CHAPTER-V

DISCUSSION
5. DISCUSSION

Teak, *Tectona grandis* Linn.f. belonging to family Lamiaceae, is one of the most important ring-porous hardwoods in tropical regions. India is considered to be the only known centre for genetic diversity and variability of teak, having its natural distribution zone confined predominantly to peninsular region below 24°N latitude (Tewari, 1992). It is well known for its strength, durability, and aesthetic qualities. The wood of old growth natural teak has been used primarily for yachts, decking, interior panelling and fine furniture (Ladrach, 2009). Most of these qualities are conferred to the teak wood by specific gravity and anatomical properties such as fibre, vessel element, axial parenchyma and ray parenchyma (Rahman et al., 2005). However, these wood properties could vary with locality factors. It is reported that locality factors contributed as much as 31.4 per cent, whereas seed origin contributed only 1.46 per cent for variability in teak growth (Purkayastha and Satyamurthi, 1975). Generally, variability within a single tree is more than among trees growing on the same site or between trees growing on different sites. The variation in wood properties may be due to environmental differences, genetic differences, and their interactions. (Zobel and Van Buijtenen, 1989; Zobel and Jett, 1995). Environmental influences are likely to lead variation not only in the quantity of wood produced, but also in its quality, in such respects as its density, strength and texture (Wilson and White, 1986). The external factors of climate and environment exert their influence directly on the crown and indirectly on the growth and wood quality. Generally, ring-width of teak is predominantly used to establish relationship between tree-growth and climate in India and abroad. But image analysis system technique provided a new approach to use anatomical structures of wood for dendroclimatic analysis. Among all anatomical features of teak only vessel parameters are used intensively for dendroclimatic analysis. However, very little information available on the other anatomical features like
ray parameters, fibre parameters and tissue proportions that how climatic variables like rainfall and temperature are correlated with these parameters and their relevance to specific gravity in teak from India. The dry deciduous forests of Chandrapur and moist deciduous forests of Thane are well known for natural-grown teak in Maharashtra of peninsular India. The present study was undertaken to study the radial variation of fibre parameters (fibre length, fibre diameter, fibre lumen diameter and fibre double wall thickness), ray parameters (ray width, ray height, and ray frequency) and tissue proportions (vessel, fibre, ray and axial parenchyma proportions) in relevance to specific gravity and how strongly these anatomical parameters and specific gravity are related to climatic variables viz. rainfall and temperature in teak from Chandrapur (dry site) and Thane (moist site) of Maharashtra. The influence of climate on anatomical properties and specific gravity would provide strong data base in assessing the wood quality and efficient utilization of timber. The results obtained during the course of present investigation entitled “Influence of climate on the radial variation of specific gravity and certain anatomical properties in teak (Tectona grandis Linn. f.) from Chandrapur and Thane, Maharashtra” have been discussed in this chapter.

5.1 GENERAL FEATURES AND GROSS ANATOMICAL STRUCTURE

Teak wood is characterized by distinct colour of heartwood from sapwood. Heartwood is generally golden brown or dark brown in colour occasionally with black streaks with an oily feel, lustrous, sometimes with white glistening deposit, distinct aromatic odour with the smell of leather; sapwood pale yellow or grayish white in colour. Wood is moderately hard; moderately heavy with an average specific gravity of 0.650 at 12 per cent moisture content; usually straight grained; medium and uneven textured (Rao and Juneja, 1971; Bhat et al. 2007). In the present study, heartwood of teak showed golden yellow to golden brown colour at moist site, while at dry site, it showed brownish red to
dark brown colour occasionally with dark streaks. The wood of both the sites was lustrous with chalky deposits, distinct aromatic odour with the smell of leather, moderately heavy with straight grain and medium coarse texture.

Bhat (1999) reported two broad colour groups according to contrasting geographic regions in Asia, the first is uniform golden yellow to brown typical of the tropical wet climates along the coasts, and the second is a darker colour commonly found in the tropical dry climates of central area. Bhat (2003) revealed that the dry locality teak wood displayed characteristic darker colour heartwood with decorative black streaks, probably due to slower growth and higher amount of extractives as related to the site or edaphic factors. A similar conclusion was also reported in the study of 7 to 15 years old teak from the north and northwest regions of Costa Rica by Moya and Alvarado (2012) that climatic variables play significant role in wood colour variation, where darker wood colour was associated with dry climates and also with deeper and fertile sites.

According to Cordero and Kanninen (2003), wet sites produce less heartwood proportion in teak trees than dry sites, even when comparing trees of similar age and size. In contrast, the present study showed more average heartwood proportion of trees at moist site than dry site. It may due to the reason that teak wood samples from moist site were much older and over mature than dry sites and generally, heartwood proportion in teak increases consistently with increasing age and with increasing diameter at breast height (Bhat and Indira, 1997; Cordero and Kanninen, 2003).

It was observed that the ring porosity was less in wider rings of trees at moist site than dry site with a little distinction between earlywood and latewood demarcation. This result is supported by report of Priya and Bhat (1999), where wood produced by nine 5-year-old trees of teak in irrigated condition showed difficulty in making demarcation between earlywood and latewood of successive growth rings in the first three years of
growth. It may be due to continuous availability of water which might have caused more or less uninterrupted cambial activity, with scarcely any dormant period and production of vessels of more or less uniform diameter through the year.

The mean value of ring-width in juvenile wood of trees did not show significant difference between two sites; however, it was significantly higher in mature wood of trees at dry site than moist site. However, the mean value of latewood proportion in both types of wood at dry site was significantly higher than moist. The wider rings had higher percentage of latewood than narrow rings. It is reported that teak trees from both the sites were slow-grown and wood samples of moist site were much older with more narrow rings than wood samples of dry sites. Generally, juvenile wood is characterized by wider rings with higher proportion of latewood than mature wood (Priya and Bhat, 1999). Bhat (1998) reported that the mean latewood content in 7, 13, 20, 40 and 147 years teak trees were 92, 90, 48, 44 and 70 per cent of the mean ring width, respectively. Recently, Sinha et al. (2014) studied the growth ring structure in juvenile and mature wood for five 120-to 150-year-old teak trees and found higher proportion of latewood in wider rings and least in narrow rings.

5.2 RADIAL VARIATION OF SPECIFIC GRAVITY

Wood specific gravity or density is a measure of amount of wood substance present in a given volume of wood (Zobel and van Buijtenen, 1989). It is the most important wood property for both yield and quality of fibre products, solid wood products and energy production. Specific gravity is widely studied in different species of both temperate and tropical regions because of its relation to strength, workability, pulpability, and ease of measurement. Higher the specific gravity, greater is the wood biomass production and higher is the efficiency of the species for carbon sink. Specific gravity varies between trees, within a tree and between species. It varies radially in a tree with
cambial age and distance from the pith (Wimmer et al., 2002). Its variation is related to
the growth ring structure in both juvenile and mature wood zone of a tree. Knowledge of
radial variation of specific gravity is essential to determine the uniformity of wood and
also to predict the effect of age on wood quality. The greater the uniformity of wood, the
greater will be the efficiency of producing a specific product with much improved quality
of the final product (Bhat et al., 1989; Zobel and van Buijtenen, 1989; Anoop et al. 2014).
Three general types for radial pattern in wood density variations were classified by
Panshin and De Zeeuw (1980), type 1 shows an increase from pith to bark, type 2 shows
an initial decrease from pith outwards and then density increases toward the bark and
type 3 shows a steady decrease in density from pith to bark.

In the present study, the mean specific gravity of all trees in juvenile wood did not
show any definite pattern of radial variation with cambial age at dry site and it was
decreased significantly in mature wood. While for trees at moist site, the mean specific
gravity decreased significantly with cambial age in juvenile and mature wood both. These
results are in conformity with the findings of Bhat (1998), who reported that specific
gravity did not show any definite pattern of radial variation in relation to cambial age of
65-year-old teak trees at three locations of diverse environmental conditions in Kerala.
Recently, Sinha et al. (2014) also reported that wood density did show a definite trend of
radial variation in juvenile wood, whereas it showed decreasing trend in mature wood of
120-to 150-year-old natural-grown teak trees from moist site in Maharashtra. They have
also reported that radial variation of wood density was more inherent in juvenile wood
than mature wood of all trees due to cambial aging. Gartner et al. (1997) recorded that
specific gravity did not vary significantly with cambial age in 40 years old trees of Alnus
rubra and Acer macrophyllum from the McDonald-Dunn forest of Oregon State
University, Oregon.
Typically, the radial trend of specific gravity or wood density decreases with cambial age in ring-porous hardwoods (Paul, 1963; Taylor and Wooten, 1973; Zhang et al., 1993). The decreasing trend of specific gravity in mature wood of teak trees at dry and moist site may be due to decrease of ring-width with cambial age in mature wood. According to Zobel and van Buijtenen (1989), the earlywood zone of ring-porous hardwoods has a relatively high proportion of vessels and the width of earlywood remains fairly constant from year to year. However, the latewood proportion, with fewer vessels, decreases as ring-width decreases and vice-versa. This results in lower specific gravity of latewood and explains the reason for decrease in specific gravity of wood with decreasing ring-width.

Richter et al. (2003) compared the radial variation of wood density between 10 to 32-year-old teak trees from plantations in Ghana and 81 to 314-year old teak trees from natural stands in Myanmar. They found that the radial trend of density increased proportionally with distance from pith in trees of Ghana. On the contrary, in trees of Myanmar, the radial trend of density decreased from pith outwards. Recently, Plourde et al. (2015) reported significant radial changes in specific gravity of 42 species from tropical trees of Costa Rica, where 37 species exhibited increasing trend from inner to outer wood and five exhibited decreasing trend. Radial increase was observed in species with inner wood specific gravity below 0.5, whereas radial decrease was observed in species with inner wood specific gravity above 0.7. Lei et al. (1996) revealed that specific gravity decreased almost linearly with cambial age in 80 years old *Quercus garryana* trees from natural forest. Similar trend was also observed by Woodcock and Shier (2002); they studied six species of hardwoods, where specific gravity showed radial decrease in three species and radial increase in another three species. Knapic et al. (2007) reported that
wood density decreased from pith towards bark more rapidly until 15th ring and then decreasing rate was slow after 15th ring in 30-60 years old Quercus suber trees.

On the contrary to present study, Izekor and Modugu (2010) had shown an increasing trend of specific gravity from pith to bark in 23 years old plantation grown teak in Nigeria. Miranda et al. (2011) also reported an increasing radial trend of wood density from pith to periphery in 50-to 70-year-old teak trees from an unmanaged forest in East Timor. Similar observation was also made by Kokutse et al. (2004) for wood density of 6-70 years old teak from five ecological zones in Togo. Moreover, Josue and Imiyabir (2011) revealed that basic density increased radially from pith to intermediate region and then it showed a more or less consistent value towards the bark in 15-year-old teak trees planted in Sabah, Malaysia.

In the present study, mean specific gravity varied significantly between juvenile and mature wood of trees at dry and moist sites. The mean value of specific gravity was significantly higher in juvenile and mature wood of trees at moist site than dry site. Considering the mean value of trees at dry site, the specific gravity ranged from 0.568 to 0.655 in juvenile wood and 0.539 to 0.674 in mature wood; whereas at moist site, it ranged from 0.602 to 0.702 in juvenile wood and 0.562 to 0.665 in mature wood. Bhat (1998) showed that the mean specific gravity varied significantly between juvenile and mature wood of 65 years old slow-grown teak trees from three locations in Kerala. The mean value of specific gravity was 0.570 and 0.540 in juvenile and mature wood respectively. Results also support those of Kokutse et al. (2004), where the wood density in 11-16 years old trees was significantly different than trees of 40-45 years old. Bhat and Priya (2004) reported that the mean air dry density for teak of 21-year- old plantation and 61-year-old plantation was ranged from 618 to 681 kg m\(^{-3}\) (sp.gv. = 0.618- 0.681) and 655 to 665 kg m\(^{-3}\) (sp.gv. = 0.655-0.665), respectively from the three major teak provenances.
of the Western Ghats in India. Bailleres and Durand (2000) found that the mean basic density for teak from natural forests in Indonesia, Thailand and Myanmar was 690, 620 and 700 kg m\(^{-3}\) (sp. gv. = 0.69, 0.62 and 0.70) respectively. Cordero and Kanninen (2003) reported that the dry density was statistically different between 8-year-old trees and 47-year-old teak trees from plantations under different climatic conditions in Costa Rica. The value of dry density was 0.77 g cm\(^{-3}\) (sp.gv. = 0.77) in the young tree and 0.73 g cm\(^{-3}\) (sp.gv. = 0.73) in the old tree. They have also found that wood dry density in moist site was higher than dry site.

5.3 RADIAL VARIATION OF FIBRE PARAMETERS

The cell morphology of the hardwoods is more complex than the softwoods. Small differences in cell morphology will probably be of greater importance in hardwoods than in softwoods. This may be due to complexity of cell types in the wood as well as small differences in cell length of 0.1 to 0.2 mm in the hardwoods can sometimes have an effect on the final product (Zobel and Jett, 1995). Cell characteristics of hardwoods can be altered by either environmental or genetic manipulation, a good assessment of genetic pattern is difficult (Lange, 1959). Wood consists of matrix of fibre walls and air spaces; therefore, its structural properties vary radially and longitudinally in the stem, branches and roots of a tree (Izekor and Fuwape, 2011). The variations in the gross anatomical structures of wood largely depend on the arrangement of cells, its size and morphology. In hardwood, the cells that make up the anatomical organization are the vessels, fibres, rays and axial parenchyma. Fibres are the principal element that is responsible for the strength of wood (Rajput and Rao, 1999). Variation in fibre dimensions does not only affect the quality of paper but also affect the quality of solid wood products (Moya et al., 2007). Fibre parameters have been extensively studied in relation to cambial age and within tree positions (Hudson et al. 1995). Fibre dimensions are determined by the dimensions of the
cambium fusiform cells from which they are derived and by processes that occur during cell differentiation (Ridoutt and Sands, 1994).

In the current study, considering the radial variation of fibre parameters viz. fibre length, diameter, lumen diameter and double wall thickness at dry site, the mean fibre parameters in juvenile and mature wood of all trees as well as within individual tree increased significantly with cambial age, except fibre length and fibre double wall thickness which were decreased insignificantly in mature wood. At moist site, the mean fibre parameters increased insignificantly with cambial age in juvenile wood, however it increased significantly in mature wood.

Similar kinds of results are already reported in teak and other species. For instance, Bhat (1998) showed that fibre length increased initially in juvenile wood, thereafter, it remained more or less constant in mature wood and finally decreased towards periphery depending upon growth rate and location in 65-year-old plantation-grown *Tectona grandis* trees of Kerala. Based on this result, he concluded that the boundary between juvenile and mature wood as defined by fibre length was 20 years of cambial age in slow-grown trees. According to Bhat et al. (1989), the radial patterns of fibre length variation in many tropical Indian tree species including teak showed a decline in fibre length near the bark after an initial increase from pith outwards. Kokutse et al. (2009) revealed that all the fibre parameters increased with tree age in juvenile wood, whereas fibre length decreased or remained more or less constant with age in mature wood. In a study of 15-25 years old teak of Nigeria, the fibre parameters like fibre length, fibre diameter and cell wall thickness showed increasing radial trend with cambial age while fibre lumen diameter decreased with increase in cambial age (Izekor and Fuwape, 2011). However, in the present study, the fibre double wall thickness in mature wood of dry site decreased with increase in cambial age. This result is supported by the findings of Bhat and Indira (1997),
where fibre wall thickness increased radially in 4th, 20th and 40th ring and decreased in 65th ring from pith in 65-year-old teak trees from three locations in Kerala. They also reported that fibre wall thickness was higher in wider rings than narrow rings.

Sousa et al. (2014) studied some of anatomical features on 34-60 year and 112-150 year aged *Quercus faginea* trees from two different sites in Portugal. It was revealed that fibre dimensions increased from pith to bark at both sites. Similar radial trend of fibre dimensions is also investigated by many authors in various species of tropical hardwoods other than teak (Pande and Dhiman, 2010; Pande, 2011; Pande et al., 2012; Anoop et al., 2014). Generally, the radial increase in fibre dimensions may be due to increase in the length of cambial initial with increasing cambial age (Izekor and Fuwape, 2011).

The result in this study showed that the mean value of fibre parameters in juvenile and mature wood of trees was non-significant between two sites, except for fibre length, where it was significantly higher in moist site in comparison to dry site. At moist site, the mean value of fibre length in juvenile and mature wood of trees was 1101.07 μm and 1227.28 μm respectively. However, for trees at dry site, the mean value of fibre length was 976.71 μm in juvenile wood and 1111.72 μm in mature wood. These results support those of Moya et al. (2009) who found that, among fibre parameters only fibre length was affected by the climate and type of growing site and it was significantly larger in the best growing site in 13 years old *Tectona grandis* trees from Costa Rica. Carrillo et al. (2013) recorded that moist locality showed higher fibre length in comparison to dry locality in *Prosopis laevigata* trees from natural forest of Northeast Mexico.

Varghese et al. (2000) reported non-significant difference in fibre characteristics of 60 years old teak trees among nine different locations in peninsular India. Bhat (1998) revealed that there was no significant difference in fibre length between juvenile (1101
μm) and mature wood (1377 μm) of 65 years old slow grown trees of teak from three moist localities in Kerala.

5.4 RADIAL VARIATION OF RAY PARAMETERS

The radial variation in cell dimensions may have an important effect on the quality in terms of processing and product manufacture (Zobel and Jett, 1995; Naji et al. 2013). Teak wood is composed of four major cell types namely fibres, vessels, axial parenchyma and ray parenchyma. Among cell types, ray parenchyma is often ignored by wood technologists or forest geneticists because of its low proportion compared to fibre or vessel proportion. Consequently, a few studies have been carried out on this tissue. Ray tissue constitutes about one-fourth to one-third of the hardwood xylem. Radial variation of ray parameters is important for determining wood quality (Taylor, 1969; Rahman et al., 2005).

In the present study, the mean ray parameters did not show any significant variation with cambial age in juvenile and mature wood of trees at dry site, except ray height which was increased significantly in mature wood. At moist site, ray width and height increased and ray frequency decreased significantly in both juvenile and mature wood. In fact, Rahman et al. (2005) revealed that radial variations of ray dimensions, ray height, ray width and ray frequency increased or decreased from pith to about 10 rings and thereafter remained more or less constant in teak trees grown in Bangladesh.

Anoop et al. (2014) recorded that ray height and ray width increased from pith and ray frequency declined from pith to periphery in Swietenia macrophylla trees grown in moist zone of Kerala. Naji et al. (2013) found that ray frequency decreased and ray height increased from pith to bark in 9 years old trees of Hevea brasiliensis from Malaysia. Loustarinen and Mottonen (2010) reported that ray width increased, while ray frequency decreased with cambial age in 33 years old plantation and 70-80 years old naturally grown
tree of *Betula pendula* from different growing sites in Finland. Similar radial trend in ray dimensions was also observed by Lev-Yadun (1998). A normal aspect of ontogeny in woody plants is a gradual increase in ray height and width with age, with distance from the pith and with distance from young leaves (Lev-Yadun and Aloni, 1995). Sousa et al. (2014) also recorded that ray dimensions such as ray width and ray height increased from pith outwards in a study of 34-60 years old trees and 112-150 years old trees of *Quercus faginea* at two different sites of Portugal. They also observed that average value of ray width was similar between two sites; however, ray height was significantly different between two sites. In the current study, the mean value of ray parameters in juvenile and mature wood of trees was significantly different between two sites; however, ray width in mature wood did not show significant difference between two sites.

### 5.5 Radial Variation of Tissue Proportion

The proportion of different tissues like fibres, vessels, axial parenchyma and rays are likely to have a bearing on strength and density of wood (Rao et al. 1966). The knowledge of its radial variation is also important that ensure the uniformity in wood quality for efficient utilization of timber. Lei et al. (1996) reported that fibre proportion decreased slowly for about 20 years and then decreased rapidly towards the bark in 80 years old trees of *Quercus garryana*. The vessel proportion showed the opposite trend, a slow increase for the first few years followed by a rapid increase. The axial parenchyma proportion increased almost linearly with cambial age, whereas the ray proportion was more or less constant and decreased slightly towards the bark.

These results were similar to the findings of the present study, where the mean vessel proportion and axial parenchyma proportion increased, while ray and fibre proportions decreased significantly with cambial age in juvenile wood of trees at dry site. In mature wood, only vessel proportion increased significantly and other parameters did
not show any significant variation. At moist site, mean vessel proportion and axial parenchyma proportion increased, whereas ray and fibre proportion decreased significantly with cambial age in mature wood. Bhat and Indira (1997) studied the anatomical variation in four radial positions from pith to periphery in 65-year-old tree of teak from three locations in Kerala and revealed that fibre proportion decreased and vessel proportion increased radially with cambial age. Gartner et al. (1997) conducted similar study in 40-year-old trees of *Alnus rubra* and *Acer macrophyllum* from Oregon State University, USA and they found that fibre proportion decreased and vessel proportion increased with increasing cambial age, while ray proportion changed little with cambial age. Axial parenchyma proportion showed no significant radial trend. Ismail et al. (1995) studied the anatomical variation in six plantation grown Kelempayan trees (*Neolamarckia cadamba*) from Negeri Sembilan, Malaysia and recorded that vessel and ray proportion increased while, fibre proportion decreased from pith to bark.

### 5.6 RELATIONSHIP BETWEEN SPECIFIC GRAVITY AND FIBRE PARAMETERS

Variation in anatomical structure may cause variation in wood quality. Fibre characteristics are highly correlated with specific gravity that affects the wood quality in many tree species (Zobel and van Buijtenen, 1989).

In the present study, the mean fibre parameters of trees did not show any significant correlation with specific gravity in juvenile wood at dry and moist sites. Fibre diameter and fibre lumen diameter showed negative correlation with specific gravity in mature wood at dry site; however, fibre length and fibre wall thickness did not show significant correlation with specific gravity. Considering the mature wood at moist site, fibre length, fibre diameter and fibre lumen diameter were negatively correlated with specific gravity; however, fibre double wall thickness did not show significant correlation with specific gravity. These results are in agreement with those results of Rao et al.
(2005) where they observed non-significant correlation between fibre parameters and basic density in 4-5 year old *Eucalyptus tereticornis* clones from Andhra Pradesh. Anoop et al. (2014) also reported similar observations in *Swietenia macrophylla* trees from Kerala. Moya and Tomazelo (2007) showed that wood density was positively correlated with fibre cell wall thickness and negatively correlated with fibre length, diameter and lumen diameter in *Gmelina arborea*. Goggans (1964) recorded negative correlations between fibre diameter and fibre lumen diameter in *Pinus taeda*. Helinska and Fabisiak (1991) revealed a negative correlation between fibre length and specific gravity in 78-year-old trees of *Quercus petraea* from Poland.

The non-significant correlation between fibre double wall thickness and specific gravity may be due to less variation in fibre wall thickness in mature wood. According to Purkayastha and Rao (1969) specific gravity could not be predicted only from fibre characteristics of wood. Only about 56 per cent of variation in the specific gravity could be accounted for fibre characteristics. Rao et al. (1997) reported that radial variation in latewood density which generally affects the annual ring density is closely associated with vessel and fibre proportions than dimensions of fibres in *Quercus robur*. It has been reported by Fujiwara et al. (1991) that fibre proportion is closely related to specific gravity. However, fibre dimensions differ from one species to another. On the contrary to current study, Purkayastha et al. (1974) reported that wall thickness, diameter and length of fibres accounted 77 per cent of the variation in density of 25 year old tree of *Michelia champaca* grown at New Forest, Dehra Dun. Purkayastha et al. (1972) observed that fibre wall thickness was highly correlated with specific gravity in teak trees from different localities. Quilho et al. (2006) recorded that fibre dimensions namely, fibre length, diameter and wall thickness showed highly significant correlation with basic density in hybrids of *Eucalyptus grandis* x *Eucalyptus urophylla* in Brazil.
5.7 RELATIONSHIP BETWEEN SPECIFIC GRAVITY AND RAY PARAMETERS

Rays are thin walled parenchyma cells which would appear to detract from the specific gravity of wood. However, species characterized by high specific gravity often contain large amount of ray tissue (Taylor, 1969). Information on the specific gravity in relation to ray dimensions is very sparse.

Results of the present study showed that ray height and ray frequency showed a significant negative and positive correlation with specific gravity in mature wood, respectively, at dry site; however, ray width did not show significant correlation with specific gravity. Considering the trees at moist site, the ray height was negatively correlated with specific gravity in juvenile wood. However, in mature wood, ray width and height were negatively correlated with specific gravity and ray frequency was positively correlated. Rahman et al. (2005) revealed that increase in ray volume which is related to ray frequency showed higher specific gravity in Tectona grandis trees from two locations in Bangladesh. A similar observation was also reported by Tayler (1969) in four different species other than teak. Generally, specific gravity is related to strength properties of wood. Toong et al. (2014) recorded that ray width and ray height showed negative correlation with strength properties in different commercial timber species.

5.8 RELATIONSHIP BETWEEN SPECIFIC GRAVITY AND TISSUE PROPORTION

Wood is a complex tissue composed of three main cell types: vessels that transport water, fibres responsible for mechanical strength, and parenchyma that stores and transports nutrients. These tissues have different structural characteristics and their relative proportions within wood influence the specific gravity or wood density (Zobel and van Buijtenen, 1989; Zieminska et al., 2013).

In the current study, among several parameters of tissue proportion, only vessel proportion showed a strong negative correlation with specific gravity in mature wood at
dry site. However, in mature wood at moist site, the proportion of vessels and axial parenchyma showed a strong negative correlation with specific gravity. In contrast, ray and fibre proportions showed a strong positive correlation with specific gravity. These results are in conformity with findings of Rao et al. (2002), who reported that specific gravity was positively correlated with ray percentage and fiber percentage and negatively correlated with vessel percentage in four and half year old *Eucalyptus tereticornis* clones. Bhat and Indira (1997) recorded that fibre proportion was positively correlated with wood density, while vessel and parenchyma proportions were negatively correlated with wood density in teak trees grown in Kerala. Fujiwara et al. (1991) revealed that fibre and ray proportions were positively correlated with basic density in fifty tree species of Japanese hardwoods. Purkayastha et al. (1972) found that increase in specific gravity was related to fibre wall thickness and proportion of fibres in *Tectona grandis*. Rahman et al. (2005) reported that ray proportions were directly correlated with specific gravity in teak of Bangladesh. A similar observation was also recorded by Rao et al. (2005) in *Eucalyptus tereticornis*.

The axial parenchyma is a thin walled tissue which is predominantly associated with vessels during beginning of the growth rings in teak and its proportion is lower than proportions of other tissues. This may be the reason for negative relationship of axial parenchyma proportion with specific gravity.

In the present study, the relationship between tissue proportion and specific gravity was non-significant in juvenile wood of trees at dry and moist sites. These findings are supported by Purkayastha and Rao (1969) who reported no definite relationship between specific gravity and tissue proportion in some of the trees of *Tectona grandis* from India. Sreevani and Rao (2014) also reported non-significant relationship between basic density and tissue proportion in *Eucalyptus tereticornis* clones from
Andhra Pradesh. Purkayashta et al. (1974) studied the variation of anatomical structure and density of *Michelia champaca* and noted that length, diameter and wall thickness of fibres contributed 77 per cent of variation in density. However, fibre proportion did not show significant relationship with density.

5.9 INFLUENCE OF CLIMATE ON THE SPECIFIC GRAVITY

Specific gravity is one of the most important properties in assessing the wood quality. The external factors of climate and environment exert their influence directly on the crown and indirectly on the growth and wood quality. Although temperature and rainfall are the integral parts of the climate, only a few studies have been carried out to correlate these climatic factors with specific gravity. According to Wiemann and Williamson (2002), extensive literature studies showed that mean specific gravity responds to a fundamental change in environment namely temperature.

In the present investigation, there was a significant negative correlation between specific gravity and mean annual temperature at both dry and moist sites. However, specific gravity did not show any significant correlation with total annual rainfall at both the sites. Briffa et al. (1998) reported that seasonal variation in wood density or specific gravity has been used for surrogate to temperature in interpreting historical climate. However, in recent years, the general positive relationship between temperature and wood density has broken down with decreasing wood density as global temperatures have risen.

Specific gravity or basic density of wood is generally determined by dimensions and percentage of the cell wall material in wood (Purkayastha et al., 1972, 1974). Considerable variation occurs in these characteristics during the growing season since the earlywood is composed of wide thin-walled, cells and latewood of narrow, thick-walled ones. The change in cell dimensions is associated with variation in environment, and especially temperature seems to be the main factor in determining cell development.
(Kellomaki, 1979). The specific gravity in teak seems to be related with the proportion of latewood formed (Bhat, 1998; Sinha et al. 2014). Considering high temperature usually means, less rainfall or water stress like condition, causing teak to produce narrow rings and lower latewood proportion, otherwise wood containing only large earlywood vessels with one or two lines and no latewood (Pumijumnong and Park, 2001). In the current study, teak trees from dry and moist sites were slow grown and mature to over mature with narrow rings. This might be due to negative correlation between specific gravity and temperature. The role that temperature plays in teak growth may be more difficult to determine than that of rainfall due to steady warm temperature in tropical or subtropical regions, this effect may be combined with complex hormonal processes also (Pumijumnong and Park, 2001).

On the contrary to the present study, Thomas et al. (2007) reported that there was a positive relationship between wood density and temperature in *Eucalyptus grandis*. Wood density increased to 20 per cent with increasing growth at 30° C temperature and declined when seedlings grown at 35° C. Wiemann and Williamson (2002) concluded that specific gravity decreases with increasing mean annual precipitation, especially among tropical sites. Variability in specific gravity among species at a site increase more dramatically with mean annual temperature than does the mean specific gravity. Oliver et al. (2009) revealed that wood density was less sensitive to temperature and precipitation variations in *Populus* spp. They also mentioned that wood density may be affected by factors other than those which affect tree radial increment and also may be due to more sensitive to environmental changes. Martinez et al. (2009) reported that wood density was more significantly correlated with precipitation and aridity than with temperature in 61 species of shrubs in North and South America.
The influence of climate on the specific gravity is complex and multifaceted; therefore, extensive study is needed to gain a deeper understanding of underlying processes in controlling specific gravity of wood, and to identify true casual links.

5.10 INFLUENCE OF CLIMATE ON THE FIBRE PARAMETERS

Variation in wood anatomy within a locality is determined by genetic factors as well as external factors and growth circumstances especially climate and location (Meena and Gupta, 2014). Limited studies have been conducted on hardwoods to investigate the relationship between climate and anatomical properties especially the fibre dimensions.

In the current study, several fibre parameters were correlated with temperature and rainfall. The fibre length and fibre double wall thickness showed a significant positive correlation with mean annual temperature. However, fibre diameter and fibre lumen diameter did not show significant correlation with mean annual temperature at dry site. At moist site, the fibre diameter and fibre wall thickness showed a significant positive correlation with total annual rainfall; however, fibre length and fibre lumen diameter did not show strong relationship with total annual rainfall. Further, only fibre length showed a significant positive correlation with mean annual temperature.

Zobel and van Buijtenen (1989) reported that higher temperature increased tracheid length but cell wall thickness was not affected in Pices sitchensis. They hypothesized that cell elongation is a direct function of temperature, while cell wall thickness is determined by net assimilation rate. Contrarily, Honjo (2002) found that fibre length increased with increase in precipitation in Acacia mangium in Malaysia. Similar observation was also recorded by Carrillo et al. (2013) in Prosopis laevigata from two regions of Mexico. Xu et al. (2013) revealed that cell wall thickness responded positively with temperature, while cell radial diameter negatively correlated with temperature in Picea crassifolia. Effect of climate on the fibre properties of 50 to 60 years old trees in
*Acer velutinum* was studied by Bakhshi et al. (2011), they found that effect of climate on the fibre length and fibre wall thickness was negligible; however, fibre diameter was positively correlated with precipitation. Moya and Fo (2008) revealed that fibre diameter and fibre lumen diameter increased with increase in annual precipitation in *Gmelina arborea* at different ecological conditions in Costa Rica. The overall result showed that some of the fibre parameters are affected by climatic factors as well as local conditions.

### 5.11 INFLUENCE OF CLIMATE ON THE RAY PARAMETERS

Rays are one of the less studied parameter of anatomical features. Very limited investigations is made on ray parameters such as ray height, ray width and ray frequency that how these parameters are influenced by climatic factors like rainfall and temperature.

In the present study, the influence of climatic factors *viz.* total annual rainfall and mean annual temperature on ray parameters was not significant in teak at both dry and moist sites. These results are supported by the findings of Moya et al. (2009) where climatic factors did not show significant influence on ray parameters in 13 years old teak trees of tropical dry and moist climates in Costa Rica. Moya and Fo (2008) did not observe any significant relationship between ray parenchyma and annual precipitation in *Gmelina arborea* trees from Costa Rica. In contrast, Olano et al. (2013) recorded influence of climatic factors on ray parenchyma in *Juniperus thurifera* trees from Spain. The overview shows that influence of climatic factors on ray parameter is insignificant. Hence, the parameters can be used to study the wood property in many species.

### 5.12 INFLUENCE OF CLIMATE ON THE TISSUE PROPORTION

The variation in proportion of different tissues like vessels, fibres, axial parenchyma and rays in growth rings of wood is likely to have an influence on the wood quality. Dendroclimatic analysis showed that climatic factors like rainfall and temperature influence the ring-width (Shah et al. 2007; Bhattacharyya and Shah, 2009; Sinha et al.
2011, Sinha, 2012). Consequently, it may influence the tissue proportion of growth rings also. Information regarding direct relationship between climatic factors and tissue proportion is very scanty.

In the present study, the influence of total annual rainfall on tissue proportion was not recorded at both dry and moist sites. Among various tissue proportions, fibre proportion showed a significantly negative correlation with mean annual temperature. In contrast, the proportion of vessels and axial parenchyma showed positive correlation with mean annual temperature at dry site. The tissue proportion did not show any significant correlation with mean annual temperature at moist site.

Martinez et al. (2009) revealed that axial parenchyma proportion was positively correlated with mean annual temperature in 61 species of shrubs in North and South America.

Pumijumnong and Park (2001) reported that high temperature in tropical regions during May month has negative correlation with tree-ring width, causing teak to produce narrow rings containing large earlywood vessels with little or no latewood proportion. In the current study, teak trees from dry and moist sites were slow grown and mature to over mature with narrow rings. Generally, earlywood is occupied by large vessels with less fibre proportions and abundant proportions of axial parenchyma. This might be the region for inverse relationship between temperature and fibre proportions and positive relationship with vessels and axial parenchyma. However the role of temperature in teak growth may be more difficult to determine than that of rainfall due to steady warm temperature in tropical or subtropical regions, combined with complex hormonal processes in tree (Pumijumnong and Park, 2001). It is very difficult to explain the direct effect of climatic factors on tissue proportion Therefore, for a better understanding, it requires extensive study on these lines.