WOOD PROPERTY PROFILE OF ROSEWOOD (*Dalbergia latifolia* Roxb.), CEYLON ROSEWOOD (*Albizia odoratissima* (Linn. f.) Benth.) AND RAINTREE (*Samanea saman* (Jacq.) Merr.)

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THESIS

submitted in partial fulfilment of the
requirement for the degree of

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DECLARATION

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Vinay Kumar Sahu

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ABBREVIATIONS

m	Meter
cu.m	Cubic meter
km	Kilometer
KJ	Kilojoule
S	Strength
p	Standard specific gravity
^{0}C	Celcius
MSL	Mean sea level
KAU	Kerala Agricultural University
Cal	Calories
UTM	Universal Testing Machine
FS at LP	Fibre stress at limit of proportionality
MOR	Modulus of rupture
MOE	Modulus of elasticity
HS at LP	Horizontal shear at limit of proportionality
ML	Maximum load
CS at LP	Compressive stress at limit of proportionality
CS at ML	Compressive stress at Maximum load
MSS	Maximum shearing stress
µm	microns
Sq.	Square
TS	Transverse section
TLS	Tangential longitudinal section
OD	Oven dry
CD	Critical difference
No.	Number
nm	nanometer
Fig.	Figure
et al.	Coworkers
SB	Static bending
CSPL	Compression parallel to grain
CSPD	Compression perpendicular to grain
SHR	Shear in radial plane
SHT	Shear in tangential plane
ml	milliliter
cm	centimeter

Dedicated to Truth, Trust and

Honesty of my parents

Introduction

INTRODUCTION

"Wood – a natural, cellular, composite material of botanical origin- posseses unique structural and chemical characteristics that render it desirable for a broad variety of end uses." (Parham and Gray, 1984). Of all biological raw materials, wood is recognized as having the widest applications in many industrial (paper pulp, wood composites etc.) and domestic fields (furniture, poles, beams etc.).

India, since historical times has been recognized for its rich forest resource. Despite an enormous and varied forest resource, our country is reportedly facing a wood shortage. Over exploitation of valuable tree species and lack of scientific forest management had lead to considerable dearth of market timber, consequently necessitating import of significant quantities of hardwoods. Timber is one of the major forest produce needed by any developing society for several applications. India is one of the biggest consumers of wood in the Asia Pacific region. Our country, with only 2.47 per cent of the world's geographical area and 1.8 per cent of the world's forests, is supporting 16.1 per cent of the world's human population. An ever exploding Indian population with its improving standards of living and new end uses of wood accentuate the pressure on the supply of processed woods products. In the last five years, India almost doubled the imports of logs of all type from 1.1 million m^3 in 1997-1998 to 2.5 million m^3 in 2001-2002 (Bansal, 2004). The National Forestry Action Plan- India, which is a comprehensive strategy and action plan of twenty years has projected that the total annual requirement of timber in the years 2001 and 2006 to be 73 and 81.8 million cu. m (GOI, 1999).

Considering the developing characteristics of Indian society it is only reasonable to expect that per capita requirement of industrial timber will grow faster and a handful of durable but highly priced timber species cannot meet the increasing demand for wood. Introduction of alternative species or less known woods possessing similar wood properties as the highly valued woods can overcome the problem to a large extent. However, wood substitution by less known species can have negative consequences in the timber market.

Wood adulteration or wood substitution is one such negative impact, which arises primarily due to the apparent similarity in the gross characteristics especially the colour of different woods. Wood of different species may resemble each other in many characteristics which can only be distinguished through detailed studies of their more reliable properties viz., anatomical, mechanical, physical and biochemical. Of late, there are a number of unconfirmed reports that the processed products of several less known, low priced timber species are being traded in the local furniture market on the basis of their identical colour and appearance with some genuine woods and are being marketed off as highly priced woods.

Dalbergia latifolia Roxb. (Indian rosewood) had been a precious, rare and highly priced wood throughout history because of its rich and vividly contrasting grain, beautiful colour and higher strength properties. Its wood is fragrant (freshly cut) and decorative and is used to make premium furniture, paneling and veneers. Since the price of the genuine Indian rosewood has moved out of the range of most buyers, many relative and substitute species that resemble Indian rosewood in colour and appearance have cropped up in the wood market at prices which are up to half the cost of the genuine one. Close relatives of Indian rosewood such as blackwood, Brazilian rosewood, Honduras rosewood, Amazon rosewood and other common substitutes such as Mexican rosewood, African rosewood and Santos rosewood are being illegally sold at high prices as Indian rosewood in different parts of the world (Dahms, 1989; Soesilotomo, 1992; Boak, 2004). The introduction of such species has created a great deal of confusion in timber market.

Reports from the local timber merchants hints to the fact that furniture made of rosewood is widely adulterated. As several local furniture marts have cropped up in the state, the competition to make quick money is intense. In this race to survive, adulteration of rosewood furniture with some lesser known species is reportedly widespread. In Kerala, furniture or parts of them made of *Dalbergia latifolia* are reportedly "adulterated" with two low priced timber species viz., *Albizia odoratissima* Linn. f. Benth (Ceylon rosewood) and *Samanea saman* Jacq. Merr. (rain tree). Ceylon rosewood and rain tree resemble closely

Indian rosewood in wood colour but may not be equally suitable for common end uses as they may be inferior in other wood properties. As the wood colour of the former two species (Ceylon rosewood and rain tree) is almost similar to that of Indian rosewood, it becomes difficult for a buyer at first instance to differentiate these woods based merely on its colour. Many a times, an unsuspecting buyer gets cheated through the purchase of the furniture made either from Ceylon rosewood or rain tree timber and sold under the identity of rosewood. After getting an order from an unsuspecting buyer, the furniture as a whole is either made from Ceylon rosewood or rain tree timber and after finishing is sold under the identity of rosewood.

In the wake of such increasing reports of adulteration of furniture made of Indian rosewood with the two less known timber species, an investigation was carried out at College of Forestry, Kerala Agricultural University, Thrissur to prepare a comprehensive profile of the different wood properties of *Dalbergia latifolia, Albizia odoratissima* and *Samanea saman*. The objective of this investigation was to highlight the differences in the anatomical, biochemical, physical and mechanical properties of these three woods to guide prospective buyers and general public about the correct identity and utility value of Indian rosewood and its alleged adulterants in the context of furniture industry.

Review of Literature

REVIEW OF LITERATURE

Wood, in the form of timber and fuel, is an important product derived from trees. The vast subcontinent of India with its rich biodiversity harbours over 4000 different woody species (Rashid, 1988) and provides a wide choice of timbers suitable for different purposes. India has a total forest area of 675,538 km^2, about 20.55 per cent of the total land area (FSI, 2001) yet it is timber deficient. The supply of wood has considerably come down due to over exploitation of few highly priced species in many regions, consequently leading to import of timbers. According to annual review and assessment of the world timber situation (ITTO, 2002), India ranks as fourth largest importer of tropical logs in the year 2001. Among some of the tropical imported species are teak, oak, red sanders, rosewood, white cedar, sal and many others (Bansal, 2004).

Wood substitution by several other lesser-known species is an important aspect that will have serious bearing upon timber imports. It is reported that rain tree, whose importance as structural timber has not been recognized, has now become an important substitute for teak in parts of Thailand (Subansenee, 1994). However, before substitution it is equally important to check the suitability indices of such woods to various end uses. A proper understanding of its nature and suitability to various end uses requires certain fundamental knowledge of its physical, mechanical, anatomical and biochemical structure (Hoyle and Woeste, 1989). Reports of the extensive studies conducted by Zobel and Talbert (1984) disclose that wood properties are bound to vary with species, tree form, genotypes, growth variations and environments. But, few to many gross wood characteristics such as wood appearance, lustre, colour, odour, and weight may be similar between different species. It is reported that due to similar heartwood colour of *Dalbergia latifolia* Roxb. (Indian rosewood) with many of its relatives viz., *Dalbergia melanoxylon* (African blackwood), *D. nigra* (Brazilian rosewood), *D. stevensonii* (Hondurus rosewood), *D. cearensis* (Brazil kingwood) and with many of its possible substitutes viz., *Cordia elaenoides, Guibourtia tessmannii, Platymiscium yueatanum, Machaerium scleroxylon, Pterocarpus spp.* a great deal of confusion and misinformation exists about many varieties of genuine rosewood and so called substitute species in timber markets of many parts of the world. (Dahms, 1989;

Soesilotomo, 1992; Boak, 2004). Several of these species, similar in appearance, weight and working characteristics are marketed under the general but misleading name "rosewood". Many of these woods are heavy and have dark coloured heartwood that closely resembles the brilliant colouration of Indian rosewood. To counter such spurious market dealings, it is required to generate adequate information about different woods to resolve disputes (FRI, 1986).

In India, unpublished information reveal that in different furniture markets of Kerala, parts of furniture made of Indian rosewood are allegedly adulterated either in part or whole with less known species viz., *Albizia odoratissima* Linn f. Benth. (Ceylon rosewood) and *Samanea saman* Jacq. Merr. (rain tree) due to its almost similar heartwood colour and density.

To make the buyers aware of the identity of genuine timber of Indian rosewood, Ceylon rosewood and Rain tree, it was felt necessary to decode the different wood properties of these species. The work was carried out with the background knowledge of literature as reviewed.

2.1 GROSS FEATURES OF THE SPECIES UNDER STUDY

2.1.1 *Dalbergia latifolia* Roxb. (Indian rosewood)

'*Dalbergia*' commemorates the Swedish botanist, Nicholas Dalberg (Tiwari, 1995). It belongs to the plant family Fabaceae and comprises 300 species occurring in tropical and subtropical regions of the world. Twenty seven species of this genus are distributed in India. Of these 15 are indigenous and 3 are endemic (Thothathri, 1987). Some of the Dalbergia species owe great value due to their dark coloured ornamental heartwood. *Dalbergia latifolia* is one among this genus, which ranks among the finest wood for furniture and cabinet work. It is well known in Europe and America in piano trade (Tiwari, 1995). It is also prized for musical instruments and decorative veneers. The heartwood is extremely hard and heavy with average weight of 815 kg/m^3 at 12 per cent moisture content. The sapwood is small and yellow or pale yellow-white with pinkish tinge. It is light purplish brown to deep purple with black longitudinal streaks often with an attractive figure and pleasant odour (Gamble, 1985; Tiwari, 1995). The wood with no distinct annual rings shows medium to close grained texture and straight to shallowly interlocked grain. Nair and Chauhan (1985) reported that the ratio of heartwood area to sapwood area shows strong correlation. In its gross structure it appears as diffuse porous wood, with a slight semi-ring porous tendency. Pores are moderately sized to large and visible to naked eye. They appear few to moderately numerous mostly solitary often filled with gummy deposits (Rao and Juneja, 1971; Rao and Purkayastha, 1972; Richter and Dallwitz, 2000).

2.1.2 *Albizia odoratissima* Linn. f. Benth. (Ceylon rosewood)

Albizia odoratissima commonly known as Ceylon rosewood is a well known construction timber of various states (Purkayastha, 1999). However in Punjab, its timber is said to be soft and only fit for fuel (Gamble, 1985). It shows distinct heartwood and sapwood. The sapwood is white or yellowish white and the heartwood attains dark brown colour with darker streaks. The heartwood turns almost black with age. It is moderately hard and moderately heavy (740 kg cm^{-3}) wood with shallowly interlocked grain and coarse texture (Purkayastha, 1999; Gamble, 1985). The premium quality wood is used for most structural purposes. Selected timbers can also be very handsome and for paneling, flooring and heavy furniture it has proved worth above average (Trotter, 1982).

2.1.3 *Samanea saman* Jacq. Merr. (Rain tree)

'Samanea' is an American genus of which 'rain tree' was introduced in India as avenue tree in the last century (Purkayastha, 1999). The sapwood is white or light yellowish white and the heartwood is greyish brown or dark chocolate brown. The wood becomes harder, heavier and darker in old trees (Little and Wadsworth, 1964). The wood shows regular lustre and characterized figure of overlapping arcs. It is odourless and tasteless (Flores, 2002). The wood is soft and light (540 kg cm^{-3}) with straight and shallowly interlocked grain and fine texture. It is a diffuse porous wood with indistinct growth rings. The pores are moderately large to small (Purkayastha, 1999). The wood is a valuable source of high quality firewood and charcoal. It possess a strong market for timber carving on account of the distinctive and highly attractive look the heartwood assumes on polishing. The beautiful wood is also used for interior trim, crafts, boxes, veneers, plywood, and general construction (Flores, 2002).

2.2 PHYSICAL PROPERTIES OF WOOD

The physical properties of timber relate to inherent qualities as appearance, colour, density, reaction to heat, and moisture content. According to Sekhar (1988) the knowledge of physical properties decides the wood working qualities. The wood properties vary from species to species. It is observed that no two species are identical with regard to all wood properties (Konwer *et al.*, 2001).

2.2.1 Calorific value (calories per gram)

Calorific value of wood is a variable parameter. Important determinants of calorific value include; ash content, wood density, moisture content, species, locality, seasonal change and tissue type. Bark and wood samples of 45 multipurpose tree species in the homegardens of Kerala were studied to assess their fuel wood characteristics by Shanavas and Kumar (2003). They reported large variations in calorific values of species and tissue types. It was also evident from these studies that ash content had a negative correlation with heat of combustion but specific gravity exerted a positive influence. By studying the fuel wood characteristics of thirteen firewood species, Singh and Khanduja (1984) reported that the ash content of wood generally lowers the heat of combustion of fuel wood. From the same study, they also interpreted that the ash per cent in thirteen firewood species showed wide variations (0.87% to 5.20%) among species. Studies on oak revealed that the ash content of oak wood changes along tree height with the highest ash content recorded at the top and lowest at the butt end (Krutul, 1997). Siagian *et al.* (1999) and Mazurkin *et al.* (1998) from their findings on *Acacia mangium* and *Abies sibirica* respectively, stated that ash content varied with tree age and wood density. Studies conducted on the fuel wood characteristics of four Australian grown species comprehends that high-density species take longer time to ignite but produces a steady heat long after the flame has died down (Groves *et al.*, 1989). The calorific value per unit volume of wood, changes with the moisture content of the wood samples. Moisture content of wood is reported to have negative correlation with fuel wood value. This was confirmed by Haufa and Wojciechowska (1986) from their studies in Norway spruce, oak and beech, where the average calorific value changed from 13.2 KJ g^{-1} to 15.675 KJ g^{-1} from green condition to air dry condition. Tissue position and stem diameter are two key factors affecting moisture content of wood. Uzunovic and Dickinson (1998) observed that the moisture content increased significantly with increasing tree height in case of Scots pine (*Pinus sylvestris*). Increase in moisture content with increasing stem diameter was reported in *Elaeagnus umbellate* by Thakur and Thakur (1998). It can be said that tree species with high specific gravity, low ash content and moisture fractions were considered as good fuel wood species (Bhatt and Todaria, 1990). Furthermore, presence of resins in most of the coniferous species account to its higher calorific value than that of broad leaved species (Wang *et al.*, 1999; Goel *et al.*, 1992). Bhatt and Todaria (1992) in their studies found that the mean calorific value of broad leaved species (16 KJ g^{-1}) was much lower than that of coniferous species (17.3 KJ g^{-1}). Variation of calorific value among trees of the same species between different localities was reported by Puri *et al.* (1994) in six indigenous Indian species. Calorific value of twelve species studied by Senelwa and Sims (1999) varied with tissue type and parts of a tree due to differences in tissue constitution.

2.2.2 Specific gravity

The wood specific gravity is a useful indicator of the basic strength of wood (Shirin *et al.*, 1998). It is the sum total of the wood substance proper, extraneous matter, and water content (Sekhar, 1988). The common methods of determining specific gravity are described in the Indian Standards (IS 1708: 1969) specified by ISI (1969). Sekhar and Rawat (1959) have investigated 140 species and established the general relation '$S=kp^n$' between specific gravity and strength (k, n are constants for various properties which varies with species; p is standard specific gravity). Specific gravity varies with species and provenance. The average specific gravity of teak from Mizoram, Orissa, Tamil Nadu, and Kerala were 0.606, 0.539, 0.639, and 0.604 respectively (Shukla and Lal, 1994). Similarly, Patlai (1982) from his studies on oak and ash reported an increasing trend of specific gravity from north to south latitude. The dry matter content (wood density) changes with position in the tree. (Damodaran and Chacko, 1999; Chen *et al.*, 1998). Variation in wood density among genotypes of poplar (Gruss and Becker, 1993) and Douglas fir (Veveries, 1982) were also reported. Edaphic, climatic and topographic factors profoundly influence specific gravity of wood. Parolin and Ferriera (1998) studied thirty five central Amazonian tree species and concluded that the specific gravity of wood from soils with low nutrient status was generally higher than that of wood grown on soils with higher nutrient status. In another study conducted by Robert and Espen (1992), it was found that the wood specific gravity of *Cieba pentandra* from four Costa Rican life zones and a moist tropical forest in west Africa exhibited marked variability. Variation in specific gravity with topographic differences was confirmed when it was noticed that the specific gravity of wood of *Grevillia robusta* from Uttar Pradesh was much higher than the specific gravity from Karnataka (Khanduri *et al.*, 2000). Tree age is another factor which influences specific gravity. It was reported that increase in tree age increased the specific gravity from 0.47 to 0.56 in case of *Acacia mangium* (Siagian *et al.*, 1999) but, in some species like teak and *Gmelina arborea*, age have no influence on specific gravity (Bhat *et al.*, 1999; Siagian and Komarayati, 1998). Variation of specific gravity from pith to periphery is also noticed for many species. The specific gravity of *Eucalyptus grandis* increased from 0.419 in the central segment to 0.472 in the outer segment along radial direction (Hans *et al.*, 1972).

2.2.3 Linear and Volumetric shrinkage of wood

As timber dries, water is lost from cell walls, causing them to shrink. Shrinkage should occur evenly across the timber for it to retain its dimensional stability. Shrinkage depends a lot on season, age of tree, and ring width. Burmester and Ranke (1982) showed that in larch, shrinkage was lowest in February-March and greatest in July. In a study conducted by Damodaran and Chacko (1999) on *Acacia mangium*, they found that radial shrinkage (green to oven dry) was 2.5 per cent and tangential shrinkage was

6.7 per cent for 8 year old trees where as, for 10 year old trees it was 3.2 per cent and 4.7 per cent respectively. It is reported that with increase in ring width in *Abies grandis*, shrinkage increases (Schwab and Stratmann, 1983). Variation in shrinkage pattern is also observed along tree height and along radial direction. Longitudinal, radial, tangential and volumetric shrinkages were observed to be higher at base than at breast height in the case of *Eucalyptus spp.* (Trugilho and Vital, 1996). A study conducted by Jain and Arora (1995) in *Eucalyptus camaldulensis* showed that the moisture content decreased from pith (105 per cent) to periphery (70 per cent) and tangential shrinkage decreased from 9.15 per cent in pith region to 7.62 per cent at periphery. In case of *Fagus orientalis*, the volumetric shrinkage of wood increased from pith to bark and from bottom to top of the tree where as in longitudinal direction, little change was observed (Rassam and Doosthoseini, 2002). In general, tangential shrinkage is the largest directional component of shrinkage. It may be 5 to 12 per cent in hardwoods. In some woods, the tangential shrinkage is twice than radial shrinkage. Longitudinal shrinkage in normal mature wood is small of the order 0.1 to 0.2 per cent when oven dried from fibre saturation point (Schniewind, 1989).

2.3 MECHANICAL PROPERTIES OF WOOD

Strength properties of different timbers are evaluated on the basis of different tests carried out for bending, compression, shear and abrasion. Since one individual timber is not likely to be better or worse than the other under all the tests and all the properties evaluated from these tests, suitability indices are derived by combining several properties relevant to a particular use and expressing them as percentage of reference timber so as to obtain a single figure for comparison. By compiling the suitability indices for 246 Indian timber species, Sekhar and Gulati (1972) revised the suitability indices prepared by Limaye (1954) which in turn was based on only 207 species. Various factors influence the strength properties of wood. The variability of wood strength from species to species or within a species can be due to environmental and genetic factors (Schniewind, 1989). Bhat *et al.* (1999) citing the example in *Tectona grandis* and *Gmelina arborea* showed that in some species, age have no influential role in altering mechanical properties. Mechanical properties within a tree vary even with position of sample. In most cases, strength initially increases and then decreases again in a radial traverse from pith to periphery (Sekhar and Negi, 1966; Sekhar, 1988). Presence of knots and deviation of grain due to knots in tissue sample is another important factor affecting timber strength (Rajput *et al.*, 1998). Dry samples are found to have higher strength than green samples (Kumar *et al.*, 1987). However, above fibre saturation point, the mechanical properties are not much affected by moisture content.

2.3.1 Static bending test

The properties of static bending test are useful in all engineering constructions and also in deciding suitability of various species for beams, deckings, axles and wood poles (Sekhar, 1988). Lohani and Sharma (2003) had investigated the stiffness-strength relationships in *Albizia procera* and *Prosopis juliflora* by subjecting the samples to static bending test. The modulus of elasticity and modulus of rupture obtained from these tests revealed their efficacy for machine grading. In a study conducted on plantation grown and natural tamarack (*Larix laricina*), the static bending and compression parallel to grain in plantation grown tamarack were found to be significantly lower than naturally grown tamaracks (Beaudoin *et al.*, 1989). Shukla *et al.* (1988) by studying the strength properties (static bending, compression parallel to grain and hardness) of 16 year old *Eucalyptus tereticornis*, concluded that overall strength properties increased from pith to periphery in the heartwood and decreased in sapwood region. Bhat and Thulasidas (1997) analyzed the physical and mechanical properties of *Eucalyptus grandis* and *E. tereticornis* grown in Kerala. They reported that the bending strength of *E. tereticornis* grown in Kerala was 11 per cent weaker than that grown in drier localities of north India. Studies on the bending properties of *Pinus radiata* wood growing in silvopastoral system revealed that the frequency of fertilizer application had no significant effect on the mechanical properties but stem height had significant effect on stress at proportional limit and modulus of rupture (Ramirez *et al.*, 2001). Kretschmann and Green (1996) analyzed various mechanical properties of clear southern pine at different moisture content. From these findings, it was reported that the elastic modulus increased with decreasing moisture content from green to four per cent moisture content. Yoshihara and Fakuda (1998) studied the influence of loading point on the static bending test of *Liriodendron tulipifera* wood. They observed that when depth/span ratio is high, loading point had little influence in Young's and shear moduli. Also, when specimen had a high depth/span ratio, bending strength increased with increase in the radius of the loading nose. Studies on the variation pattern of mechanical property of *Dendrocalamus latiflorus* timber revealed that site condition had no effect on bending strength (Lin *et al.*, 1999). Age profoundly influences bending strength properties. In a study conducted on red pine (*Pinus resinosa*), modulus of elasticity and modulus of rupture was 22 to 90 per cent greater in mature wood than in juvenile wood (Shepard and Schottafer, 1992). From the studies on the thermal behaviour of wood during static bending tests, Naito *et al.* (1998) found that in specimens of yellow cedar (*Chamaecyparis lawsoniana*) the temperature raised up to an average of 0.6 ^{0}C immediately below the loading point after the load reached the proportional limit. An alternative method to evaluate modulus of rupture is longitudinal vibration. Ayarkwa *et al.* (2001) evaluated modulus of rupture of solid and finger jointed tropical African hardwoods using longitudinal vibration. They concluded that although static bending is generally recognized as more desirable method of determining modulus of rupture, the longitudinal vibration technique may also be useful as a non destructive technique for predicting modulus of rupture of solid and finger jointed African hardwood timbers.

2.3.2 Compression strength parallel to grain

The properties determined under this test are useful for design of columns and evaluating suitability of timber species for posts and other industrial purposes where forces act in a direction parallel to the grain of the timber (Sekhar, 1988). Kolin (1988) investigated the compression strength parallel to grain in woods of *Fagus sylvatica, Quercus pedunculata*, poplar, fir and spruce at different moisture contents of 4% to 24% and at different temperatures between 20 ^{0}C to 80 ^{0}C. He found that the compression strength decreased with increase in moisture content and temperature. Variation of strength properties along pith to periphery was studied in *Eucalyptus tereticornis*. It was observed that compression strength parallel to grain increased from pith to periphery in heartwood and decreased in sapwood region (Shukla *et al.*, 1988).

Shukla and Khanduri (1990) from their studies on the effect of rate of loading on ultimate bending and compressive strength of wood conducted on *Eucalyptus, Mangifera indica* and *Tsuga dumosa*, established relation between these two strength parameters and rate of loading. It was also found that rate of loading has greater influence on maximum crushing stress under compression than on modulus of rupture in static bending. In another study to determine the variation of specific gravity and compression parallel to grain among different clones of *Populus deltoides*, it was reported that maximum crushing stress differed significantly between clones and with radial position. Along radial position, maximum crushing stress at central position was weaker than outer position (Rajput *et al.*, 1997). Rate of growth and age of tree also affects compression parallel to grain. Razali and Hamami (1993) reported a mean maximum crushing stress of 43.4 N mm^{-2} for 12-year-old *Acacia mangium*, where as Damodaran and Chacko (1999) reported a mean maximum crushing stress of 30.4 N mm^{-2} for 8-year-old and 10-year-old *Acacia mangium* trees.

2.3.3 Compression strength perpendicular to grain

Compression strength perpendicular to grain is often critical in timber design. It is usually most severe at the ends of deep, narrow beams and in connecting members at the top and bottom of short, heavily loaded columns. In this test, force is applied on the radial longitudinal surface only. The properties evaluated in this test are useful for selecting timber species for uses where timber is loaded on its lateral surfaces such as furniture, railway sleeper, instruments and some type of sports goods (Sekhar, 1988). Beaudoin *et al.* (1989) by studying the mechanical properties of plantation grown and natural tamarack timbers concluded that compression perpendicular to grain and hardness did not differ significantly between plantation grown and naturally grown tamarack woods. Like other properties viz., bending strength, compression parallel to grain, shear strength and modulus of elasticity, it was found in clear southern pine that compression perpendicular to grain increased with decreasing moisture content from green to four per cent moisture content (Kretschmann and Green, 1996).

2.3.4 Shear parallel to grain

Maximum shearing stress is useful in the design of various articles such as agricultural implements, lorry bodies, bearing and packing blocks etc. (Sekhar, 1988). This test is carried out generally by block shear test using universal testing machine. Yoshihara and Satoh (2003) put forward off axis tension test method to determine shear strength by analyzing the strength properties of *Fraxinus spaethiana*. They however concluded that this method is not suitable to determine shear properties of wood. Recent studies were carried out by Sretenovic *et al.* (2004) on Norway spruce and European larch to check the suitability of modified shear test set up upon block shear test. Test results indicated that for determination of shear strength and shear modulus, modified shear test is very suitable. Muller *et al.* (2004) used the new method to determine the longitudinal shear modulus and shear strength of solid wood in a single test. They observed that shear properties of normal wood and compression wood of *Larix decidua* were related to their microstructure i.e. density, micro fibril angle and lignin content. Their analytical models prove that the effect of increased micro fibril angle and higher lignin content on longitudinal shear modulus in cell wall balance each other to a large degree. Studies were done on western hemlock (*Tsuga heterophylla* Sarg.) to examine whether the maximum shear stress can be used to describe the shear strength. It was concluded that in short beam test under asymmetric four point loading, the value of the maximum shear stress is an effective parameter for comparing the shear strength of materials with each other. Lin *et al.* (1999) analyzed the variation pattern of mechanical properties of *Dendrocalamus latiflorus*. They concluded that site has no significant effect on shearing strength parallel to grain but age has a positive influence on shearing strength. They also found that this property was better at upper position of culms followed by middle and lower positions

2.3.5 Abrasion test

Woods are extensively used as flooring boards in massive freight containers, decks, boards, in transport vehicles etc. These woods and wood panels are subjected to wear during usage. In order to assess suitability of these woods for a specific end use, the wear resistance characteristics of the panels are of utmost importance. Thomas (1998) studied the wear resistance properties of *Toona ciliata, Dysoxylum malabaricum, Fagus spp* and plywood derivatives of *Dipterocarpus spp.* using Taber 5130 abraser. The wear index values observed at 100 cycles of revolution were 586, 275, 602 and 709 respectively.

2.4 ANATOMICAL PROPERTIES OF WOOD

Anatomy forms a strong basis for identification of species. It is found that transverse section of wood under magnification will serve in the majority of cases as a sure means of identification (Howard, 1941). de-la-P-Perez-Olvera and Quintanar-Isaias (1999) revealed the diversity of 3 species of genus *Quercus* growing in Mexico by analyzing the anatomical and biochemical attributes. The results showed outstanding differences in wood colour, porosity, width and number of ray series, type and abundance of cell contents among and between species. Some of the anatomical features like presence of ray cells separation and number of cells in transverse section of earlywood were used by Visscher and Jagels (2003) to differentiate the identity of *Metasequoia* and *Glyptostrobus*. Sun *et al.* (2002) prepared comparative anatomy of 17 Cinnamomum wood species and segregated *Cinnamomum lious* and *Cinnamomum chinggii* as two separate species. In west African savannas, charcoal samples recovered at archaelogical sites were identified based on the wood anatomy of 31 species growing in Sudanian savanna. Heterocellular rays and storied structure allowed for first differentiation. Vessel pitting, silica, axial canals, septate fibre and non-chambered ray cells were additional features. Parenchyma distribution and ray width, due to their large variability were not reliable (Hohn, 1999).

2.4.1 Vessel size and arrangement

Generally, in most hardwoods, the vessels as seen in transverse sections are scattered. Wilson and White (1986) classified the various types of vessel arrangement as diffuse porous, ring porous and semi-ring porous. They also reported that ring porous trees are always deciduous. Vessel dimensions show marked variability along radial and axial directions within a tree. Rao *et al.* (2003b) studied the radial variation in anatomical properties of plantation grown *Tecomella undulata*. They found that vessel frequency, vessel diameter and percentage of solitary vessels were interrelated and significantly varied from pith to periphery. In another study in *Fraxinus excelsor* L., the radial variation of vessel lumen diameter and frequency were limited adjacent to pith. It was observed that the diameter of early wood vessels increased along cambial age where as, frequency of vessels decreased (Helinska and Fabisiak, 1999). Florsheim *et al.* (1999) reported that in *Myracrodruon urundeuva*, the vessel frequency decreased towards bark where as, the vessel diameter increased. Along the longitudinal axis, it was observed that vessel diameter and length decreased towards the base where as, the vessel frequency increased towards the base. Similar results were observed in *Khaya ivorensis* A. Juss, where plant height was found to have significant effect on vessel length. In this species, the vessel length increased up to a height of four meters and then decreased. The distance from pith however had no significant effect on vessel length (Okoegwale and Gill, 1990). Kitin *et al.* (1999) studied the variation in the length of fusiform cambial cells and vessel elements in *Kalopanax pictus*. The species had ring porous wood and exhibited wide variation in length of vessel elements. It was reported that the length of early wood vessels does not change during differentiation but might be directly derived from short and long cambial cells.

Woodcock (1999) studied the ecological relationships of wood anatomy. Woods from different forest types viz., low riverside vegetation, flood plain forest growing on a low terrace, clay soil forest on upper terrace, sand soil forest and swamp forest were tested for their diversity. It was found that vessel element length was greater on flood plain forest trees. On the other hand, fibre length and vessel diameter were not affected by vegetation type. In a case study to examine the latitudinal trends in wood anatomy within a species and genera of *Cornus*, it was found that at species level, vessel length, fibre length, vessel frequency, tangential vessel diameter and vessel grouping index show no trend variation with latitude. However, at genus level, the correlation coefficient with latitude were markedly high (Noshiro and Bass, 2000). Age of a tree is reported to affect the vessel dimensions. Gimenez and Lopez (2000) reported that in

Schinopsis quebrachocolorado (Schlecht) Barkl et. Meyer, significant differences were observed among age classes for vessel frequency, vessel diameter and vessel area.

2.4.2 Distribution of parenchyma

The distribution of axial parenchyma in wood shows marked diversity. The various patterns of its arrangement have therefore been classified and defined in many literatures (Jane, 1956; Wilson and White, 1986). Using light microscope and scanning electron microscope, the wood structure of 51 genera representing 19 tribes of Acalyphoideae were studied. The parenchyma distribution is reported to vary from diffuse porous, diffuse to aggregate and scanty paratracheal (Hayden and Hayden, 2000).

2.4.3 Ray height and width

The ray tissue in hardwoods account up to 18 per cent and upwards. It shows considerable variation in both size and number of the rays. Lev (1998) studied the relationship between growth ring width, ray density and ray height in early wood of *Pinus haplensis* and *Pinus pinea*. He found that all trees of *Pinus* species showed gradual tendency for increase and decrease in ray number in ray height from pith to periphery. Similar study in *Terminalia ivorensis* A. Chev., indicated that ray frequency, length of rays show well defined trend of variation along radial stem direction. On the other hand, along axial direction the differences were not significant (Urbinati *et al.*, 2003). Rajput and Rao (2003) studied the cambial variation and xylem structure in the stems of *Cocculus hirsutus*. Xylem rays which were found to be multiseriate compound and heterocellular, showed a gradual increase in length and width of rays from center towards the periphery of the stem. In *Cordia thaisiana*, clear patterns of radial variation in ray height were observed. However, ray frequency showed little radial variation (Leon and Espinoza-de-Pernia, 1998). From the same study, it was also reported that ray height shows no definite patterns of variability along axial direction of the stem. Ray frequency as in radial direction shows little axial variation. Arias and Terrazas (2001) found that ray height was significantly correlated with altitude in *Pachycereus* *pectin-aboriginum*. Florsheim *et al.* (1999) investigated the variation in ray dimensions in twelve trees of *Myracrodruon urundeuva*. They reported that spacing and diameter class do not influence anatomical characters. From their studies it was observed that rays in longitudinal direction have highest frequency and greatest height at the top of the stem, while ray width exhibited highest values at the base. In the radial direction the frequency of rays was lowest in the bark region, while ray height and width were highest in that region.

2.4.4 Special characters of wood

Special characteristics such as crystals and deposits of silica in wood, resin canals, gum ducts, latex canals, included phloem, tyloses and calcium oxalate deposits can form species identifying features of wood (Wilson and White, 1986; Carlquist, 1988). Sun *et al.* (2002) compared the wood anatomy of seventeen native species belonging to *Cinnamomum* of Lauraceae. They found that all woods of seventeen species possess oil cells and mucilage cells in axial parenchyma cells or ray cells. Presence of silica and crystals in non chambered ray cells were regarded as characteristic features of few selected species of Caesalpinoideae from west Africa (Hohn, 1999). Wood anatomy of forty one species of *Buddleja* L. revealed that thirty five per cent of the species contain prismatic crystals of different sizes in their ray cells (Aguilar and Terrazas, 2001). After studying the wood anatomy of twenty wood species of Indonesia west region, Mandang and Sudardji (2000) reported that presence of silica bodies in fibers of *Santina laevigata* is a marked feature for its identification. Hayden and Hayden (2000) identified that presence of prismatic crystals in parenchyma cells and lysigenous radial canals supports recognition of tribe Alchorreae. Reddish brown gum deposits and silica deposits are found in the vessels of *Dalbergia latifolia* (Pearson and Brown, 1981).

2.5 BIOCHEMICAL PROPERTIES OF WOOD

Biochemical constituents of wood include lignin, cellulose, hemicellulose and extraneous matter. Holocellulose refers to the total polysaccharide content in the wood

(Zobel and van Buijtenen, 1989). The chemical constituents of wood are defined and listed for a number of species by different methods of extraction by Rydholm (1965). Purba and Sumarua (1987) analyzed the chemical constituents of twenty seven species of west Java including *Samanea saman.*

2.5.1 Lignin

Lignin polymer is a crucial constituent in plants. In that it provides mechanical strength reduces water permeability of the cell walls and participates in the plants defense as a physico-chemical barrier against pathogens (Baucher *et al.*, 1998). Lignin is considered nature's adhesive. Sjostrom (1981) in his literatures reports that normal hardwood contains 20-25 per cent lignin, although tropical hardwoods can have a lignin content exceeding 30 percent. Lignin can be isolated from extractive free wood as an insoluble residue after removing the polysaccarides from the extracted wood by hydrolysis with 72 percent sulphuric acid. Lignin content among different species show large individual differences. Nikitin (1966) from his studies found that lignin content varied greatly among species found in USSR. He also reported that the lignin content in oak varied from 21.6 % to 23.1 % when moved towards upper latitudes. Lignin content is found to vary with stem diameter within a tree. Thakur and Thakur (1998) reported that the lignin content measured in the stems of *Elaegnus umbellate* collected from Pooh (H.P.) varied significantly between different diameter classes. In another study to determine the variation in content and composition of lignin in Norway spruce, it was observed that lignin content did not vary significantly among and within different full sib families. They noticed an increase of four per cent lignin in the mature trees than young plants (Wadenback *et al.*, 2004).

2.5.2 Cellulose

Cellulose is the main constituent of wood. Approximately 40-45 per cent of the dry substance in most species is cellulose, located predominantly in the secondary cell wall (Sjostrom, 1981). Isogai *et al.* (1989) analyzed the residual lignin and hemicellulose in wood cellulose of spruce and beech by using new permethylation method. They found that there exist some chemical linkages between cellulose, residual hemicellulose and residual lignin in mature wood and some of these linkages are thought to inhibit isolation of pure cellulose. There exist few other methods to isolate cellulose. Brendel *et al.* (2000) put forward a rapid and simple method to isolate pure alpha cellulose. By using this method they isolated 350 cellulose samples from pine wood and concluded that the purity of cellulose obtained was 99 per cent. For analysis of carbon isotope discrimination of wood, cellulose or holocellulose is often preferred because of the variability in isotopic composition of different wood components and the relative variability of cellulose (Macfarlane *et al.*, 1999). Bertaud and Holmbom (2004) studied the chemical composition of earlywood and latewood in Norway spruce. They found that the cellulose content decreased along the cross section from sapwood to heartwood with a corresponding increase in lignin. In a chemical analysis of mature pine wood and spruce wood, Nikitin (1966) found that the methyl pentosans and mannans increased from pith to periphery in the trunk. On the other hand, the amount of pentosans and xylans decreased from the pith to periphery and from top to the base of the trunk. The content of methyl pentosans and mannan continuously decreased from the base of the trunk to its top.

2.5.3 Extractives and colouring matter

Extractives play a major role in attributing colour to wood (Chang *et al.*, 1998). The colouring matter of wood may comprise unsaturated hydrocarbons, ketones, quinones, flavonoids, isoflavonoids, and substances of uncertain structures. Some of these wood constituents, although representing only a minor proportion, can be extracted with organic solvents such as ethanol, acetone or dichloromethane. (Sjostrom, 1981). They also decide the strength properties of wood, suitability for paper making (Nunez, 1999), and suitability for fuel wood (de-Araujo *et al.*, 2000; Pereira *et al.*, 2001). Extractives soluble in neutral solvents constitute 4 to 20 per cent of the dry weight of normal wood of tropical species (Rowell, 1984). There are numerous chemically related examples of wood variation. For instance, Scurfield *et al.* (1974) showed where and how silica is deposited in wood (Zobel and van Buijtenen, 1989). The content of extractives and their composition vary greatly among different wood species and also within the different parts of the same tree. Heartwood mainly consists of accumulation of phenolic compounds (Sjostrom, 1981). Thakur and Thakur (1998) reported that lignin, holocellulose and alcohol-benzene extractives varied significantly between diameter classes in *Elaeagnus umbellate*. In *Juglans regia*, the radial distribution of phenolics showed that, Hydro-Juglan Glucoside (HJG) and Ellagic acid (El) concentration increased from sapwood to sapwood-heartwood transition and decreased drastically in heartwood. In the same study, it was concluded that HJG was major precursor of heartwood colour providing chromophores through hydrolysis, oxidation and polymerization processes (Burtin *et al.*, 1998). In some species of Eucalyptus hybrid, it is reported that the extractives showed a decreasing trend along the stem from base upwards (Gominho *et al.*, 2001). The biosynthesis of extractives is controlled genetically and hence each wood species tends to produce specific substances (Sjostrom, 1981). Extractive content also vary between clones and between species, which is a strong indicator of role of genetic component in their control (Mosedale *et al.*, 1996). Extractives have fungicidal property and thus effectively protect the tree against microbial attack (Sjostrom, 1981; Aoyama and Doi, 1992). It was found in *Juniperus spp.* that the growth of *Chaetomium globosum* was largely inhibited due to the extractives (Balaban *et al.*, 2003). There exist various methods by which various components of extractives can be identified and estimated. They can be isolated by using Thin Layer Chromatography (Yusiasih *et al.*, 2003), Column chromatography (Sawa, 1988), and Gas chromatography-Mass spectroscopy methods (Gutierrez *et al.*, 1999; Fernandez *et al.*, 2001).

2.6 INTERRELATIONSHIP BETWEEN PHYSICAL AND MECHANICAL PROPERTIES OF WOOD

Wood density is considered the best single index of wood quality because it is most dependable characteristic for predicting timber strength (Shirin *et al.*, 1998). Sekhar and Rawat (1959) established relationships between specific gravity and different strength properties analyzing the wood properties of 140 species and Shukla and Rajput (1989) revised these relationships on the basis of 350 consignments of different species. When information about a species is not available, they are often estimated from the strength-specific gravity relationships. Hernandez and Almeida (2003) from their studies on three Amazonian tropical hardwood species reported that wood density positively affected the apparent shear strength of wood. Ordonez-Candelaria and Davalos-Sotelo (1996) studied the variation of mechanical properties in the structural timber of Mexican pine by change in its moisture content. They reported that the moisture content of wood and its variation with atmospheric changes is one of the factors which influence the wood properties most. Similar studies were carried out in clear southern pine to determine the moisture content-mechanical properties relationships. It was found that the tensile stress parallel and perpendicular to grain increased with decreasing moisture content from green to a peak between 7 % and 13% moisture content. Upon additional drying, these properties decreased. Maximum fibre stress in bending, compression parallel to grain, shear strength and all elastic moduli increased with decreasing moisture content from green to 4 % (Kretschmann and Green, 1996).

Watanabe (1998) reported that in normal woods, radial shrinkage and elastic moduli increases with increase in specific gravity. However, tangential and volumetric shrinkage showed no correlation with specific gravity. They explained that wood has a regular arrangement in series in radial direction, so it is probable that the increase in specific gravity increases radial shrinkage. In an another study, *Eucalyptus regnans* exhibited a negative correlation between basic density and shrinkage and a positive correlation between moisture content and shrinkage (Ilic, 1999). Sining (1989) studied the relationship between shrinkage and basic density of wood. They observed that the shrinkage decreased as the basic density increased in *Acacia mangium.* However, a study by Bello (1997) in 80 Philippine wood species showed that volumetric shrinkage increased with increase in green specific gravity. A similar result of positive correlation between specific gravity and shrinkage was reported in *Cassia siamea* by Choudhary (1997) and in *Eucalyptus* species by Trugilho and Vital (1996). Chen *et al.*, (1998) from their findings indicated that the moisture content showed negative correlation with specific gravity in *Cryptomeria japonica.* Based on a study of six species, Wang and Wang (1999) reported that a negative correlation existed between moisture content and strength properties and a positive correlation between specific gravity and strength properties. They also observed that, a change of one per cent moisture content changed the MOE by 0.58 per cent to 2.5 per cent, MOR by 2.6 per cent to 3.9 per cent, and hardness by 1.1 per cent to 3.3 per cent. Shukla and Rajput (1990) established a relationship between different mechanical properties and modulus of rupture in static bending as well as maximum crushing stress in compression parallel to grain and the average correlation co-efficient for the three parameters (modulus of rupture, maximum crushing stress and specific gravity).

2.7 INFLUENCE OF ANATOMICAL AND BIOCHEMICAL PROPERTIES ON THE PHYSICAL AND MECHANICAL PROPERTIES OF WOOD

Zink *et al.* (1999) reported that in oak and maple different failure modes during mechanical tests were observed which was attributed to the different anatomical structures of the two species, mainly, ray and vessel size. Vessel diameter and diameter of parenchyma cells positively affects the longitudinal permeability of wood (Nasroun and Al-Shahrani, 1998b). Oh (1997) studied the relationship between anatomical properties and compression parallel to grain in *Pinus densiflora*. From these studies he reported that compression strength parallel to grain increased with increase in trachied length and wall thickness. He also concluded that the major factors affecting compression strength parallel to the grain in the heartwood were radial diameter of latewood trachieds and wall thickness of earlywood trachieds, but in sapwood, length and tangential diameter of latewood trachieds were important factors. In an another study conducted by Oh (1998) in major species of Lepidobalanus (*Quercus variabilis*, *Q. aliena*, *Q. serrata*, *Q. mongolica*, *Q. acutissima*), it was found the major factors affecting compression strength parallel to grain are proportion of rays in earlywood in *Q. variabilis* and *Q. acutissima*, proportion of wood fibre in latewood in *Q. aliena* and *Q. serrata* and proportion of vessels in earlywood in *Q. mongolica* respectively. Among the size of anatomical features, micro fibril angle in *Q. variabilis, Q. serrata, Q. mongolica* and length of wood fibre in *Q. aliena* and *Q. acutissima* had greatest influence on compression strength parallel to grain. Fibre wall thickness is reported to bear positive correlation with specific gravity (Aguilar *et al.*, 2001).

The physical and chemical properties of cellulose, hemicellulose, and lignin play a major role in the chemistry of strength. The influence of structural, physical and chemical properties on the mechanical characteristics of wood was discussed in detail in robinia wood (*Robinina pseudoacacia* L.) by Kopitovic *et al.* (1989). Hildebrandt (1960) emphasizes the importance of chemical composition and its influence in mechanical wood properties. For example, as the amount of lignin increases, the crushing strength and brittleness increases, while the tensile strength resistance to rupture and shock decreases. Lignin holds the cell components together and is responsible for part of stiffness of wood (Winandy and Rowell, 1984). Its ability to act as an encrusting agent on and around the carbohydrate fraction and thereby limiting water's influence on carbohydrate fractions is the cornerstone of wood's ability to retain its strength and stiffness. However, Rao (1988) reported that excessive lignification leads to decrease in the flexibility and an increase in brittleness of wood. The source of strength in solid wood is the wood fibre. Generally, cellulose is responsible for strength in wood fibre because of its high degree of polymerization and linear orientation. Cellulose is an unbranched, rigid chain, linear polymer composed of anhydro-D-glucupyranose ring units bonded together by 1-4-glycosidic linkages. The greater the length of polymerization greater will be the strength of wood (Mark, 1967). Hydrogen bonds within the cellulose provide rigidity to the cellulose molecule via stress transfer and allow the molecule to absorb shock by subsequently breaking and reforming. Hemicellulose act as matrix for the cellulose and increases the packing density of the cell wall. (Rowell, 1984). Wood extractives content form a good index of fuel wood value. de-Araujo *et al.* (2000) studied the various chemical constituents of the wood of *Azadirachta indica* and concluded that it to be good representative for energy production. Scurfield *et al.* (1974) reported that the variability resulting from differences in extractives or chemical composition influences specific gravity and causes great differences in the utility of wood.

Materials and Methods

MATERIALS AND METHODS

The present investigation was carried out in College of Forestry, Kerala Agricultural University, Vellanikkara during 2003-2005. The study area is located in Thrissur district between 10^0 32' North latitude and 76^0 26' East longitude, at 22.25 m above MSL. The site experiences warm and humid climate with distinct summer and rainy season.

3.1 SPECIES UNDER STUDY

Evident from the problem of adulteration/substitution of the processed timber products of *Dalbergia latifolia* in Kerala with its alleged substitutes viz., *Albizia odoratissima* and *Samanea saman,* in the furniture industry sector, the major wood properties of these tree species were studied for developing a comparative wood property profile.

3.1.1 *Albizia odoratissima* Linn. f. Benth

A. odoratissima commonly known as Ceylon rosewood belongs to the family Mimosoideae. It is a moderate sized to large tree usually about 20 m in height and two meters in girth with a clear bole upto nine meters, but occasionally reaches 24 m in height (Purkayastha, 1999). The tree is widely distributed throughout India in mixed and dry deciduous forest and also in semi evergreen forest ascending upto 1500 m in sub Himalayan forest (Purkayastha, 1999). It is a well-known construction timber of various states (Trotter, 1982).

3.1.2 *Samanea saman* Jacq. Merr.

S. saman commonly known as rain tree is a medium to large sized evergreen tree. It generally grows to a height of 18 to 24 m and over three meters in girth with a short bole and enormous umbrella shaped crown, extending up to 30 m in diameter (Purkayastha, 1999). Traditionally, this species has been considered to be of low potential for the international timber trade on account of small height of the trunk (Longwood, 1962). Escalante (1997) from his findings reported its best utility within domestic timber markets of Venezuela, where it is used in furniture construction and other light uses. Moreover, it is preferred for crafts work on account of its attractive heartwood colour (NAS, 1979).

3.1.3 *Dalbergia latifolia* Roxb.

D. latifolia commonly known as Indian rosewood is a large tree with a cylindrical and straight bole but varying in size according to the locality. The tree attains its maximum size in south India (Pearson and Brown, 1981). It is deciduous (nearly evergreen) tree with a full rounded crown. The tree reaches maximum size in western ghats, where it is found along the whole length in dry deciduous forest, rising to an altitude of 1067 m. It may reach a height of 24 m with a girth of 3 to 4.5 m (Gamble, 1985). *D. latifolia* ranks among the finest wood for furniture and cabinet work. It is also priced for musical instruments and decorative veneers. Tiwari (1995) reported that it has been a well known timber for piano manufacture in Europe and America.

3.2 PREPARATION OF SAMPLES

3.2.1 Selection of trees

Trees located in the main campus of Kerala Agricultural University (KAU) were surveyed. Mature disease free trees with straight bole and balanced form were identified and one tree each of Ceylon rosewood (Plate 1) and rain tree were selected. The dimensions of the trees selected for conversion into small clear specimens are furnished in Table 1.

Table 1 Dimensions of the trees selected for conversion

S. No	Species	Location	Height of the tree (m)	Girth at breast height (cm)	Heartwood diameter of log (cm)	
					Butt end	Small end
1.	*A. odoratissima*	Kishkinda division, KAU	18	138	50.6	41.6
2.	*S. saman*	Kishkinda division, KAU	14	144	49.6	44.6

Since *D. latifolia* is a highly priced timber, felling a tree for conversion into small clear specimens was not economical For the realization of sufficiently mature heartwood, a tree of much bigger girth had to be felled, which was not available and also again not economical Due to these limitations it was not subjected to testing (except biochemical properties) for its wood properties. Instead the other two species were tested for their wood properties and they were compared with properties of rosewood reported in relevant literature.

3.2.2 Felling and conversion of trees

Height and girth of the selected trees were measured using abney's level and linen tape, respectively. A line along the north facing side of the tree was marked using oil paint in the month of November 2004. The trees were felled using hand axe and hand saw. The basal portion of the trunks were converted to a log of 1.8 m each and the heartwood diameters both at the butt end and small end of logs were measured (Plate 2; Plate 3). The end surfaces were coated with oil paint to avoid instant loss of moisture. The logs were transported to the Rubber Wood Testing Laboratory (RWTL) of Rubber Research Institute, Kottayam for further conversion (Plate 4). One disc each measuring eight centimeters in thickness was cut from the base of each log using power saw. Small clear samples for

Plate 1. Ceylon rosewood selected for felling

Plate 2. Felled log of Ceylon rosewood being measured

Plate 3. Felled log of rain tree

Plate 4. Conversion of log to small clear specimens

analyzing the physical properties were sawn out from these discs. The remaining portion of the log was sawn to 5 x 5 cm^2 scantlings, which were finally converted to small clear specimens as per IS 2455:1990 (ISI, 1990) for analyzing the mechanical properties.

3.3 PHYSICAL PROPERTIES

The following physical properties of the heartwood and sapwood of Ceylon rosewood and rain tree were studied in detail.

3.3.1 Calorific value of wood

Samples of 2 x 2 x 2 cm^3 were air dried till constant weights were attained. The samples were then chipped separately to smaller size of approximately 0.3-0.4 cm thickness. The sample chips were then ground in an electric mill. The ground samples were stored in double-sealed polythene covers. One gram of the ground material from each sample was accurately weighed and calorific value estimated using an oxygen bomb calorimeter (No. 128978/Advanced Instruments Co., New Delhi) (Plate 5).

One gram of air-dried sample was used for finding out the calorific value. It was estimated by the following formulae:

$$H = \frac{T.W - (a + b + c)}{m}$$

Where

H = Heat of combustion of sample (cal)
T = Difference in initial and final bucket temperature (^{0}C)
W = Energy equivalent of bomb calorimeter (cal/^{0}C)
a = Acid correction (cal)

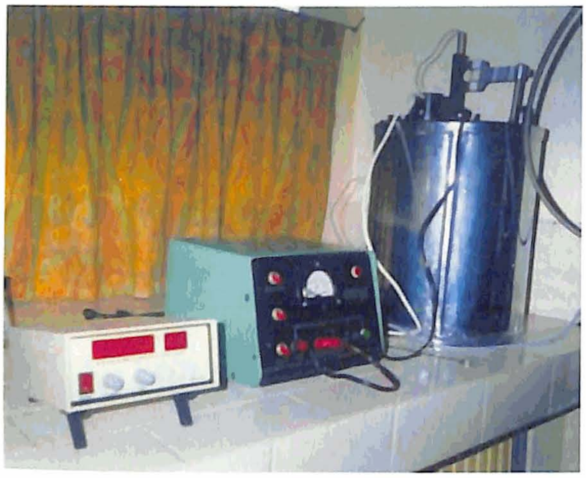


Plate 5. Oxygen Bomb Calorimeter

Plate 6. Weighing the specimens for calculating moisture content

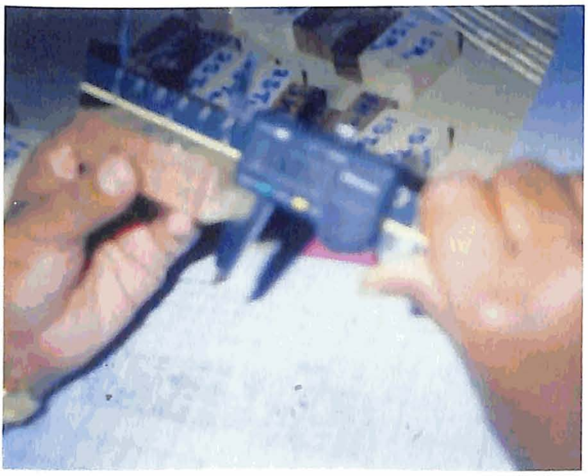


Plate 7. Measuring the dimensions of small clear specimens

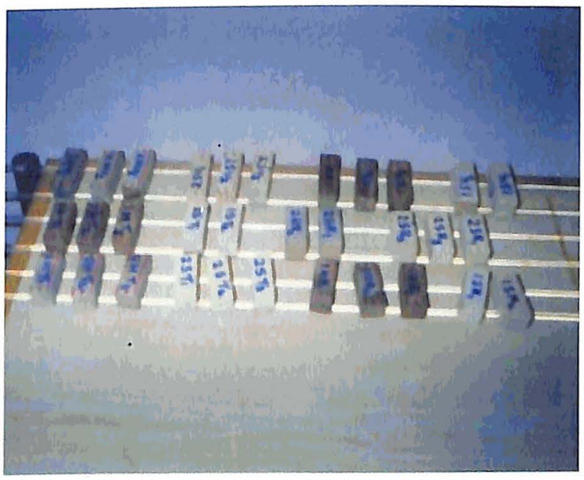


Plate 8. Fresh test specimens kept for air drying

b = Calories liberated during the ignition of tungsten wire (cal)
c = Calories liberated during the ignition of cotton thread (cal)
m = Weight of sample (g)

3.3.2 Specific gravity

Samples of $2 \times 2\ \text{cm}^2$ cross section and six centimeters in length were converted from each disc as per IS 2455: 1990 (ISI, 1990) The specific gravity was calculated by daily measurements of weight (Plate 6) and volume (Plate 7) of each test sample in the green, air dry and oven dry conditions. Sample was weighed in its green condition and its length, breadth and width were measured, which was used to calculate the volume by the formula given below.

$$V = l \times b \times w$$

Where,

V = Volume of the sample
l = Length of the sample
b = Breadth of the sample
w = Width of the sample

The samples were allowed to air dry (Plate 8). Daily observations of these parameters were recorded and the data was used to calculate daily moisture percent of wood using following formulae.

$$\text{Moisture content at green condition (\%)} = \frac{\text{Green weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100$$

$$\text{Moisture content at air dry condition (\%)} = \frac{\text{Air dry weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100$$

Air-drying was continued till the weight became constant and the samples showed no further decrease in volume. The samples were then oven dried till the weights became constant. The weight and linear dimensions were measured again. The data was used to calculate the density at green, air dry and oven dry conditions. The specific gravity at various conditions was calculated using following formulae (ISI, 1986).

$$\text{Specific gravity (green)} = \frac{\text{Green weight}}{\text{Green volume}}$$

$$\text{Specific gravity (air dry)} = \frac{\text{Oven dry weight}}{\text{Air dry volume}}$$

$$\text{Specific gravity (basic)} = \frac{\text{Oven dry weight}}{\text{Green volume}}$$

$$\text{Specific gravity (oven dry)} = \frac{\text{Oven dry weight}}{\text{Oven dry volume}}$$

3.3.3 Radial and tangential shrinkage

Samples of 2 x 2 cm^2 cross section and five centimeter length were converted from the disc as per IS 2455: 1990 (ISI, 1990). Samples for radial and tangential shrinkage were marked differently. Each sample was weighed in green condition and its length measured. The samples were allowed to air dry. Daily observations of these parameters were recorded. The daily observation of shrinkage along the length of radial and tangential samples yields radial and tangential shrinkage percent respectively. The air-drying was allowed till the samples achieved constant moisture content approximating 12 per cent and no further decrease in linear dimensions. The samples were then oven dried at 103±2 ^{0}C till constant weights were attained. The samples were then remeasured at oven dry conditions. Radial and tangential shrinkage was calculated using the following formulae as per IS 1708 (Part 4): 1986 (ISI, 1986).

$$\text{Radial or tangential shrinkages from green to air-dry condition (\%)} = \frac{L_g - L_a}{L_g} \times 100$$

$$\text{Radial or tangential shrinkages from air-dry to oven dry condition (\%)} = \frac{L_a - L_o}{L_o} \times 100$$

$$\text{Radial or tangential shrinkages from green to oven-dry condition (\%)} = \frac{L_g - L_o}{L_o} \times 100$$

Where

L_g = Length of the specimen along radial or tangential plane at green condition (cm)
L_a = Length of the specimen along radial or tangential plane at air-dry condition (cm)
L_o = Length of the specimen along radial or tangential plane at oven-dry condition (cm)

3.3.4 Volumetric shrinkage

Samples of 2 x 2 cm^2 cross section and six centimeters in length were converted as per IS 2455: 1990 (ISI, 1990). Samples were weighed in green condition and their linear dimensions viz., length, breadth and width measured. These parameters were used to calculate volume of sample. The samples were allowed to air dry till constant weights were attained. The samples were then oven dried and their dimensions recorded at oven dry condition. Volumetric shrinkage from green to air dry, air dry to oven dry, and from green to oven dry conditions were calculated using the formulae given in IS 1708 (Part 3): 1986 (ISI, 1986).

$$\text{Volumetric shrinkage from green to air-dry condition (\%)} = \frac{V_g - V_a}{V_g} \times 100$$

$$\text{Volumetric shrinkage from air-dry to oven-dry condition (\%)} = \frac{V_a - V_o}{V_o} \times 100$$

$$\text{Volumetric shrinkage from green to oven-dry condition (\%)} = \frac{V_g - V_o}{V_o} \times 100$$

Where

V_g = Volume of the sample at green condition (cm^3).
V_a = Volume of the sample at air dry condition (cm^3).
V_o = Volume of the sample at oven dry condition (cm^3).

3.4 MECHANICAL PROPERTIES

The test for mechanical properties of rain tree and Ceylon rosewood experimental samples were carried out as per IS 1708: 1986 (ISI, 1986) at Rubber Wood Testing Laboratory, Kottayam. Static bending strength, compression strength parallel to grain, compression strength perpendicular to grain and shear strength of these two timbers were tested using 'Automatic Universal Testing Machine' (UTM- Shimadzu 100 kgN), where as abrasion test was done using 'Taber Digital Abraser (Model 5131).

3.4.1 Testing Instruments

3.4.1.1 Automatic Universal Testing Machine (Shimadzu 100 kgN)

It is a highly computerized and sophisticated version of manual UTM. The instrument is an assemblage of different units. The testing unit consists of a jig where the samples are loaded for test and a head, whose upward or downward movement applies stress in the sample. The calibration of the instrument is controlled by a control keypad. This set up is associated with a computer system installed with software 'Winsoft', which sense the deflection and stress, and plots the load x deflection curve on the monitor simultaneously with the test. Before the start of a test, the instrument is calibrated with type of test, rate of loading, dimensions of sample as per IS 1708: 1986 (ISI, 1986). On the completion of the test the stress x strain graph can be directly read from the monitor and various parameter corresponding to the test can be recorded (Plate 9).

3.4.1.2 Taber Digital Abraser (Model 5131)

Model 5131 abraser has been designed to evaluate the resistance of surface of wood to abrasion. The characteristic rub wear action of the abraser is produced by the contact of a test sample turning on a vertical axis against the sliding rotation of the two abrading wheels. The cyclic rotational action of the disc plates drives the wheel in opposite direction. The samples for test are discs of 10 x 10 cm^2 cross section and six millimeter thickness with a screw hole at the center. A provision is provided at the center of disc for fitting into the spindle of the Taber 5131 abraser. Number of cycles of revolution, load, and vacuum level are calibrated initially before the start of the test (Plate 10).

3.4.2 Preparation of test samples

Scantlings of 5 x 5 cm^2 cross section and 1.2 m length were cut from logs in green condition and allowed to air dry for some days. The scantlings were converted to standard small clear specimens for different tests as per IS 2455: 1990 specified by ISI (1990). The samples were air dried to moisture content of 12 to 20 per cent. The samples were transferred to conditioning chamber to condition all the samples to a uniform moisture per cent of 12±2 per cent. Shear test was carried out using large samples (5 x 5 x 6.25 cm^3) as per IS 1708:1986 (ISI, 1986).

Plate 9. '*Shimadzu*' Universal Testing Machine (UTM)

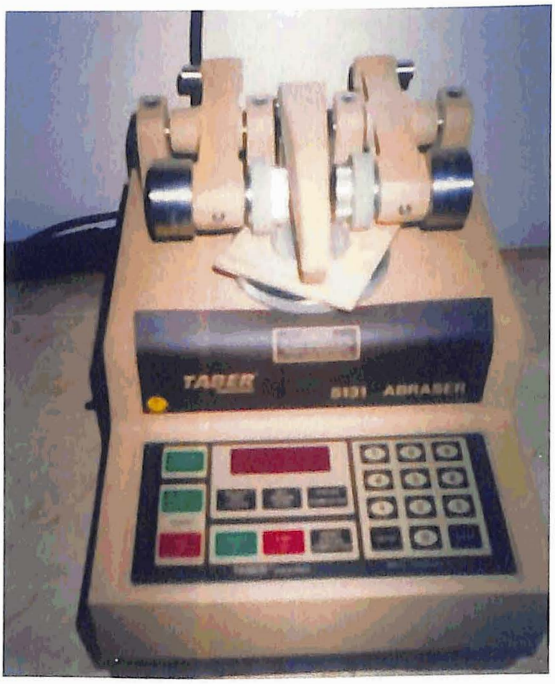


Plate 10. Taber Abraser

3.4.3 Testing of samples

3.4.3.1 Static bending test

Samples of 2 x 2 cm^2 cross section and 30 cm in length (Fig. 1a) were tested as per IS 1708 (Part 5): 1986 (ISI, 1986). Before loading the sample for testing, the width and thickness were accurately measured. The samples were loaded such that the stress in on the tangential plane. The machine was calibrated to set the deflection and load at zero and the rate of loading was set at 1 mm/minute. Load x deflection curve was read from the monitor. The parameters viz., modulus of elasticity (MOE), modulus of rupture (MOR), maximum load, fiber stress at limit of proportionality (FS at LP), horizontal shear at limit of proportionality (HS at LP) and horizontal shear at maximum load (HS at ML) were recorded for further reanalysis.

Reanalysis of the derived data was done to calculate MOE accurately. The software calculates MOE over a range of deflection at limit of proportionality. To overcome this discrepancy, the tangent of the curve was adjusted to the maximum and deflection corresponding to the proportionality limit was recorded. By substituting the value thus attained in the following formulae, various parameters were reanalyzed.

(a) Fiber stress at limit of proportionality ($kg\ cm^{-2}$) (FS at LP) $= \dfrac{3\ Pl}{2\ bh^2}$

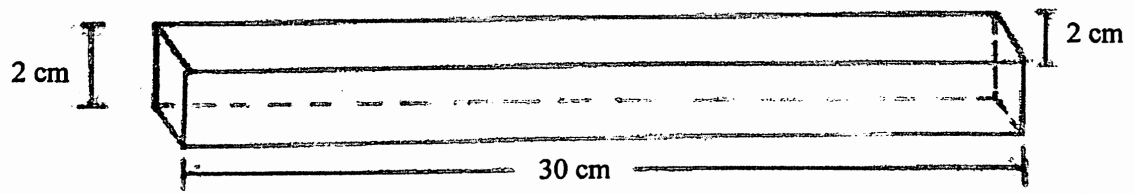
(b) Modulus of rupture ($kg\ cm^{-2}$) (MOR) $= \dfrac{3\ P'l}{2\ bh^2}$

(c) Modulus of elasticity ($kg\ cm^{-2}$) (MOE) $= \dfrac{Pl^3}{4\ \Delta\ bh^3}$

(d) Horizontal shear stress on neutral plane at limit of proportionality ($kg\ cm^{-2}$) (HS at LP) $= \dfrac{3\ P}{4\ bh}$

Diagrammatic representation of small clear wood specimens for testing different mechanical properties.

Fig 1a. Specimen for testing static bending strength



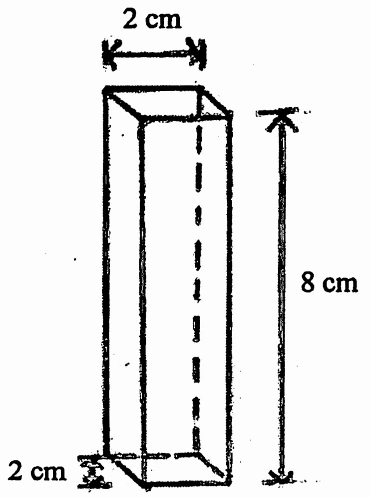


Fig 1b. Specimen for testing compression strength parallel to grain

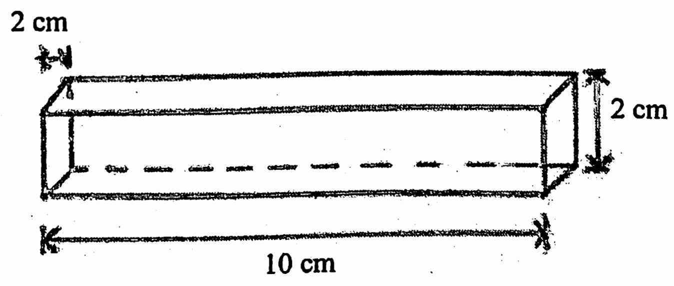


Fig 1c. Specimen for testing compression strength perpendicular to grain

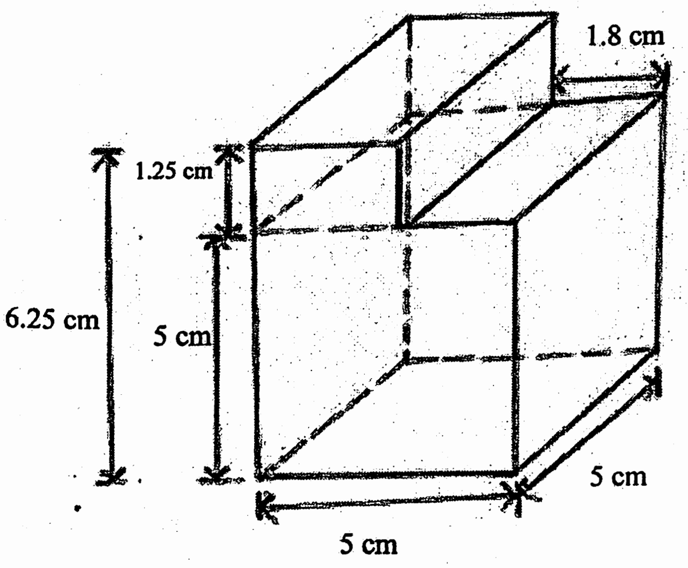


Fig 1d. Specimen for testing shear strength

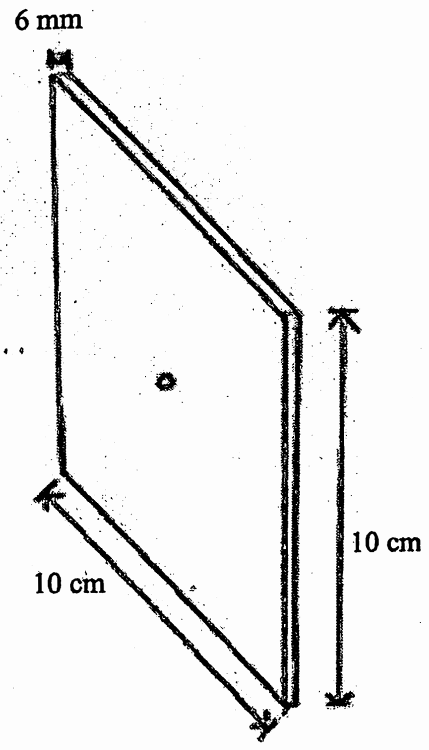


Fig 1e. Specimen for abrasion test

(e) Horizontal shear stress at maximum load (kg cm^{-2}) (HS at ML) $= \dfrac{3 P'}{4 bh}$

(h) Maximum Load (kg) (ML) $= \dfrac{CA''}{lbh}$

Where,

P = Load in 'kg' at the limit of proportionality which shall be taken as the point in load-deflection curve above which the graph deviates from the straight line.

l = Span of the test specimen in cm

b = Breadth of test specimen in cm

h = Height of the test specimen in cm

P' = Maximum load in kg

Δ = Deflection in cm at the limit of proportionality.

C = Area constant in kg.cm (the energy represented by one square centimeter which is equal to load in kg, represented by one centimeter ordinate multiplied by deflection in centimeters, represented by one centimeter abscissa).

A = Area in cm^2 of load-deflection curve up to limit of proportionality

The samples being tested are illustrated in Plate 11

3.4.3.2 Compression strength parallel to grain

Samples of cross section 2 x 2 cm^2 and eight centimeters in length (Fig. 1b) were tested as per IS 1708 (Part 8): 1986 (ISI, 1986). Before test, the width, thickness and length of the sample were recorded. The rate of loading was calibrated to 0.6 mm/min and the load and deflection was set to zero. The sample was loaded with its longitudinal axis along the direction of movement of head. The machine was stopped when the deflection reached 2.5 mm. Various parameters were recorded from the monitor and MOE reanalyzed by the formulae given below.

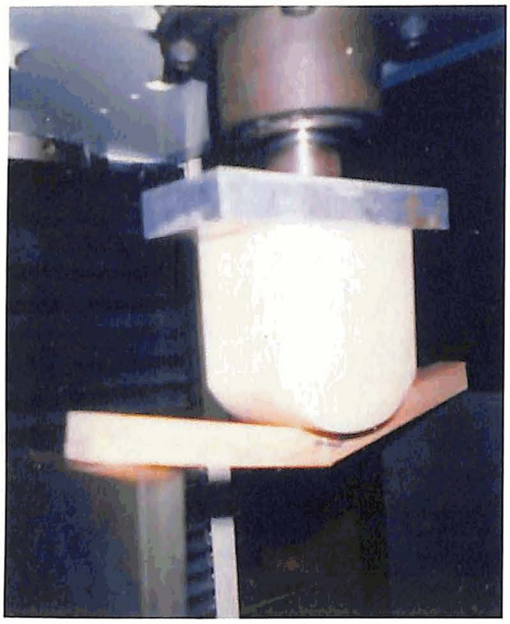


Plate 11. Static bending test

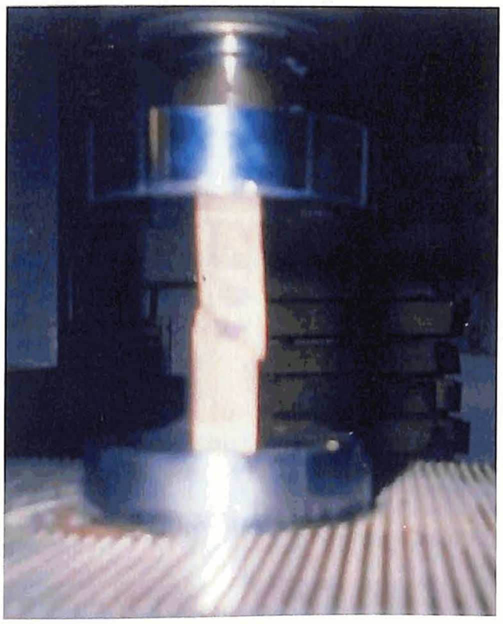


Plate 12. Test for compression strength parallel to grain

Plate 13. Test for compression strength perpendicular to grain

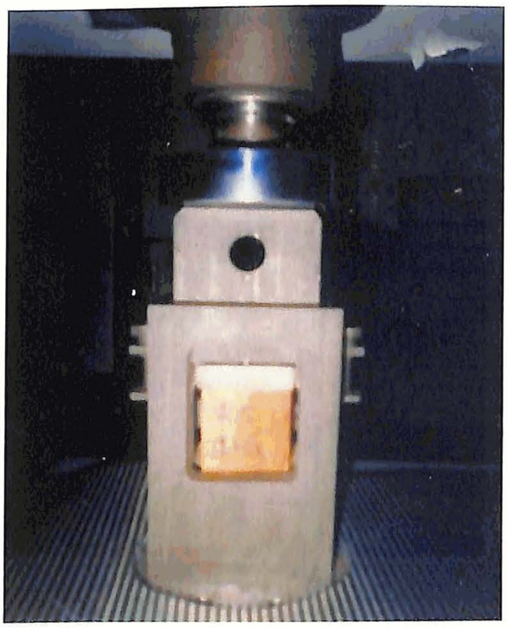


Plate 14. Test for shear strength

(a) Compressive stress at limit of proportionality ($kg\ cm^{-2}$) $= \frac{P}{A}$
(CS at LP)

(b) Compressive stress at maximum load ($kg\ cm^{-2}$) $= \frac{P'}{A}$
(CS at ML)

(c) Modulus of elasticity in compression parallel to grain ($kg\ cm^{-2}$) $= \frac{LP}{\Delta A}$
(MOE)

Where,

P = Load at limit of proportionality in kg

A = Cross-sectional area of specimen in cm^2

P'= Maximum crushing load in kg

L = Gauge length between the compressometer points in cm (equal to the length of the specimen)

Δ = Deformation at the limit of proportionality in cm

The samples being tested are illustrated in Plate 12

3.4.3.3 Compression strength perpendicular to grain

Samples of 2 x 2 cm^2 cross section and 10 cm in length (Fig. 1c) were tested as per IS 1708 (Part 9): 1986 (ISI, 1986). The sample was loaded such that the tangential plane faces the stress. The linear dimensions of the sample were recorded before test. Rate of loading was calibrated to 0.6 mm/minute and the deflection and load were set to zero. The machine was stopped at a deflection of 2.5 mm or above. Various parameters were read from the monitor and graph adjusted to reanalyze the MOE. The following parameters were calculated using the following formulae.

(a) Compressive stress at limit of proportionality (kg cm^{-2}) $= \dfrac{P}{A}$

(b) Crushing strength at compression of 2.5 mm (kg cm^{-2}) $= \dfrac{P'}{A}$

(c) Modulus of elasticity (kg cm^{-2}) $= \dfrac{P}{A} \times \dfrac{h}{\Delta}$

Where,

P = Load at the limit of proportionality in kg

A =Area of cross section of the specimen in cm^2

P'= Load at 2.5 mm compression in kg

h = Height of the specimen in cm

Δ = Deformation at the limit of proportionality in cm

The samples being tested are illustrated in Plate 13

3.4.3.4 Shear test

Samples of cross section 5 x 5 cm^2 and 6.25 cm in length (Fig. 1d) with a notch at one end were tested as per IS 1708 (Part 11): 1986 (ISI, 1986). The surface of failure decides the test in tangential and radial plane. Under present study samples were tested for shear strength along both tangential and radial plane. The samples were loaded such that the head of the machine rests exactly in the notch. Rate of loading was calibrated to 0.4 mm/minute and the load and deflection were set to zero. Various parameters were analyzed by the following formulae. Reanalysis was not done, as the parameters studied were independent of deflection at limit of proportionality.

Maximum shearing stress (kg cm^{-2}) $= \dfrac{P}{A}$
(MSS)

Where

P = Maximum load in kg
A =Cross section area of specimen in cm^2
The samples being tested are illustrated in Plate 14

3.4.3.5 Abrasion test

This test was performed on samples of 10 x 10 cm^2 cross section and 6 mm in thickness (Fig. 1e). Samples were placed with the centre of disc fitting into the spindle of the Taber Abraser. Before and after abrasion, the weight of the specimen was accurately measured by an electronic balance (Precia Z-4000). Each sample was placed on the circular table, rotating at a constant speed and clamped rigidly with a clamp ring and screw. The instrument was calibrated to 100 cycles of revolution at 500 g load. The standardized abrasive wheels (H-18 calibrade) were then lowered on the surface of the test specimen and the machine set on. The wear index was calculated by the formula given below.

$$\underset{\text{(Per 1000 cycles)}}{\text{Wear Index}} = \frac{\text{(Before test weight in mg – After test weight in mg)}}{\text{Number of cycles of revolution}} \times 10^6$$

Soon after each test the samples were weighed correct to 0.002 cm. The samples were oven dried at 103±2 ^0C and reweighed to calculate the moisture content at test condition using formulae given below.

$$\text{Moisture content (\%)} = \frac{\text{(After test weight – Oven dry weight)}}{\text{Oven dry weight}} \times 100$$

For comparison of mechanical properties of wood, the value of test obtained at moisture per cent at test condition were converted to test values at 12 % moisture content using the formulae as per IS 8745 (Section 5.2): 1998 (ISI, 1998).

$S_{12} \times 12 = S_d \times$ Moisture content (%) at air dry condition

3.5 ANATOMICAL PROPERTIES

Three samples each of dimension 2 x 2 x 2 cm^3 were prised out separately from the heartwood and sapwood regions of both *A. odoratissima* and *S. saman*. From these wood samples thin microscopic sections of size 15 to 20 µm were taken using '*Leica* Sledge Microtome'. Temporary slides were made by staining these sections with safranin stain and subjected to measurements and photography using Image analysis system (Labomed Digi-2; Plate 15). Measurement of various parameters was done using the software 'Labomed DigiPro-2'. For each parameter studied, three wooden cubes each of the two species were taken (one cube each from inner, middle and outer region) from each tissue type viz., sapwood and heartwood. One section each was taken from the three cubes. Temporary slides were prepared and the sectioned images studied using an image analyzer. Observations were recorded on atleast three fields on each section. The number of counts in each field was based on the parameter to be studied.

3.5.1 Vessel diameter

Tangential diameter (µm) of the vessels were measured on the transverse sections (TS) using the Image Analysis software. At least ten observations per sample were recorded for measuring vessel diameter.

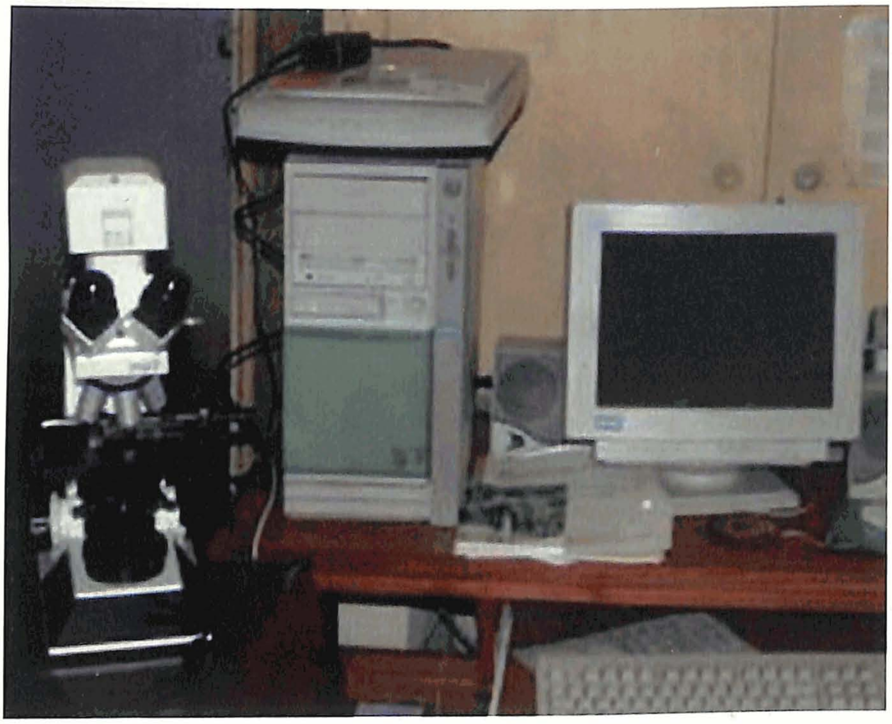


Plate 15. '*Labomed Digi-2*' Image Analysis System for anatomical studies

3.5.2 Vessel frequency (Number of vessels per sq. mm)

Frequency of vessels per sq. mm was calculated by counting the number of vessels in a randomly selected area per field and using the formulae given below as per Juneja and Rao (1971). In each field three count areas were taken.

$$\text{Vessel frequency} = \frac{\text{Number of vessels}}{\text{Area in sq. microns}} \times 10^6$$

3.5.3 Vessel arrangement

The vessel arrangement in sapwood and heartwood of both the species were identified by studying the transverse sections as per Juneja and Rao (1971)

3.5.4 Parenchyma arrangement

Arrangement of parenchyma was studied by observing the transverse sections (TS) of the samples as per Juneja and Rao (1971).

3.5.5 Ray height

Ray height (µm) was measured on the tangential longitudinal sections (TLS) for each tissue type.

3.5.6 Ray width

The width of the rays (µm) was measured on the tangential longitudinal sections (TLS) for each tissue type.

3.5.7 Ray frequency

Frequency of rays per mm was calculated by counting the number of rays intersect with a transect line drawn randomly in each field. Observations were recorded by counting the rays at three different lines

3.5.8 Special characters

Presence of special characters viz., gum deposits, tyloses etc. were studied on all three planes of the section.

3.6 BIOCHEMICAL PROPERTIES

Lignin content, cellulose content and presence of colouring matter in the heartwood of the three species were tested under this study. The tests were conducted for all the three species.

3.6.1 Estimation of lignin

Lignin was estimated by the procedure recommended by Adams (1965) as followed.

About 2 g of dry finely powdered wood was weighed accurately and wrapped into a filter paper. It was extracted in soxhlets' extractor with methanol for 4 h to remove tannins and phenols. The solvent was removed after extraction and the sample was again extracted with methanol-benzene (1:1) for 4 h in the same soxhlet. The sample was removed and washed with 2 x 25ml methanol to remove the residual benzene. The material was transferred to 500 ml beaker and boiled with water for 3 h. The mixture was filtered and the residue washed thoroughly with hot water followed by methanol. The sample was dried and the dry material was transferred to a 250 ml conical flask containing 30 ml of cold 72

% sulphuric acid and was stirred for 1min. The mixture was kept cold (18-20 ^{0}C) for 24hrs by keeping in water bath. This solution containing lignin sulphate was transferred to a 2000ml conical flask, diluted with 970 ml distilled water. The mixture was boiled for 4h with occasional addition of hot water to keep a constant volume. The mixture was allowed to settle. It was filtered, washed with water (500-1000 ml), dried and weighed. Lignin percent was calculated by the formulae given below.

$$\text{Lignin percent} = \frac{\text{Weight of dried residue}}{\text{Initial wt. of wood powder}} \times 100$$

3.6.2 Estimation of cellulose

Cellulose content was estimated by procedure recommended by Green (1963). Firstly, lignin was removed by treating the wood powder with sodium chlorite. The holocellulose thus obtained was treated with increasing concentration of sodium hydroxide to yield cellulose. The detailed procedure followed is as given below.

A known amount of powdered wood was extracted with benzene-methanol (2:1) followed by 95 % methanol in soxhlets' extractor. The sample was dried and suspended in 800 ml hot water in a 2000 ml Erlenmeyer flask containing 3 ml glacial acetic acid. To this 7.5 g of sodium chlorite was added. The flask was stoppered with an inverted 50 ml Erlenmeyer flask and heated on a steam bath for 30-60 min at a temperature of 70 ± 2^{0}C. The heating was stopped and fresh portions of acetic acid (3 ml) and sodium chlorite (7.5 g) were added and heated for 1 h. Six aliquots of acetic acid and sodium chlorite was added and heated for 6 h successively. The mixture was filtered on a buchner funnel when the residue turned white in colour. The holocellulose was thoroughly washed with 2000 ml of cold water and dried.

2 g of holocellulose was taken in 100 ml wide mouthed bottle and 100 ml of 12 % sodium hydroxide was added. Nitrogen was bubbled through this mixture for 1 min. The bottle was closed tightly and stirred using a magnetic stirrer for 24 h at room temperature. The mixture was then filtered through glass buchner funnel using water suction system. The residue waqs transferred to the bottle again and 100 ml of 7.1 % NaOH solution was added and the extraction continued for 24 h. This mixture was filtered and the process of extraction with 7.1 % NaOH was done two more times. After the final extraction, the mixture was filtered and the residue was washed with 5 % NaOH and then with cold water. The final washing was done with 10 % acetic acid for 10 min. After filtration, the residue was washed thoroughly with water, dried and weighed. The weight of the residue yielded cellulose percent in wood.

$$\text{Cellulose content (\%)} = \frac{\text{Weight of dry residue}}{\text{Initial wt. of wood powder}} \times 100$$

3.6.3 Estimation of colouring matter

Column chromatography of extract of heartwood was done to identify and estimate the colouring matter of heartwood. The general procedure followed is given below:

5 g of heartwood powder was grinded with pestle and mortar with addition of 20 ml of benzene and methanol mixture (2:1). The extract was filtered and the filtrate transferred to separatory funnel. 10 ml of distilled water was added to the extract and allowed to settle till the layers were separated. The lower aqueous layer was removed and water was added. The process of removal of lower layer was done 2–3 times till the lower layer became colourless. The remnant extract in separatory funnel was taken in a beaker and placed over steam bath, to evaporate the benzene in solvent, leaving a pasty residue. The residue was dissolved in 5 ml benzene and solid Na_2SO_4 (anhydrous) was added to remove traces of water. The benzene layer was decanted and evaporated to dryness.

Simultaneously, a dry burette was clamped vertically and the bottom was plugged with cotton from inside. 5 g of alumina (adsorbent) was taken in a beaker and benzene was added to make slurry. This slurry was poured in burette with gentle tapping and allowed to settle. Further, 20 ml of benzene was added and allowed to pass through the column.

Dried wood extract, thus obtained was dissolved in 1 ml of benzene and quantitatively transferred to the top of the column and the stopcock opened to allow the solution to percolate. Benzene was added when the solvent reached the surface of the adsorbent. Movement of column and bands were not noted. When 20 ml of benzene was run, 5 ml of 5 per cent acetone was added in benzene from top and the changes were recorded.

Different fractions were collected in test tubes and studied under spectrophotometer for recording the peak wavelengths absorbed by the fractions.

3.7 STATISTICAL ANALYSIS

Data pertaining to the various wood properties were subjected to analysis of variance (ANOVA) and t – test using the statistical package SPSS (Ver. 10) and M-STAT.

Results

RESULTS

A study to profile the selected wood properties of *Albizia odoratissima, Samanea saman* and *Dalbergia latifolia* was conducted at the College of Forestry, Vellanikkara during 2003-2005 in the wake of increasing reports of wood adulteration by the furniture making industry. The results obtained from the present study are presented in this chapter.

4.1 PHYSICAL PROPERTIES

Various physical properties were analyzed for the woods of *A. odoratissima, S. saman* and compared with the wood properties of *D. latifolia* available from the following literature (Krishna and Ramaswamy, 1932; Sekhar and Bhatnagar, 1957; Rajput *et al.*, 1985).

4.1.1 Calorific value

The mean calorific value of heartwood differed among the three species under study. It was found that the heartwood calorific value of *D. latifolia* (5049 cal g^{-1}) was highest, followed by *S. saman* (4981.08 cal g^{-1}). The heartwood calorific value of *A. odoratissima* was least (3920.18 cal g^{-1}). It was noticed that the mean heartwood calorific value of *S. saman* was significantly higher than that of *A. odoratissima* whereas, the difference between the calorific value of *D. latifolia* and *S. saman* was less (Table 2).

For sapwood, the mean calorific value of *A. odoratissima* (4365.56 cal g^{-1}) varied non significantly with *S. saman* (3748.41 cal g^{-1}). It was also revealed that in *A. odoratissima*, the difference between the mean calorific value of sapwood and heartwood was non significant, whereas in *S. saman*, the heartwood mean calorific value was significantly higher than its sapwood (Table 3).

Table 2 Comparative profile of physical properties of heartwood of *Albizia odoratissima, Samanea saman* and *Dalbergia latifolia*

S. No	Physical property	*Albizia odoratissima*	*Samanea saman*	*Dalbergia latifolia*	CD for comparing *Albizia odoratissima* and *Samanea saman*
1	Calorific value (cal g^{-1})	3920.18^b	4981.08^a	*5049.00	187.656
2	Moisture content- Green (%)	84.80^b	135.65^a	#74.50	25.261
3	Moisture content- Air dry (%)	13.43^a	13.47^a	#12.00	1.449
4	Specific gravity- Basic	0.65^a	0.48^b	£0.75	0.067
5	Specific gravity- Air dry	0.69^a	0.50^b	#0.68	0.073
6	Radial shrinkage- Green-OD (%)	3.63^a	2.53^b	#2.30	0.497
7	Tangential shrinkage- Green-OD (%)	6.81^a	4.11^b	#5.60	1.891
8	Volumetric shrinkage- Green-OD (%)	14.12^a	6.95^b	#8.50	0.947

Means column wise comparison for each parameter

Values with same superscript do not differ significantly between themselves

* Krishna and Ramaswamy (1932)

\# Sekhar and Bhatnagar (1957)

£ Rajput *et al.* (1985)

Table 3 Calorific value of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Calorific value (Calories per gram)		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	4365.56^{b}	3920.18^{b}	728.093
2	*Samanea saman*	3748.41^{b}	4981.08^{a}	162.545
CD for comparing species ($p < 0.05$))		722.029	187.656	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 4 Moisture content of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Moisture content	Tissue type		CD for comparing tissue type ($p < 0.05$)
		(%)	Sapwood	Heartwood	
1	*Albizia odoratissima*	Green	70.80^{c}	84.80^{b}	13.796
		Air dry	15.50^{a}	13.43^{c}	1.365
2	*Samanea saman*	Green	69.80^{c}	135.65^{a}	29.259
		Air dry	14.60^{b}	13.47^{c}	0.746
CD for comparing species ($p < 0.05$)		Green	20.187	25.261	
		Air dry	0.569	1.449	

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

4.1.2 Moisture content

4.1.2.1 Moisture content (green)

The mean moisture content of heartwood of *S. saman* (135.65 %) at green condition was significantly higher than *A. odoratissima* (84.80 %), and greater than *D. latifolia* (74.5 %) where as, lesser difference was observed between heartwood moisture content of *A. odoratissima* and *D. latifolia* (Table 2).

The difference in sapwood mean moisture content was found to be non significant between *A. odoratissima* (70.80 %) and *S. saman* (69.80 %). It was also found that in both *A. odoratissima* and *S. saman,* the mean heartwood moisture content was significantly higher than their respective sapwoods (Table 4).

4.1.2.2 Moisture content (air dry)

At air dry condition, the mean heartwood moisture content of *A. odoratissima* (13.43 %) did not differ significantly with mean heartwood moisture content of *S. saman* (13.47 %). Where as, the mean heartwood moisture content of *S. saman* and *A. odoratissima* was found to be more than that of *D. latifolia* (Table 2).

The sapwood of *A. odoratissima* (15.50 %) was found to possess significantly higher mean moisture content than sapwood of *S. saman* (14.60 %). Irrespective of both these species, it was noticed that the sapwood of both these species holds significantly higher moisture than their respective heartwoods at air dry condition (Table 4).

4.1.3 Specific gravity

4.1.3.1 Specific gravity (green)

A. odoratissima at green condition exhibited a significantly greater mean specific gravity for both sapwood (1.160) and heartwood (1.191) as compared to sapwood (0.837)

Table 5 Specific gravity of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Specific gravity	Tissue type		CD for comparing tissue type ($p < 0.05$)
			Sapwood	Heartwood	
1	*Albizia odoratissima*	Green	1.160^a	1.191^a	0.032
		Basic	0.703^a	0.649^a	0.173
		Air dry	0.735^a	0.680^a	0.083
		Oven dry	0.799^a	0.740^a	0.090
2	*Samanea saman*	Green	0.837^c	1.100^b	0.049
		Basic	0.488^b	0.479^b	0.072
		Air dry	0.510^b	0.495^b	0.075
		Oven dry	0.530^b	0.512^b	0.082
CD for comparing species ($p < 0.05$)		Green	0.054	0.023	
		Basic	0.077	0.067	
		Air dry	0.085	0.073	
		Oven dry	0.100	0.069	

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

Table 6 Radial shrinkage of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Radial shrinkage	Tissue type		CD for comparing tissue type ($p < 0.05$)
		(%)	Sapwood	Heartwood	
1	*Albizia odoratissima*	Green-Air dry	1.603^a	1.470^a	0.632
		Air dry-Oven dry	3.413^a	2.105^b	1.206
		Green-Oven dry	5.100^a	3.627^a	1.621
2	*Samanea saman*	Green-Air dry	0.805^c	1.024^b	0.137
		Air dry-Oven dry	1.542^b	1.480^b	0.399
		Green-Oven dry	2.366^b	2.530^b	0.489
CD for comparing species ($p < 0.05$)		Green-Air dry	0.521	0.383	
		Air dry-Oven dry	1.058	0.702	
		Green-Oven dry	1.618	0.497	

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

and heartwood (1.100) of *S. saman* respectively. It was also observed that no significant difference exist between mean specific gravity of sapwood and heartwood in *A. odoratissima*. On the contrary, the mean specific gravity of the heartwood of *S. saman* was significantly greater than the mean specific gravity of its sapwood (Table 5).

4.1.3.2 Specific gravity (basic/standard)

The basic specific gravity of heartwood was found to vary among the three species. Results tabulated in Table 2 reveals that the heartwood of *D. latifolia* possessed highest basic specific gravity (0.75), which was followed by *A. odoratissima* (0.649) and *S. saman* (0.479).

Among the basic specific gravity of sapwood, the sapwood of *A. odoratissima* (0.703) was found to have significantly greater mean basic specific gravity than the sapwood of *S. saman* (0.488). In both these species no significant differences was observed to exist between the mean basic specific gravity of sapwood and heartwood (Table 5).

4.1.3.3 Specific gravity (air dry)

It was found that at air dry condition, there exist less difference in mean specific gravity of heartwood of *A. odoratissima* (0.687) and *D. latifolia* (0.680). *S. saman* which showed least specific gravity (0.495) was found to differ significantly from *A. odoratissima* (Table 2).

The mean specific gravity of sapwood of *A. odoratissima* (0.735) was significantly greater than the mean specific gravity of the sapwood of *S. saman* (0.510). Investigations in both these species revealed that there was no significant difference between mean specific gravity of their respective sapwood and heartwood (Table 5).

4.1.3.4 Specific gravity (oven dry)

Table 5 depicts the oven dry specific gravity as influenced by species and tissue type. It was found that the sapwood (0.799) and heartwood (0.740) of *A. odoratissima* at oven dry condition possessed significantly higher specific gravity as compared to the sapwood (0.530) and heartwood (0.512) of *S. saman,* respectively. However, between sapwood and heartwood no significant difference was noted in the specific gravities of *A. odoratissima* and *S. saman.*

4.1.4 Radial shrinkage

4.1.4.1 Radial shrinkage (green to air dry)

The sapwood (1.603 %) and heartwood (1.470) of *A. odoratissima* showed significantly greater mean radial shrinkage than the sapwood (0.805 %) and heartwood (1.024 %) of *S. saman,* respectively. In *A. odoratissima*, it was noticed that the mean radial shrinkage of sapwood was not significantly different from the radial shrinkage exhibited by its heartwood. Where as, in *S. saman* the heartwood radial shrinkage was significantly greater than sapwood radial shrinkage (Table 6).

4.1.4.2 Radial shrinkage (air dry to oven dry)

The air dried wood samples when oven dried revealed that the mean radial shrinkage of the sapwood (3.413 %) and heartwood (2.105 %) of *A. odoratissima* was larger than the mean radial shrinkage of sapwood (1.542 %) and heartwood (1.480 %) of *S. saman.* The radial shrinkage of sapwood of *A. odoratissima* was found to be significantly greater than its heartwood shrinkage. Where as, in *S. saman,* no significant difference in shrinkage pattern was observed between sapwood and heartwood (Table 6).

4.1.4.3 Radial shrinkage (green to oven dry)

Results tabulated in Table 2 indicate that the radial shrinkage of heartwood differed among the three species. It was noticed that the heartwood shrinkage of *A. odoratissima* (3.627 %) was highest, which was followed by *S. saman* (2.530 %) and *D. latifolia* (2.300 %).

The sapwood of *A. odoratissima* (5.100 %) also exhibited significantly greater shrinkage than sapwood of *S. saman* (2.366 %). In both these species, no significant differences were observed between the tangential shrinkages of heartwood and sapwood (Table 6).

4.1.5 Tangential shrinkage

4.1.5.1 Tangential shrinkage (green to air dry)

Tangential shrinkage from green to air dry condition was greater than radial shrinkage from green to air dry condition in both *A. odoratissima* and *S. saman.* The shrinkage in sapwood of *A. odoratissima* (2.841 %) was observed to be significantly greater than shrinkage of sapwood of *S. saman* (1.877 %). Also, the heartwood shrinkage of *A. odoratissima* (2.240 %) was higher than heartwood shrinkage of *S. saman* (1.417 %), but the differences were found to be non significant. In *S. saman,* it was noted that the sapwood and heartwood shrinkage did not differ significantly. Where as, in *A. odoratissima,* the sapwood shrinkage was significantly greater than its heartwood shrinkage (Table 7).

4.1.5.2 Tangential shrinkage (air dry to oven dry)

When the air dried samples were oven dried it was observed that the sapwood shrinkage (5.521 %) and heartwood shrinkage (4.421 %) of *A. odoratissima* was significantly greater than the sapwood shrinkage (3.837 %) and heartwood shrinkage value

Table 7 Tangential shrinkage of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Tangential shrinkage	Tissue type		CD for comparing tissue type ($p < 0.05$)
		(%)	Sapwood	Heartwood	
1	*Albizia odoratissima*	Green-Air dry	2.841^{a}	2.240^{b}	0.472
		Air dry-Oven dry	5.521^{a}	4.421^{b}	0.788
		Green-Oven dry	8.606^{a}	6.815^{b}	1.223
2	*Samanea saman*	Green-Air dry	1.877^{b}	1.417^{b}	0.864
		Air dry-Oven dry	3.837^{b}	2.629^{c}	0.788
		Green-Oven dry	5.824^{b}	4.107^{c}	1.530
CD for comparing species ($p < 0.05$)		Green-Air dry	0.533	0.827	
		Air dry-Oven dry	0.290	1.076	
		Green-Oven dry	0.512	1.891	

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

Table 8 Volumetric shrinkage of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Volumetric shrinkage	Tissue type		CD for comparing tissue type ($p < 0.05$)
		(%)	Sapwood	Heartwood	
1	*Albizia odoratissima*	Green-Air dry	4.360^{b}	5.515^{a}	1.015
		Air dry-Oven dry	8.727^{a}	7.825^{a}	1.645
		Green-Oven dry	13.689^{a}	14.117^{a}	1.837
2	*Samanea saman*	Green-Air dry	4.306^{b}	3.274^{c}	0.881
		Air dry-Oven dry	4.236^{b}	3.451^{b}	2.995
		Green-Oven dry	8.922^{b}	6.952^{b}	2.248
CD for comparing species ($p < 0.05$)		Green-Air dry	1.093	0.781	
		Air dry-Oven dry	2.994	1.648	
		Green-Oven dry	2.745	0.947	

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

(2.629 %) of *S. saman*. Also, it was noticed that in both *A. odoratissima* and *S. saman*, the sapwood shrinkage was significantly greater than heartwood shrinkage. The shrinkage of experimental samples from air dry to oven dry condition was found to be greater than shrinkage from green to air dry condition for both the species (Table 7).

4.1.5.3 Tangential shrinkage (green to oven dry)

Tangential shrinkage from green to oven dry condition for the heartwood of *A. odoratissima* (6.815 %) was found to be highest among the three species. It differed significantly from the heartwood shrinkage of *S. saman* (4.107 %), but the difference was less when compared to heartwood shrinkage of *D. latifolia* (5.600 %). *S. saman* exhibited least tangential shrinkage of its heartwood. The difference between the tangential shrinkage of heartwood of *S. saman* and *D. latifolia* was less (Table 2).

In both *A. odoratissima* and *S. saman*, it was noticed that the sapwood tangential shrinkage was significantly greater than their respective heartwood tangential shrinkage (Table 7). Between sapwoods of these species, the sapwood of *A. odoratissima* (8.606 %) showed a significantly higher tangential shrinkage than that of *S. saman* (5.824 %).

4.1.6 Volumetric shrinkage

4.1.6.1 Volumetric shrinkage (green to air dry)

The heartwood of *A. odoratissima* (5.515 %) was found to have a significantly greater volumetric shrinkage than its sapwood (4.360 %) where as, in *S. saman* the sapwood shrinkage (4.306 %) was significantly greater than heartwood shrinkage (3.274 %). Non significant difference was observed between the sapwood volumetric shrinkage of *A. odoratissima* and *S. saman*. However, the heartwood volumetric shrinkage of *A. odoratissima* was recorded to be significantly greater than heartwood shrinkage of *S. saman* (Table 8).

4.1.6.2 Volumetric shrinkage (air dry to oven dry)

The sapwood (8.727 %) and heartwood (7.825 %) of *A. odoratissima* were found to have a significantly greater volumetric shrinkage than sapwood (4.236 %) and heartwood (3.451 %) of *S. saman*. It was also noticed that irrespective of *A. odoratissima* and *S. saman*, no significant differences were observed between the sapwood volumetric shrinkage and heartwood volumetric shrinkage (Table 8).

4.1.6.3 Volumetric shrinkage (green to oven dry)

Table 2 reveals that the volumetric shrinkage from green to oven dry condition differed among the heartwood of the three species under study. *A. odoratissima* was found to have greatest shrinkage (14.117 %) followed by *D. latifolia* (8.500 %) and *S. saman* (6.952 %). Among the sapwoods, it was observed that the volumetric shrinkage of sapwood of *A. odoratissima* (13.689 %) was significantly greater than the same tissue type of *S. saman* (8.922 %). It was also noticed that the differences between volumetric shrinkage of sapwood and heartwood were non significant in both *A. odoratissima* and *S. saman* (Table 8).

4.2 MECHANICAL PROPERTIES

Mechanical properties were tested for the woods of *Albizia odoratissima, Samanea saman* and compared with the wood properties of *Dalbergia latifolia* available from following literature (Sekhar and Bhatnagar, 1957; Sekhar, 1988).

4.2.1 Static bending test

4.2.1.1 Fibre stress at limit of proportionality

Fibre stress at elastic limit differed greatly among the heartwoods of the three species under study (Table 9). The heartwood of *Albizia odoratissima* was found to have

Table 9 Comparative profile of mechanical properties for heartwoods of *Albizia odoratissima, Samanea saman* and *Dalbergia latifolia*

S. No	Mechanical property	*Albizia odoratissima*	*Samanea saman*	*Dalbergia latifolia*	CD for comparing *Albizia odoratissima* and *Samanea. saman*
1	Static bending- FS at LP (kg/cm^2)	982.69^a	604.32^b	#127.00	78.230
2	Static bending- MOR (kg/cm^2)	1406.58^a	983.34^b	#943.00	74.485
3	Static bending- MOE (1000 kg/cm^2)	131.36^a	69.01^b	#101.70	5.996
4	Compression strength parallel to grain- CS at LP (kg/cm^2)	598.60^a	299.02^b	@338.00	76.369
5	Compression strength parallel to grain- CS at ML (kg/cm^2)	704.88^a	458.67^b	#486.00	57.466
6	Compression strength parallel to grain- MOE (1000 kg/cm^2)	69.21^a	36.92^b	@115.40	6.965
7	Compression strength perpendicular to grain- CS at LP (kg/cm^2)	180.39^a	116.69^b	@153.00	48.048
8	Shear radial- Maximum shearing stress (kg/cm^2)	149.10^a	118.13^b	#107.90	23.460
9	Shear tangential-Maximum shearing stress (kg/cm^2)	142.94^a	92.92^b	#156.10	20.247

Means column wise comparison for each parameter
Values with same superscript do not differ significantly between themselves
@ Sekhar (1988)
# Sekhar and Bhatnagar (1957)

relatively greater fibre stress (982.69 kg cm^{-2}), followed by *S. saman* (604.32 kg cm^{-2}) and *D. latifolia* (127.00 kg cm^{-2}). The sapwood of *A. odoratissima* was also found to have significantly greater fibre stress (821.11 kg cm^{-2}) as compared to sapwood fibre stress of *S. saman* (527.30 kg cm^{-2}). It was also recorded that, the heartwood fibre stress of *A. odoratissima* was significantly greater than its sapwood fibre stress. However, in *S. saman* no significant difference was observed with reference to sapwood and heartwood fibre stress (Table 10).

4.2.1.2 Modulus of rupture

Modulus of rupture of the heartwood of *A. odoratissima* (1406.58 kg cm^{-2}) differed extremely with modulus of rupture of *S. saman* (983.34 kg cm^{-2}) and *D. latifolia* (943.00 kg cm^{-2}). The modulus of rupture of the heartwood of *A. odoratissima* was highest, which was followed by *S. saman* and *D. latifolia.* Between the heartwoods of *S. saman* and *D. latifolia*, the difference in modulus of rupture was found to be smaller (Table 9).

The modulus of rupture for sapwood also differed significantly between *A. odoratissima* and *S. saman.* The modulus of rupture for sapwood of *A. odoratissima* (1417.41 kg cm^{-2}) was greater than the modulus of rupture for sapwood of *S. saman* (801.92 kg cm^{-2}). The modulus of rupture for sapwood and heartwood did not differ significantly in both *A. odoratissima* and *S. saman* (Table 11).

4.2.1.3 Modulus of elasticity

The modulus of elasticity for heartwood differed extremely among the three species under study (Table 9). The modulus of elasticity for heartwood decreased from *A. odoratissima* (131.36 x 10^{3}kg cm^{-2}) > *D. latifolia* (101.70 x 10^{3}kg cm^{-2}) > *S. saman* (69.01 x 10^{3}kg cm^{-2}). For both *A. odoratissima* and *S. saman*, it was observed that the difference between modulus of elasticity for sapwood and heartwood was non significant (Table 12). Furthermore, it was also noticed that the modulus of elasticity for the sapwood of *Albizia*

Table 10 Fibre stress at limit of proportionality of sapwood and heartwood of *A. odoratissima* and *S. saman* in static bending

S. No.	Species	FS at LP (kg cm^{-2})		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	821.11^{b}	982.69^{a}	65.577
2	*Samanea saman*	527.30^{c}	604.32^{c}	254.737
CD for comparing species ($p < 0.05$)		251.135	78.230	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 11 Modulus of rupture of sapwood and heartwood of *A. odoratissima* and *S. saman* in static bending

S. No.	Species	MOR (kg cm^{-2})		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	1417.41^{a}	1406.58^{a}	129.054
2	*Samanea saman*	801.92^{b}	983.34^{b}	297.138
CD for comparing species ($p < 0.05$)		251.135	315.275	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 12 Modulus of elasticity of sapwood and heartwood of *A. odoratissima* and *S. saman* in static bending

S. No.	Species	MOE (1000 kg cm^{-2})		LSD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	139.4^{a}	131.36^{a}	14.368
2	*Samanea saman*	68.84^{b}	69.01^{b}	20.465
CD for comparing species ($p < 0.05$)		24.276	5.996	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

odoratissima (139.40 x 10^3kg cm^{-2}) was significantly larger than sapwood of *S. saman* (68.84 x 10^3kg cm^{-2}).

4.2.1.4 Horizontal shear stress at limit of proportionality

Horizontal shear stress at elastic limit for both sapwood (30.36 kg cm^{-2}) and heartwood (35.56 kg cm^{-2}) of *A. odoratissima* differed significantly from the sapwood (19.16 kg cm^{-2}) and heartwood (21.85 kg cm^{-2}) of *S. saman* respectively. *A. odoratissima* showed significantly higher horizontal shear stress than *S. saman* for both sapwood and heartwood. Horizontal shear stress for heartwood was found to be significantly greater than horizontal shear stress of sapwood in *A. odoratissima*. But, in *S. saman* the horizontal shear stress of sapwood was significantly greater than its horizontal shear stress of heartwood (Table 13).

4.2.1.5 Horizontal shear stress at maximum load

At maximum load, the sapwood and heartwood of *A. odoratissima* and *S. saman* did not differ significantly in terms of horizontal shear stress. However, the horizontal shear stress for sapwood (50.97 kg cm^{-2}) and heartwood (50.42 kg cm^{-2}) of *A. odoratissima* was significantly greater than the horizontal shear stress for sapwood (28.89 kg cm^{-2}) and heartwood (35.57 kg cm^{-2}) of *S. saman* (Table 14).

4.2.1.6 Maximum load

Maximum load sustained by the sapwood (274.17 kg) and heartwood (270.75 kg) of *A. odoratissima* were found to be significantly higher than maximum load for sapwood (156.94 kg) and heartwood (190.28 kg) of *S. saman*. No significant difference was noticed between the sapwood and heartwood with respect to its maximum load in both *A. odoratissima* and *S. saman* (Table 15).

Table 13 Horizontal shear tress on neutral plane at limit of proportionality of sapwood and heartwood of *A. odoratissima* and *S. saman* in static bending

S. No.	Species	HS at LP (kg cm^{-2})		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	30.36^{b}	35.56^{a}	2.113
2	*Samanea saman*	19.16^{c}	21.85^{c}	9.222
CD for comparing species ($p < 0.05$)		9.109	2.558	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 14 Horizontal shear stress at maximum load of sapwood and heartwood of *A. odoratissima* and *S. saman* in static bending

S. No.	Species	HS at ML (kg cm^{-2})		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	50.97^{a}	50.42^{a}	4.571
2	*Samanea saman*	28.89^{b}	35.57^{b}	10.718
CD for comparing species ($p < 0.05$)		11.361	2.587	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 15 Maximum load of sapwood and heartwood of *A. odoratissima* and *S. saman* in static bending

S. No.	Species	Maximum load (kg)		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	274.17^{a}	270.75^{a}	24.500
2	*Samanea saman*	156.94^{b}	190.28^{b}	57.721
CD for comparing species ($p < 0.05$)		61.083	14.173	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

4.2.2 Compression strength parallel to grain

4.2.2.1 Compressive stress at limit of proportionality

At elastic limit, the heartwood of *A. odoratissima* was found to have highest compressive stress (598.60 kg cm^{-2}). It differed to a large extent from the heartwood of *S. saman* (299.02 kg cm^{-2}) and *D. latifolia* (338.00 kg cm^{-2}). The heartwood of *S. saman* with least compression stress showed relatively smaller difference with heartwood of *D. latifolia* (Table 9).

Compressive stress for sapwood also varied significantly among *A. odoratissima* and *S. saman* (Table 16). The sapwood of *A. odoratissima* (571.74 kg cm^{-2}) was found to possess greater compressive stress than sapwood of *S. saman* (261.40 kg cm^{-2}). In both these species it was observed that no significant difference exist between the compressive stress values of sapwood and heartwood.

4.2.2.2 Compressive stress at maximum load

At maximum load, the heartwood of *A. odoratissima* (704.88 kg cm^{-2}) was found to have relatively greater compressive stress than heartwood of *D. latifolia* (486.00 kg cm^{-2}) and *S. saman* (458.67 kg cm^{-2}). But, the compressive stress of heartwood of *S. saman* and *D. latifolia* varied to a smaller extent (Table 9).

The compressive stress of sapwood at maximum load also differed significantly between *A. odoratissima* and *S. saman*. The sapwood of *A. odoratissima* (656.95 kg cm^{-2}) showed a significantly higher compressive stress than sapwood of *S. saman* (405.51 kg cm^{-2}). It was also noticed that, the heartwood compressive stress of *A. odoratissima* was significantly greater than its sapwood compressive stress. Differences were observed for compressive stress between the sapwood and heartwood of *S. saman* but the difference was non significant (Table 16).

Table 16 Compressive stress at limit of proportionality and compressive stress at maximum load of sapwood and heartwood of *A. odoratissima* and *S. saman* in compression parallel to grain

S. No.	Species	CS at LP (kg cm^{-2})		CS at ML (kg cm^{-2})		CD for CS at LP between tissue type ($p < 0.05$)	CD for CS at ML between tissue type ($p < 0.05$)
		Sapwood	Heartwood	Sapwood	Heartwood		
1	*Albizia odoratissima*	571.74^{a}	598.60^{a}	656.95^{b}	704.88^{a}	64.671	39.269
2	*Samanea saman*	261.40^{b}	299.02^{b}	405.51^{c}	458.67^{c}	75.135	61.396
CD for comparing species ($p < 0.05$)		63.209	76.369	44.824	57.466		

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

Table 17 Modulus of elasticity and Maximum load of sapwood and heartwood of *A. odoratissima* and *S. saman* in compression parallel to grain

S. No.	Species	MOE (1000 kg cm^{-2})		ML (kg)		CD for MOE between tissue type ($p < 0.05$)	CD for ML between tissue type ($p < 0.05$)
		Sapwood	Heartwood	Sapwood	Heartwood		
1	*Albizia odoratissima*	66.71^{a}	69.21^{a}	2605.44^{a}	2849.21^{a}	13.835	257.094
2	*Samanea saman*	35.70^{b}	36.92^{b}	1651.75^{b}	1860.58^{b}	6.489	247.969
CD for comparing species ($p < 0.05$)		13.602	6.965	273.458	229.797		

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

4.2.2.3 Modulus of elasticity

Modulus of elasticity differed extremely among the heartwood of the three species under study (Table 9). The heartwood of *D. latifolia* (115.40 x 10^3kg cm^{-2}) exhibited relatively greater modulus of elasticity followed by *A. odoratissima* (69.21 x 10^3kg cm^{-2}) and *S. saman* (36.92 x 10^3kg cm^{-2}). The modulus of elasticity of sapwood of *A. odoratissima* (66.71 x 10^3kg cm^{-2}) was significantly greater than modulus of elasticity of sapwood of *S. saman* (35.70 x 10^3kg cm^{-2}). It was also observed that no significant difference exist between sapwood and heartwood in terms of modulus of elasticity (Table 17).

4.2.2.4 Maximum load

In both *A. odoratissima* and *S. saman*, the maximum load sustained by sapwood and heartwood were found to vary non significantly. It was revealed that the sapwood (2605.44 kg) and heartwood (2849.21 kg) of *A. odoratissima* sustained significantly higher maximum load than the sapwood (1651.75 kg) and heartwood (1860.58 kg) of *S. saman* (Table 17).

4.2.3 Compression strength perpendicular to grain

4.2.3.1 Compressive stress at limit of proportionality

The test for compression strength in the direction perpendicular to grain revealed that the compressive stress for heartwood of *A. odoratissima* (180.39 kg cm^{-2}) was significantly greater than compressive stress for heartwood of *S. saman* (116.89 kg cm^{-2}). However, the difference in compressive stress values for the heartwoods of *A. odoratissima* (180.39 kg cm^{-2}) and *D. latifolia* (153.00 kg cm^{-2}) was comparatively smaller. The heartwood of *S. saman* showed least compressive stress value and did not differed very much with heartwood of *D. latifolia* (Table 9).

In both *A. odoratissima* and *S. saman*, the compressive stress of sapwood was found to vary non significantly with compressive stress of heartwood. Moreover, the sapwood of *A. odoratissima* (199.11 kg cm^{-2}) varied with the compressive stress of the sapwood of *S. saman* (140.20 kg cm^{-2}) but the differences were non significant. Further, it was also observed that the differences in compressive stress between the sapwood and heartwood were non significant in both *A. odoratissima* and *S. saman* (Table 18).

4.2.3.2 Compressive stress at 2.5 mm deflection

The sapwood (418.95 kg cm^{-2}) and heartwood (351.27 kg cm^{-2}) of *A. odoratissima* showed higher compression stress values, which differed significantly from the sapwood (271.68 kg cm^{-2}) and heartwood (216.85 kg cm^{-2}) compressive stress value of *S. saman.* In both these species it was observed that the compression stress of sapwood was larger than the compressive stress of their heartwoods. However, the difference between compressive stress values of sapwood and heartwood were non significant (Table 19).

4.2.3.3 Modulus of elasticity

The modulus of elasticity did not differ significantly between the sapwood and heartwood in both *A. odoratissima* and *S. saman.* However, between species difference of modulus of elasticity for heartwood was significant. *A. odoratissima* showed a higher modulus of elasticity for both sapwood (37.67 x 10^{3}kg cm^{-2}) and heartwood (42.07 x 10^{3}kg cm^{-2}) as compared to sapwood (33.17 x 10^{3}kg cm^{-2}) and heartwood (28.66 x 10^{3}kg cm^{-2}) of *S. saman,* respectively. The difference in modulus of elasticity of sapwoods between *A. odoratissima* and *S. saman* were non significant (Table 20).

Table 18 Compressive stress at limit of proportionality of sapwood and heartwood of *A. odoratissima* and *S. saman* in compression perpendicular to grain

S. No.	Species	CS at LP (kg cm^{-2})		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	199.11^{a}	180.39^{a}	79.754
2	*Samanea saman*	140.20^{ab}	116.89^{b}	36.925
CD for comparing species ($p < 0.05$)		73.591	48.048	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 19 Compressive stress at 2.5 mm deflection of sapwood and heartwood of *A. odoratissima* and *S. saman* in compression perpendicular to grain

S. No.	Species	CS at 2.5 mm deflection (kg cm^{-2})		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	418.95^{a}	351.27^{a}	136.782
2	*Samanea saman*	271.68^{b}	216.85^{b}	61.367
CD for comparing species ($p < 0.05$)		139.460	55.233	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 20 Modulus of elasticity of sapwood and heartwood of *A. odoratissima* and *S. saman* in compression perpendicular to grain

S. No.	Species	Modulus of elasticity (1000 kg cm^{-2})		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	37.67^{a}	42.07^{a}	17.391
2	*Samanea saman*	33.17^{ab}	28.66^{b}	9.283
CD for comparing species ($p < 0.05$)		18.004	8.030	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

4.2.4 Shear strength in radial plane

4.2.4.1 Maximum shearing stress

The maximum shearing stress along the radial plane for heartwood of *A. odoratissima* (149.10 kg cm^{-2}) was relatively higher than the heartwoods of both *S. saman* (118.13 kg cm^{-2}) and *D. latifolia* (107.90 kg cm^{-2}). The maximum shearing stress of heartwood of *S. saman* was lesser than *A. odoratissima* but greater than *D. latifolia.* It differed from the heartwood of *D. latifolia* to a smaller extent (Table 9).

It was also found that the maximum shearing stress of *A. odoratissima* sapwood (175.35 kg cm^{-2}) was significantly greater than the sapwood of *S. saman* (124.06 kg cm^{-2}). It was also noticed that the maximum shearing stress differed significantly between sapwood and heartwood of *A. odoratissima* but the difference between sapwood and heartwood was non significant in *S. saman* (Table 21).

4.2.4.2 Maximum load

The maximum load sustained by sapwood (4256.06 kg) and heartwood (3665.66 kg) of *A. odoratissima* was found to be significantly greater than the sapwood (3097.59 kg) and heartwood (2953.35 kg) of *S. saman,* respectively. In *A. odoratissima,* it was observed that the maximum load sustained by sapwood was significantly greater than its heartwood where as, in *S. saman* the differences between sapwood and heartwood appeared to be non significant (Table 21).

4.2.5 Shear strength in tangential plane

4.2.5.1 Maximum shearing stress

The maximum shearing stress along the tangential plane varied among the heartwood of the three species (Table 9). The heartwood of *D. latifolia* (156.10 kg cm^{-2}) was found to have highest maximum shearing stress, followed by *A. odoratissima* (142.94

Table 21 Maximum shear stress and Maximum load of sapwood and heartwood of *A. odoratissima* and *S. saman* during shear in radial plane

S. No.	Species	Maximum shear stress (kg cm^{-2})		Maximum load (kg)		CD for MSS between tissue type ($p < 0.05$)	CD for ML between tissue type ($p < 0.05$)
		Sapwood	Heartwood	Sapwood	Heartwood		
1	*Albizia odoratissima*	175.35^{a}	149.1^{b}	4256.06^{a}	3665.66^{b}	21.347	493.890
2	*Samanea saman*	124.06^{c}	118.1^{c}	3097.59^{c}	2953.35^{c}	28.933	714.147
CD for comparing species ($p < 0.05$)		27.248	23.460	647.451	578.568		

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

Table 22 Maximum shear stress and Maximum load of sapwood and heartwood of *A. odoratissima* and *S. saman* during shear in tangential plane

S. No.	Species	Maximum shear stress (kg cm^{-2})		Maximum load (kg)		CD for MSS between tissue type ($p < 0.05$)	CD for ML between tissue type ($p < 0.05$)
		Sapwood	Heartwood	Sapwood	Heartwood		
1	*Albizia odoratissima*	162.41^{a}	142.94^{a}	3935.13^{a}	3546.70^{a}	30.405	693.188
2	*Samanea saman*	92.39^{b}	92.92^{b}	2307.26^{b}	2320.67^{b}	24.054	603.898
CD for comparing species ($p < 0.05$)		33.062	20.247	748.999	533.108		

Means comparison between species and between tissue types individually for each parameter
Values with same superscript do not differ significantly between themselves

kg cm^{-2}) and *S. saman* (92.92 kg cm^{-2}). The maximum shearing stress differed greatly among the heartwoods of *D. latifolia* and *S. saman* but the difference between *A. odoratissima* and *D. latifolia* appeared to be relatively less.

The sapwood of *A. odoratissima* (162.41 kg cm^{-2}) exhibited significantly greater maximum shearing stress as compared to the sapwood of *S. saman* (92.39 kg cm^{-2}). However, within each species it was noticed that the difference in maximum shearing stress between sapwood and heartwood was non significant (Table 22).

4.2.5.2 Maximum load

The sapwood (3935.13 kg) and heartwood (3546.70 kg) of *A. odoratissima* exhibited significantly higher maximum load than the sapwood (2307.26 kg) and heartwood (2320.67 kg) of *S. saman* respectively (Table 22). In *A. odoratissima,* the maximum load sustained by its sapwood was greater than its heartwood but the difference was non significant. On the other hand, the heartwood of *S. saman* was found to sustain higher maximum load than its sapwood but in this case also the difference was non significant.

4.2.6 Abrasion (Wear index)

The abrasion test results revealed that the average sapwood wear index (236.33) and heartwood wear index (225.00) for *A. odoratissima* were significantly greater than the average wear indexes for sapwood (182.67) and heartwood (94.33) of *S. saman. S. saman* exhibited significant difference between its sapwood and heartwood wear index values. But in case of *A. odoratissima*, the difference between sapwood and heartwood wear index was non significant (Table 23).

Table 23 Wear index of sapwood and heartwood of *A. odoratissima* and *S. saman* during abrasion

S. No.	Species	Wear index		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	236.33^a	225.00^a	226.042
2	*Samanea saman*	182.67^b	94.33^c	46.525
CD for comparing species ($p < 0.05$)		43.352	76.94	

Means both row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

4.3 ANATOMICAL PROPERTIES

Anatomical properties were tested for the woods of *Albizia odoratissima, Samanea saman* and compared with the anatomical properties of heartwood of *Dalbergia latifolia* available from following literature (Pearson and Brown, 1981; Quirk, 1983; Anoop *et al.*, 2005).

4.3.1 Vessel size and arrangement

4.3.1.1 Vessel diameter

Among the heartwood of the three species, *D. latifolia* had very narrow vessels with diameter ranging from 125 µm to 210 µm. The vessel diameter of the heartwood of *A. odoratissima* was observed to be widest ranging from 204 µm to 291 µm. *S. saman* showed an intermediate vessel diameter ranging of 158 µm to 264 µm (Table 24).

Vessel diameter differed significantly between the tissue types in both *A. odoratissima* and *S. saman.* In both these species, sapwood showed significantly larger vessels as compared to their respective heartwoods. The average vessel diameter in both sapwood (296.54 µm) and heartwood (250.25 µm) of *A. odoratissima* was greater than that of the sapwood (288.98 µm) and heartwood (216.39 µm) of *S. saman* respectively (Table 25). The difference in vessel diameter of sapwood were non significant between species where as, differences were found to be significant in the case of heartwoods.

The effect of position in sapwood and heartwood of *A. odoratissima* and *S. saman* revealed that the average vessel diameter at three positions of sapwood viz., inner, middle and outer did not differ significantly in both these species. At the same time, the average vessel diameter at the inner, middle and outer positions in heartwood portion varied significantly (Table 26). The ascending trend of vessel diameter in heartwood of both *A. odoratissima* and *S. saman* was observed as inner < middle < outer. It was noticed that in these two species, the vessel diameter increased from inner heartwood to outer heartwood

Table 24 Comparative profile of anatomical properties of heartwoods of *Albizia odoratissima*, *Samanea saman* and *Dalbergia latifolia*

S. No	Anatomical property	*A. odoratissima*	*S. saman*	*D. latifolia*
1	Vessel diameter (µm)	203.76 – 291.50	158.19 – 268.63	*125 – 210
2	Vessel frequency (number/mm^2)	1 – 5	1 – 3	#2 – 12
3	Vessel arrangement	Diffuse porous	Diffuse porous	#Diffuse porous/ Semi-ring porous
4	Parenchyma arrangement	Aliform, aliform confluent or banded	Vasicentric, aliform or aliform confluent	#Vasicentric, aliform or aliform confluent
5	Ray height (µm)	188.24 – 305.74	201.23 – 324.49	*170 – 315
6	Ray width (µm)	31.11 – 37.49	25.62 – 42.05	#30 – 45
7	Ray frequency (rays/mm)	13 – 19	9 – 17	#11 – 16
8	Special characters	Reddish brown deposits in vessels	Reddish brown deposits in vessels	#Reddish brown deposits in vessels, silica deposits

* Anoop *et al.* (2005)
\# Pearson and Brown (1981); Quirk (1983)

Table 25 Vessel diameter (µm) of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Vessel diameter (µm)		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	296.54^{a}	250.25^{b}	15.039
2	*Samanea saman*	288.98^{a}	216.39^{c}	15.526
CD for comparing species ($p < 0.05$)		12.954	17.304	

Means row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 26 Vessel diameter (µm) at different radial position of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Vessel diameter (µm)					
		Sapwood			Heartwood		
		Inner	Middle	Outer	Inner	Middle	Outer
1	*Albizia odoratissima*	309.30^{a}	289.43^{a}	290.89^{a}	203.76^{c}	255.46^{b}	291.50^{a}
2	*Samanea saman*	294.12^{a}	283.89^{a}	288.92^{a}	158.19^{c}	222.36^{b}	268.63^{a}
CD for comparing position within *Albizia odoratissima* ($p < 0.05$)		22.047			23.133		
CD for comparing position within *Samanea saman* ($p < 0.05$)		22.865			20.058		

DMRT column wise comparison with in each tissue type
Values with same superscript do not differ significantly between themselves

Table 27 Vessel frequency (number of vessels per mm^{2}) of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Vessel frequency (number of vessels per mm^{-2})		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	0.99^{c}	2.67^{a}	0.860
2	*Samanea saman*	1.49^{b}	2.24^{a}	0.442
CD for comparing species ($p < 0.05$)		0.212	0.943	

eans row wise and column wise comparison
alues with same superscript do not differ significantly between themselves

and reached its maximum size at the inner sapwood and thereafter again decreased towards bark. However, the difference of vessel diameter at various positions in sapwood were non significant.

4.3.1.2 Vessel arrangement

All the three species showed diffuse porous type of vessel arrangement in their heartwoods. However, at times *D. latifolia* showed semi- ring porous tendency (Table 24).

4.3.2 Vessel frequency

It is evident from the table 24 that the vessel frequency of the heartwood of *A. odoratissima* ranged between 1-5 vessels per sq. mm. The range was comparatively lower in the heartwood of *S. saman* (1-3 vessels per sq. mm). The heartwood of *D. latifolia* exhibited a very wide range of vessel frequency (2-12 vessels per sq. mm).

In both *A. odoratissima* and *S. saman*, it was observed that the heartwood vessel frequency was significantly higher than their respective sapwood vessel frequency. Between species difference in terms of the vessel frequency of heartwood appeared to be non significant. On the contrary, the vessel frequency of sapwood of *S. saman* was significantly greater than the vessel frequency of sapwood of *A. odoratissima* (Table 27).

The average vessel frequency at the three different positions in sapwood were found to vary as inner > middle < outer in both *A. odoratissima* and *S. saman.* The differences between these positions appeared non significant. Where as, the average vessel frequency at inner position of heartwood in both these species was significantly greater than vessel frequency at middle and outer heartwood positions. The difference between the vessel frequencies of middle and outer heartwood was non significant in both *A. odoratissima* and *S. saman* (Table 28).

Table 28 Vessel frequency (number of vessels per mm^2) at different radial position of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Vessel frequency (number of vessels per mm^2)					
		Sapwood			Heartwood		
		Inner	Middle	Outer	Inner	Middle	Outer
1	*Albizia odoratissima*	1.08^{a}	0.87^{a}	1.02^{a}	5.39^{a}	1.42^{b}	1.19^{b}
2	*Samanea saman*	1.84^{a}	1.18^{b}	1.44^{ab}	3.45^{a}	1.43^{b}	1.86^{b}
CD for comparing position within *Albizia odoratissima* ($p < 0.05$)		0.219			1.034		
CD for comparing position within *Samanea saman* ($p < 0.05$)		0.418			0.538		

DMRT column wise comparison with in each tissue type

Values with same superscript do not differ significantly between themselves

Table 29 Ray height (µm) of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Ray height (µm)		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	270.12^{b}	247.56^{b}	25.746
2	*Samanea saman*	292.71^{a}	266.12^{b}	23.550
CD for comparing species ($p < 0.05$)		21.782	27.259	

Means row wise and column wise comparison

Values with same superscript do not differ significantly between themselves

Table 30 Ray height (µm) at different radial position of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Ray height (µm)					
		Sapwood			Heartwood		
		Inner	Middle	Outer	Inner	Middle	Outer
1	*Albizia odoratissima*	268.15^{a}	266.65^{a}	275.55^{a}	188.24^{c}	248.69^{b}	305.74^{a}
2	*Samanea saman*	286.12^{a}	294.92^{a}	297.10^{a}	201.23^{c}	272.64^{b}	324.49^{a}
CD for comparing position within *Albizia odoratissima* ($p < 0.05$)		36.869			45.849		
CD for comparing position within *Samanea saman* ($p < 0.05$)		39.489			34.106		

DMRT column wise comparison with in each tissue type

Values with same superscript do not differ significantly between themselves

4.3.3 Parenchyma arrangement

D. latifolia is reported to exhibit vasicentric, aliform or aliform confluent type of parenchyma. Transverse anatomical sections revealed that the wood of *A. odoratissima* exhibits aliform, aliform confluent or banded type of parenchyma (Plate 16). *S. saman* exhibited similarity to *D. latifolia* in terms of parenchyma. The wood of *S. saman* also showed vasicentric, aliform or aliform confluent type of parenchyma (Table 24; Plate 17).

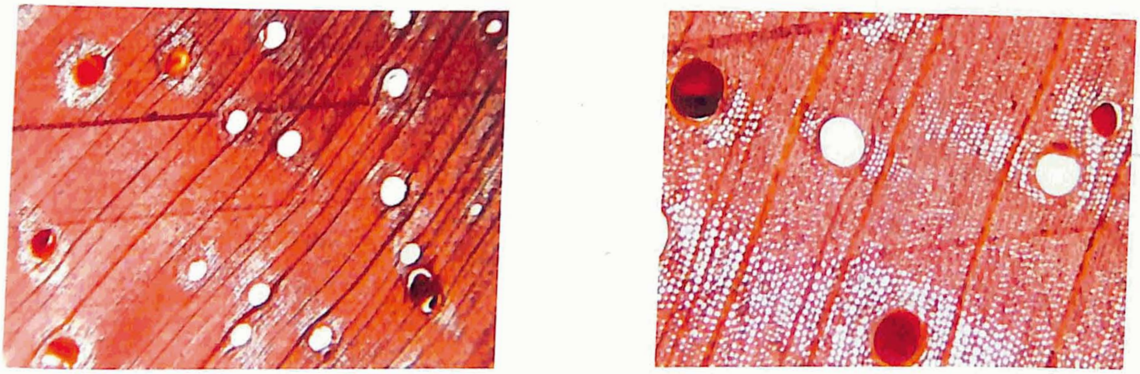
4.3.4 Ray size and number

4.3.4.1 Ray height

The average ray height in the heartwood of *A. odoratissima* and *S. saman* were found to range between 188.24 µm to 305.74 µm and 201.23 µm to 324.99 µm, respectively. The average heights of the rays in the heartwood of *D. latifolia* were observed to range from 170 µm to 315 µm (Table 24).

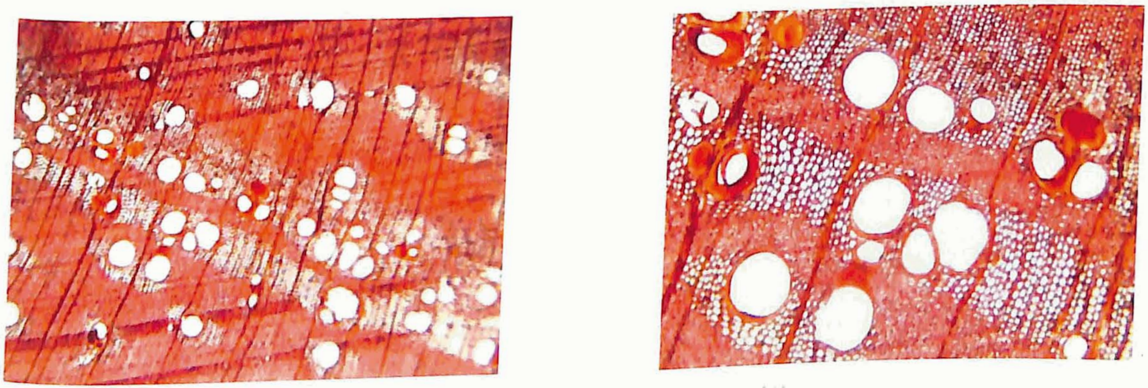
The average height of the rays in the sapwoods of *A. odoratissima* and *S. saman* also varied significantly (Table 29). It was found that the average ray height of sapwood of *S. saman* (292.71 µm) was significantly greater than the average ray height of sapwood of *A. odoratissima* (270.12 µm). The ray height also showed variation between tissue types in both the species. In *S. saman*, it was observed that the average ray of sapwood is significantly longer than average ray in its heartwood. However, no significant difference was observed between the average ray heights of sapwood (247.56 µm) and heartwood (266.12 µm) in *A. odoratissima*.

In both *A. odoratissima* and *S. saman*, no definite trend was observed for ray height at different positions in sapwood. However, variation in ray height was observed at different positions but the differences were non significant. On the contrary, the ray heights at different positions of heartwood were found to vary significantly in both *A. odoratissima*



Aliform and aliform confluent parenchyma under 4 X

Aliform parenchyma under 10 X

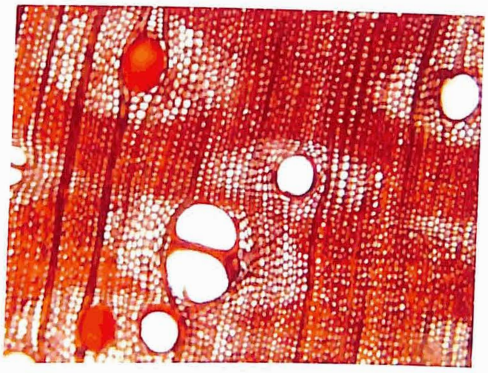


Aliform confluent and banded confluent parenchyma under 4 X

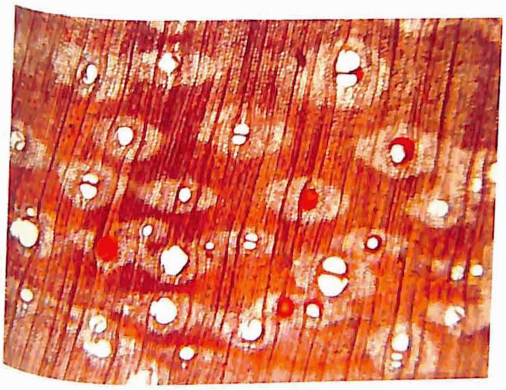
Banded confluent parenchyma under 10 X

Plate 16. Distribution of parenchyma in *Albizia odoratissima*

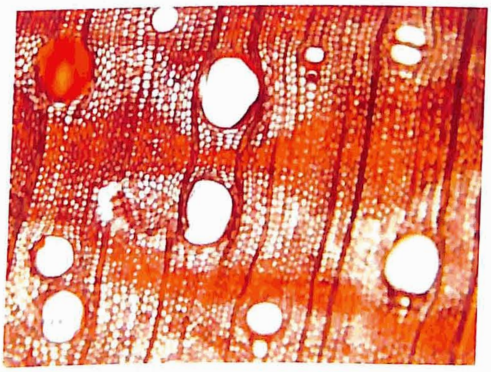
Vasicentric parenchyma under 4 X



Aliform parenchyma under 10 X



Aliform and aliform confluent parenchyma under 4 X



Aliform confluent parenchyma under 10 X

Plate 17. Distribution of parenchyma in *Samanea saman*

and *S. saman*. The ray height significantly increased from inner heartwood to outer heartwood as inner < middle < outer in both these species (Table 30).

4.3.4.2 Ray width

Ray width of the heartwood of *A. odoratissima*, *S. saman* and *D. latifolia* were found to range between 31.11 µm to 37.49 µm, 25.62 µm to 42.05 µm and 30 µm to 45 µm, respectively (Table 24). It was observed that the average ray width of the sapwood of *A. odoratissima* was significantly greater than ray width of the sapwood of *S. saman*. It was also found that in both *A. odoratissima* and *S. saman*, the rays in sapwood were significantly wider than those in their respective heartwoods (Table 31).

The average ray width at different positions of sapwood in both *A. odoratissima* and *S. saman* were found to vary non significantly between these positions. But in heartwood the ray width increased from inner to outer region. The differences between all the three positions were significant only in *S. saman*. But, in *A. odoratissima*, the ray width of only the inner region of heartwood varied significantly with middle and outer regions which in turn were not significantly different with reference to ray width (Table 32).

4.3.4.3 Ray frequency

The ray frequency of the heartwood of *A. odoratissima* ranged from 13 to 19 rays per mm. The heartwoods of *S. saman* and *D. latifolia* also showed similar range of 9 to 17 rays per mm and 11 to 16 rays per mm, respectively (Table 24). The average ray frequency of both the sapwood and heartwood of *A. odoratissima* was significantly greater than the ray frequency of sapwood and heartwood of *S. saman*. With in *A. odoratissima*, it was observed that the sapwood consist of significantly higher number of rays as compared to its heartwood. Where as, in *S. saman*, the heartwood possessed larger number of rays than its sapwood, but the differences observed within *S. saman* were non significant (Table 33).

Table 31 Ray width (µm) of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Ray width (µm)		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	45.13^{a}	35.03^{c}	2.734
2	*Samanea saman*	41.60^{b}	35.46^{c}	2.354
CD for comparing species ($p < 0.05$)		2.223	2.842	

Means row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

Table 32 Ray width (µm) at different radial position of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Ray width (µm)					
		Sapwood			Heartwood		
		Inner	Middle	Outer	Inner	Middle	Outer
1	*Albizia odoratissima*	45.75^{a}	45.75^{a}	43.68^{a}	31.11^{b}	36.50^{a}	37.49^{a}
2	*Samanea saman*	43.01^{a}	40.5^{a}	41.29^{a}	25.62^{c}	38.72^{b}	42.05^{a}
CD for comparing position within *Albizia odoratissima* ($p < 0.05$)		4.525			4.831		
CD for comparing position within *Samanea saman* ($p < 0.05$)		3.086			3.271		

DMRT column wise comparison with in each tissue type
Values with same superscript do not differ significantly between themselves

Table 33 Ray frequency (rays per mm) of sapwood and heartwood of *A. odoratissima* and *S. saman*

S. No.	Species	Ray frequency (rays per mm)		CD for comparing tissue type ($p < 0.05$)
		Sapwood	Heartwood	
1	*Albizia odoratissima*	21.08^{a}	17.21^{b}	2.024
2	*Samanea saman*	11.79^{c}	13.36^{c}	1.605
CD for comparing species ($p < 0.05$)		1.510	2.096	

Means row wise and column wise comparison
Values with same superscript do not differ significantly between themselves

In both *A. odoratissima* and *S. saman,* no definite trend of variation was observed for ray frequency at different positions of sapwood. Also, the minute differences observed at these positions were found to be non significant. In heartwood, the ray frequency decreased from inner to outer region and was observed to vary as inner > middle > outer. The difference at these positions of heartwood appeared to be significant only for *S. saman* and non significant for *A. odoratissima* (Table 34).

4.3.5 Special characters

The special character observed in the wood of D. latifolia was the presence of silica deposits. No silica deposits were observed in the other two species. Moreover, the vessels of the *A. odoratissima, S. saman* and *D. latifolia* showed reddish brown gums depositions (Table 24; Plate 18).

4.4 BIOCHEMICAL PROPERTIES

Biochemical properties were tested for the heartwoods of all the three species under study.

4.4.1 Lignin content of wood

Lignin content of the heartwood of *A. odoratissima* (40.04 %) and *S. saman* (40.85 %) were significantly greater than that of the heartwood of *D. latifolia* (30.18 %). The heartwood of *S. saman* showed comparatively higher lignin percentage than *A. odoratissima*. However, the differences in lignin content between *A. odoratissima* and *S. saman* were non significant (Table 35).

Table 34 Ray frequency (rays per mm) at different radial position of sapwood and heartwood of *A. odoratissima* and *S. saman*

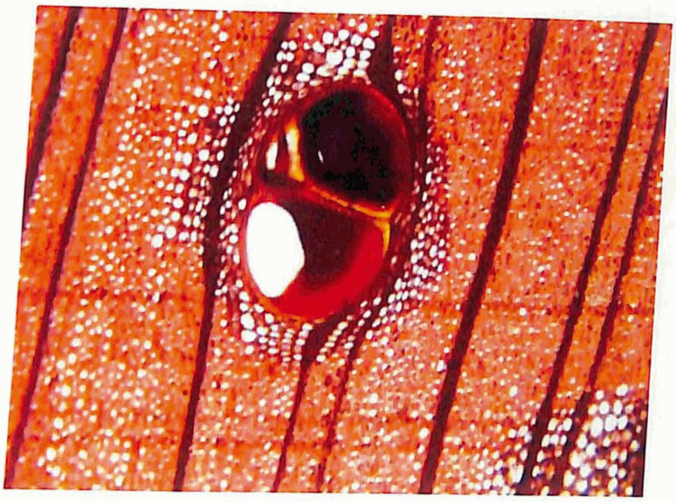
S. No.	Species	Ray frequency (rays per mm)					
		Sapwood			Heartwood		
		Inner	Middle	Outer	Inner	Middle	Outer
1	*Albizia odoratissima*	18.69^{b}	21.04^{ab}	23.52^{a}	19.48^{a}	18.54^{a}	13.59^{b}
2	*Samanea saman*	12.72^{a}	12.67^{a}	9.99^{b}	17.11^{a}	13.58^{b}	9.41^{c}
CD for comparing position within *Albizia odoratissima* ($p < 0.05$)		2.565			3.218		
CD for comparing position within *Samanea saman* ($p < 0.05$)		0.985			1.488		

DMRT column wise comparison with in each tissue type
Values with same superscript do not differ significantly between themselves

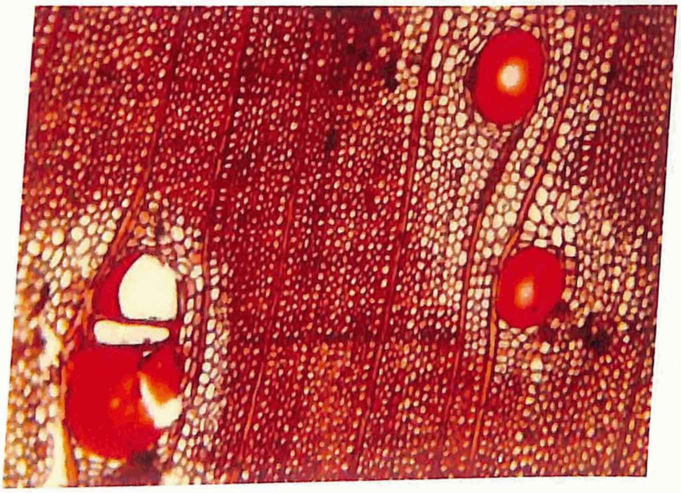
Table 35 Lignin, holocellulose, cellulose of heartwood and percent cellulose in holocellulose of heartwood of *A. odoratissima*, *S. saman* and *D. latifolia*

S. No.	Species	Lignin	Holocellulose	Cellulose in wood	Cellulose in holocellulose
		(%)	(%)	(%)	(%)
1	*Albizia odoratissima*	40.04^{a}	52.27^{b}	37.54^{a}	71.78^{a}
2	*Samanea saman*	40.85^{a}	57.34^{a}	36.12^{a}	62.83^{b}
3	*Dalbergia latifolia*	30.18^{b}	44.33^{c}	24.14^{b}	54.43^{c}
CD for comparing species ($p < 0.05$)		4.479	2.265	2.544	3.079

DMRT row wise comparison
Values with same superscript do not differ significantly between themselves



Transverse section of *Albizia odoratissima* under 10 X



Transverse section of *Samanea saman* under 10 X

Plate 18. Reddish brown gum deposits in the vessels of *Albizia odoratissima* and *Samanea saman*

4.4.2 Holocellulose content of wood

The holocellulose content of heartwood varied significantly among the three species (Table 35). *S. saman* exhibited highest holocellulose content of heartwood (57.34 %) which was followed by *A. odoratissima* (52.27 %) and *D. latifolia* (44.33 %).

4.4.3 Cellulose content of wood

The heartwood of *A. odoratissima* possessed highest alpha cellulose content (37.54 %) when compared to heartwood of *S. saman* (36.12 %) and *D. latifolia* (24.14 %). The cellulose content varied non significantly between *A. odoratissima* and *S. saman*. However, the cellulose content of heartwood of *A. odoratissima* was significantly different when compared to *D. latifolia* (Table 35).

4.4.4 Percentage of cellulose in the holocellulose of wood

The percentage of cellulose in the holocellulose of heartwood varied significantly among the three species (Table 35). It was observed that the holocellulose of the heartwood of *A. odoratissima* contained the highest percentage of cellulose (71.78 %), followed by *S. saman* (62.83 %) and *D. latifolia* (54.43 %).

4.4.5 Colouring matter

Column chromatography and spectroscopic analyses revealed that the methanol-acetone extract of the three species showed specific wavelength peaks of absorbance. *D. latifolia* exhibited highest number of total peaks (48) followed by *A. odoratissima* (45) and *S. saman* (44). *D. latifolia* had 10 peaks, *S. saman* (8) and *A. odoratissima* (3) which are unique for each of the species. Two peaks (418 nm and 427 nm) found in *A. odoratissima* and *D. latifolia* were not found in the *S. saman*. On the other hand, 7 peaks (415 nm, 475 nm, 511 nm, 586 nm, 597 nm, 604 nm, 658 nm) were found only in *Samanea saman* and

Table 36. Absorbance peak wavelength for components present in different species.

Sl. No.	Species constituting components	Absorbance peak wavelengths (nm)
1.	*Albizia odoratissima, Samanea saman, Dalbergia latifolia*	406, 412, 430, 445, 451, 454, 472, 481, 487, 490, 496, 499, 508, 562, 565, 574, 577, 589, 616, 619, 622, 625, 637, 640, 664, 673, 676, 691, 694
2.	*Albizia odoratissima and Samanea saman*	406, 412, 430, 445, 451, 454, 472, 487, 490, 496, 499, 508, 562, 565, 574, 577, 589, 616, 619, 622, 625, 637, 640, 664, 673, 676, 691, 694
3.	*Samanea saman and Dalbergia latifolia*	406, 412, 415, 430, 445, 451, 454, 472, 475, 481, 487, 490, 496, 499, 508, 511, 562, 565, 574, 577, 586, 589, 592, 604, 616, 619, 622, 625, 637, 640, 658, 664, 673, 676, 691, 694
4.	*Albizia odoratissima and Dalbergia latifolia*	406, 412, 418, 427, 430, 445, 451, 454, 472, 481, 487, 490, 496, 499, 508, 562, 565, 574, 577, 589, 616, 619, 622, 625, 637, 640, 664, 673, 676, 691, 694
5.	Only in *Albizia odoratissima*	463, 580, 682
6.	Only in *Samanea saman*	439, 442, 457, 469, 502, 595, 601, 688
7.	Only in *Dalbergia latifolia*	403, 484, 493, 505, 541, 643, 649, 655, 674, 679

D. latifolia and was absent in *A. odoratissima* (Table 36). All the three species showed 29 common peaks occurring among all these three species. However, *D. latifolia* showed slightly different peaks for the components which absorb wavelength between 620 nm to 780 nm which in turn were not observed in other two species.

Discussion

DISCUSSION

Increasing reports of adulteration of the furniture of Indian rosewood with its possible alleged substitutes viz., Ceylon rosewood and rain tree has been reported from many parts of the state. In awake of such a spurious timber deal, a study was conducted to profile the selected wood properties of Indian rosewood, Ceylon rosewood and rain tree. The results interpreted from the present study are discussed below.

5.1. PHYSICAL PROPERTIES

5.1.1 Calorific value

Results obtained from the analysis of calorific value data set (Table 2; Fig. 2) indicate that the calorific values of heartwood of *Dalbergia latifolia* and *Samanea saman* were comparatively greater than that of *Albizia odoratissima.* This observation is in conformity with earlier reports for variation of calorific value among species and tissue types (Singh and Khanduja, 1984; Bhatt and Todaria, 1992). Shanavas (2001) studied the calorific value variability of a few agroforestry tree species of Kerala and also quantified the variations in their tissue types. He grouped the species and their tissue types into three different calorific value categories viz., high, medium and low calorific values. With reference to this categorization, the three species under the present study along with their tissue types can be grouped into high (> 4500 cal g^{-1}), medium (3750 – 4500 cal g^{-1}) and low (< 3750 cal g^{-1}) categories. The sapwood and heartwood of *D. latifolia* and heartwood of *S. saman* falls under first category and possess high calorific value. Sapwood and heartwood of *A. odoratissima* exhibited medium calorific value. Where as, the sapwood of *S. saman* exhibited low calorific value.

The high calorific value of heartwood of *S. saman* as compared to *A. odoratissima* (Table 3; Fig. 3) can be due to higher lignin, cellulose and holocellulose content in its wood samples (Table 35; Fig. 33). On the other hand, high calorific value of the heartwood of *D. latifolia* may be due to low moisture content (Fig. 4) and high specific gravity of the wood

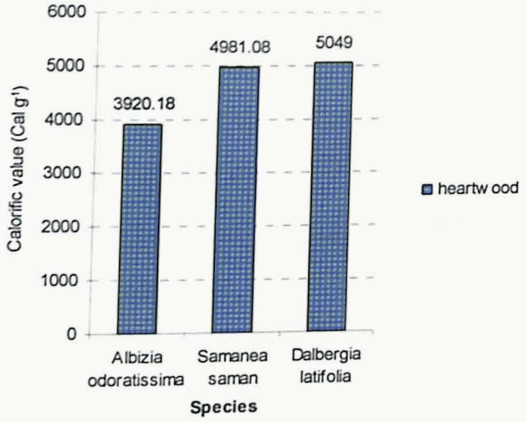


Fig. 2. Calorific value of heartwood of *A. odoratissima, S. saman* and *D. latifolia*

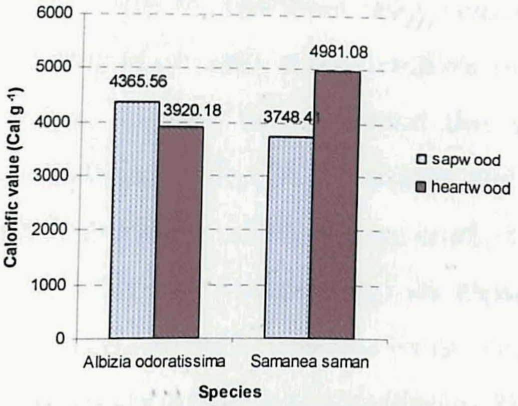


Fig. 3. Calorific value of sapwood and heartwood of *A. odoratissima* and *S. saman*

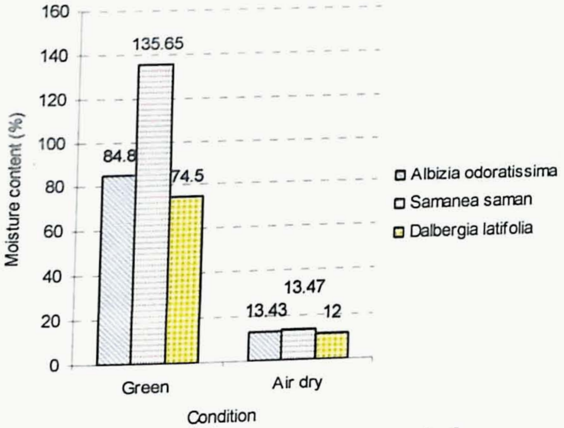


Fig. 4. Moisture content of heartwood of *A. odoratissima, S. saman* and *D. latifolia* at green and air dry condition

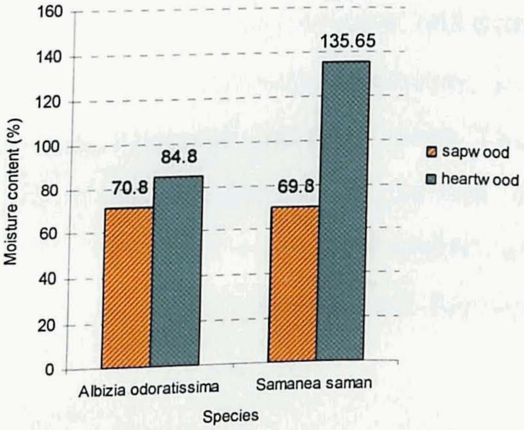


Fig. 5. Moisture content of sapwood and heartwood of *A. odoratissima* and *S. saman* at green condition

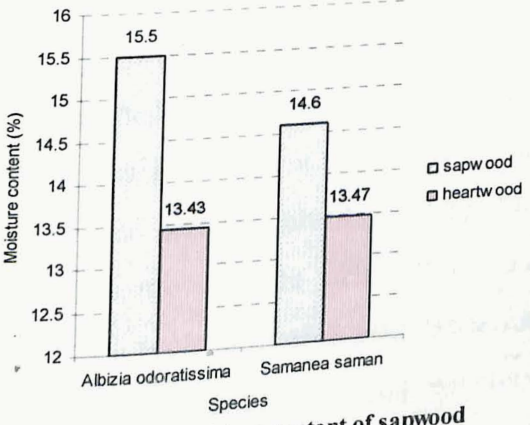


Fig. 6. Air dry moisture content of sapwood and heartwood of *A. odoratissima* and *S. saman*

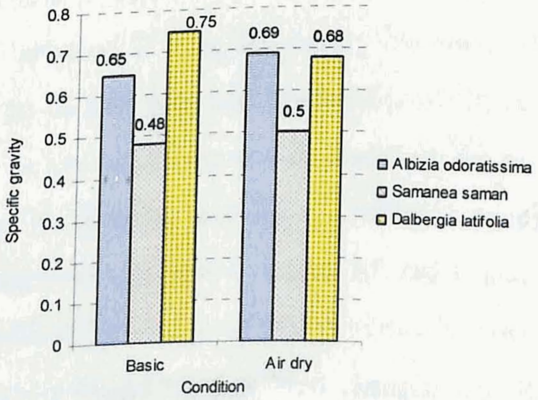


Fig. 7. Basic specific gravity and specific gravity air dry condition of heartwood of *A. odoratissima, S. saman* and *D. latifolia*

samples (Table 2; Fig. 7). Similarly the high calorific value for heartwood of *S. saman* over its sapwood (Table 3; Fig. 3) can be due to higher amount of lignin and extractives and low moisture content (Table 4; Fig. 6). Many previous workers have reported this strong correlation between lignin, cellulose and pentosan concentration in the tissues and their calorific values (Krishna and Ramaswamy, 1932; Breag *et al.*, 1984; Fussey *et al.*, 1984). Shanavas (2001) had also reported higher calorific values for heartwoods over sapwoods for the many species he investigated. According to him, the high calorific value obtained for coconut shell is due to its high lignin, pentosan and cellulose contents (lignin- 29.4%, pentosans- 27.7%, uronic anhydrids- 3.5% and cellulose-26.6%). Thus, the higher concentration of constituent chemical components explains the higher calorific values in wood. In general higher calorific value of heartwoods is due to higher lignin and extractive fractions which occurs during sapwood to heartwood transformation. However, in some cases moisture content and specific gravity may also influence calorific values. Thus, the higher calorific value observed for the sapwood of *A. odoratissima* can be due to high specific gravity of its sapwood (Table 5; Fig. 3). Similar observation of higher calorific value for sapwood over heartwood is reported in *D. latifolia* by Krishna and Ramaswamy (1932).

5.1.2 Specific gravity

The basic specific gravity of heartwood of *D. latifolia* was comparatively greater than that of *A. odoratissima* and *S. saman* (Table 2; Fig. 7). However, the air dry specific gravity varied slightly with *A. odoratissima*. Variation in specific gravity between different timber species is quite large, ranging from 60 to 70 per cent within species, while variation in the radial direction from pith to periphery in the same species is found in the range of 20-30 per cent (Tsoumis, 1991). Differences in specific gravity in different species or within same species arise from the formation of different types of cells and their distribution per unit area and the amount of voids created during this process. Variations in wood specific gravity among species have been extensively reported (Sekhar and Rawat, 1959; Rajput *et al.*, 1985). The higher specific gravity of *D. latifolia* can be explained based on its moisture holding capacity at green and dry condition and also anatomical elements. The comparatively lower moisture content in wood samples of *D. latifolia* at both green and air dry condition (Table 3; Fig. 4) can be attributed to its higher specific gravity. Also, the observed difference for the moisture content at air dry condition (Table 2) may be responsible for slight differences in the specific gravities at air dry condition between *D. latifolia* and *A. odoratissima* (Table 2). A comparison of *A. odoratissima* and *S. saman* sapwood and heartwood revealed that the sapwood and heartwood specific gravity of *A. odoratissima* is larger than that of *S. saman* (Table 5; Fig. 8; Fig. 9). Higher moisture content in wood samples of *S. saman* (Table 4; Fig. 6) might be responsible for its comparatively lower specific gravity. The observed higher specific gravity of sapwood samples over heartwood samples in both the species can be attributed to the presence of diametrically larger vessels (Table 25; Fig. 20; Fig. 21) and higher percentage of rays (Table 35; Fig. 20). Rao *et al.* (2003a) had also reported such a correlation for basic density and vessel diameter in *Eucalyptus tereticornis*. Rao *et al.* (2002) had earlier also reported a positive correlation between ray percent and specific gravity. Increase in specific gravity from inner to outer wood sample position is also reported by various authors (Bamber *et al.*, 1969; Jain and Arora, 1995; Shanavas, 2001).

5.1.3 Shrinkage of wood

Radial shrinkage from green to oven dry differed among all the three species studied (Table 2; Fig. 11). The observed radial shrinkage for *A. odoratissima* from green to oven dry (3.6%) was closer to those reported from studies done at Coimbatore (3 %) by Sekhar (1988). In the present study also, radial, tangential and volumetric shrinkage values as observed for both sapwood and heartwood of *A. odoratissima* were greater over *S. saman* (Table 7, 8; Fig. 11, 12, 13). Larger vessel diameter (Table 25; Fig. 22, 23) and larger ray dimensions (Table 29, 31, 33) might be the governing factors. Nasroun and Al-Shahrani (1998a) reported similar effects in five locally grown wood species in Saudi Arabia. It was evident from his study that vessel diameter is positively correlated to shrinkage. It may also be stated that a significantly higher specific gravity (Table 5; Fig. 8,

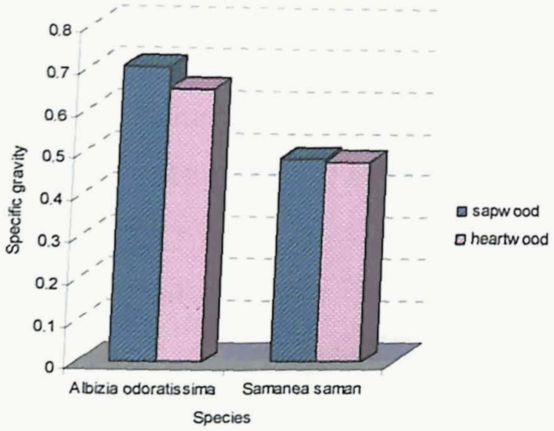


Fig. 8. Basic specific gravity of sapwood and heartwood of *A. odoratissima* and *S. saman*

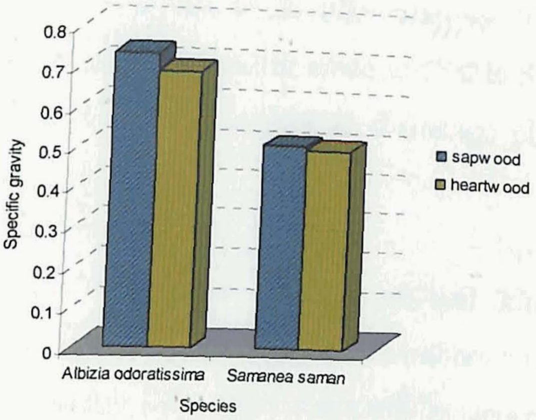


Fig. 9. Specific gravity of sapwood and heartwood of *A. odoratissima* and *S. saman* at air dry condition

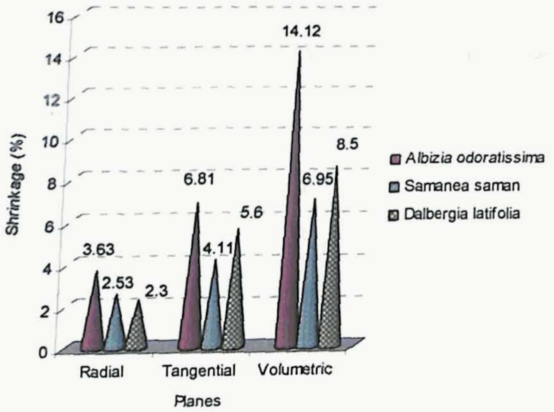


Fig. 10. Radial, tangential and volumetric shrinkage of the heartwoods of *A. odoratissima, S. saman* and *D. latifolia*

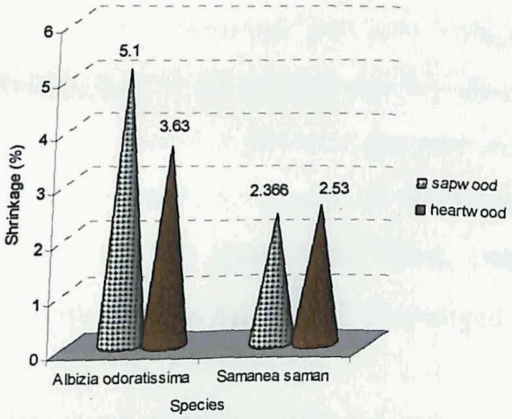


Fig. 11. Radial shrinkage from green to oven dry condition of sapwood and heartwood of *A. odoratissima* and *S. saman*

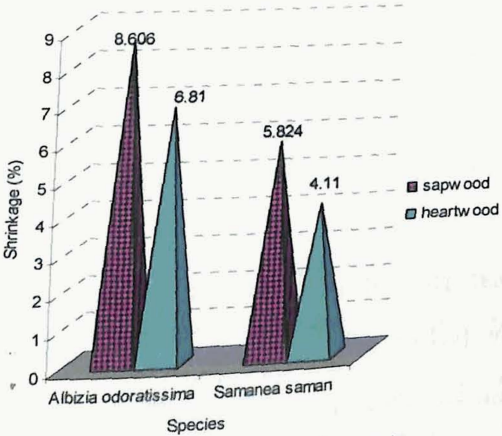


Fig. 12. Tangential shrinkage (green to oven dry) of sapwood and heartwood of *A. odoratissima* and *S. saman*

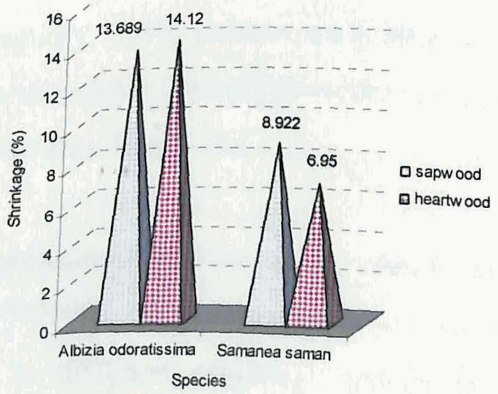


Fig. 13. Volumetric shrinkage (green to oven dry) of sapwood and heartwood of *A. odoratissima* and *S. saman*

9) may add up to the higher shrinkage values observed in *A. odoratissima*. The non significant difference in specific gravity between sapwood and heartwood (Table 5) might have resulted in non significant differences in radial and tangential shrinkage observed between sapwood and heartwood (Table 6, 7).

Water moves through wood as liquid or vapour through several kinds of passageways. These are the cavities of fibers and vessels, ray cells, pit chambers and their pit membrane openings, resin ducts of certain softwoods, other intercellular spaces and transitory cell wall passageways (Panshin and de Zeeuw, 1980). Most water lost by wood during drying moves through cell cavities and pits. It moves in these passageways in all directions, both along and across the grain. Lighter species in general dry faster than heavier species because their structure contains more openings per unit volume. The magnitude of shrinkage is higher at higher density, i.e. wood of high density shrinks and swells more. This is due to the larger amount of wood substance (greater cell wall thickness) in woods of higher density. It is also due to exterior change of cell dimensions and has been observed by numerous workers (Stamm, 1964; Siau, 1984; Skarr, 1988) that when moisture is lost or gained, the size of cell cavity remains practically unchanged.

The higher shrinkage observed from air dry to oven dry over green to air dry (Table 6, 7, 8) may possibly be due to removal of cell wall bound water forcibly. Shukla *et al.* (2003) observed that in *Tecomella undulata*, the three shrinkages increased slowly with decreasing moisture content from green to nearly fibre saturation point (20-25 %). Thereafter, they were found to increase very rapidly. In the present study also, the removal of water below fibre saturation point, explain the higher shrinkage values. Loss of bound water from the cell wall (Stamm, 1964) increases shrinkage values.

It was observed that in both *A. odoratissima* and *Samanea saman*, tangential shrinkage was greater than radial shrinkage (Table 6, 7). As it is well known, wood is highly anisotropic in nature which results in different shrinkage values in various directions. The shrinkage in tangential direction is quite high and is generally twice as great as shrinkage in radial direction. Many different reasons have been attributed for the lower shrinkage values in radial direction compared with the tangential direction. Some of them are due to presence of ray cells and their restricting effect in radial direction, difference in degree of lignification between the radial and tangential walls, small difference in microfibril angle between two walls, increased thickness of middle lamella in the tangential direction compared to that in radial direction, presence of bands of lower density earlywood and higher density latewood (Panshin and de Zeeuw, 1980; Skaar, 1988). The higher tangential shrinkage observed also can be attributed to all or some of these reasons which can only be conclusively established by attempting further studies in these lines.

5.2 MECHANICAL PROPERTIES

5.2.1 Static bending

Static bending is a measure of the strength of the material as a beam. All the static bending properties were significantly higher in *A. odoratissima* (Table 9; Fig. 14, 15). This can be attributed to its high specific gravity (Table 2; Fig. 7), high cellulose, holocellulose and high lignin content (Table 35; Fig. 32). Modulus of rupture observed for heartwood of *A. odoratissima* was greater than the values of wood samples from Coimbatore as reported by Sekhar (1988). However, the comparatively lower MOE observed under present study over the value reported from the Coimbatore study might be due to the comparatively younger trees selected for the present study. Younger trees produce "juvenile wood" characterized by shorter cells, steeper S_2 cell wall microfibril angles and altered chemical composition (Cutter *et al.*, 2004). The heartwood of *Samanea saman,* meanwhile showed higher fibre stress at elastic limit and higher MOR over *D. latifolia* (Table 9; Fig. 14) probably due to its high lignin and cellulose content (Table 35; Fig. 32). However, the lower MOE values can be due to the effect of "juvenile wood". Siagian *et al.* (1999) earlier reported that increase in age increased the physical and mechanical properties. Modulus of rupture reported by Damodaran and Chacko (1999) for 8-yr old *Acacia mangium* was lower than that of 10 yr old trees as reported by Shanavas (2001).

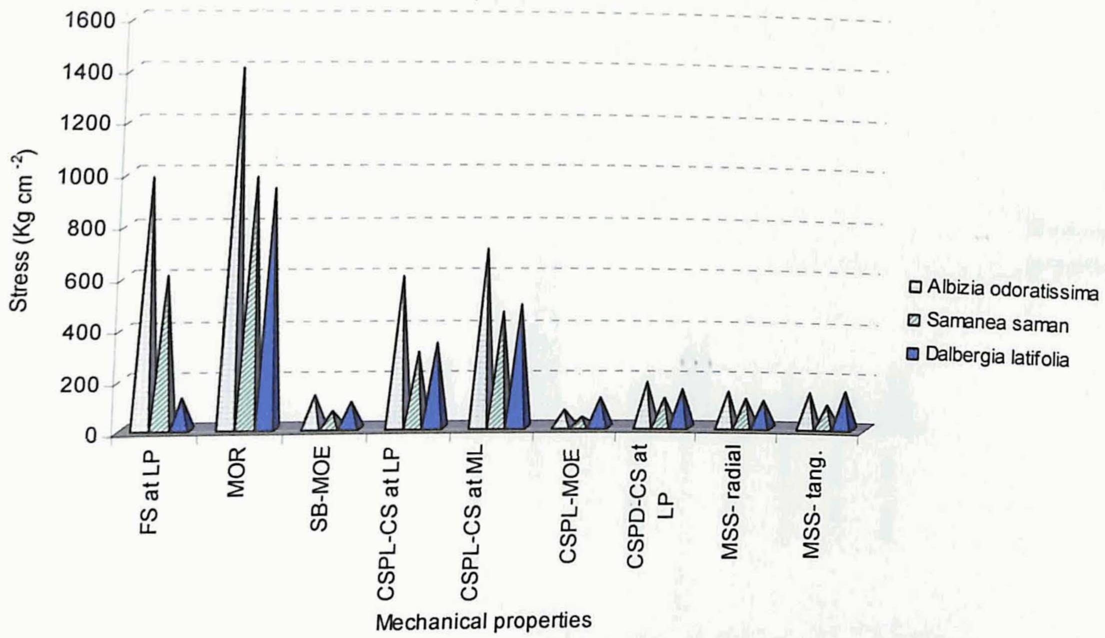


Fig. 14. Mechanical properties of the heartwood of *A. odoratissima, S. saman* and *D. latifolia*

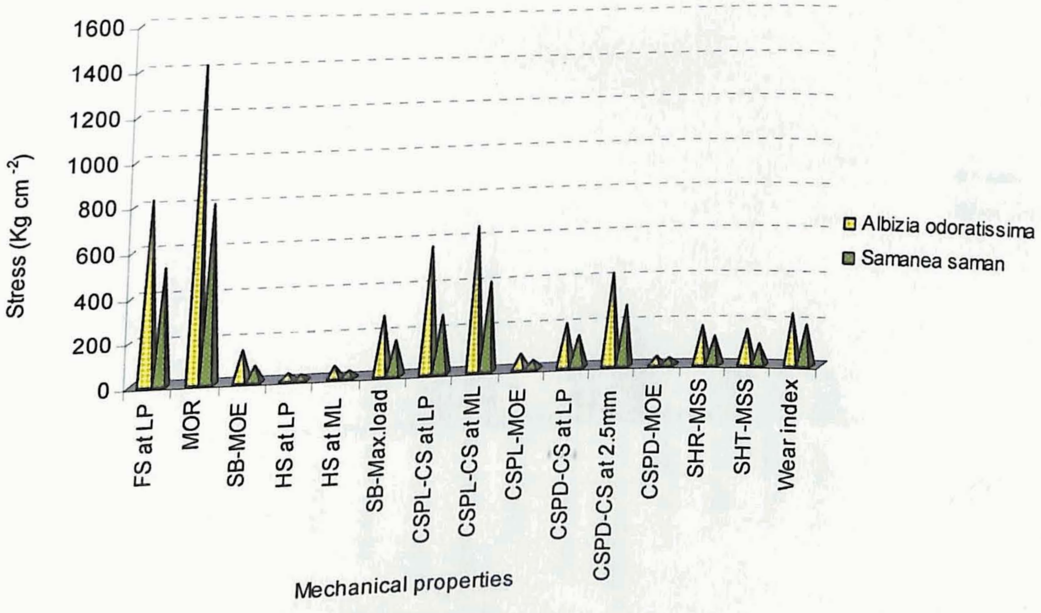


Fig.15. Mechanical properties of the sapwood of *A. odoratissima* and *S. saman*

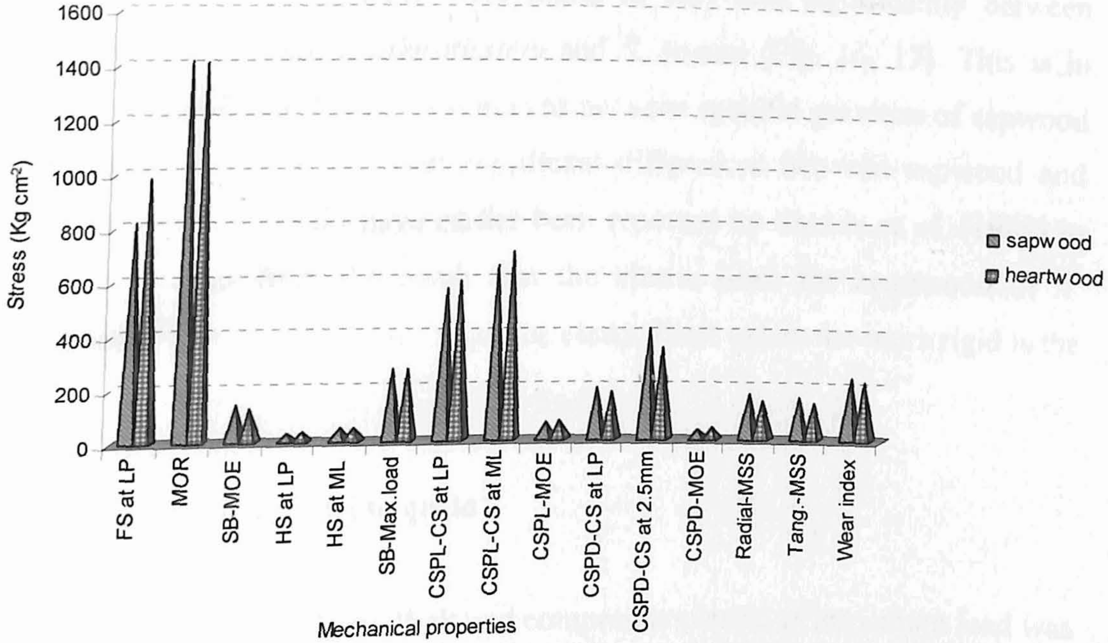


Fig. 16. Mechanical properties of the sapwood and heartwood of *A. odoratissima*

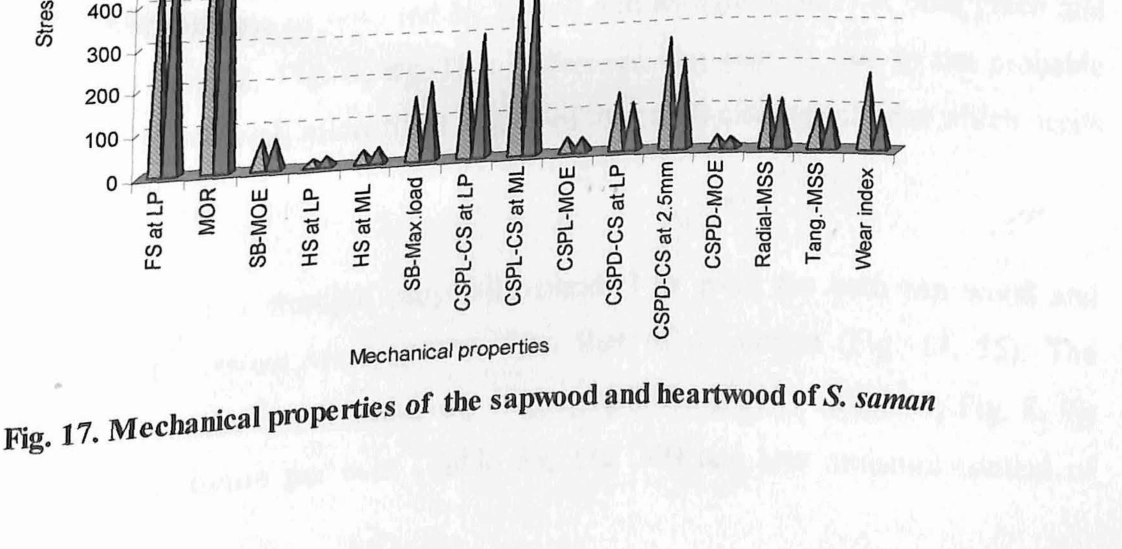


Fig. 17. Mechanical properties of the sapwood and heartwood of *S. saman*

All the static bending properties were found to vary non significantly between sapwood and heartwood in both *A. odoratissima* and *S. saman* (Fig. 16, 17). This is in accordance with non significant difference observed between specific gravities of sapwood and heartwood (Table 5; Fig. 8, 9). Non significant differences between sapwood and heartwood static bending properties have earlier been reported by Shukla *et al.* (1988) in *Eucalyptus*. It was evident from the result that the elastic limit for heartwood of *A. odoratissima* is greater than its sapwood. Larger the elastic limit value, the more rigid is the material (Canell and Morgan, 1987).

5.2.2 Compression strength parallel to grain

The compressive stress at elastic limit and compressive stress at maximum load was observed to be highest (Table 9; Fig. 14) for heartwood of *A. odoratissima*. The observed values of compressive stress at elastic limit and at maximum load for heartwood of *A. odoratissima* were much higher than those reported by Sekhar (1988) for wood samples from Coimbatore. On the other hand the MOE reported by Sekhar (1988) was much higher over the corresponding values observed under present study. The higher compressive stress at elastic limit and compressive stress at maximum load can be attributed to wood variation due to locality differences. Khanduri *et al.* (2000) reported higher compressive strength values for *Grevillea robusta* of Uttar Pradesh as compared to wood samples from Karnataka. The lower MOE values observed can be due to comparatively higher moisture content of the test specimens as reported by Canell and Morgan (1987) at both green and air dry conditions (Table 2; Fig. 5, 6). This difference can also be due to the probable presence of steeper S_2 cell wall microfibril angles of the small clear specimens which needs to be looked into.

All the compression strength properties parallel to grain for both sap wood and heartwood of *A. odoratissima* were greater than that of *S. saman* (Fig. 14, 15). The probable cause of it can be a comparatively higher specific gravity (Table 5; Fig. 8, 9), higher cellulose, lower lignin per cent (Table 35; Fig. 32) and low moisture content of heartwood (Table 2; Fig. 16). Where as the higher values observed for sapwood may be due to lower ray height of sap wood ray elements (Table 29; Fig. 19). Similar correlation for compression strength parallel to grain and height of rays has been reported by Oh (1997) in *Pinus densiflora*. In both the species investigated under present study, non significant difference was observed between sapwood and heartwood for all the parameters of compression strength parallel to grain except for compressive stress at maximum load in *A. odoratissima*. The non significant difference between tissue types is an expression of non significant difference between specific gravities, ray height of sapwood and heartwood in *A. odoratissima*.

5.2.3 Compression strength perpendicular to grain

Compressive stress at elastic limit for heartwood of *A. odoratissima* was significantly higher than that for *S. saman* (Table 9; Fig. 14) but differed slightly with *Dalbergia latifolia*. Sekhar (1988) had earlier reported considerably lower compressive stress values at elastic limit for heartwood of *A. odoratissima*. Locality affect explains this variation. For example, as per the reports of Khanduri *et al.* (2000), *Grevillea robusta* from Dehra Dun showed twice the compressive stress at elastic limit under green condition over the wood samples from Karnataka (48 kg cm $^{-2}$ and 23 kg cm^{-2} respectively). Also the influence of age on the physical and mechanical properties of timber has been reviewed by Cutter *et al.* (2004). Siagian *et al.* (1999) reported that increase in age increased the wood specific gravity from 0.47 to 0.56 in *Acacia mangium* which in turn improved the strength properties. Thus, wood maturity may be another probable reason for the higher compressive stress at elastic limit values observed for *A. odoratissima* under the present study.

All the compressive strength properties perpendicular to grain for both sapwood and heartwood of *A. odoratissima* were found to be significantly greater than that of *S. saman* (Fig. 14, 15) except for compressive stress at elastic limit and modulus of elasticity of sapwood where the differences were non significant (Table 18, 20). It was also observed that irrespective of species the sapwood strength properties were higher than that of heartwood (Fig. 16, 17) but the differences were non significant. These non significant differences between species and tissue types are probably due to non significant difference in specific gravities among species at air dried condition (Table 2). An increased specific gravity (air dry) of sapwood and heartwood of *A. odoratissima* (Table 2; Fig. 7) had probably resulted in increased compression strength properties perpendicular to grain. Species with higher density have less porosity and thicker cell walls, which makes the cells much more resistant to collapse (Schniewind, 1989).

5.2.4 Shear strength (radial, tangential)

It was observed that the maximum shearing stress along radial and tangential direction was highest in *A. odoratissima* and significantly least in *S. saman* (Table 2; Fig. 14). Hernandez and Almieda (2003) observed that in three Amazonian tropical hardwood species, specific gravity positively affects the shear strength. The differences for maximum shearing stress between the species observed under present investigation can also be attributed to differences in the specific gravity (Table 2) between species.

All the properties of shear strength for both sapwood and heartwood were significantly greater for *A. odoratissima* as compared to *S. saman* (Fig. 14, 15). The greater specific gravity of sapwood and its non significant difference with heartwood (Table 5; Fig. 8, 9) resulted in slightly higher shear properties for sapwood which differed non significantly with heartwood (Fig. 16, 17).

5.2.5 Abrasion

The heartwood and sapwood of *A. odoratissima* exhibited high wear index (Table 23) which suggest that it is prone to abrasion and restricts its suitability for flooring and other similar uses, where it can exposed to wear. *S. saman* on the other hand exhibited higher resistance (Table 23) to wear abrasion. Higher quantity of gum deposits, higher lignin, cellulose and holocellulose (Table 35; Fig. 32) and low moisture content (Table 4; Fig. 6) might be the factors responsible for its higher resistance against abrasion. Sapwoods of both *A. odoratissima* and *S. saman* were found to be less resistant to abrasion as compared to heartwood. Sapwoods in general contain low extractives and lignin, which are found in higher amounts in heartwood. Lignin, extractives and gums have also adhesive tendency (Sjostrom, 1981). Thus, all these factors might have resulted in higher resistance of heartwoods against abrasive stresses compared to sapwoods.

5.3 ANATOMICAL PROPERTIES

5.3.1 Vessel size and arrangement

The vessel diameter observed in the sapwood and heartwood of *A. odoratissima* (Table 24, 25) was greater than that of both *D. latifolia* and *S. saman* (Fig. 18, 19). The observed vessel diameter and vessel frequency for *A. odoratissima* and *S. saman* were 203.76 µm to 291.50 µm, 1 to 5 vessels per sq. mm and 158.19 µm to 268.63 µm, 1 to 3 vessels per sq. mm, respectively. Anoop *et al.* (2005) also reported similar values of vessel diameter and vessel frequency for *A. odoratissima* and *S. saman* which were 210 µm to 300 µm, 2 to 3 vessels per sq. mm and 170 µm to 280 µm, 1 to 4 vessels per sq. mm, respectively. The range of vessel frequency observed under present study was included in the range reported by Pearson and Brown (1981). Since all the three species are found in deciduous to semi evergreen forests, they show diffuse porous vessel arrangement. The diffuse porous nature of *A. odoratissima* and *S. saman* is also reported by Anoop *et al.* (2005).

The sapwood of both *A. odoratissima* and *S. saman* possessed wider vessels and low vessel frequency as compared to their heartwoods (Fig. 20, 21). The sapwood is physiologically active tissue of wood and is responsible for translocation of sap. Thus, they show relatively diametrically larger vessels and subsequently lower vessel frequency. The observed trend of increase in vessel diameter (Fig. 22, 23) and decrease in vessel frequency (Fig. 24) transcending from inner to outer portion of heartwood has also been reported

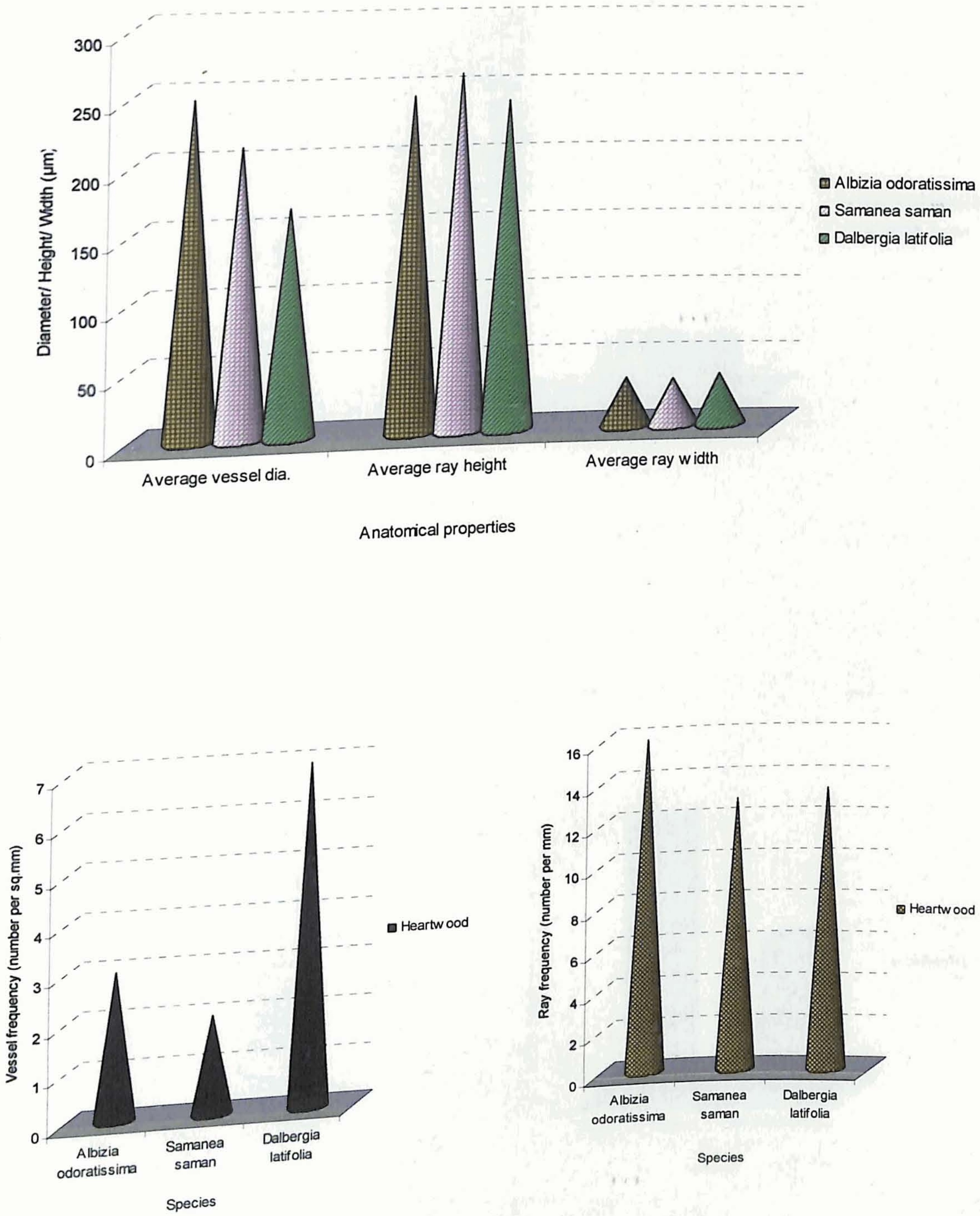


Fig. 18 Anatomical properties of the heartwoods of *A. odoratissima*, *S. saman* and *D. latifolia*

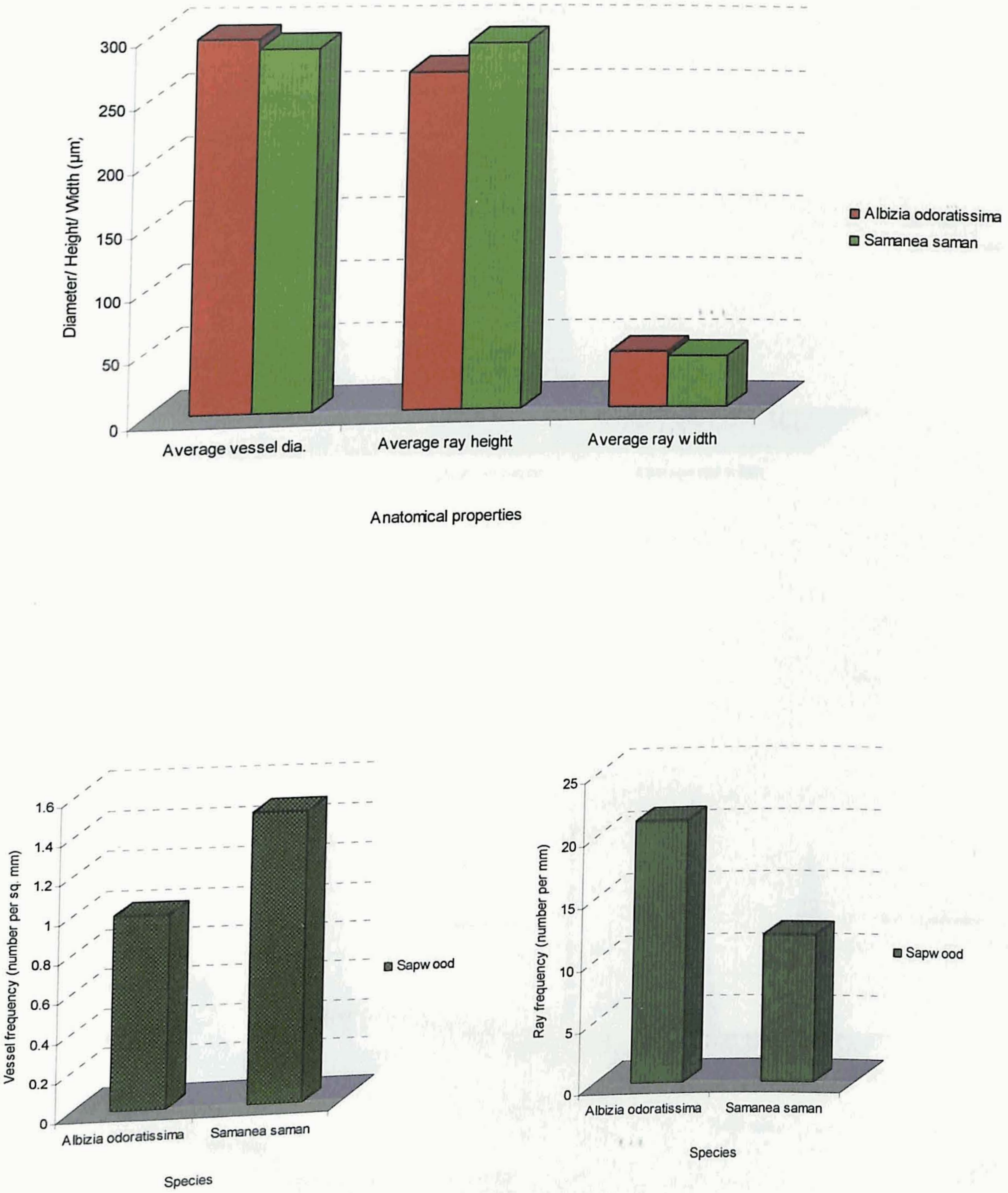


Fig. 19 Anatomical properties of the sapwood of *A. odoratissima* and *S. saman*

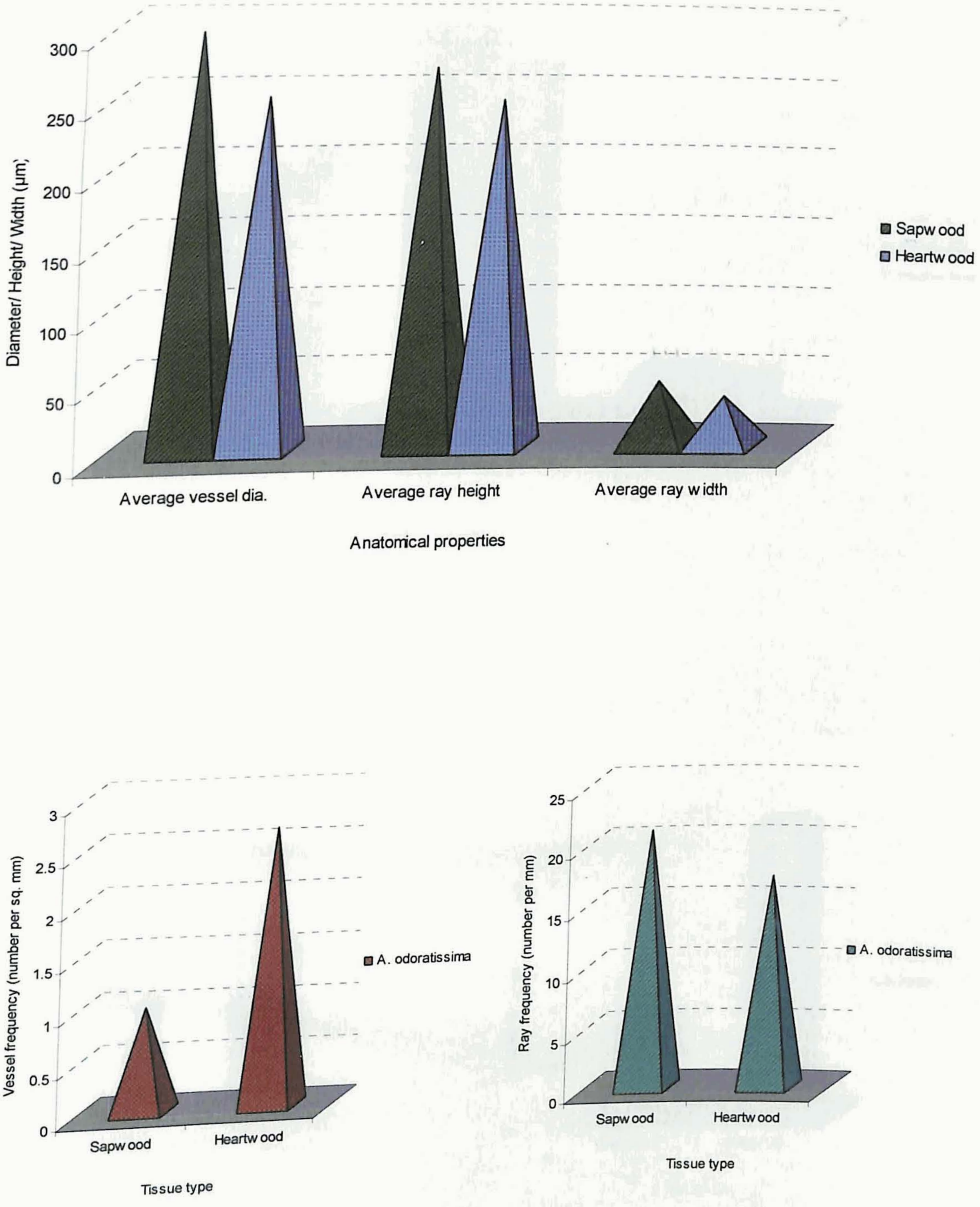


Fig. 20 Anatomical properties of sapwood and heartwood of *A. odoratissima*

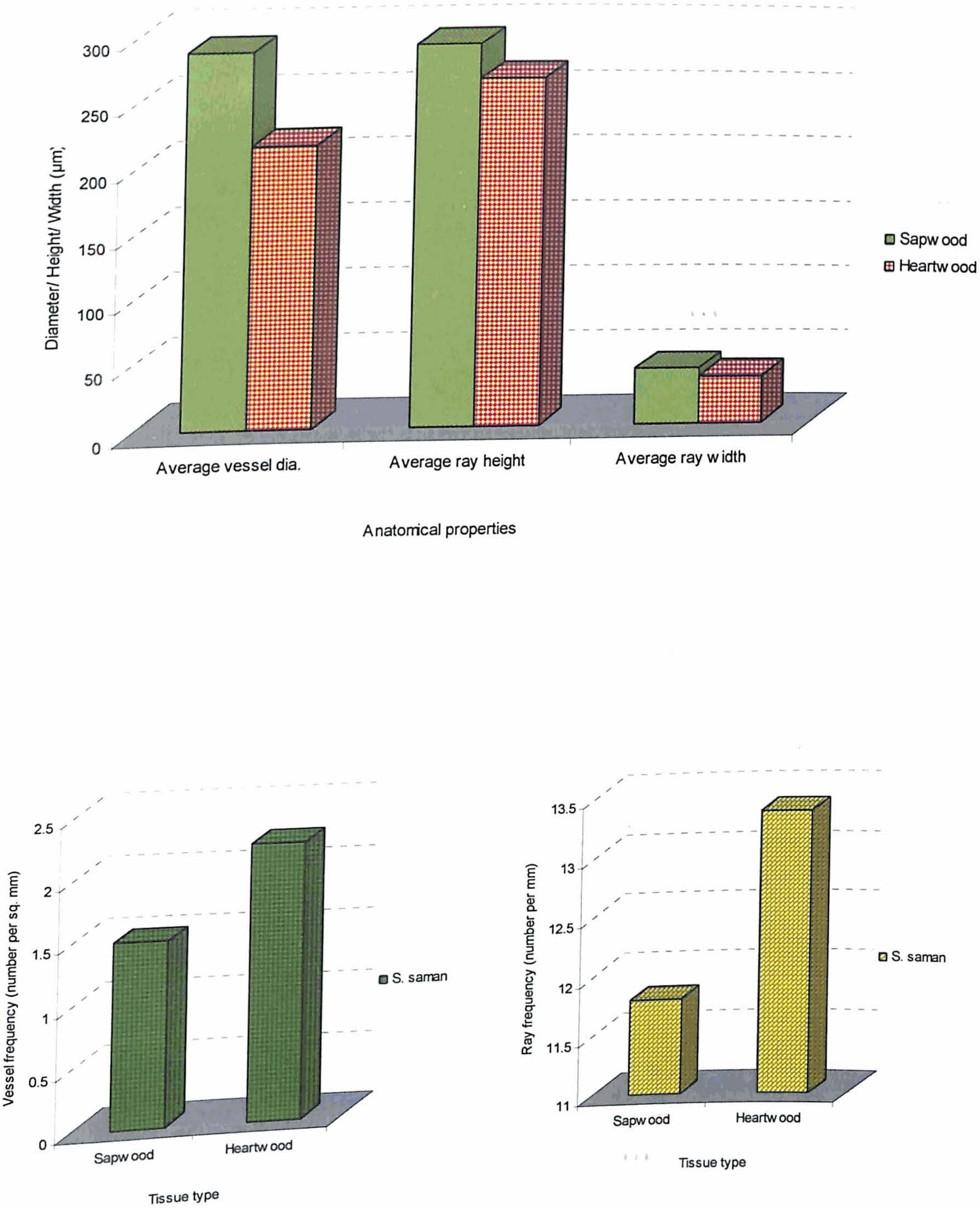


Fig. 21 Anatomical properties of sapwood and heartwood of *S. saman*

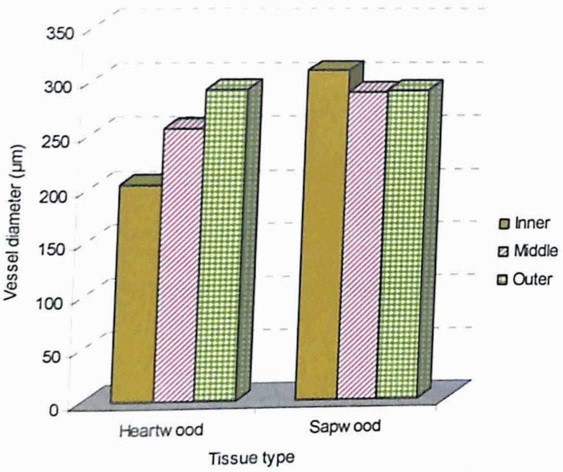


Fig. 22 Variation of vessel diameter at different positions along radial axis in the tissue types of *Albizia odoratissima*

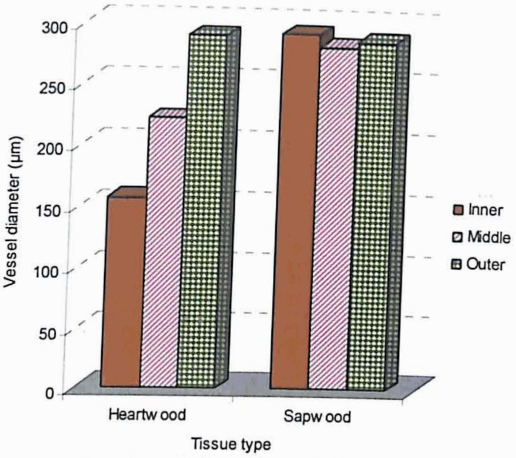


Fig. 23 Variation of vessel diameter at different positions along radial axis in the tissue types of *Samanea saman*

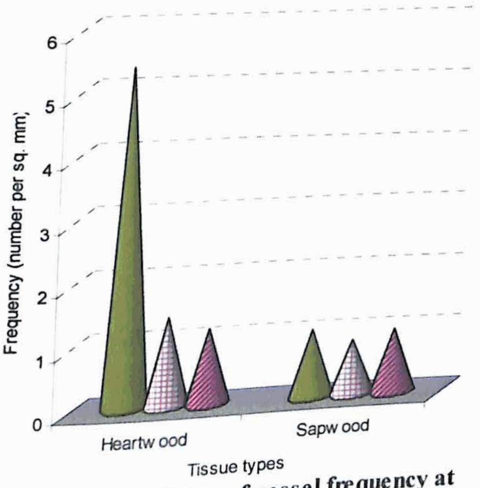


Fig. 24 Variation of vessel frequency at different positions along radial axis for tissue types of *Albizia odoratissima*

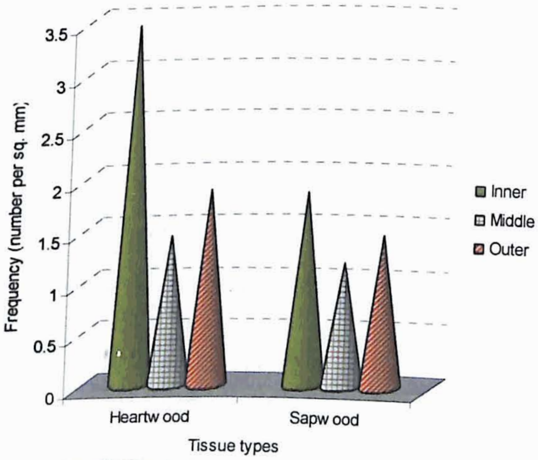


Fig. 25 Variation of vessel frequency at different positions along the radial axis in tissue type of *Samanea saman*

earlier. Helinska and Fabisiak (1999) reported a similar increase in vessel lumen diameter and decrease in vessel frequency up to 30th annual ring in *Fraxinus excelsor*. They explained this variation based on the presence of juvenile wood. Florsheim *et al.* (1999) reported that in *Myracrodruon urundeuva*, the vessel frequency decreased towards bark where as, the vessel diameter increased.

5.3.2 Parenchyma arrangement

A. odoratissima exhibited aliform, aliform confluent or banded type (Plate 16) of paratracheal parenchyma. *S. saman* in addition to aliform or aliform confluent also showed vasicentric parenchyma (Plate 17). Similar observations are also reported by Anoop *et al.* (2005) for both *A. odoratissima* and *S. saman* from the wood samples collected from Kerala.

5.3.3 Ray size and number

Ray height and ray frequency for both *A. odoratissima* and *S. saman* were closer to that of *D. latifolia* (Table 24; Fig. 18). But the range for ray width as observed for *A. odoratissima* and *S. saman* were included in the range specified for *Dalbergia latifolia*. The ray height and width reported by Pearson and Brown (1981) for *A. odoratissima* falls within the range observed under present investigation. The observed ray height and ray frequency for *A. odoratissima* and *S. saman* were 188.24 µm to 305.74 µm, 13 to 19 rays per mm and 201.23 µm to 324.49 µm, 9 to 17 rays per mm, respectively. Anoop *et al.* (2005) also reported closer ray height and ray frequency for *A. odoratissima* and *S. saman* which were 160 to 450 µm, 5 to 9 rays per mm and 170 to 370 µm, 4 to 8 rays per mm, respectively. Earlier workers have also reported variation in ray dimensions and number among species. de-la-P-Perez-Olvera and Quintanar-Isaías (1999) revealed the diversity of 3 species of genus *Quercus* growing in Mexico by locating the outstanding differences in width and number of ray series. Average ray height for sapwood and heartwood of *S. saman* was greater than that of *A. odoratissima* (Fig. 18, 19). Contrarily, ray width and ray

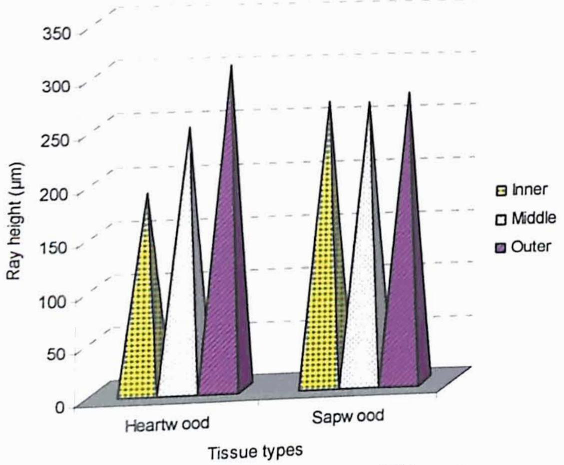


Fig. 26 Variation of ray height at different position along radial axis for tissue types of *Albizia odoratissima*

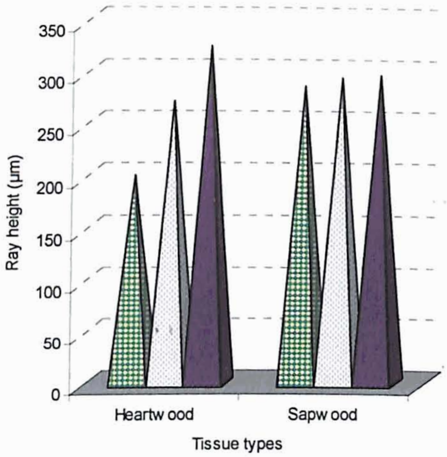


Fig. 27 Variation of ray height at different positions along radial axis for tissue types of *Samanea saman*

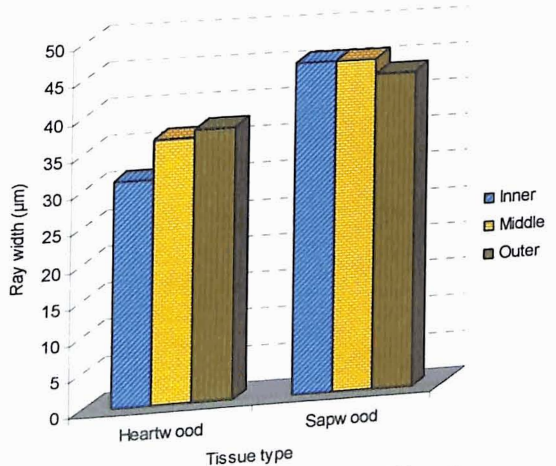


Fig. 28 Variation of ray width at different positions along radial axis for tissue types of *Albizia odoratissima*

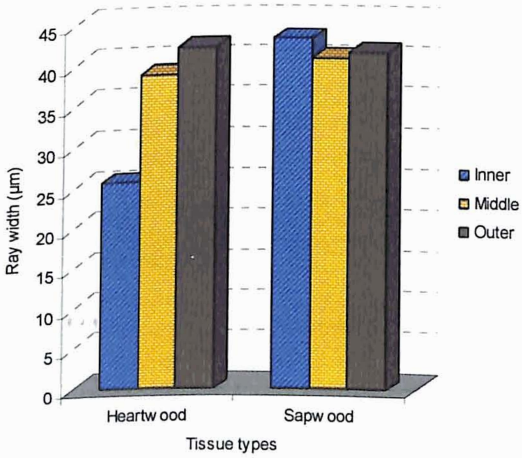


Fig. 29 Variation of ray width at different positions along radial axis in tissue types of *Samanea saman*

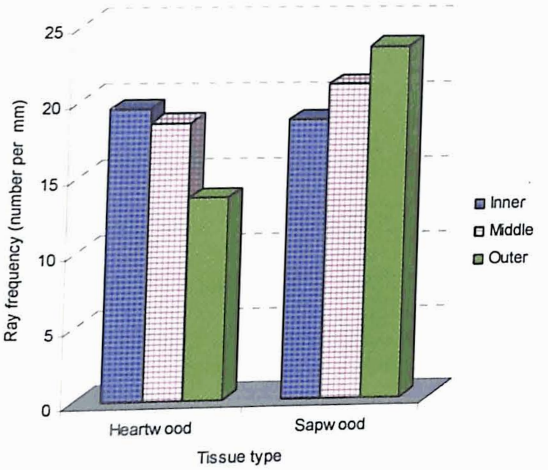


Fig. 30 Variation of ray frequency at different positions along radial axis for tissue types of *Albizia odoratissima*

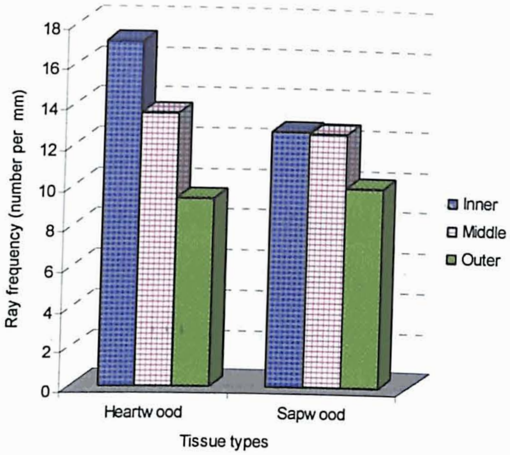


Fig. 31 Variation of ray frequency at different positions along radial axis for tissue types of *Samanea saman*

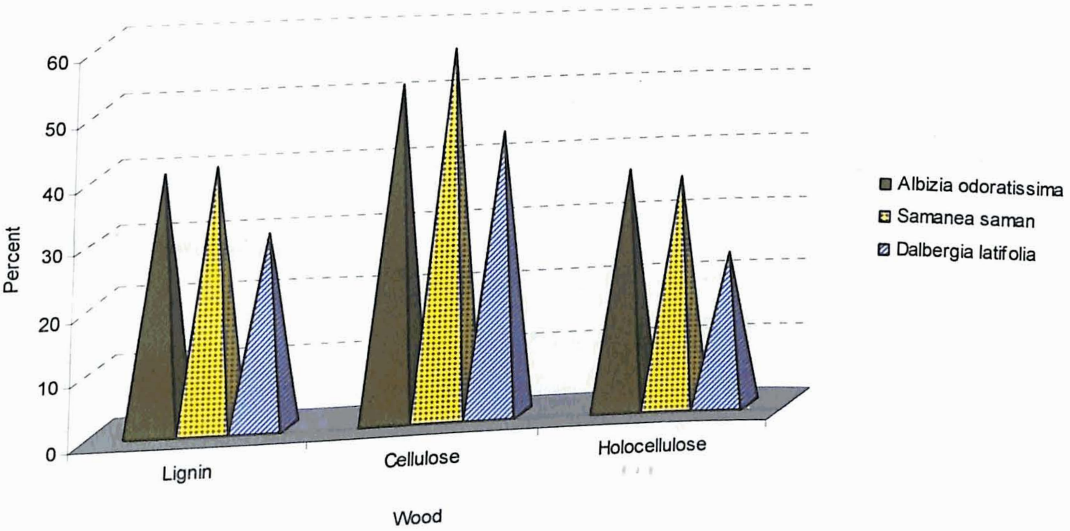


Fig. 32 Lignin, cellulose and holocellulose content of heartwood of *A. odoratissima*, *S. saman* and *D. latifolia*

frequency (Fig. 18, 19) were significantly lower in *Samanea saman*. Transcending from inner heartwood to outer region ray height increased whereas, the ray frequency decreased irrespective of the species. Lev (1998) also observed similar trend of increase in ray height and decrease in ray number from pith to outer ring for *Pinus* species. Florsheim *et al.* (1999) had also reported that in *Myracrodruon urundeuva*, the frequency of rays was lowest in bark region and ray height and width was highest in that region. Thus, from these findings, it is evident that an increase in ray dimensions and decrease in ray number had resulted in greater average ray height and width of sapwood over heartwood (Table 29, 31).

5.3.4 Special characters

Reddish brown deposits of gum in the vessels of *A. odoratissima* and *S. saman* (Plate 18) as observed under the present investigation has also been reported by Pearson and Brown (1981) and Anoop *et al.* (2005). *D. latifolia* also showed similar reddish brown gum deposits and also brownish black gum deposits at some times. Presence of silica is also reported in *D. latifolia* (Quirk, 1983).

5.4 BIOCHEMICAL PROPERTIES

Lignin, cellulose and holocellulose content in the heartwood of *A. odoratissima* and *S. saman* were significantly greater than that of *D. latifolia* (Table 35; Fig. 32). It is reported that tropical hardwoods contain higher lignin. Rowell (1984) had observed comparatively higher lignin values in some species. He reported that in tropical hardwoods namely *Albizia* spp the lignin percent can go up to 33 per cent. The holocellulose and cellulose content can reach up to 79 per cent and 43 per cent, respectively. The observed values of lignin (40.85 %), holocellulose (57.34 %) and cellulose (36.12 %) in the heartwood of *S. saman* were greater than the reported values from Phillipines, which were 30 per cent, 75 per cent and 38 per cent, respectively (Reyes, 1938). Juvenile woods have higher lignin percent than the mature woods (Timell, 1989). As the trees selected under present investigation were comparatively younger, the presence of juvenile wood might have resulted in higher lignin content of the wood samples

With regard to colouring matter, the spectral analysis of ethanol and acetone extract of *D. latifolia* exhibited specific peaks not observed in other two species (Table 36). These peaks were 403 nm, 484 nm, 493 nm, 505 nm, 541 nm, 643 nm, 649 nm, 655 nm, 674 nm, 679 nm. Literatures on visible and UV spectroscopy indicate that the pigment responsible for imparting red colour exhibit peak wavelengths between 620 nm to 780 nm and 2, 4-dinitrophenylhydrazone derivatives of aldehydes and ketones exhibit a colour from bright yellow to deep red, which depends upon the double bond conjugation. It was observed that the pigments in *D. latifolia* exhibited peak absorbance at 643 nm, 649 nm, 655 nm, 674 nm and 679 nm, which fall under the above category and may be thought to impart red colour to the wood. More detailed investigations are required to identify the exact factor responsible for imparting the specific wood colour in the species investigated.

The three species can be differentiated by observing the specific peaks recorded from the spectrometric analysis of their heartwood tissues. From the present study, it was observed that *D. latifolia* possess more components as compared to *A. odoratissima* and *S. saman*. Components responsible for imparting colour are formed from the biochemical changes of polysaccharides. The observed low polysaccharide for the heartwood of *D. latifolia* and high polysaccharide for *A. odoratissima* and *S. saman* are endorsing the same that the wood of *D. latifolia* has more number of phenolic components. Based on the observation of colour and biochemical analysis, it can be very well presumed that the phenolic content of *D. latifolia* might have contributed for it's better wood quality.

It can also be seen from the present study that lower number of phenolic compounds as seen in the case of *A. odoratissima* and *S. saman*, might have resulted in higher moisture content in these woods. *D. latifolia* with more phenolic compounds has low moisture content. It was observed that two peaks (418 nm and 427 nm) which are common in *A. odoratissima* and *D. latifolia* might also be responsible for higher specific gravity exhibited by these species. At the same time lignin and polysaccaharide content was higher in *A. odoratissima* while it was lower in *D. latifolia*. These two components can also be the precursors of the phenolic compounds which may impart blackish colour and dark shade to their heartwoods by enzyme action.

Similarly, *D. latifolia* and *S. saman* showed 7 peaks (415 nm, 475 nm, 511 nm, 586 nm, 597 nm, 604 nm, 658 nm) which were not observed in *A. odoratissim*. The compounds which are responsible for these peaks are also possibly responsible for few of the common properties exhibited by these two species. Compounds which exhibited absorbance peaks (415 nm, 475 nm, 511 nm, 586 nm, 597 nm, 604 nm, 658 nm) might have influenced the calorific value and shrinkage of the woods of these two species in positive and negative way, respectively. It can very well be presumed that the presence of phenolic compounds of the above seven peaks of *D. latifolia* and *S. saman* contributed to the lower shrinkage properties. However, these observations can only be confirmed by extensive research in these aspects by studying the effect of phenolic components on the wood properties so that the colour analysis can be an index to decide the quality of wood.

5.5 WOOD PROPERTY PROFILE

The wood property profile of the three timber species taken up for investigation is outlined in Table 37.

5.6 COMPARISON OF WOOD PROPERTIES OF *A. odoratissima, Samanea samanm* AND *D. latifolia* WITH *Tectona grandis.*

Sekhar (1988) has reported the various mechanical and physical properties desirable for various end uses of timber. The parameters to be evaluated for suitability as furniture material are shrinkage (radial, tangential and volumetric), MOR in static bending, compressive stress at elastic limit and maximum crushing stress during compression parallel to grain and cleavage strength. A general comparison of the observed wood

Table 37 Wood property profile of *A. odoratissima* Linn. f. Benth., *S. saman* Jacq. Merr. and *D. latifolia* Roxb.

S. No	Wood property (heartwood)	*Albizia odoratissima*	*Samanea saman*	*Dalbergia latifolia*
1	PHYSICAL			
	Calorific value (cal/g) [Table 2; Fig. 2]	3920.18	4981.08	5049
	Moisture content- Green (%) [Table 2; Fig. 4]	84.80	135.65	74.50
	Moisture content- Air dry (%) [Table 2; Fig. 4]	13.43	13.47	12.00
	Specific gravity- Basic [Table 2; Fig. 7]	0.65	0.48	0.75
	Specific gravity- Air dry [Table 2; Fig. 7]	0.69	0.50	0.68
	Radial shrinkage- Green-OD (%) [Table 2; Fig. 10]	3.63	2.53	2.3
	Tangential shrinkage- Green-OD (%) [Table 2; Fig. 10]	6.81	4.11	5.6
	Volumetric shrinkage- Green-OD (%) [Table 2; Fig. 10]	14.12	6.95	8.5
2	MECHANICAL			
	Static bending- FS at LP (kg cm^{-2}) [Table 9; Fig. 14]	982.69	604.32	127.00
	Static bending- MOR (kg cm^{-2}) [Table 9; Fig. 14]	1406.58	983.34	943.00
	Static bending- MOE (1000kg cm^{-2}) [Table 9; Fig. 14]	131.36	69.01	101.70
	Compression strength parallel to grain- CS at LP (kg cm^{-2}) [Table 9; Fig. 14]	598.60	299.02	338.00
	Compression strength parallel to grain- CS at ML (kg cm^{-2}) [Table 9; Fig. 14]	704.88	458.67	486.00
	Compression strength parallel to grain- MOE (1000kg cm^{-2}) [Table 9; Fig. 14]	69.21	36.92	115.40
	Compression strength perpendicular to grain- CS at LP (kg cm^{-2}) [Table 9; Fig. 14]	180.39	116.69	153.00
	Maximum radial shearing stress (kg cm^{-2}) [Fig. 14]	149.10	118.13	107.90
	Maximum tangential shearing stress (kg cm^{-2})	142.94	92.92	156.10
3	ANATOMICAL			
	Vessel diameter (µm) [Fig. 18]	208-292	158-269	125-210
	Vessel frequency (no. of vessels/mm^2) [Fig. 18]	1-5	1-3	2-12
	Vessel arrangement	Diffuse porous	Diffuse porous	Diffuse porous/ semi ring porous
	Parenchyma arrangement (Plate 16, 17)	Aliform, aliform confluent, banded	Vasicentric, aliform, aliform confluent	Vasicentric, aliform, aliform confluent
	Ray height (µm) [Fig. 18]	188-306	201-324	170-315
	Ray width (µm) [Fig. 18]	31-37	26-42	30-45
	Ray frequency (rays/mm) [Fig. 18]	13-19	9-17	11-16
	Special features	Reddish brown gum deposits	Reddish brown gum deposits	Reddish brown gum deposits
4	BIOCHEMICAL			
	Lignin in wood (%) [Table 35; Fig. 32]	40.04	40.85	30.18
	Cellulose in wood (%) [Table 35; Fig. 32]	37.54	36.12	24.14
	Holocellulose in wood (%) [Table 35; Fig. 32]	52.27	57.34	44.33
	Cellulose in holocellulose (%) [Table 35; Fig. 32]	71.78	62.83	54.43

properties of *A. odoratissima* and *S. saman* with *D. latifolia* and teak (Table 38) is attempted to check their suitability for furniture engineering. In general, the values of the wood properties recommended for furniture construction are observed to be quite favorable for *A. odoratissima.* Thus, based on observed strength properties, *A. odoratissima* can be recommended for furniture making but its high tendency for shrinkages can lead to wood defects in long term use. However, it shows weak MOE in compression parallel to grain direction which renders it unsuitable for uses as columns, props and chair legs. All the other wood properties are fairly closer to teak. Thus it may also be suitable for tool handles, doors, window shutters and frames and packing cases. *Samanea saman*, on the other hand, has comparatively weaker mechanical properties in comparison to Ceylon rosewood and teak. Like in the case of *A. odoratissima,* it has low MOE values for stress acting along grain, which restricts its usage as chair legs. The other properties appears favorable for various low value end uses like, manufacture of agricultural implements, boxes, packing cases, crates, carving and flooring.

The observations made in this investigation confirm the suitability of the timber of *A. odoratissima* as a competent furniture raw material. By virtue of its reduced or limited wood properties, the timber of *S. saman* can only be used for making low value products as described earlier. However, the apparent similarity in the wood colour of both these woods to *D. latifolia* along with some favorable mechanical properties, and more importantly, their ready availability in the local wood market confirm their potential as an adulterant/ substitute of *D. latifolia* wood *vis a vis* furniture industry. However, a reliable recommendation of the final end uses of these two woods or any other species can only be made after working out their comparative suitability indices. As the colour of woods of these three species is confusing for a common man, it some times becomes difficult for an common man to differentiate these woods at market level. However, from the present study it can be suggested that these woods can be differentiate by analyzing the different woods properties. For authentic and quick identification of these three species, anatomical studies and biochemical components (wavelength absorbance peaks of the methanol-acetone

Table 38 Comparison of wood properties of *A. odoratissima, S. saman, D. latifolia* with teak

S. No.	Wood properties	*Albizia odoratissima*	*Samanea saman*	*Dalbergia latifolia*	* *Tectona grandis* from Malabar, Nilambur and Coimbatore
1	Specific gravity (air dry)	0.690	0.495	0.680	0.604
2	Moisture content (%)	84.8	135.6	74.5	76.6
3	Radial shrinkage (%) (green to oven dry)	3.63	2.53	2.30	2.30
4	Tangential shrinkage (%) (green to oven dry)	6.81	4.11	5.60	4.80
5	Volumetric shrinkage (%) (green to oven dry)	14.12	6.95	8.50	6.90
6	Static bending				
	a) Fibre stress at limit of proportionality (kg cm^{-2})	982.69	604.32	127.00	651.00
	b) Modulus of rupture (kg cm^{-2})	1406.58	983.34	943.00	959.00
	c) Modulus of elasticity (kg cm^{-2})	131.36	69.01	101.00	119.00
7	Compression parallel to grain				
	a) Compressive stress at limit of proportionality (kg cm^{-2})	598.60	299.02	338.00	376.00
	b) Maximum crushing stress (kg cm^{-2})	704.88	458.67	486.00	532.00
	c) Modulus of elasticity (kg cm^{-2})	69.21	36.92	115.40	137.00
8	Compression perpendicular to grain				
	a) Compressive stress at limit of proportionality (kg cm^{-2})	180.39	116.89	153.00	101.00

Sekhar (1988)

extracts of wood powder, which shows species specific peaks) form the foremost marks of genuine identity of the species.

Summary

SUMMARY

Indian rosewood (*D. latifolia)* from time immemorial had ranked among the finest wood for furniture and other structural purposes. Laymen readily identify rosewood timber by the beautiful dark red colour of its heartwood. However, a few other lesser known wood species also possess similar wood colour. The apparent similarity in colour of different woods can create confusion about the identity of a particular species and can even facilitate to adulteration of processed wood products of one valuable species with other similar coloured lesser valued species.

Unconfirmed reports of adulteration of furniture made of Indian rosewood with its alleged substitutes viz., Ceylon rosewood (*A. odoratissima*) and raintree (*S. saman*) in the state of Kerala is a cause of serious concern in timber trade. In the awake of such an emerging problem, it was felt necessary to discern the various wood properties of all these three timber species, so as to highlight the characteristic wood properties of these species for easy differentiation. A study was carried out in College of Forestry, Vellanikkara during 2003-2005 to profile the selected wood properties of all these three species. The results are summarized below:

1. The heartwood calorific value was highest for *D. latifolia*, followed by *S. saman* and *A. odoratissima*. Heartwood calorific value of *D. latifolia* as cited showed slight difference with *S. saman*. Contrarily both these species differed largely with *A. odoratissima*. Based on the calorific value, the species and their tissue types can be classified into following category:

i. High calorific value (> 4500 cal g^{-1}) : Sapwood and heartwood of *D. latifolia*,
: Heartwood of *S. saman*

ii. Medium calorific value (3750 – 4500 cal g^{-1}) : Sapwood, heartwood of *A. odoratissima*

iii. Low calorific value (<3750 cal g^{-1}) : Sapwood of *S. saman*

2. Moisture content at green and air dry condition were found to decrease as *S. saman* > *A. odoratissima* > *D. latifolia*. Differences between *A. odoratissima* and *D. latifolia* were relatively less. The heartwoods of *A. odoratissima* and *S. saman* possessed significantly greater moisture content than sapwoods at green condition. Where as, at air dry condition sapwoods of both these species possessed significantly higher moisture content than heartwoods.

3. Basic specific gravity differed among the three species. Specific gravity followed the order *D. latifolia* > *A. odoratissima* > *S. saman*. Air dry specific gravity differed to a smaller extent between *D. latifolia* and *A. odoratissima*. Contrarily both these species differed to a large extent with *S. saman*. The differences between specific gravities of sapwood and heartwood were non significant. The sapwood specific gravity though non significantly different with heartwood, was slightly greater than heartwood.

4. Radial shrinkage and volumetric shrinkage differed greatly among the species and followed the descending order *A. odoratissima* > *S. saman* > *D. latifolia* and *A. odoratissima* > *D. latifolia* > *S. saman* respectively. Radial and volumetric shrinkage did not differ significantly between tissue types for both *A. odoratissima* and *S. saman*.

5. Radial, tangential and volumetric shrinkages at all three condition i.e. from green to air dry, air dry to oven dry and green to oven dry for both sapwood and heartwood of *A. odoratissima* were significantly greater over the respective shrinkage value for *S. saman* .

6. Tangential shrinkage of *D. latifolia* was intermediate between *A. odoratissima* and *S. saman* and showed comparatively little difference with both these species. In both *A. odoratissima* and *S. saman*, tangential shrinkage of sapwood was significantly greater than that of heartwood. Irrespective of species and tissue type, tangential shrinkage was greater than radial shrinkage

7. Fiber stress at limit of proportionality and modulus of elasticity in static bending test differed extremely among the three species and followed the sequence *A. odoratissima* > *S. saman* > *D. latifolia* and *A. odoratissima* > *D. latifolia* > *S. saman* respectively. Modulus of rupture also decreased with *A. odoratissima* > *S. saman* > *D. latifolia* but the differences between *S. saman* and *D. latifolia* were relatively less.

8. Compressive stress at limit of proportionality and at maximum load in compression parallel to grain showed similar trend of decrease from *A. odoratissima* > *D. latifolia* > *S. saman* . These two properties varied slightly between *D. latifolia* and *S. saman*. On contrary, modulus of rupture in compression parallel to grain differed largely among the three species and was found to decrease as *D. latifolia* > *A. odoratissima* > *S. saman* .

9. The maximum shearing stress in shear along radial plane for heartwoods of *D. latifolia* and *S. saman* showed little differences among them and followed to decrease as *A. odoratissima* > *S. saman* > *D. latifolia* .

10. The maximum shearing stress for heartwoods in shear along tangential plane was found to decrease in the order *D. latifolia* > *A. odoratissima* > *S. saman*. *D. latifolia* and *A. odoratissima* showed comparatively little differences with reference to maximum shearing stress (tangential). Contrarily, both *D. latifolia* and *A. odoratissima* differed greatly with *S. saman*.

11. All the mechanical properties of both sapwood and heartwood of *A. odoratissima* were significantly greater over the corresponding properties of sapwood and heartwood tissues of *S. saman*.

12. All the mechanical properties did not differ significantly between tissue types for both *A. odoratissima* and *S. saman* except for fiber stress at limit of proportionality,

horizontal stress at limit of proportionality and shear strength properties along radial direction in *A. odoratissima.*

13. Wear index for both sapwood and heartwood of *A. odoratissima* is greater than that of *S. saman*, which indicates that *A. odoratissima* is more prone to wear and abrasion.

14. The vessel diameter of *A. odoratissima, S. saman* , *D. latifolia* were found to range from 203.76 µm – 291.50 µm, 158.19 µm – 268.63 µm and 125 µm – 210 µm, respectively. Average vessel diameter of sapwood was found to be significantly greater than that of its heartwood in both *A. odoratissima* and *S. saman.* Transcending from pith to periphery the vessel diameter in the heartwood was found to increase with inner < middle < outer regions. However in sapwood, the vessel diameter showed non significant differences between inner, middle and outer regions.

15. The vessel frequency among the heartwood of the three species were closer and were found to be 1-5 vessels per sq. mm, 1-3 vessels per sq. mm and 2-12 vessels per sq. mm, respectively. The vessel frequency of heartwoods was significantly greater than that of sapwoods in both *A. odoratissima* and *S. saman.* Along the radial direction in the heartwood the vessel frequency was found to decrease along inner > middle > outer regions. However, among the different regions of sapwood, the vessel frequency varied non significantly and showed no definite trend.

16. All the three species possessed diffuse porous type of vessel arrangement.

17. The parenchyma arrangement in *A. odoratissima* is aliform, aliform confluent or banded. In *D. latifolia* and *S. saman,* paratracheal parenchyma shows vasicentric, alifom or aliform confluent distribution.

18. Ray height of *A. odoratissima, S. saman* and *D. latifolia* were found to vary from 188.24 µm – 305.74 µm, 201.23 µm – 324.49 µm and 170 µm – 315 µm respectively.

Ray height of sapwood was found to be greater than heartwood, but the differences between tissue types in *A. odoratissima* were non significant. Ray height at different regions of heartwood differed significantly and showed an increasing trend from pith to periphery i.e. inner < middle < outer. Where as, ray height showed non significant differences among different regions of sapwood.

19. Ray width of *A. odoratissima, S. saman* and *D. latifolia* were found to range from 31.11 µm – 37.49 µm, 25.62 µm – 42.05 µm and 30 µm – 45 µm, respectively. Average ray width of sapwood was significantly greater than heartwood. No definite trend was observed in the sapwood and heartwood ray width along radial direction except for heartwood of *S. saman* where the ray width increased from inner to outer regions of heartwood.

20. Ray frequency of *A. odoratissima, S. saman, D. latifolia* were found to range from 13 – 19 rays per mm, 9 - 17 rays per mm and 11 - 16 rays per mm, respectively. In *A. odoratissima*, the sapwood ray frequency was significantly greater than that of heartwood. Where as, in *S. saman* the ray frequency did not differ significantly between tissue types. No definite trend was observed with respect to ray frequency in both sapwood and heartwood except for heartwood of *S. saman*, where ray frequency decreased from inner > middle > outer regions.

21. All the three species showed reddish brown gum deposits in their vessels.

22. Lignin content of heartwood of *A. odoratissima* and *S. saman* showed no significant differences and were significantly greater than the lignin content of *D. latifolia* i.e. the lignin content varied as *S. saman > A. odoratissima > D. latifolia* .

23. Holocellulose content of heartwood varied significantly among the three species and followed *S. saman > A. odoratissima > D. latifolia* .

24. Cellulose content of heartwoods heartwood of *A. odoratissima* and *S. saman* showed no significant differences and were significantly greater than the cellulose content of *D. latifolia* i.e. the celluose content varied as *S. saman* > *A. odoratissima* > *D. latifolia* .

25. The percentage of cellulose in the holocellulose varied significantly between species and was found to follow *A. odoratissima* > *S. saman* > *D. latifolia* .

26. *D. latifolia* showed slightly different peaks (403 nm, 484 nm, 493 nm, 505 nm, 541 nm, 643 nm, 649 nm, 655 nm, 674 nm, 679 nm) for the components which in turn were not observed in other two species. *A. odoratissima* showed three specific peaks (463 nm, 580 nm, 682 nm). S. saman showed eight specific peaks (439 nm, 442 nm, 457 nm, 469 nm, 502 nm, 595 nm, 601 nm, 688 nm).

27. Phenolic compounds might have negative influence on the wood moisture content and positive influence on specific gravity. Peaks wavelengths viz., 418 nm and 427 nm may be the precursors of phenolic compounds which may impart blackish colour and dark shade to the woods of *A. odoratissima* and *D. latifolia.*

28. Phenolic compounds of *D. latifolia* and *S. saman* showing the peaks 415 nm, 475 nm, 511 nm, 586 nm, 597 nm, 604 nm, 658 nm may influence calorific value and shrinkage positively and negatively, respectively. These observations can be confirmed by extensive research in these aspects by studying the effect of phenolic components on the wood properties so that the colour analysis can be an index to decide the quality of wood

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WOOD PROPERTY PROFILE OF ROSEWOOD (*Dalbergia latifolia* Roxb.), CEYLON ROSEWOOD *Albizia odoratissima* (Linn. f.) Benth.) AND RAINTREE (*Samanea saman* (Jacq.) Merr.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

In the state of Kerala, heartwoods of lesser known timber species viz., *Albizia odoratissima* (Ceylon rosewood) and *Samanea saman* (rain tree) are allegedly being used as "substitutes" and "adulterants" for making furniture of *Dalbergia. latifolia* (Indian rosewood) mainly due to their similar wood colour. As this spurious practice has serious implication in timber trade, a study was undertaken to profile the selected wood properties of all these three species to highlight their similarities and differences. The study involved analyzing selected physical, mechanical, anatomical and biochemical properties of *A. odoratissima* and *S. saman* and comparing it with the wood properties of *D. latifolia* as available from relevant literatures.

Variations of higher magnitude were noted between the three species for some wood properties, and with respect to few other properties, the differences were lesser. Significant variations were also observed between tissue types viz., sapwood and heartwood for some wood properties.

Heartwood tissue types of *S. saman* and *D. latifolia* displayed high calorific value, where as, for *A. odoratissima* both tissue types (sapwood and heartwood) exhibited medium calorific value. The physical properties of the heartwood of *A. odoratissima* were observed to be higher than that of *D. latifolia. S. saman* possessed lower values for the physical properties as compared to *D. latifolia.* Basic specific gravity, radial and volumetric shrinkages (green to oven dry) were considerably different for all the three species. Generally, for both Ceylon rosewood and rain tree tangential shrinkage was higher than radial shrinkage for both the tissue types.

Mechanical properties of *A. odoratissima* were superior to *D. latifolia* and *S. saman,* except modulus of elasticity in compression parallel to grain. On the other hand mechanical properties of *S. saman* were closer to *D. latifolia.* Measure of fibre stress at limit of proportionality and modulus of elasticity in static bending and modulus of

elasticity in compression parallel to grain are considerably different for the three species. In *A. odoratissima* and *S. saman,* the mechanical properties of sapwoods varied non significantly with the strength properties of heartwoods. *S. saman* exhibited superior strength properties for heartwood over its sapwood.

Vessel diameter, distribution of parenchyma and ray height can be used to differentiate the three species. In all the species, along the radial axis from pith towards periphery, the vessel diameter, ray height, ray width increased along the region of heart wood. Likewise, ray frequency, and vessel frequency decreased along radial axis in heartwood region. Average vessel diameter, ray height and ray width of sapwoods were greater than that of the heartwoods.

Lignin, cellulose and holocellulose percent of *A. odoratissima* and *S. saman were* significantly greater than *D. latifolia.* Higher lignin, cellulose and holocellulose content are responsible for the higher strength properties of *A. odoratissima.* Methanol-acetone extracts of heartwood of *D. latifolia* exhibits specific peak wavelengths under spectrometric analysis, which are not found in the other two species. Phenolic compounds were observed to influence some of the physical properties.