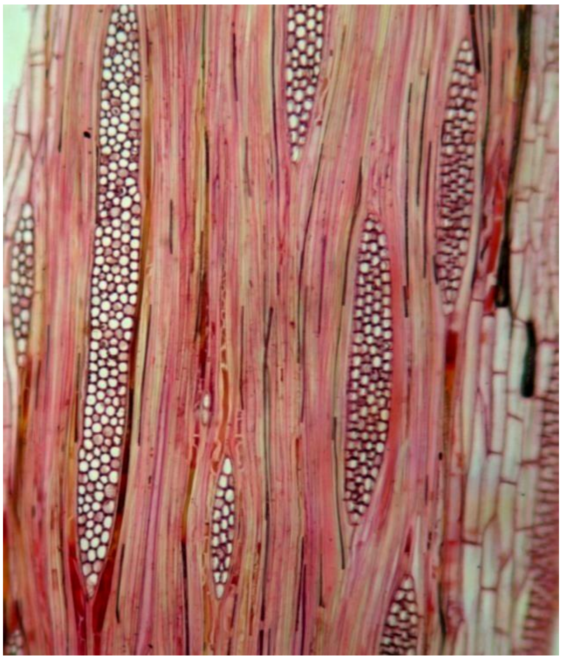


Dalbergia latifolia (TS 4X)

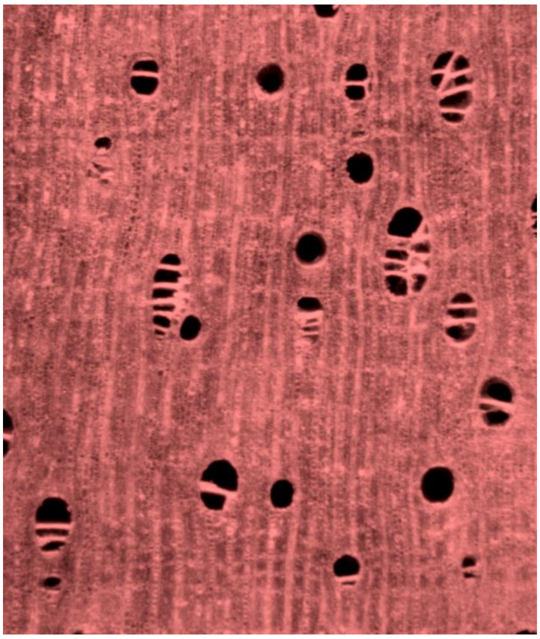
Dalbergia latifolia (TLS 4X)



Dalbergia nigra (TS 4X)

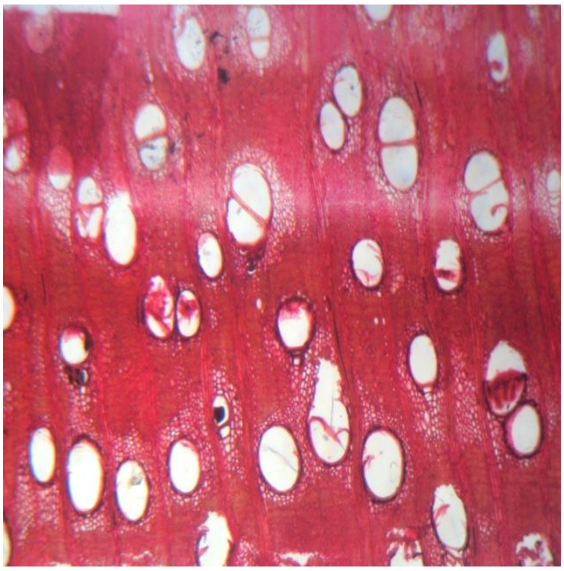


Dalbergia nigra (TLS 10X)



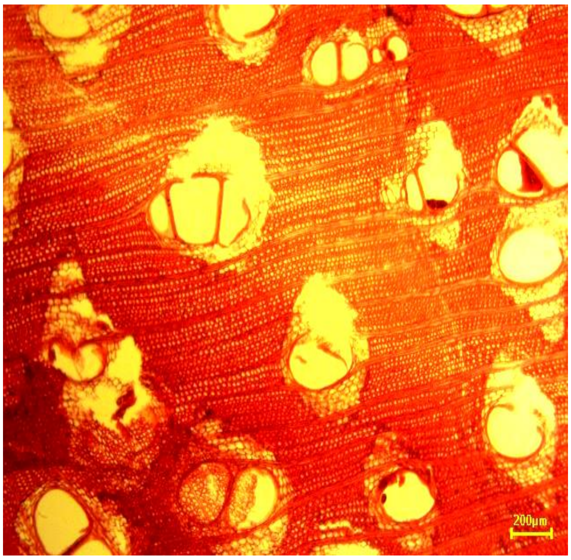
Hevea braziliensis (TS 4X)

Hevea braziliensis (TLS 4X)



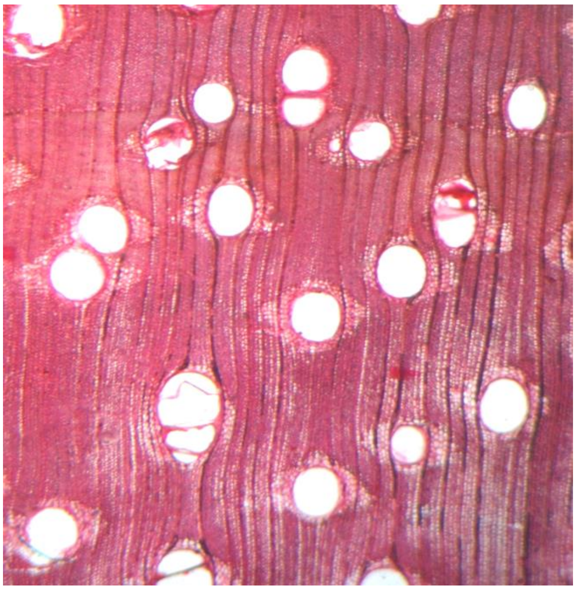
Hopea parviflora (TS 4X)

Hopea parviflora (TLS 4X)



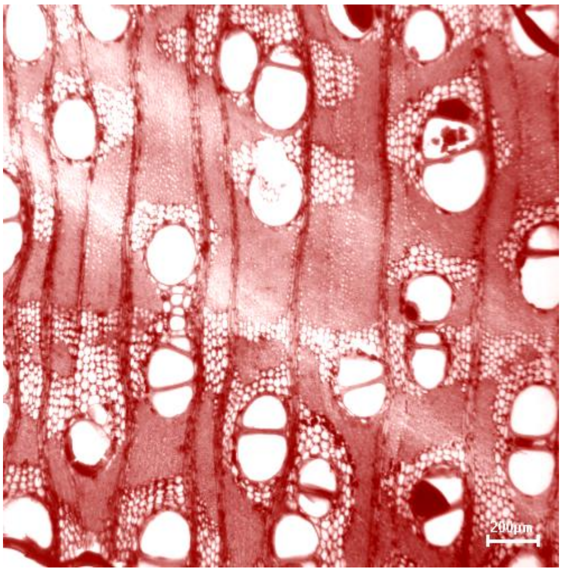
Intsia bijuga (TS 4X)

Intsia bijuga (TLS 4X)

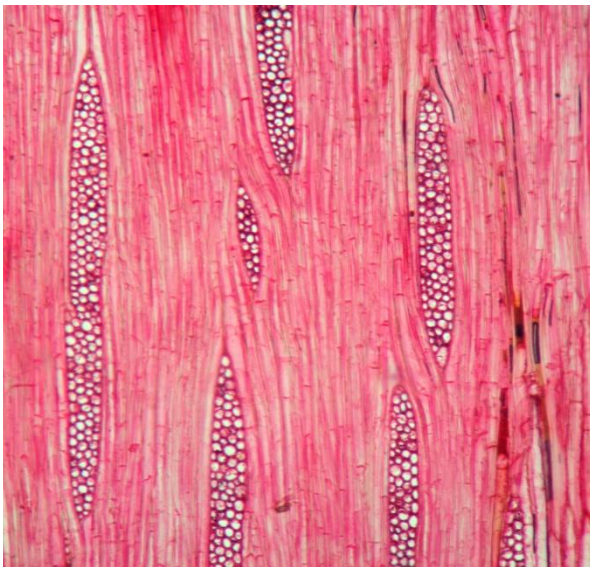


Ocotea rodiaei (TS 4X)

Ocotea rodiaei (TLS 10X)

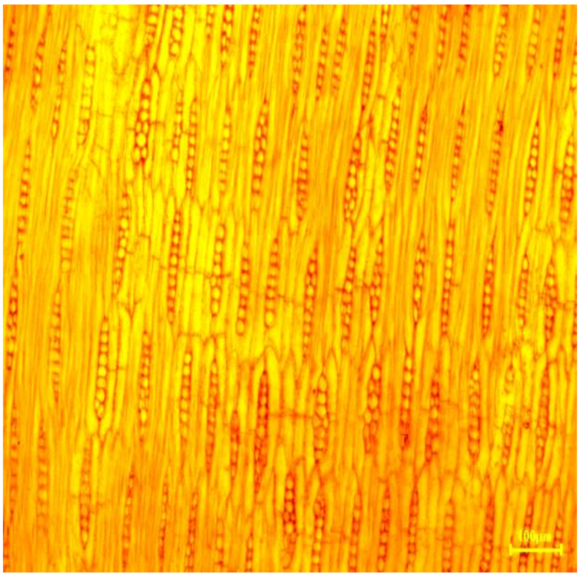


Peltogyne paniculata (TS 4X)

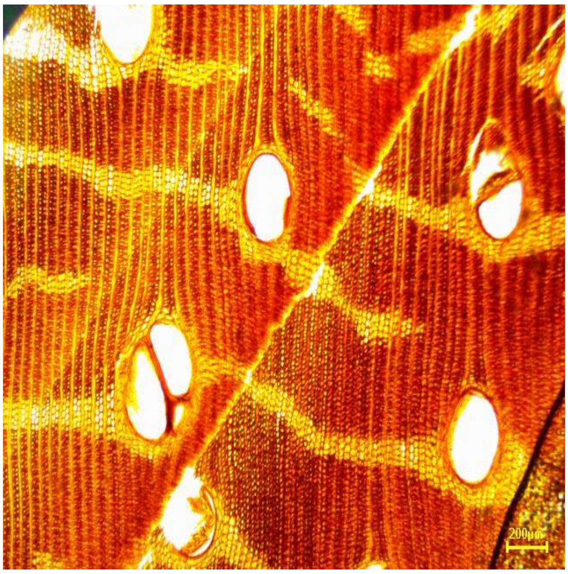


Peltogyne paniculata (TLS 10X)

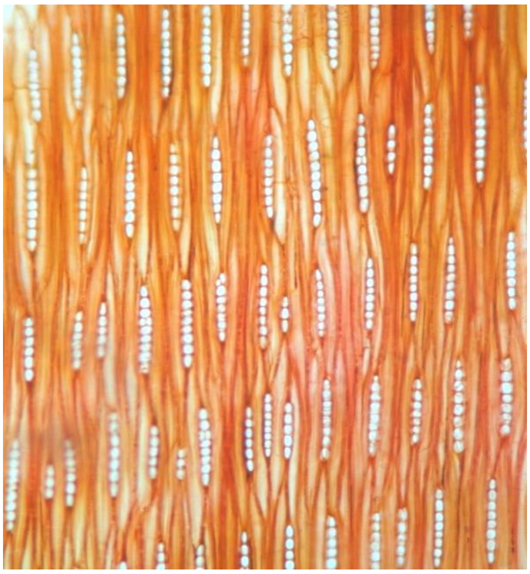
Pterocarpus marsupium (TS 4X)



Pterocarpus marsupium (TLS 4X)

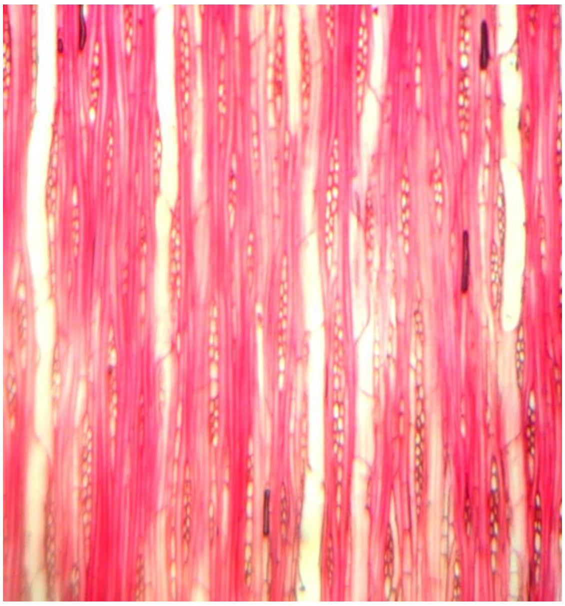


Pterocarpus dalbergioides (TS 4X)

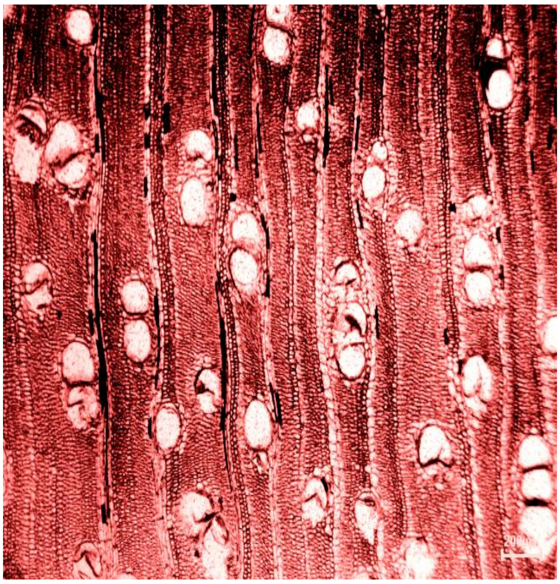


Pterocarpus dalbergioides (TLS 10X)

Santalum album (TS 10X)

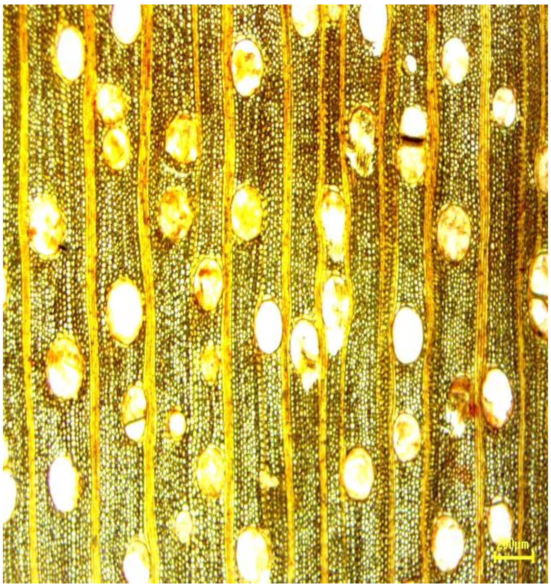


Santalum album (TLS 4X)

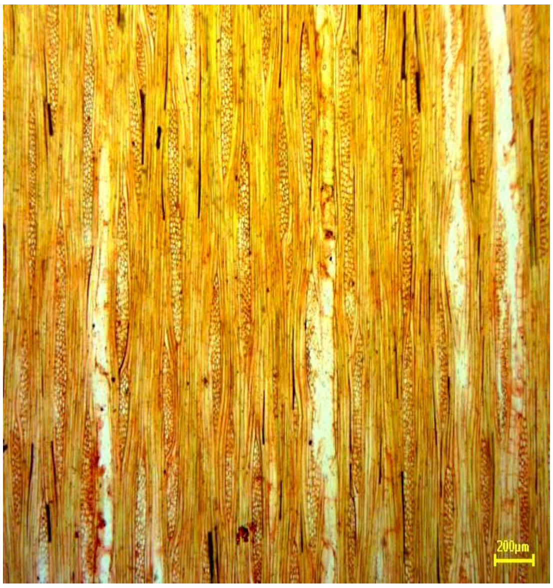


Swietenia macrophylla (TS 4X)

Swietenia macrophylla (TLS 4X)



Tectona grandis (TS 4X)

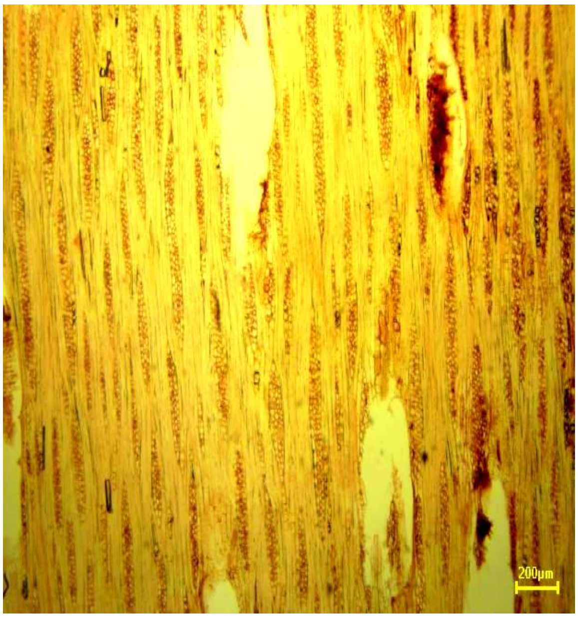


Tectona grandis (TLS 4X)

Xylia dolabriformis (TS 4X)

Xylia dolabriformis (TLS 4X)

Xylia xylocarpa (TS 4X)



Xylia xylocarpa (TLS 4X)

The anatomical observation from the current study is tabularized below (Table 2).

Table2. Anatomical observations from the current study.

Sl. No.	Name of the tree	Vessel diameter (μm)	Vessel area (μm^2)	Vessel frequency (no/mm^2)	Ray width (μm)	Ray height (μm)	Ray frequency (no/mm)	Sp. gravity
1	*Acacia auriculiformis* A. Cunn. Ex Benth.	180.00	18675.98	20	28.76	260.00	6	0.61
2	*Acacia mangium* Willd.	220.00	41676.78	13	22.76	310.00	10	0.65
3	*Albizzia lebbeck*	243.00	18754.98	10	21.98	287.00	8	0.58
4	*Albizzia odoratissima* (L.f) Benth.	260.00	17988.71	2	20.45	260.00	7	0.63
5	*Artocarpus heterophyllus* Lamk.	220.00	18678.87	3	54.87	610.00	3	0.65
6	*Artocarpus hirsutus* Lamk	167.75	19360.40	4	53.08	882.10	5	0.61
7	*Dalbergia latifolia* Roxb.	217.39	38332.90	3	25.42	139.29	13	0.72
8	*Dalbergia nigra* Fr. All.	260.00	41657.52	9	34.67	680.00	6	0.75
9	*Hevea braziliensis* (H. B. K.) M.-A	185.00	20762.78	2	43.76	515.00	10	0.57
10	*Hopea parviflora* Bedd.	219.29	36551.00	5	64.38	453.43	4	0.86

11	*Intsia bijuga*	316.88	78877.40	4	49.91	433.11	4	0.788
12	*Ocotea rodiaei* (Schomb) Mez.	200.00	19986.98	7	49.67	880.00	3	0.750
13	*Peltogyne paniculata-*	196.64	28593.20	9	53.95	546.90	5	0.712
14	*Pterocarpus marsupium* Roxb.	155.54	17298.10	5	20.32	122.69	13	0.712
15	*Pterocarpus dalbergioides*	315.68	68633.60	2	31.16	222.10	11	0.660
16	*Santalum album* Linn.	350.00	8967.78	25	23.67	295.00	7	0.945
17	*Swietenia macrophylla* king.	172.35	19732.50	8	141.6 0	322.20	6	0.514
18	*Tectona grandis* Linn.	145.47	16228.50	8	43.44	462.37	4	0.570
19	*Xylia dolabriformis* Benth.	235.00	27038.76	16	67.70	480.00	6	0.984
20	*Xylia xylocarpa* (Roxb.) *Taub.*	170.57	21420.20	13	32.60	377.70	9	0.874

DISCUSSION

5. DISCUSSION

5.2. Physical properties

5.2.1. Specific gravity

Specific gravity is a key wood property in forest products because of its effect on the yield and quality of both fibrous and solid wood products (Bhat, 1985; Haslett and Young, 1990). It is the most widely studied property of wood and is a function of the proportion of cell wall materials versus cellular voids. As such, specific gravity is often considered as a measure of wood quality (Zobel and Buitjenen, 1989; Woodcock and Shier, 2002). Numerous authors have classified timber species based on the specific gravity as it is the single best index that can be easily measured to predict strength properties of wood (Bhat, 1985; Amarasekara, 1996).

The present study revealed that the wood specific gravity differed significantly between species. The highest specific gravity was found in the *Xylia xylocarpa* and *Xylia dolabriformis.* The lowest specific gravity was for the *Swietenia macrophylla* , *Hevea braziliensis* and *Tectona grandis*. Keating and Bolza (1982) reported the specific gravity of *X. xylocarpa* to range between 0.81-1.01 in Burma. Ramesh and Juneja (1971) found it to be 0.85 in India. But the the specific gravity of 9-year-old *X. xylocarpa* planted in Sabah was higher than the ranges of the same species studied from various places (Josue, 2004). The specific gravity of *X. xylocarpa* in our study was 0.87, which is really comparable with the other studies.

The specific gravity of *Peltogyne paniculata* is 0.80 in the observations of Bhat *et al.* (2007). In our observations we found that the specific gravity as 0.712. From the studies made by Chudnoff (1984) basic specific gravity for *I. bijuga* is 0.68. But in this study we found that the specific gravity is 0.78. Thus we found a slight variation in the specific gravity of *I. bijuga* from the previously studied value. The specific gravity of Pterocarpus spp. was found to be 0.66 and this value coincides with 0.64 the value obtained by Mojeremane and Lumbile (2016) in their study on *Pterocarpus* spp. of Miombo woodlands. In the study of Chudnoff (1984) basic specific gravity varies considerably within the species of Pterocarpus from 0.28 to 0.60.

The specific gravity of *Dalbergia latifolia* was found to be 0.722 in this study, but in the database of KAU (Timbers of Kerala) it is 0.66. In the timber identification manual of Anoop *et al*. (2005) the specific gravity of *S. macrophylla* is 0.65 and from this study, found that it is 0.51. In the database, Timbers of Kerala, it is 0.68. And the same for the *Tectona grandis* was 0.62 in the data base and from this study it was measured as 0.57. The specific gravity of teak is 0.65 in the studies made by Nazma *et al*. (1981). As the values are similar we can conclude these as same species.

Pterocarpus marsupium is a moderately heavy wood and the specific gravity is 0.72-0.88 (Nazma *et al*., 1981). In this study the specific gravity was founded 0.71.

According to Anoop *et al*. (2005) the *Artocarpus hirsustus* is moderately hard and moderately heavy and the specific gravity is 0.59 and in this study it was found that the specific gravity of the above species as 0.61. In the studies of Nazma *et al*. (1981) the weight of this species is moderately heavy and it is 0.59.

5.3. Anatomical properties

Anatomy forms the strong basis for identification of species. It is found that transverse section of wood under magnification will serve in the majority of cases as sure means of identification (Howard, 1941).

5.3.1. Vessel morphology

The radial variation in anatomical properties of plantation grown *Tecomella undulata* was reported by Rao *et al.* (2003). They found that vessel frequency; vessel diameter and percentage of solitary vessels were interrelated and significantly varied from pith to periphery. It was observed that the diameter of early wood vessels increased along cambial age whereas, frequency of vessels decreased (Helinska and Fabisiak, 1999). So that, slight variations in the observation from current study can be of above-described factors. The highest vessel frequency is found for *Santalum album* and lowest for Pterocarpus sps. In comparison with the measurements of the databases available, the vessel frequencies are almost similar and as a result the species are identified. The highest vessel diameter is found in two species, *Intsia bijuga* and Pterocarpus spp. and lowest for the *Santalum album*. The vessel diameter is similar as in the databases and the identification is confirmed.

The comparison between the data obtained from the current study and the data bases available are discussed in the table below. The vessel frequency is discussed in the table 3 and vessel diameter is discussed in the table 4.

Table 3. The comparison of vessel frequency between the current study and databases.

No.	Name of the tree	Measurements of Inside wood. (no/mm^2)	Measurements of Timbers of Kerala(no/mm^2)	Measurements of current study. (no/mm^2)
1	*Acacia auriculiformis* A. Cunn. Ex Benth.	<=5	-	20
2	*Acacia mangium* Willd.	5-20	-	13
3	*Albizzia lebbeck*	5-20	-	12
4	*Albizzia odoratissima* (L.f) Benth.	<=5	-	8
5	*Artocarpus heterophyllus Lamk.*	5-20	9-15	6
6	*Artocarpus hirsutus* Lamk	<=5	2-3	4
7	*Dalbergia latifolia* Roxb.	<=5	8-12	3
8	*Dalbergia nigra* Fr. All.	5-20	-	18

9	*Hevea braziliensis* (H. B. K.) M.-A	5-20	-	15
10	*Hopea parviflora* Bedd.	5-20	-	5
11	*Intsia bijuga*	<=5	2-3	4
12	*Ocotea rodiaei* (Schomb) Mez.	5-20	-	15
13	*Peltogyne paniculata*	<=5	-	9
14	*Pterocarpus marsupium* Roxb.	5-20	12-16	5
15	*Pterocarpus dalbergioides*	<=5	3-5	2
16	*Santalum album* Linn.	5-20	-	30
17	*Swietenia macrophylla* king.	5-20	10-15	8
18	*Tectona grandis* Linn.	5-20	7-15	8
19	*Xylia dolabriformis* Benth.	5-20	-	16
20	*Xylia xylocarpa* (Roxb.) *Taub.*	5-20	6-12	13

Table 4. The comparison of vessel diameter between the current study and databases.

No.	**Name of the tree**	**Measurements of inside wood. (µm)**	**Measurements of timbers of Kerala(µm)**	**Measurement from current study(µm)**
1	*Acacia auriculiformis* A. Cunn. Ex Benth.	100-200	220	186.54

2	*Acacia mangium* Willd.	100-200	180	169.53
3	*Albizzia lebbeck*	>=200	100-200	176.55
4	*Albizzia odoratissima* (L.f) Benth.	>=200	260	254.23
5	*Artocarpus heterophyllus Lamk.*	100-200	220	172.67
6	*Artocarpus hirsutus* Lamk	>200	220-320	222.66
7	*Dalbergia latifolia* Roxb.	>=200	125-210	209.23
8	*Dalbergia nigra* Fr. All.	100-200	-	157.23
9	*Hevea braziliensis* (H. B. K.) M.-A	100-200	185	167.65
10	*Hopea parviflora*	100-200	-	211.13
11	*Intsia bijuga*	>=200	130-260	308.72
12	*Ocotea rodiaei* (Schomb) Mez.	100-200	-	159.93
13	*Peltogyne paniculata*	>=200	-	243.54
14	*Pterocarpus marsupium* Roxb.	>=200	170-290	147.38
15	*Pterocarpus dalbergioides*	100-200	100-320	307.52
16	*Santalum album* Linn.	100-200	60	79.48
17	*Swietenia macrophylla* king.	>=200	130-205	164.19
18	*Tectona grandis* Linn.	100-200	200-400	137.31

19	*Xylia dolabriformis* Benth.	100-200	270	179
20	*Xylia xylocarpa* (Roxb.) *Taub.*	100-200	110-185	162.41

5.3.2. Ray morphology

Wood properties such as 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. Ray tissue constitutes on an average of 17% of hardwood xylem, and sometimes it may reach more than 30% (Haygreen and Bower, 1982). Various studies (Liese *et al.,* 1975; Eckstein *et al.,* 1974; Grill *et al*., 1979; Schneider and Halbwacks, 1989) have found that the number of rays was significantly greater and the rays were shorter in height in conditions with increasing environmental stress. Higher rays were observed in species of more mesic habitat (Barajas- Morales, 1985) and a trend towards lower rays was observed in species of drier regions (Lens *et al.*, 2011). With decrease in ray height, increased ray width is not a common trend observed here. So variations may observe in the current study.

The ray frequency is highest for *Dalbergia latifolia* and *Pterocarpus marsupium* and in the case of ray height, highest value obtained for *Artocarpus hirsutus* and lowest for *Pterocarpus marsupium.*

The comparison between the data obtained from the current study and the data bases available are discussed in the table below. The ray frequency is discussed in the table 5 and ray height is discussed in the table 6.

Table 5. The comparison of ray frequency between the current study and databases.

No.	Name of the tree	Measurements of inside wood. (no/mm)	Measurements of timbers of Kerala(no/mm)	Measurements of current study. (no/mm)
1.	*Acacia auriculiformis* A. Cunn. Ex Benth.	4-12	5-7	5
2.	*Acacia mangium* Willd.	>=12	9-12	8
3.	*Albizzia lebbeck*	4-12	4-12	6
4.	*Albizzia odoratissima* (L.f) Benth.	4-12	5-9	4
5.	*Artocarpus heterophyllus Lamk.*	4-12	3-4	4
6.	*Artocarpus hirsutus* Lamk	4-12	2-3	4
7.	*Dalbergia latifolia* Roxb.	>=12	8-11	13
8.	*Dalbergia nigra* Fr. All.	4-12	-	11
9.	*Hevea braziliensis* (H. B. K.) M.-A	4-12	7-11	9
10.	*Hopea parviflora*	4-12	-	6
11.	*Intsia bijuga*	4-12	4-6	4
12.	*Ocotea rodiaei* (Schomb) Mez.	>=12	-	5

13.	*Peltogyne paniculata*	4-12	-	5
14.	*Pterocarpus marsupium* Roxb.	4-12	13-18	14
15.	*Pterocarpus dalbergioides*	4-12	10-14	11
16.	*Santalum album* Linn.	>=12	6-9	8
17.	*Swietenia macrophylla* king.	4-12	4-7	6
18.	*Tectona grandis* Linn.	4-12	3-4	4
19.	*Xylia dolabriformis* Benth.	4-12	-	6
20.	*Xylia xylocarpa* (Roxb.) *Taub.*	4-12	5-7	10

Table 6. The comparison of ray height between the current study and databases.

No.	Name of the tree	Measurements of timbers of Kerala. (µm)	Measurements of current study. (µm)
1	*Acacia auriculiformis* A. Cunn. Ex Benth.	260	248.98
2	*Acacia mangium* Willd.	310	369.67
3	*Albizzia lebbeck*	-	267.76
4	*Albizzia odoratissima* (L.f) Benth.	260	256.33
5	*Artocarpus heterophyllus* Lamk.	610	598.43
6	*Artocarpus hirsutus* Lamk	500-920	891.66
7	*Dalbergia latifolia* Roxb.	240	148.85

8	*Dalbergia nigra* Fr. All.	-	680
9	*Hevea braziliensis* (H. B. K.) M.-A	515	487
10	*Hopea parviflora*	-	462.99
11	*Intsia bijuga*	200-460	442.67
12	*Ocotea rodiaei* (Schomb) Mez.	-	880
13	*Peltogyne paniculata*	-	556.46
14	*Pterocarpus marsupium* Roxb.	210-290	132.25
15	*Pterocarpus dalbergioides*	185	173.23
16	*Santalum album* Linn.	295	256.67
17	*Swietenia macrophylla* king.	480	459.56
18	*Tectona grandis* Linn.	510-930	471.93
19	*Xylia dolabriformis* Benth.	655	623.89
20	*Xylia xylocarpa* (Roxb.) Taub.	575-1350	387.26

5.3.3 Fibre Morphology

The analysis of fibre morphological variations of the Nigerian guinea savannah timber species shows that there were significant differences in the fibre length, fibre diameter, lumen width and the cell wall thickness of the timber species. Fibre length and width of both woody and non-woody species vary depending on plant species (Illvessalo-Pfaffli, 1995). Pande *et al.,* (2012) reported an increase in fiber length from base to top in *Populus deltoides*. Fiber length was low at the bottom and higher in mid of the Populus species (Kauubaa *et al.,* 1998). Yang and Chang (1990) reported a pattern of increased fiber length from base to top. Fibre length has been described by Dinwoodie (1965) as one of the major factor controlling the strength properties of paper. Variations in fibre wall thickness from tree to tree and within individual trees are similar to the patterns of variation in density as a result of the close relationship between these two wood properties (Bhat *el al.*, 1990).

Table 7. The comparison of fibre length between the current study and databases.

No.	Name of the tree	**Measurements from inside wood (μm)**	**Measurements from timbers of Kerala(μm)**	**Measurements from current study (μm)**
1	*Acacia auriculiformis* A. Cunn. Ex Benth.	900-1600	1180	1203
2	*Acacia mangium* Willd.	900-1600	1130	1159
3	*Albizzia lebbeck*	<=900, 900-1600	1250	1167
4	*Albizzia odoratissima* (L.f) Benth.	900-1600	1430	1464

5	*Artocarpus heterophyllus Lamk.*	900-1600	1230	1278
6	*Artocarpus hirsutus* Lamk	<=900, 900-1600	1880	1765
7	*Dalbergia latifolia* Roxb.	900-1600	1385	1532
8	*Dalbergia nigra* Fr. All.	<=900, 900-1600	-	1534
9	*Hevea braziliensis* (H. B. K.) M.-A	900-1600	1150	1250
10	*Hopea parviflora*	<=900, 900-1600	-	1678
11	*Intsia bijuga* (Colebr.) O. Kuntze.	900-1600	-	1245
12	*Ocotea rodiaei* (Schomb) Mez.	<=900, 900-1600	-	1456
13	*Peltogyne paniculata*	<900	680	848
14	*Pterocarpus marsupium* Roxb.	<=900, 900-1600	1260	1296
15	*Pterocarpus dalbergioides*	900-1600	1250	1378
16	*Santalum album* Linn.	<=900, 900-1600	1160	1190
17	*Swietenia macrophylla* king.	900-1600	1260	1442

18	*Tectona grandis* Linn.	<=900, 900-1600	1435	1267
19	*Xylia dolabriformis* Benth.	900-1600	-	1367
20	*Xylia xylocarpa* (Roxb.) *Taub.*	900-1600	1180	1145

5.4. EVOLUTIONARY TRENDS IN WOOD ANATOMY.

Wood anatomy is a great source of traits that may be used in the studies of evolutionary relationships within flowering plants (Wroblewska, 2015). Solitary vessels should be considered as primitive according to the wood advancement code (Yatnsenko-Khmelevskiy, 1948). They were evolutionarily succeeded by the grouped vessels in most dicotyledons. The specialization of the vessel results in a gradual reduction in length of the vessel segments i. e; highly specialized structure have narrow and small vessels (Frost, 1930; Calquist, 2001).

In the current study smallest vessels were observed in *T. grandis* and comparatively larger vessels were observed in *I. bijuga.* So the evolutionary trend of vessel frequency showed that the most primitive species will be *T. grandis* and the advanced one will be *I. bijuga.* According to the study of Kribs (1935), ray evolution involved a gradual decrease in height and number of upright and square cells as seen in longitudinal section, eventually evolving into a homocellular ray.

In this study, the rays in the species are seen varied, which possess a mixture of homocellular and heterocellular to exclusively homocellular rays. In the current study the most primitive type heterogenous type I rays to the most advanced homogenous type were seen in different species. Heterogenous type I is seen in the *T. grandis*, heterogenous type II is seen in the *A. hirsutus* and heterogenous type III is seen in the *D. latifolia* and *S. macrophylla.* So these are the primitive members and the *A. hirsutus* shows a tendency towards homogeneity. All other species under study shows homogenous type rays.

The primitive type of axial parenchyma was inferred as apotracheal scanty or diffuse, evolving towards progressively larger volumes of parenchyma within the stem and in association with the vessels (paratracheal) (Kribs, 1937). Most of the species under study shows paratracheal parenchyma, which is an advanced character. In the *I. bijuga* apotracheal parenchyma appearing as narrow, inconspicuous bands demarcating growth rings. Predominently apotracheal-diffuse-in-aggregate parenchyma is observed in *H. parviflora.* So these two species shows the presence of primitive rays.

5.5. ANATOMICAL KEY FOR THE IDENTIFICATION OF CURRENTLY USED TIMBERS.

Growth rings distinct……….........…………………………………………..2.

Growth rings indistinct……...........……………………………………...6.

2. Wood diffuse porous…………………......……………………………….3.

2. Wood ring/semi ring porous…………......…………………….…………...5.

3. Distinct odour is present…….……....................……*Swetenia macrophylla*.

3. Distinct odour is absent…......…………………….4.

4. Brownish gummy deposits are present……….........*Xylia xylocarpa.*

4. Dark yellow deposits are present……………..............*Intsia bijuga.*

5. Soft tissue forms inconspicuous sheath around vessels…......*Tectona grandis*.

5. Soft tissue forms rhomboidal/wavy patches around vessels..……*Pterocarpus dalbergioides*.

6. Vessels solitary or radial multiples of 2-3……..……..7.

6. Vessels solitary or radial multiples of 2-5..……………..9.

7. Chalky deposits are present…....……………………8

7. Chalky deposits are absent... ………....................10.

8. Heart wood yellow..*A.heterophyllus*

8 .Heart wood brown..*A.hirsutus.*

9. Vessels are filled with tyloses…………….........……*Hopea parviflora.*

9. Vessels are not filled with tyloses…..…..………..*Dalbergia latifolia.*

10. Ripple marks are present………………………11

10. Ripple marks are absent……...…………………..*Peltogyne paniculata*.

11. Aqueous extract fluorescent.................................*Peltogyne marsupium.*

11. Aqueous extract non - fluorescent..........................12

12. Soft tissue as discontinuous bands delimiting growth rings present………………..............*D.latifolia.*

12. Soft tissue as discontinuous bands delimiting growth rings present......................................*D.nigra.*

13. Wood hard and heavy..14

13. Wood light to moderately heavy............................15

15. Soft tissue distinct as round/diamond shaped patches.............*A.odoratissima.*

15. Soft tissue not distinct to naked eye..................................*X.dolabriformis*

16. Softwood as round patches around vessels..................................*17*

16. Softwood as diffuse tangential lines..............................*Hevea braziliensis.*

17. Heartwood pale coloured..*A. mangium.*

17. Heartwood dark coloured..*A. auriculiformis.*

18. Vessels exclusively solitary ....*Santalum album.*

18. Vessels solitary/radial multiples of 2-4................................19.

19. Gummy deposits present.....................................*Pterocarpus marsupium*.

19. Gummy deposits absent.....................................*Pterocarpus dalbergioides*.

5.6. LIST OF MACROSCOPIC CARD KEY FEATURES (IAWA) FOR IDENTIFICATION OF THE TIMBER SPECIES.

1. *Acacia auriculiformis* A. Cunn. Ex Benth. – 1, 5, 13, 22, 23, 26, 30, 42, 47, 52, 61, 66, 68, 72, 79, 91, 97, 104, 115, 169, 176, 189, 192, 194, 197

2. *Acacia mangium* Willd. – 1, 2, 13, 22, 23, 26, 29, 30, 43, 47, 53, 61, 66, 72, 79, 92, 97, 104, 115, 169, 176, 189, 192, 194, 196, 197

3. *Albizzia odoratissima* (L.f) Benth. – 1,5 , 13, 22, 23, 26, 27, 29, 30, 43, 46, 53, 58, 61, 65, 68, 72, 76, 80, 81, 83, 86, 92, 97, 104, 115, 142, 169, 189, 192, 194, 196, 197, 201

4. *Artocarpus heterophyllus* Lamk. – 2, 5, 13, 22, 23, 27, 29, 30, 43, 46, 52, 58, 61, 66, 68, 73, 79, 80, 83, 92, 98, 106, 114, 169, 189, 192, 194, 196, 199

5. *Artocarpus hirsutus* Lamk.– 2, 5, 13, 22, 23, 26, 27, 31, 32, 35, 42, 43, 45, 46, 47, 53, 61, 66, 69, 72, 80, 81, 82, 86, 91, 92, 97, 98, 106, 107, 110, 163, 168, 169, 170, 171, 172, 173, 174, 189, 192, 193, 194, 196,197, 203.

6. *Dalbergia latifolia* Roxb. – 2, 5, 13, 22, 23, 26, 29, 30, 42, 46, 47, 52, 53, 58, 61, 66, 69, 70, 71, 79, 80, 81, 82, 83, 86, 89, 92, 93, 97, 104, 115, 118, 120 ,121, 136, 142, 168, 169, 189, 192, 195, 196, 197, 201, 202, 203.

7. *Dalbergia nigra* Fr. All. – 2, 5, 9 , 13, 22, 23, 26, 27, 29, 30, 43, 47, 53, 58, 61, 65, 66, 69, 72, 80, 81, 83, 85, 92, 97, 98, 104, 115, 142, 143, 186, 189, 192, 194, 196, 201,202

8. *Hevea braziliensis* (H. B. K.) M.-A. – 1,5, 13, 22, 25, 31, 42,47, 52, 58, 61, 66, 68, 69, 72, 80, 82, 83, 92, 97, 106, 115, 118, 169, 189, 192, 194, 194, 202

9. *Intsia bijuga* (Colebr.) O. Kuntze – 2, 5, 13, 22, 23, 25, 26, 29, 30, 43, 46, 53, 58, 61, 66, 69, 72, 80, 81, 82, 83, 89, 91, 92, 97, 104, 115, 136, 142, 168, 169, 170, 171, 172, 173, 189, 192 ,194, 199, 200, 203.

10. *Ocotea rodiaei* (Schomb) Mez. – 2, 5, 13, 22, 23, 25, 30, 42, 47, 53, 56, 61, 66, 70, 72, 79, 80, 81, 83, 92, 97, 98, 105, 106, 107, 114, 186, 189, 192, 195, 196, 201

11. *Peltogyne paniculata* Benth. - 1, 2, 5, 13, 22, 23?, 24, 25, 29, 30, 41, 42, 47, 52, 53, 58, 61, 66, 70, 72, 80, 82, 83, 84, 89, 92, 97, 98, 104, 115, 120, 129, 136, 142, 183, 186, 189, 192, 195, 196, 197, 198, 202, 204

12. *Pterocarpus marsupium* Roxb. – 2, 5, 13, 22, 23, 26, 29, 30, 42, 43, 46, 47, 52, 58, 61, 66, 69, 71, 72, 77, 79, 80, 82, 83, 84, 91, 92, 97, 104, 115, 116v, 118, 120, 121, 136, 142, 168, 169, 189, 192, 194, 195, 196, 197, 199, 204.

13. *Pterocarpus dalbergioides* Roxb. ex DC. – 1, 4, 5, 13, 22, 23, 25, 26, 27, 29, 30, 42, 43, 45, 46, 47, 52, 53, 58, 61, 66, 69, 71, 72, 76, 77, 79, 80, 82, 83, 86, 89, 91, 92, 96, 104, 115, 116, 118, 120, 121, 136, 142, 168, 169, 189, 192, 194, 196, 197, 198, 201, 203.

14. *Santalum album* Linn. - 1, 5 , 9 ,13 ,22 ,23 ,25 ,26 ,30 ,31 ,41 ,48 ,53 ,61 ,66 ,69 ,72 ,76 ,77 ,78 ,93 ,97 ,106 ,115 ,142 ,169,189 ,192 ,195 ,196 ,199 ,203

15. *Swietenia macrophylla* King. - 1, 2, 5, 13, 22, 23, 24, 30, 42, 46, 47, 53, 58, 61, 65, 66, 69, 72, 76, 78, 79, 85, 89, 93, 97, 98, 106, 107, 115, 118, 122, 131, 136, 137, 138, 141, 142, 183, 184, 189, 192, 194, 196, 197, 198.

16. *Tectona grandis* Linn. – 1, 3, 4, 13, 22, 23, 25, 26, 30, 42, 43, 47, 52, 53, 56, 58, 61, 65, 66, 69, 71, 72, 79, 89, 92, 93, 97, 98, 104, 106, 115, 163, 168, 169, 170, 171, 172, 189, 192, 194, 196, 197, 201, 203.

17. *Xylia dolabriformis* Benth. – 2, 5, 13, 22, 23, 26, 27, 29, 30, 43, 47, 53, 56, 61, 66, 70, 72, 77, 78, 79, 80, 92, 97, 104, 115, 142, 169, 170, 173, 189, 192, 195, 196, 197, 201

18. *Xylia xylocarpa* (Roxb.) Taub. – 2, 5, 13, 22, 23, 25, 26, 29, 30, 42, 43, 47, 53, 58, 61, 65, 66, 69, 70, 72, 76, 79, 80, 81, 89, 92, 97, 104, 115, 116, 136, 142, 168, 169, 170, 171, 172, 173, 189, 192, 195, 196, 197, 201.

.

SUMMARY

6. SUMMARY

A detailed investigation in the anatomical features of currently used timbers was involved in the present research. The wood samples of 20 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 analyzed in this study. The general features like colour, weight, texture etc. were also considered in the procedure of identification.

Keys based on the anatomical characters and the available databases like Inside wood, Timbers of Kerala etc. were used in the study for the identification of the unknown samples. They can be successfully employed in the preparation of identification keys, since it is constant for each species. They assist in the accurate identification of studied 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 anatomical information obtained from this study is also useful to find the evolutionary trends in the available species. The results of the investigations are given below.

1. There was a representation of more members from Fabaceae family (60%) in the current investigation. The remaining families comprising Moraceae - 2 members and Euphorbiacea, Santalaceae, Dipterocarpaceae, Meliaceae, Lauraceae and Lamiaceae represented one member each.

2. Among the 20 species, *Intsia bijuga* (Colebr.) O. Kuntze. , *Ocotea rodiaei* (Schomb) Mez. , *Peltogyne paniculata* Benth. *Dalbergia nigra* Fr. All. and *Xylia dolabriformis* Benth are imported species traded in the markets of Kerala and rest all are indigenous.

3. Between species the wood specific gravity was differed significantly. The highest specific gravity was found in the *X. xylocarpa* and *X. dolabriformis.* The lowest specific gravity was for the *S. Macrophylla, H. braziliensis* and *T. grandis.*

4. Diffuse porous wood is observed in *Acacia auriculiformis, Acacia mangium, Albizzia lebbeck, Albizzia odoratissima, Artocarpus heterophyllus, Artocarpus hirsutus, Dalbergia latifolia, Dalbergia nigra, Hevea braziliensis, Hopea parviflora, Intsia bijuga, Ocotea rodiaei, Peltogyne paniculata, Santalum album, Swietenia macrophylla, Xylia dolabriformis, Xylia xylocarpa* and ring porous wood is observed in *Tectona grandis, Pterocarpus marsupium* and *Pterocarpus santalinus.*

5. Small vessels are found in *S. album and* comparatively larger vessels were observed in *I. bijuga.* So the evolutionary trend of vessel frequency showed that the most primitive species will be *S. album* and the advanced one will be *I. bijuga.*

6. Vessels were solitary and radial multiples of 2-3 in most of the studied species except *D. latifolia* and *H. parviflora* where vessels are radial multiples of 2-5. In *S. album*, it is exclusively solitary.

7. The highest vessel frequency is for the *S. album* and lowest for *P. dalbergioides*. The highest vessel diameter is found in two species, I. *bijuga* and *P. dalbergioides* and the lowest for *S. album.*

8. Vessel frequency, vessel diameter and percentage of solitary vessels were interrelated and significantly varied from pith to periphery, so that the slight variations in the observations of current study from the databases were observed.

9. Rays are variable, which possess a mixture of homocellular and heterocellular to exclusively homocellular rays.

10. It is observed that the ray frequency is highest for *D. latifolia* and *P. marsupium* and in the case of ray height; it is highest for *A. hirsutus* and lowest for *P. marsupium.*

11. With decrease in ray height, increased ray width was not a common trend.

12. Heterogenous type I ray is seen in *T. grandis*, heterogenous type II is seen in *A. hirsutus* and heterogenous type III is seen in *D. latifolia* and *S. macrophylla.*

13. *I. bijuga* and *H. parviflora* shows the presence of primitive rays. *A. hirsutus* shows a tendency towards homogeneity. All other species shows homogenous advanced type rays.

14. Paratracheal parenchyma is an advanced character was observed in most of the species.

16. In *Pterocarpus* spp. and *P. marsupium*, ripple marks were observed.

17. Chalky deposits present in *A. hirsutus* were found as one of the distinguishable characters of that species.

18. In *H. Parviflora*, majority of the vessels were filled with tyloses and presence of resin canals was observed.

19. The specific odour of *S. macrophylla* and *T. grandis* were also identified as the key characters.

20. By utilizing all these information obtained from the anatomical studies a dichotomous key and an IAWA key was prepared for the 20 currently used timbers.

21. Dichotomous keys direct the observer to look for the features by which the key constructor considered, that will be useful for distinguishing tree species. A well-constructed dichotomous key can quickly lead to identification.

22. When the data from Inside wood database and Timbers of Kerala was compared with the data from current study, slight variations in the cell dimensions are only noticed.

23. No considerable variation in the tissue characteristics were observed when the observed results are compared with the existing database.

REFERENCES

6. REFERENCES

Alves, E. S. and Angyalossy-Alfonso,V. 2002. Ecological trends in the wood anatomy of some Brazilian species. 2. Axial parenchyma, rays and fibers. *IAWA Journal*, 23: 391– 418.

Amarasekara, H. S. 1996. Alternative timber species, A review of their properties and uses. In: Amarasekara, H. S. and Banyard, S. G. (eds), *Forestry for development, Proceedings of the annual forestry symposium*. 1995, December. Sri Lanka. Development of Forestry and Environmental Sciences: 76-88.

Anoop, E. V. 2017. Vessel morphology variation and ecoanatomical properties of anjily (*Artocarpus hirsutus* Lam.) wood grown in different agro-climatic zones of Thrissur, Kerala. *Journal of Tropical Agriculture, 55*(1): 40-44.

Anoop, E. V., Jijeesh, C .M., Sindhumathi, C. R., and Jayasree, C. E. 2014. Wood physical, Anatomical and Mechanical properties of Big Leaf Mahogany (*Swietenia macrophylla* Roxb.) a potential exotic for South India. *Research Journal of Agriculture and Forestry Sciences*, 2(8): 7-13.

Anoop, E.V., Antony, F., Bhat, K.V., Davis, L.A. and Babu, L.C., 2005. Anatomical key for the identification of important timbers of Kerala. *Kerala Agricultural University, Thrissur,* 226pp.

Baas, P., Esser, P.M., van der Westen, M.E. and Zandee, M., 1988. Wood anatomy of the Oleaceae. *IAWA Journal*, *9*(2): 103-182.

Baas, P., Werker, E. and Fahn, A. 1983. Some Ecological Trends in Vessel Characters. *IAWA Journal*, 4(2–3): 141–159.

Barajas-Morales, J., 1985. Wood structural differences between trees of two tropical forests in Mexico. *IAWA journal*, *6*(4): 355-364.

Beeckman, H., 2016. Wood anatomy and trait-based ecology. *IAWA journal*, *37*(2): 127-151.

Bhat, K. M., Thulasidas, P. K., and Hussain, K. H. 2007. A hand book of lesser known timbers. KFRI Research Report No. 304. 180p.

Bhat, K.M., 1985. Properties of selected less-known tropical hardwood. *Journal of the Indian Academy of Wood Science*, *16*(1): 26-35.

Bhat, K.V. 1994. Physical And Anatomical Characteristic of Wood of Some Less-known Tree Species of Kerala. KFRI Research Report 96. 25p.

Bravo, S. 2010. Anatomical changes induced by fire-damaged cambium in two native tree species of the Chaco Region, Argentina. *IAWA Journal*, 31(3): 283–292.

Brazier, J. D., 1975. The changing pattern of research in wood anatomy. *Journal of Microscopy*, *104*(1): 53-64.

Brazier, J., Trockenbrodt, M., Suzuki, M., Joshi, L., Fujii, T., Noshiro, S., de Pernia, N.E., Miller, R.B., Wu, J.L., Hao, B.Z. and Aloni, R., 1991. Bernard J. Rendle. *IAWA Journal*, *12*(1): 3-4.

Brodersen, C.R., Mc Elrone, A. J., Choat, B., Matthews, M. A., and Shackel, K. A. 2010. The Dynamics of Embolism Repair in Xylem: In Vivo Visualizations Using High-Resolution Computed Tomography. *Plant Physiology*, 154(3): 1088–1095.

Brunner, M., Kucera, L. J., and Zurcher, E. 1994. *Major Timber Trees of Guyana - A Lens Key*. Tropenbos Series 10. The Tropenbos Foundation, Wageningen & Swiss Federal Institute of Technology, Zurich. 189p.

Burley, J. and Palmer, E. R. 1979. Pulp and wood densitometric properties of pinus caribaea from Fiji. Oxford Forestry Institute, 66p.

Carlquist, S. 1988. *Comparative Wood Anatomy. Systematic and Evolutionary Aspects of Dicotyledon Woods*. Springer, Berlin. 436p.

Carlquist, S. 1989. Anatomy of vine and liana stems: a review and synthesis. In: Putz, F. E., and Mooney, H. A. (eds). *The Biology of Vines*. Cambridge University Press, Cambridge, UK. pp. 53–71.

Carlquist, S. 2001. Comparative wood anatomy. Systematic, ecological, and evolutionary aspects of dicotyledon wood. 2nd Ed. Springer. 448p.

Carlquist, S., 1980. Further concepts in ecological wood anatomy, with comments on recent work in wood anatomy and evolution. *Aliso: A Journal of Systematic and Evolutionary Botany*, *9*(4): 499-553.

Carrillo, A., Mayer, I., Koch, G. and Hapla, F., 2008. Wood anatomical characteristics and chemical composition of Prosopis laevigata grown in the northeast of Mexico. *IAWA journal*, *29*(1): 25-34.

Carrillo-Parra, A., Foroughbakhch-Pournavab, R., Bustamante-García, V., Sandoval-Torres, S., Garza-Ocañas, F. and Moreno-Limón, S. (2013). Differences of Wood Elements of *Prosopis laevigata* from Two Areas of Northeast Mexico. *American Journal of Plant Sciences*, 04(05): 56–60.

Chalk, L., 1955. Ray volumes in hardwoods. *Tropical Woods*, *101*: 1-10.

Chimelo, J. P. and Mattos-Filho, A. 1988. Preliminary wood structure observations of five hardwood species from different sites in Brazil. In: *Annals of 5th Conference of International Union of Forestry Research Organization (IUFRO)*, Sao Paulo–Brazil II: p. 100.

Chong, S. H. 1992. Studies on the wood properties of lesser known species grown in Indonesia. Wood properties of Kereta, Kenari, Bitanagur, Giam and Kempas. *Research report of the Forestry Research Institute*. Seoul. 46: pp. 73-93.

Chowdhury, K. A. 1945. *The Identification of Burma Commercial Timbers*. Ind. For. Rec. Forest Research Institute, DehraDun. 26p.

Chowdhury, K. A. and Gosh, S. S. 1958. *Indian Woods, Their Identification, Properties and Uses.* Vol I. Manager of Publications, Delhi. p. 304.

Chudnoff, M., 1984. *Tropical timbers of the world* (No. 607). US Department of Agriculture, Forest Service. 451p.

Dadswell, H. E. 1957. Tree growth Characteristics and their influence on wood structures and properties. In: *British Commonwealth Forestry Conference 1957: Australia and New Zealand*. CSIRO.

De Micco, V. E., Aronne, E. G., and Baas, P. 2008. Wood anatomy and hydraulic architecture of stems and twigs of some Mediterranean trees and shrubs along a mesic-xeric gradient. *Trees*, 22(1): 643-655.

Dickison, W.C., 2000. *Integrative plant anatomy*. Academic press. 533p.

Dinwoodie, J.M., 1961. Tracheid and Fibre Length in Timber a Review of Literature. *Forestry: An International Journal of Forest Research*, *34*(2):125-144.

Dunisch, O. and Puls, J., 2003. Changes in content of reserve materials in an evergreen, a semi-deciduous, and a deciduous Meliaceae species from the Amazon. *Journal of applied botany (1995)*, *77*(1-2): 10-16.

Eckstein, D., Frisse, E., and Liese, W. 1974. Holzanatomische Untersuchungen an umweltgeschaÈdigten StraûenbaÈumen der Hamburger Innenstadt. *Eur.J.For.Path*., 4(1): 232-244.

Edlin, H. L. 1977. *What Wood is That? A Manual of Wood Identification*. Stobart and son Limited. London. 160p.

Esteban, L. G. and De Palacios, P. 2009. Comparative wood anatomy in Abietoideae (Pinaceae). The Linnean Society of London, *Botanical Journal of the Linnean Society*, 160(2): 184–196.

Farmer, R. H. 1972. *Handbook of Hardwoods*. Her Majesty's Stationery Office. London. 243p.

Fichtler, E. and Worbes, M., 2012. Wood anatomical variables in tropical trees and their relation to site conditions and individual tree morphology. *Iawa Journal*, *33*(2):119-140.

Fonti P., Von Arx, G., Garcia-Gonzalez, I., Eilmann, B., Sass-Klaassen, B., Gartner, H., and Eckstein, D. 2010. Studying global change through investigation of the plastic responses of xylem anatomy in tree rings. *New Phytol*., 185(1),pp. 42–53.

Frost, F.H. 1930. Specialization of secondary xylem in dicotyledons. II. Evolution of end wall of vessel segments. *Bot. Gaz*. 909(1): 198–212.

Gamble, J.S., 1922. *A manual of Indian timbers: an account of the growth, distribution, and uses of the trees and shrubs of India and Ceylon, with descriptions of their wood-structure*. S. Low, Marston & Company Limited. 868p.

Gasson, P., Baas, P., and Wheeler, E. 2011. Wood Anatomy Of CITES-Listed Tree Species. *IAWA J.*, 32 (2): 55–198.

Gasson, P., Miller, R., Stekel, D.J., Whinder, F., and Zieminska, K. 2010. Wood identification of *Dalbergia nigra* (CITES Appendix I) using quantitative wood anatomy, principal components analysis and naive Bayes classification. *Annals of Botany, 105*(1): 45-56.

Ghosh, S. S. 1960. Identification of timbers with special reference to the perforated card key. *Timber Trade*, 2(1): 1-13.

Grill, D., Liegl, E. and Windisch, E., 1979. Holzanatomische Untersuchungen an abgasbelasteten Bäumen. *Journal of Phytopathology*, *94*(4): 335-342.

Gupta, A. 2016. Variations in wood anatomy of hardwood species collected from the coal mines of Jharkhand. Thesis: Forest Research Institute (Deemed) University, Dehra Dun, Uttarakhand. 257p.

Hacke, U.G., Jacobsen, A.L. and Pratt, R.B., 2009. Xylem function of arid-land shrubs from California, USA: an ecological and evolutionary analysis. *Plant, Cell & Environment*, *32*(10): 1324-1333.

Halbwachs, G. and Kisser, J., 1967. Durch Rauchimmissionen bedingter Zwergwuchs bei Fichte und Birke. *Cbl. ges. Forstwes, 84*: 156-173.

Harikrishnan, M. 1960. Twenty five important commercial timbers of Madras state with a key to their identification. Special paper submitted for the diploma in Forestry. Forest Research Institute, Dehra Dun. 58p.

Haygreen, J.G. and Bowyer, J.L., 1996. *Forest products and wood science: an introduction* (No. Ed.3). Iowa state university press. 483p.

Heinz, E. 1997. Entwicklung von Systemkomponente furdie Computerunterstutzte Bestimmung von Nadelholzern in DELTA / INTKEY. Thesis (unpublished), Institute for Wood Biology, Leuschnerstrasse 91, Hamburg, Germany.

Helinska, R. L. and Fabisiak, E. 1999. Radial variation of early wood vessel lumen diameter as an indicator of the juvenile growth period in ash (*Fraxinus excelsor* L.). *Holz Roh Werkst.*, *57*(4): 283-286.

Herendeen, P.S. and Miller, R.B., 2000. Utility of wood anatomical characters in cladistic analyses. *IAWA journal*, *21*(3): 247-276.

Herendeen, P.S., Wheeler, E.A. and Baas, P., 1999. Angiosperm wood evolution and the potential contribution of paleontological data. *The Botanical Review*, *65*(3), 278p.

Hidayat, W., Kim, Y., Jeon, W., Lee, J., Kim, A., Park, S., Maail, R.S. and Kim, N., 2017. Qualitative and quantitative anatomical characteristics of four tropical wood species from Moluccas, Indonesia. *Journal of the Korean Wood Science and Technology*, *45*(4): 369-381.

Howard, A. L. 1941. Studies of the identification of timbers. International Book Distributors, Dehra Dun, India, 110p.

IAWA Journal, E. (1981). Standard List of Characters Suitable for Computerized Hardwood Identification. *IAWA Journal*, 2(2–3): 99–110.

Ilic, J. 1991. *CSIRO Atlas of Hardwoods*. CSIRO Division of Forestry and Forest Products, Highett, Vic., Australia, 525p.

InsideWood- The Modern Wood Database.Identifier:http://insidewood.lib.ncsu.edu/search North Carolina State University. 2013.

Izumoto, Y. and Hayashi, S. S.1990. Identification system of wood assisted by microcomputer II. Mem. Osaka Kyoiku Univ. sero III, 39 (1): 87-102.

Jane, F.W., 1933. The microscopic examination of woody materials. *Watson's microscopic record*, (30): 1-9.

Jorge, F., Quilhó, T. and Pereira, H., 2000. Variability of fibre length in wood and bark in Eucalyptus globulus. *IAWA journal*, *21*(1): 41-48.

Josue, J. 2004. Some wood properties of *Xylia xylocarpa* planted in Sabah. *Sepilok Bulletin*, 1: 1-15.

Kartusch, B. and Halbwachs, G. 1985. Holzanatomische Untersuchungen an unterschiedlich immissionsgestreûten Exemplaren von Alnus glutinosa. *Ang. Bot*., 59(1): 249-260.

Keating, W.G. and Bolza, E. 1982. *Characteristics, Properties and Uses of Timbers. Vol. 1*. South East Asia, Northern Australia and the Pacific. CSIRO, Melbourne. 362p.

Kleeberg, A. 1885. Die Markstrahlen der Coniferen. Botanische Zeitung, 43(1): 673–686.

Kribs, D. A. 1935. Salient lines of structural specialization in the wood rays of dicotyledons. *Bot. Gaz*., 96(1): 547-557.

Kribs, D. A. 1937. Salient lines of structural specialization in the wood parenchyma of dicotyledons. *Bull. Torrey Bot. Club*, 64(1): 177–186.

Kuroda, K. (1987). Hardwood Identificatlon Using a Microcomputer and Iawa Codes. *IAWA Journal*, 8(1): 69–77.

Kywe, U. T. and Soe, K. 1983. Morphological and anatomical characteristics of (25) commercial Burmese timbers. 37p.

Lens, F., Sperry, J. S., Christman, M. A., Choat, B., Rabaey, D., and Jansen, S. 2011. Testing hypotheses that link wood anatomy to cavitation resistance and hydraulic conductivity in the genus Acer. *New Phytol.* 190(1): 709–723.

Liang, C.B., Baas, P., Wheeler, E.A. and Shuming, W., 1993. Wood anatomy of trees and shrubs from China. VI. Magnoliaceae. *IAWA journal*, *14*(4): 391-412.

Liese W., Schneider, M., and Eckstein, D. D. 1975. Histometrische Untersuchungen am Holz einer rauchgeschaÈdigten Fichte. *Eur. J. For. Path.*, 5(1),pp. 152-161.

Longui, E. L., Romeiro, D., Testoni, L.N., Aguiar, O. T. D., Filho, R. C., Lima, I. L. D., and Florsheim, S.M.B. 2012. Water deficit affects wood vessels of *Croton floribundus* Spreng. in different vegetation types, Sao Paulo State, Brazil. *Hoehnea*. 39(1): 113-123.

Luchi, A.E., Silva, L.C.P. and Moraes, M.A. 2005. Anatomia comparada do lenho de Xylopia aromatica (Lam.) Mart. em áreas de cerrado e de plantação de Pinus elliottii Engelm. *Revista Brasileira de Botânica*, 28(4).

Lushington, A. W. 1919. *Nature and Uses of Madras Timbers*. S.P.C.K. Press, Madras. 358p.

Maiti, R., Rodriguez, H.G., Para, A.C., Aruna Kumari, C.H. and Sarkar, N.C., 2016. A comparative wood anatomy of 15 woody species in north-eastern Mexico. *Forest Research*, *5*(1): 100-166.

Menon, P. K. B, 1959. The wood anatomy of Malayan timbers. Commercial timbers. 3. Light hardwoods. *Res. Pamphl. For. Dept. Malaya*, *27*: 1-30.

Menon, P. K. B. 1955. The wood anatomy of Malayan timbers: commercial timbers 1. Heavy hardwoods 2. Medium hardwoods. *Res. Pamph. For. Res. Inst. Kepong*. 18: 19-29.

Menon, P. K. B. 1971. The anatomy and identification of Malaysian Hardwoods. *Malayan For. Rec*. 27: p. 124.

Metcalfe, C. R and Chalk, L. 1983. *Anatomy of the Dicotyledons*, 2nd ed. Vol. 2. Clarendon Press, Oxford. 297p.

Miller, R. B. and Detienne, P. 2001. *Major Timber Trees of Guyana Wood Anatomy*. Tropenbos International Wageningen, the Netherlands. 226p.

Monteoliva, S. and Olivera, H., 1994. Introduction to the use of computer systems for wood identification in Argentina. *IAWA J*, *15*, p.329.

Muniz, G.I.B., Nisgoski, S. and Lomelí-Ramírez, M.G., 2010. Anatomía y ultraestructura de la madera de tres especies de Prosopis (Leguminosae-Mimosoideae) del Parque Chaqueño seco, Argentina. *Madera y Bosques*, *16*(4): 21-38.

Nazma, M.F., Ganapathy P. M., Sasidharan N., Bhat K. M., and Gnanaharan R. 1981. *A Handbook of Kerala Timbers*. Kerala Forest Research Institute. Peechi. 260p.

Novruzova, Z., 1972. The effect ofecological conditions on relation of ring with to solid matterin trees and shrubs. In *For. Abstr* (Vol. 34, p. 42).

Pace, M.R. and Angyalossy, V., 2013. Wood anatomy and evolution: a case study in the Bignoniaceae. *International Journal of Plant Sciences*, *174*(7): 1014-1048.

Pande, P. K., Rao R.V., Agarwal S. P., and Singh, M. 1995. Variation in the dimensions of trachied elements of Pinus caribaea var. bahamensis. *J. Trop. For. Products*. 1(2): 117-123.

Pande, P.K., 2012. Status of Anatomy and Physical Properties of Wood in Poplars. *Forestry Bulletin*, *12*(1): 132-150.

Pankhurst, R. J. 1978. *Biological Identification. The Principles And Practice Of Identification Methods In Biology*. University Park Press, Baltimore. p. 1978.

Pankhurst, R. J. 1991. *Practical Taxonomic Computing*. Cambridge University Press, Cambridge. p. *1991*.

Pearson, R.S. and Brown, H.P., 1932. Commercial Timbers of India: their Distribution, Supplies, Anatomical Structure, Physical and Mechanical Properties and Uses. *Nature,* 132(3341): 727–728.

Poorter, L., McDonald, I., Alarcón, A., Fichtler, E., Licona, J.C., Peña-Claros, M., Sterck, F., Villegas, Z. and Sass-Klaassen, U., 2010. The importance of wood traits and hydraulic conductance for the performance and life history strategies of 42 rainforest tree species. *New phytologist*, *185*(2): 481-492.

Purkayastha, S. K. 1982. *Indian Woods, their Identification, Properties and Uses*. Vol IV. Myrtaceae to Symplococaceae. Controller of publications, New Delhi. 172p.

Purkayastha, S. K. 1985. *Indian Woods, their Identification, Properties and Uses*. Vol V. Oleaceae to Santalaceae. Controller of publications, New Delhi. 172p.

Purkayastha, S. K., Juneja, K. B. S., and Husain, K. S. M. 1976. *Anatomy of More Important Andaman Commercial Timbers (With Notes On Their Supply, Properties And Use)*. Ind. For. Rec. Vol 1 & 2. Forest Research Institute Press, DehraDun. 42p.

Rajput, K.S., Rao, K.S. and Kim, Y.S., 2008. Cambial activity and wood anatomy in Prosopis spicigera (Mimosaceae) affected by combined air pollutants. *IAWA journal*, *29*(2): 209-219.

Ramesh, R. and Juneja, K. B. S. 1971. *A Handbook for Field Identification of Fifty Important Timbers of India*. Manager of Publication, Delhi, India. 345p.

Rao, B. S. S. and Rao, R. V. 1978. Variation in length of vertical elements within one tree of *Betula pubercens* Ehrh. *J.Indian Acad. Wood Sci*. 9(2): 105-110

Rao, K. R. and Juneja, K. B. S. 1971. *A Handbook For Field Identification Of Fifty Important Timbers Of India*. Manager of Publication, New Delhi, India. 123p.

Rao, K. R. and Purkayastha, S.K. 1972. *Indian Woods, Their Identification, Properties and Uses.* Vol III. Leguminosae to Combretacae. Manager of Publications, New Delhi. 262p.

Rao, R. V., Sujata, M., and Hemavathi, T. R. 2003. Radial variation in anatomical properties of plantation grown *Tecomella undulata*. *Journal of Tropical Forest Products,* 9(12): 68-76.

Richter, H. G. and Trockenbrodt, M. 1993. *IAWA List Of Features For Hardwood Identification Adapted To The DELTA System*. Federal Research Centre for Forestry and Forest Products, Hamburg. 24p.

Richter, H. G. and Trockenbrodt, M. 1996. Computer-aided wood identification with DELTA / INTKEY - a demonstration. *IAWA J*. 17(1): 262.

Rouffa, A.S. and Carlquist, S. 1976. Ecological Strategies of Xylem Evolution. *Bulletin of the Torrey Botanical Club,* 103(3), p.136.

Santini, N.S., Schmitz, N. and Lovelock, C.E., 2012. Variation in wood density and anatomy in a widespread mangrove species. *Trees*, *26*(5): 1555-1563.

Saxena, V. and Gupta, S. 2011. Wood Anatomy of Family Salvadoraceae from the Indian Subcontinent with Special Reference to the Ultrastructure of the Vessel Wall. *Aliso,* 29(1), pp. 59–63.

Schmid, R., Newman, M.F., Burgess, P.F. and Whitmore, T.C. (1997). Borneo Island Light Hardwoods: Anisoptera, Parashorea, Shorea (Red, White and Yellow Meranti). *Taxon*, 46(2), p. 384.

Schneider, M. and Halbwachs, G., 1989. Anatomische und morphologische Untersuchungen zur Regenerationsfähigkeit einer durch Fluorimmissionen geschädigten Fichte. *European Journal of Forest Pathology*, *19*(1): 29-46.

Sharma, M., Sharma, C. L., Kharkongor, B. M., and Carter, M. J. 2011. Wood anatomical variations in some species of Quercus of Meghalaya. *J. Indian Acad. Wood Sci*. 8(2): 152–157.

Singh, M. K., Sharma, M. B., and Sharma, C. L. 2013. Wood Anatomical Variations in Some Terminalia Species of Assam. *International Journal of Botany and Research*, 3(2): 13-18.

Solereder, H. (1908) SJwemaric Anatomy of rhe Dicotvledotzs. (English translation by L. A. Boodle and F. E. Fritsch), 2 vol. Clarendon Press, Oxford. 234p.

Sperry, J. S. and Hacke, U. G. 2004. Analysis of circular bordered pit function. Angiosperm vessels with homogenous pit membranes. *American Journal of Botany*, 91(3): 369–385.

Sperry, J.S. (2003). Evolution of Water Transport and Xylem Structure. *International Journal of Plant Sciences*, 164(S3): S115–S127.

Titmuss, F. H. 1971. *Commercial Timbers of the World*. The Technical Press Limited. London. 366p.

Tochigi T., Shiokura, T., Lantican, C. B., Salud, C. C., and Madamba, C. B. 1984. Computer assisted tropical wood identification (CATWI). In: *Proc. Pacific Regional Wood Anatorny Conference, Tsukuba, Japan*: 1: 174-176.

Trotter, H. 1929. The common commercial timbers of India and their uses; description of common Indian woods; Culcutta Government of India Central Publication Branch. 153p.

Trotter, H. 1959. *The Common Commercial Timbers Of India And Their Uses*. Controller of Publications, New Delhi. 296p.

Troup, R. S. 1909. *Indian Woods And Their Uses*. Soni Reprint Agency. New Delhi. 273p.

Tyree, M. T, Davis, S. D., and Cochard, H. 1994. Biophysical perspectives of xylem evolution: is there a trade off of hydraulic efficiency for vulnerability to dysfunction? *IAWA J.*, 15(4): 335–360.

Wallich, N. 1832. Catalogue of Indian woods. Transactions of the Society, Instituted at London, for the Encouragement of Arts, Manufactures, and Commerce, 48: 439-481.

Wheeler, E. A. and Baas, P. 1993. The potentials and limitations of dicotyledonous wood anatomy for climatic reconstructions. *Paleobiology*, 19(4): 487-498.

Wheeler, E. A. and Baas, P. 1998. Wood Identification -A Review. *IAWA J.*, 19 (3): 241-264.

Wheeler, E. A., Baas, P., and Rodgers, S. 2007. Variations in dicot wood anatomy: A Global Analysis Based on the Insidewood Database. *IAWA J.* 28(3): 229–258.

Wheeler, E. A., Bass, P. and Gasson, P. E. 1989. IAWA list of microscopic features for hardwood identification. *IAWA Bull*. 10: 219 – 332.

Wheeler, J. K., Sperry, J., Hacke, U. G., and Hoang, N. , 2005 Inter-vessel pitting and cavitation in woody Rosaceae and other vesselled plants: a basis for a safety versus efficiency trade-off in xylem transport. *Plant, Cell and Environment*, 28(6): 800–812.

Wiesehuegel, E.G. 1932. Diagnostic Characteristics of the Xylem of the North American Abies. *Botanical Gazette*, 93(1): 55–70.

Wróblewska, M.M. 2015. The progressive and ancestral traits of the secondary xylem within Magnolia clad – the early diverging lineage of flowering plants. *Acta Societatis Botanicorum Poloniae*, 84(1): 87–96.

Yang, J. and Cheng, F. 1990. Microcomputer-assisted wood identification system WIP-89. *J. Beijing For. Univ*. 12 (4): 88-94.

Zhang, Q. C., Cheng, F., and Lian, Y. H. 1986. Microcomputer identification of hardwood species. *Scientia Silvae Sin*., 22: 213-217.

Zimmermann, M. H. 1983. *Xylem Structure And The Ascent Of Sap*. Springer-Verlag, New York. 127p.

Zobel, B. J. and Van Buijtenen, J. P. 1989. *Wood Variations: Its Causes And Control*. Berlin, Springer-Verlag. 363p.

DEVELOPMENT OF ANATOMICAL KEY FOR THE IDENTIFICATION OF SELECTED TIMBERS OF KERALA

By

NIMMI SATHISH

(2018-17-002)

Abstract of thesis

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Forestry

Faculty of Forestry

Kerala Agricultural University

DEPARTMENT OF FOREST PRODUCTS AND UTILIZATION

COLLEGE OF FORESTRY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2020

ABSTRACT

Title: Development of an anatomical key for the identification of selected timbers of Kerala

Deforestation poses a massive threat to global biodiversity with illegal logging and the associated trade in illegally sourced wood products. This is a significant contributor to the continuation of unsustainable deforestation rates. Reputed timber traders are also struggling to police their own supply chains and comply with the growing requirement for due diligence with respect to timber origin and legality. A range of scientific methods have been developed independently with the potential to provide the required identification information.

Wood anatomy is considered as a highly specialised science discipline which is used in combination with various technologies in forensic timber identification. Wood anatomical features are generally considered not prone to changes under normal circumstances and therefore it forms the basis of wood identification. Analysis can be undertaken at both the macroscopic and microscopic scale, but microscopic examination is usually required to achieve a diagnostic identification. Different features of interest in this scenario include cell size, arrangements of different elements, cell proportion and most importantly, specific gravity.

There are thousands of species of trees from which timber can be obtained, each with different rates of growth, structural properties and degrees of durability. Some timbers are highly decorative, some are very strong, some have good resistance to rot - in fact almost every species of wood has features that can be good in some uses, but not so good in others. Therefore, knowing what type of wood you have in front of you can be extremely important, either because you may have paid a lot of money for something you didn't actually get, or maybe because the wood you've got is unsuitable for the job you have in mind for it. Timber identification is a skill that must be gained with practice and with a bit of extra help from a skilled wood scientist.

The IAWA (International Association of Wood Anatomists) List of Microscopic Features for Hardwood Identification is an important standardized list of

characters and terminology that can be used in descriptive wood anatomical studies and identification obtained through comparison to reference materials.. The commonly used keys for wood identification are the dichotomous key, perforated card key and the computer aided identification key. Dichotomous keys are the most simple and easy to use keys. These types of keys have been used for over centuries in biological identification. The multiple entry perforated card type of key was introduced by the Forest Products Research Laboratory in 1936, when a key for the identification of hardwoods based on microscopic features was conducted.

Hence, the preparation of anatomical key is very important in the field of wood industries for the identification of the suitable material or the tree. Anatomical keys of different timbers assists in a large way do away with the confusion in the identification of timbers. The anatomical keys can also support the molecular studies like DNA bar coding, molecular markers etc. Wood anatomical analysis is the most frequently used method for taxonomic identification, both on the front-line for screening purposes, and in the laboratory for diagnostic identification.

In this study, 20 species of trees were considered in the preparation of anatomical keys for identification. The species of trees used for the study are *Acacia auriculiformis,* A. Cunn. Ex Benth. , *Acacia mangium* Willd.. , *Albizia lebbeck* (L.) Benth. , *Albizzia odoratissima* (L.f) Benth. , *Artocarpus heterophyllus Lamk.* , *Artocarpus hirsutus* Lamk. , *Dalbergia latifolia* Roxb. , *Dalbergia nigra* Fr. All. , *Hevea braziliensis* (H. B. K.) M.A. , *Hopea parviflora*. Bedd., *Intsia bijuga* (Colebr.) , *Ocotea rodiaei* (Schomb) Mez. , *Peltogyne paniculata* Benth. , *Pterocarpus marsupium* Roxb. , *Pterocarpus dalbergioides* Roxb. ex DC. , *Santalum album* Linn. , *Swietenia macrophylla* king. , *Tectona grandis* Linn. , *Xylia dolabriformis* Benth. , *Xylia xylocarpa* (Roxb.) *Taub.*