Wood is the important produce of the trees and forests. Wood anatomy has a great role in timber identification and in correlating their properties and uses. Several studies highlight the importance of the wood anatomy in relation to wood properties and uses (Desch, 1941, Brazier and Franklin, 1961, Brazier, 1956).

Wood, a most useful substance, varies greatly. Wood properties are changing throughout the world (Zobel et al. 1983) and the magnitude and causes of the changes must be known. Wood quality has become a major concern in the forest product industry only very recently due to the steady increase in intensively managed plantations and the move in forest management towards short rotations (Vargas-Hernandez and Adams 1991; Zhang, 1995). Further, ever increasing costs of raw material call for realizing better ratio of finished goods from wood with better anatomical traits. Tree breeders have realized that wood quantity (volume growth) and wood quality cannot be treated as independent traits and that wood quality improvement should form an integral part of tree breeding programmes (Van Buijtenen, 1986; Magnussen and Keith 1990).

The variability in anatomical characteristics has profound influence on properties of wood (Dadswell, 1957; Burley and Palmer, 1979). Features of interest in this connection include cell size, proportion and arrangements of different elements and specific gravity. The general pattern of variation in wood element dimensions is not only within a species but also observed within a tree (Dinowoodie, 1961; Zobel, 1965; Rao and Rao, 1978; Pande et al., 1995). Of the various wood quality parameters, specific gravity is the most widely studied. This easily accessible property is of key importance in forest product manufacture because it has a major effect on both yield and quality of fibrous and solid wood products (Davis, 1961; Barefoot et al., 1970; Lewark, 1979) and because it can be changed by silvicultural manipulation (Williams and Hamilton, 1961) as well as genetic manipulations (Zobel, 1961; Van Buijtenen, 1962). Length of cells also has a marked effect on product quality. It is generally the cell dimension next in importance to wall thickness in determining the final product value (Megraw, 1985). Although all characteristics of the cell have some effect on the quality of a manufactured product, most are minor in comparison to cell length (Zobel
and Buijtenen, 1989). These include cell wall thickness, width of cell, ray characteristics, cell dimension ratios and grain characteristics, micro fibril angle, etc. Other wood properties such as juvenile wood content, fiber quality, compressed wood, heartwood content, chemical properties, etc. should also be considered in future tree improvement programmes (Zhang and Chui, 1996).

The fast growing plantations have increased steadily over the past throughout the world. The proportions of softwood and hardwood plantations will continue to increase until it predominates in the next century (Zobel, 1980). As a consequence, changing resources through out the world would lead to changing quality of wood supply (Senft et al., 1985; Zobel and van Buijtenen, 1989). A deeper understanding of the changing quality of wood from fast grown plantations will be helpful in its efficient processing and utilization. Hence, it would be worthwhile to consider the characteristics of wood supply and factors contributing to the variability of wood from trees of different species. Due to wide spread interest in paper making industries majority of the work done in the area of wood variation was confined to tracheid length (Zobel and Van Buijtenen, 1989).

Comparative study on anatomical features of the main structure of the common “wingceltis” woods was reported by Xu Bin et al. (2005). The main structure molecule, vessel element, wood ray, longitudinal parenchyma and fiber in *Tabebuia* spp., *Manduca utilis*, etc. were carried out. The similarities and differences among these wood were found out and the key anatomical features as the microcosmic discersn standard was confirmed (Xu Bin et al., 2005). Studies on anatomical properties of fast-growing trees species *viz.* *Albizia falcata* (14-yr-old), *Acacia confusa* (14-yr-old), *Liquidambar formosana* (16-yr-old), and *Taiwania cryptomerioides* (20-yr-old), were reported (Wang Ying Shen, 1996). The diameter at breast height of all trees was 20-30 cm.

The study was conducted to determine the longitudinal gradient of variation of wood elements of *Schinopsis quebracho-colorado* (Anacardiaceae). The anatomical variables studied were width of growth rings, vessel number/mm² vessel tangential diameter, vessels and length of rays, proportion of tissues, pore types and the external and internal diameter and thickness of fiber walls. The wood showed a longitudinal gradient of variation from base to apex (Gimenez and Lopez, 2002).
A major objective in forestry is to reduce wood variability by one of any number of techniques, such as reducing the magnitude of the transition from early to late wood (McGraw, 1985) or by reducing tree to tree difference (Zobel et al., 1983).

Most trees have pattern in wood property from the centre of the tree outwards, from the base to the top of the tree, within an annual ring and sometimes even on different sides of the tree in relation to the sun and temperature (Dadswell and Nicholls, 1960; Polge and Illy, 1967; Sluder, 1972). The within tree patterns of variation have been intensively studied for many species. There is no norm; each species in each environment can develop its own pattern. The magnitude of within-tree differences can be very large and are important. For example, in his comments on the quality of the wood of tropical pines grown in South Africa, De Villiers (1973) states, problems experienced with the utilization of the timber of tropical pines grown in South Africa are due in the first place to the presence of a radial density gradient in the stem.

The best known and most studied within tree variability in wood is the change from the tree centre (the pith) to the bark, which is frequently referred to as the characteristics of juvenile and mature wood.

2.1 Intra-ramet variation

2.1.1 Variations in fiber dimension

2.1.1.1 Radial variations

Most reports on radial pattern of variation in hardwoods deal with fiber-length and most agree that fibers are the shortest near the centre of the tree. In the tropical hardwood *Tripllochiton scleroxylon* from Ghana, Oteng-Amoako et al. (1983) noticed an increase in fiber-length of less than 30 per cent from pith to mature wood. This is the usual pattern for hardwood trees. A few reports indicated a reduction in fiber-length towards the bark.

Physical properties and anatomical features of 14-yr-old *Acacia mangium* were reported. The result showed that the fiber length tended to increase from the centre to the intermediate regions before decreasing slightly towards the outer regions in most cases (Lim and Gan, 2000).

The anatomical characteristics of major Korean ash species were reported. Some of the characteristics such as shape, size of vessel elements, arrangement of axial parenchyma in
cross section and cell volumetric composition showed significant differences between the sample species. In radial variation of elements, fiber length increased from pith for approximately 10 to 15 years and then reached more or less constant (Hwang et al., 2002).

Pith to periphery variation in anatomical properties such as fiber-diameter, fiber-lumen-diameter, fiber-wall-thickness were studied in tropical broad leaved species such as Broussonetia papyrifera, Poinciana regia, Pittosporum tetraspermu, Grevillea robusta and Tamarindus indicus by Rao, R (1966).

The radial variation of fiber length increment and its relation with internal and external factors were investigated for Acacia mangium trees collected in Indonesia and Malaysia. The result showed that the radial variation of fiber length was related to the growth rate rather than the age of the cambium (Honjo et al., 2002).

Fiber length increased radially from pith to bark for natural and plantation trees of both species; ranging from 1.92 to 2.98 mm (natural) and 1.45 to 2.71 mm (plantation) for Hyeronima; and from 0.63 to 1.75 mm (natural) and 0.69 to 1.47 mm (plantation) for Vochysia. Neither species had a clearly defined juvenile wood zone. Fiber length continued to increase with distance from pith (Butterfield et al., 1993).

Radial and longitudinal variation (%) in fiber wall area, vessels and resin canals and specific gravity was studied in five superior six-year-old plantation grown trees of red meranti (Shorea leprosula, Shore. parvifolia and Shorea pauciflora). Variation within the trees appeared small and did not show any consistent patterns for any of the three parameters observed. The variance between trees of a species however was significantly larger than the variance within the trees and among the species (Bosman, 1997).

The radial wood variation patterns were determined for quebrancho blanco (Aspidosperma quebrancho blanco). Patterns of variation of fiber diameter, lumen diameter, lumen fiber, fiber cell wall thickness, were examined using locations, trees and radial distances as sources of variation. Results showed that distance to the pith was the main source of variation for the traits studied. The wood anatomical features were not affected by location difference. Fiber diameter, fiber cell wall thickness showed an increasing pattern along the radius. The diameter lumen fiber, fibers (%) and rays showed an indefinite pattern of radial change. Along the radius, the tissue proportion of fiber diameter and fiber cell wall thickness increased more rapidly up to a distance of 10.5 cm (Moglia and Lopez, 2001).
Radial variability of the axial element length in oak-wood is the most prominent in the juvenile wood which includes approximately 30 annual rings. The length of fibers increased from the pith outwards according to a second degree curve. This dependence is most apparent for wood fibers. In mature zone, anatomical elements are on average, 10 to 20% longer than juvenile wood. With deteriorating conditions of tree growth, the length of the anatomical elements tends to increase. There is a negative correlation between length of the measured elements and growth ring width; this is most clearly so for fibers. A similar relationship exists between the length of anatomical elements and wood density (Raczkowska and Fabisiak, 1991).

Variation in the wood properties of Paraserianthes falcataria trees planted in Indonesia demonstrated a significant variation in the growth rate and wood properties. Log properties were different among trees. Significant differences in the fiber length were observed between the core and outer wood (Ishiguri et al., 2007).

Fiber lengths of Eucalyptus camaldulensis clones slowly increased from pith to outwards while that of seedling rapidly increased (Veenin et al., 2005).

Fiber length variation within growth rings of yellow poplar (Liriodendron tulipfera L) was investigated by removing tangential microtome sections from various positions within annual rings. Three zones in five different trees were studied. Individual microtome sections were macerated and the whole fibers from these sections were measured. Fiber length increased linearly from springwood to summerwood and that summerwood fiber approximately 25% longer than springwood fibers (Taylor, 1963).

Ten trees of Eucalyptus globulus Labill from three different locations within Portugal were felled at 12-15 years to study fiber length variation in bark and wood. The results proved that the fibers of Eucalyptus globulus were morphologically similar in bark and wood, but generally longer in the bark (on average, 0.97 mm in wood and 1.11 mm in bark). The axial variation was small; fiber length in wood increased significantly from pith to bark at all heights levels. The measurement of fiber length at 1.3 m height level was representative for the tree average for both wood and bark (Jorge et al., 2000).

Maximum lumen radii and maximum fiber length both increases from pith to bark and with increasing height in the tree (Stamm, 1970).
Non-significant differences were observed between the fiber dimensions (length, diameter and wall thickness) of 10 bamboo species. There were no significant correlations between fiber length, diameter and wall thickness. There was only minimal increase in fiber length with increasing age of plantation-grown (Shanmughavel et al., 1998).

Knigge and Koltzenburg (1965) found a rapid increase in cell length during the first 10 to 20 years in hardwoods, followed by a leveling off. This pattern was present in eucalyptus (Bisset and Dadswell, 1949) and Carya spp. (Pritchard and Bailey, 1916). Other genera, such as Quercus, Fagus and Fraxinus have a continuous increase in fiber-length for 40 to over 100 years, depending on the species.

Fiber length in European Black Alder roots, branches, and stems was studied by Vurdu and Bensend (1979). This study examined the fiber length variations for two 8-year-old trees. The measurements were made in the roots, branches and at three different stem heights. Fiber length increased 63% from the pith to the bark in the branches, 59% in the stems and 21% in the roots. Vertically, fiber length was 0.92 mm in the roots, 0.89 mm in the lower parts of the stems and 0.80 mm in both upper parts of the stem and in the branches. There was no significant difference in fiber length between lower and upper sides of either roots or branches.

Intra-tree radial variations in fiber morphology were studied by Pande et al. (2008) in 12 years old tree of Leucanea leucocephala. They observed that the variations were non-significant except for fiber-diameter from pith to outwards. They also observed significant variations among main bole, first and second branch.

2.1.1.2 Vertical variations

Many trees have wood properties that vary at different heights in the tree. For those species in which juvenile wood greatly differs from mature wood, a change in wood properties with height is automatic since the proportion of juvenile wood in stem increases extensively from the base to top.

Fiber length was largest in Liquidambar styraciflua at the stump and decreased steadily with increasing height (Webb 1964). Acacia mangium trees showed a decrease in fiber length from the base of the tree to upwards (Wang and A.K Razali, 2000).

Variation in stem characteristics with reference to anatomical features of 6-, 8-, 10- and 12-year-old locally planted rotan getah (Daemonorops angustifolia) was assessed by
Kadir (2002). Anatomical features like fiber area and fiber length were not influenced by age. Significant correlation was observed between anatomical feature and height of stem.

Dimensional variation in fibers along the vertical axis of 28 years old *Daniellia oliveria* (Rolfe) Hutch and Dalz was carried out by Idu and Ijomah (2000). The variation observed was investigated non-significant along vertical axis of the plant, while fiber diameter and lumen diameter varied significantly only along the vertical axis.

Dimensional variation was investigated in fiber along vertical and horizontal axes of a 40-year-old tree of *Afzelia Africana* felled in Gerei forest Nigeria. Mean dimensional values were: fiber length 1116.23 µm, fiber diameter 21.94 µm, lumen diameter 11.8 µm, fiber wall thickness 5.55 µm, Runkel Ratio 0.98, flexibility coefficient 0.5, relative fiber length 50.56, vessel length 194.02 µm and fiber length varied significantly on both axes investigated (showing patterns of alternate increase and decrease with increasing height and distance to pith), while fiber diameter and lumen diameter varied significantly only along vertical axis. Other traits analyzed showed considerable variation but were not significantly related to distance along either axis (Idu and Ijomah, 1996).

In an analytical study on cell size variation in *Acacia nilotica*, Iqbal and Ghouse (1983) found that the length of vessel segments decreased from base to top and later stabilizing in the old trunk. Length of xylem fibers after an initial increase became more or less constant. Variation in fiber-length and cell wall percentage along the height of the tree was studied in *Acacia mangium* and *Acacia auriculiformis* trees by Wu and Wang (1988). Variation was generally less in *Acacia auriculiformis*. Similar studies were also made by Ku and Chen (1984) in the above two *Acacia* species.

Anatomical characters were investigated in stems of rotan semambu (*Calamus scipionum*), 6-12 years old, from a plantation in Sarawak, Malaysia. The fiber length, diameter and wall thickness decreased with height of stem while the fiber lumen diameter increased with height. Fiber diameter, fiber lumen diameter slightly increased from the centre to periphery Rosazanini, (2000). In terms of trends, only fiber diameter, percentage of fiber area, decreased with age.

The variability of fiber length in wood and bark in ten trees of *Eucalyptus globules* Labill from three different locations within Portugal were studied. The axial variation was
small and in wood and bark; fiber length decreased in the wood and increased in the bark from the base to the top Jorge et al., (2000).

Within-tree variation in growth rate and cell dimensions in the wood of black locust *Robina pseudoacacia* was reported from the University Forest of Taxiarchi, Chalkidiki, Greece by (Adamopolus and Voulgaridis, 2002). Oblique variation of growth rate did not exhibit any clear tendency but decreased at the top. In the case of vertical variation, growth rate decreased gradually with the year of the cambium formation. Oblique and vertical variation of cell dimensions did not exhibit any clear tendencies.

Within tree, vertical variation in anatomical properties of *Eucalyptus tereticornis* clones was investigated in detail by (Rao et al. 2003). Fiber length was found to vary significantly from base to top with no definite trend. Fiber-length was found to be positively correlated with fiber-diameter and fiber double wall thickness in this study. Specific gravity was found to be positively correlated with vessel (%), fiber (%) by vessel (%) ratio and negatively correlated with vessel frequency while all other anatomical parameters had no effect at all.

2.1.2 Variation in the vessel dimensions

2.1.2.1 Radial variation

*Quercus suber* L. is an important species producing cork. Vessel size and distribution were studied in approximately 40 year-old. The vessel size increases with age from 7660 ± 2286 to 21136 ± 6119 μm², the conductive area from 5.4 ±2.2 to 11.6 ±3.9% and the vessel density remains approximately constant between 5.2± 1.5 and 7.3 ± 3.5 vessel/mm² Leal and Peraira, (2006).

Dimensional variation in vessel characters both along vertical and horizontal axis of 28 years old *Daniellia oliveri* (Rolfe) Hutch and Dalz was carried out (Idu and Ijomah, 2000). Vessel element dimensions showed considerable variation but were not statistically significant.

Radial variation in anatomical properties was also studied by Rao et al., (2003c) in an 8-year-old plantation grown *Tacomella undulata*. Significant pith to periphery variations in vessel frequency, vessel element diameter, percentage of solitary vessels, fiber length, fiber diameter, fiber lumen diameter and ray frequency were observed.
Variation in dimensions from pith to the bark in trees of *Myracrodruon urundeuva* reported (Florsheim et al., 1999). In the radial direction the lowest values for vessel length were found in the regions near the pith and the vessel diameter increased towards the bark.

Variation in anatomical properties of plantation grown *Acacia mangium* was reported. The radial variation in vessel morphology and tissue proportions in *Acacia mangium* was studied. The girth ranged from 32-42 cm at breast height. Significant radial variation from pith outwards was observed in respect of fiber diameter, fiber lumen diameter, vessel %, parenchyma % and ray % only. Correlation studies indicated that fiber, vessel morphology and tissue proportions were independent of basic density (Rao and Sujatha, 2004).

In radial variation of elements, vessel size increased from pith for approximately 10 to 15 years and then reached more or less constant (Joong and Joong, 2002). The length of vessel elements increased from the pith outwards according to a second degree curve. This dependence is the least distinct for vessel elements. In mature zone, anatomical elements are on average, 10 to 20% longer than juvenile wood. With deteriorating conditions of tree growth, the length of the anatomical elements tends to increase. There is a negative correlation between length of the measured elements and growth ring width. A similar relationship exists between the length of anatomical elements and wood density (Raczkowska and Fabisiak, 1991).

### 2.1.2.2 Vertical variations

A comparison of the wood structure of trees from the two forests was reported. Species from the deciduous forest have generally shorter and narrower vessel elements and rays, greater pore abundance and greater vessel wall thickness than the species from the rain forest (Morales, 1985).

Dimensional variation was investigated in vessel characters along vertical and horizontal axes of a 40-year-old tree of *Afzelia africana*. Mean dimensional values were: vessel diameter, 233.46 µm and F/V length ratio 2.25. Other traits analyzed showed considerable variation but were not significantly related to distance along either axis (Idu and Ijomah, 1996).

Variation in dimensions from stem base to the top in trees of *Myracrodruon urundeuva* reported (Florsheim et al., 1999). In the longitudinal direction the lowest value of
vessel length and diameter were found at the base, while the highest were found at 50% of commercial height.

2.1.3 Variations in the specific gravity

2.1.3.1 Radial variations

Different patterns for the variation of specific gravity from pith to bark were found in hardwoods. Some species such as *Swietenia macrophylla*, *Liquidambar styraciflua*, *Liriodendron tulipifera* and others have an increase in specific gravity from the pith to outward (Briscoe *et al.*, 1963; Hunter and Goggans, 1968; van Eck and Woessner, 1964; Herpka, 1965; Sluder, 1970). Of particular importance are the *Eucalyptus*, which generally show a small increase from the tree centre outward (Ferreira, 1972; Hans *et al.*, 1972; Skolman, 1972).

Five superior clones of *Eucalyptus camaldulensis* were investigated and the result showed that mean specific gravity showed significantly different values among the 5 clones and the seedlings. Each clone and seedling had a different specific gravity and anatomical characteristics and it also showed that clones had a narrower juvenile wood zone than the seedling due to the older cambial age of the clones (Veenin *et al.*, 2005).

Radial variation in wood specific gravity, for *Hieronima alchoreneoides* and *Vochysia guatemalensis* natural and plantation-growth hardwood trees increased radially from pith to bark for both species ranging from 0.23 to 0.70 (natural) and 0.23 to 0.50 (plantation) for *Hieronima*; and from 0.27 to 0.51 (natural) and 0.26 to 0.38 (plantation) for *Vochysia*. Natural-grown trees of both species had significant tree-to-tree variation in specific gravity (Butterfield *et al.*, 1993).

Bosman *et al.* (1994) also reported that the wood quality parameters of cell wall percentage, tissue proportions and basic specific gravity were determined for three naturally and nine plantation grown trees of light Red Meranti (*Shorea leprosula* and *Shorea parvifolia*). In both, variation in specific gravity is most significant within trees i.e., it increase from pith to bark. The plantation grown trees have slightly less variable wood than the ‘wild’ trees. Within and among trees specific gravity and anatomical parameters vary considerably.
Variation of the physical and anatomical properties of *Fagus orientalis* was observed by Rassam and Doosthoseini (2002). The variations were studied in the radial direction. The results showed that there was little change in the moisture content of wood in the radial direction. The specific gravity and total volumetric shrinkage of wood increased from pith to bark of the tree, whereas there was little change in moisture content, dry specific gravity and volumetric shrinkage of bark in longitudinal direction of tree trunk.

Wood specific gravity and its radial variations were studied by Woodcock and Shier (2002). In this study, radial trends in specific gravity of approx 100 individuals of six mixed-northern-hardwood-forest tree species, three species (*Acer rubrum, Pinus strobus* and *Betula papyrifera*) showed radial increase and three species (*Quercus ruburum, Tsuga Canadensis* and *Fagus grandiflora*) radially decreases. Radial increase was associated with low values of specific gravity in early-successional characteristics and radial decrease was associated with high values of specific gravity in late-successional characteristics.

The change in specific gravity was studied in radial direction, from pith to the bark (Moya, 2002). Results showed that specific gravity increased from pith to bark. Briscoe *et al.*, (1963) found that specific gravity increased outwards from pith in *Swietenia macrophylla*. Lamb (1968) and also found a similar pattern of increase in *Gmelina arborea*; Ferreira (1972) and Hans *et al.*, (1972) in *Eucalyptus grandis*. Purkayastha *et al.*, (1974) however, did not find any consistent pattern of radial variation with respect to density in the wood of *Michelia champaca* grown in New Forest, Dehradun (India). Horizontal pattern of variation in wood physical properties within a tree of *Eucalyptus camaldulensis* was reported by Jain and Arora (1995). Moisture content was found to decrease radially from pith to periphery in the heartwood, attaining the lowest value in the outer most heartwood ring and then increase slightly in the sapwood portion. Specific gravity increased towards periphery. The outermost zone was 1.38 times denser than the central zone near the pith. *Ceiba pentandra* stems also demonstrated increase in specific gravity with distance from the pith (Fimbel and Sjaastad, 1994). Purkayastha *et al.*, (1982) explained the increase from pith to outwards in *Eucalyptus* using linear regression models. The deviation from expected trend observed in this study was similar to those found by Hans (1974) in young *Eucalyptus* hybrid trees.
Specific gravity continued to increase with distance from pith (Butterfield et al., 1993). Specific gravity was studied in six-year-old plantation grown trees of red meranti (Shorea leprosula, Shorea parvifolia and Shorea pauciflora). Specific gravity in the planted trees is not significantly correlated to the growth rate parameters, height and diameter. It also showed that light and humidity may influence specific gravity (Bosman, 1997).

Variation in the wood properties of Paraserianthes falcataria trees planted in Indonesia demonstrated a significant variation in the growth rate and wood properties. Significant differences in the basic density were observed between the core and outer wood. In particular, the basic density of core wood showed significant differences among trees (Ishiguri et al., 2007).

Physical properties and anatomical features of 14-yr-old Acacia mangium were reported. The result showed that the density tended to increase from the pith to intermediate region before decreasing towards the bark (Rao and Sujatha, 2004).

Radial gradient in wood specific gravity in trees of Central Amazonian flood plains was reported (Parolin, 2002). Increase in wood specific gravity with distance from pith was associated with growth strategies of trees and their environment.

Purkayastha et al. (1974) studied in detail the variation in wood structure and density within a single tree of Michelia champaca. No consistent pattern of variation was noticeable in any of the characters studied.

The wood specific gravity of 4-5 year old Acacia mangium trees was studied by Ani and Lim (1993). Specific gravity was found to increase in the radial direction from the centre to the outer region near the bark. They also reported that the low specific gravity of juvenile wood reduced its utilization potential. In another study on the variation in wood density and other wood properties within and between trees as well as between three provenances of 8-year old Acacia mangium in Sabah by Sining (1989), between provenances and between tree variations were less significant than the within tree variation of wood properties. Basic density was found to increase from pith to bark.

2.1.3.2 Vertical variations

The effect of height on wood properties is equally as variable in hardwoods as it is in conifers. Perhaps the most common pattern is to have only minor changes with height, but some species, such as Swietenia macrophylla (Briscoe et al.1963), Liriodendron tulipifera
(Taylor, 1963), *Populus tremuloides* (Einspahr et al., 1972, Yanchuk et al., 1983) and *Liquidambar styraciflua* by Webb (1964) showed a high density at the base, a decrease for some distance up the tree, followed by an increase toward the merchantable top.

Specific gravity in European Black Alder roots, branches and stems was studied by Vurdu and Bensend (1979) at three different stem heights. Specific gravity was 0.24 in the roots, 0.43 in the branches and 0.42 in the stems.

Variations observed in specific gravity of wood in segregating populations of F₂ and F₃ hybrids of *Eucalyptus citriodora* and *Eucalyptus torelliana* in 10-year-old plants was studied by Verma et al. (2001). A subtle range in variation in specific gravity of wood was observed due to segregation, a wide spectrum of variation has been observed in individual tree specific gravity of wood belonging to F₂ and F₃ generation hybrids.

Curo (1960) observed in Euro-American poplars that basic density increased from butt to top while moisture content decreased. The wood density in the top part of the stem was greater than at the base in *Populus* spp. reported by Gohre (1960). Basic density increased up the tree for one-third to two-thirds of merchantable height in *Eucalyptus regnans* studied by Dargavel (1968).

Some reports showed an increase in density with height in the *Eucalyptus* and poplars (Gohre, 1960; Dargavel, 1968; Skolman, 1972; Taylor, 1973). The same pattern as in conifers, with the highest density at the base and lowest at top, was evident in some hardwoods, but most diffuse porous hardwoods have little variation in specific gravity from the base to the top.

Kennedy (1970) studied the relationship between buds bursting (flushing) time and specific gravity in Douglas-fir. The greater specific gravity of the early-flushing trees was associated with earlier initiation of latewood formation.

It was reported that the moisture content and specific gravity of yellow-poplar (*Liriodendron tulipfera* L.) wood and bark were determined at various height levels in 60 trees. The specific gravity and moisture content of total wood, heartwood, sapwood and bark showed extreme variation with height in the tree. The greatest changes occurred between the butt and 25 percent of tree height (Schroeder and Phillips, 1973).

Physical and mechanical properties of *Grevillea robusta* were studied. Variation was found significant with height for specific gravity (Kamala et al., 2000). Purkayastha et al.
(1982) also studied vertical variation in specific gravity, heartwood proportion and fiber-length in plantation grown *Eucalyptus tereticornis* trees. No significant effect was observed with regard to height level on specific gravity and fiber-length, but a significant difference was observed in heartwood proportion. Similarly, Bhat *et al.* (1988) found a decline in density values up to 25 per cent height and a gradual increase there after in a curvilinear manner.

Within-tree density gradient was studied in *Gmelina arborea* in Venezuela. Variation of wood specific gravity from base to the top of tree was observed. The result showed that specific gravity decreased from stump to half of the total height, then increased towards the top of the stem. No correlation between specific gravity and height of the tree was found (Espinoza, 2004).

Basic specific gravity and some microscopic wood characteristics such as length of vessel elements and fibers, tangential diameter of vessels, vessel frequency and fiber wall thickness of 29 species from a xerophytic region from the state of Puebla were obtained (Rodriguez *et al.*, 2001). Results showed significant differences in specific gravity, length of vessel elements, fiber length and fiber wall thickness. There was a positive relationship between specific gravity and fiber wall thickness. It was cleared that species with thick-walled fibers and high density were predominant in dry forest, whereas species with medium or low specific gravity and thin walled fibers were found in places with high humidity.

Wood specific gravity of trees and forest types in the southern Peruvian Amazon was reported. Results demonstrated the high degree of variability in specific gravity in trees at single locations; a positive relationship between specific gravity and diameter for a species was observed (Woodcock, 2000).

Variation of the physical and anatomical properties of *Fagus orientalis* in Siahkal forest was observed by Rassam and Doosthoseini (2002). The specific gravity and total volumetric shrinkage of wood increased from base to top of the tree.

Physical properties and anatomical features of 14-yr-old *Acacia mangium* were reported by Lim and Gan (2000). The results showed that the longitudinal variation however showed that the density tended to decrease from 10% height until about 50% height before increasing towards the top of the tree in most cases. Kholik and Marsoem (2002) investigated the physical properties such as moisture content, swelling and shrinkage, co-efficient of
rigidity and flexibility apart from specific gravity in the wood of *Acacia auriculiformis* trees.

The axial variation of basic density of wood of seven year old *Acacia mangium* by Vale-at-do *et al.*, (1999). Basic density values decreased up to about half of the stem height and then increased from this point up to the top but without reaching the value at the stem base. The effect of height level within tree within age was found to be statistically significant in an investigation on physical properties such as relative density, moisture content and shrinkage of *Acacia mangium* wood (Alipon *et al.*, 2003).

### 2.2 Inter-ramet variations

Inter-tree variations in physico-chemical and wood anatomical features in *Leucaena leucocephala* (Lam.) De Wit was reported by Pande *et al.* (2008). Inter-tree variations for wood anatomical properties were significant and accounted for genetic variability in trees for wood traits. Location also affected anatomical properties and pulping and paper quality ratios significantly.

Bhat (1990) however, did not find any significant variation between trees with respect to density and fiber length in all the four age groups of *Eucalyptus grandis* trees studied, the reason may be due to low sampling intensity. These findings deviate from the general view that in eucalyptus, density and fiber length variations between the trees can exceed 50% and 25% respectively (Wilkes, 1988). Fatima *et al.* (1998) observed significant differences in wood specific gravity between the 11 trees of *Pinus radiata* sampled and non significant difference for ring width. Similarly, Fimbel and Sjaastad (1994) who studied wood specific gravity variability in *Ceiba pentandra* trees from four Costa Rican life zones found that tree to tree variation accounted for 76-90 per cent of the total variability. The author attributed this high within location variability to the greater genetic influence of the parent tree than the overall environmental factors associated with the location.

Inter-tree variations in wood traits of 4 years old plus trees of *Eucalyptus tereticornis* Sm., selected from 13 provenances and 91 families was reported by Uniyal *et al.* (2008). The inter-tree variations for all blocks were significant from base to top and centre to outwards and non significant for peripheral direction. The dimensions of wood elements increased from pith to periphery. So, the variations in wood elements in 4 years old seedling seed
raised trees showed the impact of juvenile wood. Significant inter-tree variations indicated that each tree has separate entity and we can screen the different provenances for wood traits in *E. tereticornis* even at the age of four years.

Between-tree variation in the biometry of wood rays and fibers in cork oak (*Quercus suber* L.) studied at three radial positions (10, 50 and 90% of radius) in 5 cork oaks by Leal *et al.* (2006). Fiber dimensions increased radially but differed little between trees: on average, 960-1,220 µm length, 18.40-21.49 µm width and 6.66-8.07 µm wall thickness.

For *Eucalyptus camaldulensis*, Chudnoff (1961) reported that usually there was more variability among trees on the same location than the average differences between locations. Tree to tree variation is so large that it commonly masks other causes of wood variability. Mc Kimmy, (1959) and Palmer *et al.* (1982) reported in *Eucalyptus* that the density varied from 470 to 570 kg/m$^3$ among the trees.

### 2.3 Intra- and inter-clonal variations

Intra-clonal, intre-clonal and single tree variation of wood anatomical properties and specific gravity of 8 year clonal ramets of *Dalbergia sissoo* was studied by Pande and Singh (2005). The results revealed that inter-clonal variations were non-significant for anatomical properties and specific gravity for all six clones, whereas within tree variations in specific gravity were significant due to height.

The variation in wood elements within a ramet of *Dalbergia sissoo* Linn was studied by Pande and Singh (2003). Height, location and direction had no significant impact on the variations of the wood elements. The wood elements dimensions showed non-significant correlation with each other and with specific gravity. Variations in specific gravity were significant due to height.

Intra- and inter- clonal variation in basic density and anatomical properties of wood of six to seven years old trees of *Eucalyptus tereticornis* were evaluated by Shashikala and Rao (2005). The girth had a positive influence on basic density and basic density was positively influenced by fiber length. Furthermore, the negative correlation between vessel characteristics with girth on one hand and basic density on the other is advantageous both to clonal propagation and preparation of quality paper and pulp. Since the shrinkage values
observed are very low, it is suggested that the wood may be utilized for different purposes where high dimensional stability against changes in moisture content is desirable.

Gupta and Kukreti (1983) reported that the wood of *Acacia mearnsi* from its native range has better properties than the same material when grown in India.

Temperate hardwoods appear to have limited amount of variation in wood properties, tropical hardwood species such as teak (*Tectona grandis*) was reported to have large differences in specific gravity and strength properties of trees from different areas (Nair and Mukerji, 1957). Similarly, Purkayastha *et al.* (1973), who studied the variation in wood density in 36 year old teak trees from different seed origins, found that seed source had significant effect on wood density, even though the influence of environment is comparatively more. Boone and Chudnoff (1970) obtained very dense wood from Mahogany (*Swietenia macrophylla*) from southern Mexico and Nicaragua and a lower density from Guatemala and Costa Rica.

Variation of wood density and fiber length in six 13-year-old willows (*Salix* spp.) clones observed growing under two different location conditions in Argentina. The location and clones were considered as sources of variation. Location influence was significant for basic density whereas the fiber length values of the continental location were significantly higher. The clones "americano" and "3-44" stand out because of their high density and long fibers (Monteoliva *et al.*, 2005).

Influence of provenance variation on wood properties of *Tectona grandis* from the Western Ghats region in India was studied. Three major teak provenances were characterized in terms of mechanical and anatomical wood properties within the same age of 21-year-old plantations (Bhat and Priya, 2004).

Clonal and location variation of vessels in 7-year-old *Eucalyptus globulus* was studied (Leal *et al.*, 2003). Pith to bark variation of vessel anatomy was studied in 17 clones of 7-year-old *Eucalyptus globulus* trees grown on two locations in Portugal. The mean vessel area increased gradually from pith to bark, whereas the vessel frequency decreased outwards from the inner-most ring on and leveled off towards bark. The proportion of vessels relative to other tissues remained constant across the radius. The effect of location and clone on vessel variability was significant. Clonal variation accounted for 30% and location explained 67% of the total variance of vessel proportion. At the least water stressed location, vessels
appeared to be generally larger and occupied a greater proportion of total cross-sectional area.

The effects of location and clone origin on basic wood density of teak (*Tectona grandis*) were studied in 18 clones grown in two different locations in Kerela and showed that location has a great influence on wood density while place of origin of clones has no effect. Inter-clonal variation was significant at 5% level. Exploitation of tree to tree variation will also improve the wood density in teak (Indira and Bhat, 1998).

Provenances variation in fiber-length in *Acacia mangium* was studied by Sining (1989) in Sabah. Fiber length and length/width ratios were recorded for plantations of *Acacia mangium* and *Acacia auriculiformis* by Ku and Chen (1984). Fiber-dimensions and ratios were compared by Varghese *et al.* (1999) for plantation grown *Acacia mangium*, *Acacia auriculiformis* and *Acacia crassicarpa* from Thane, Maharashtra. *Acacia crassicarpa* had long fibers and vessel-elements.

Species from the deciduous forest have generally shorter and narrower vessel elements, shorter fibers and rays, greater pore abundance, greater specific gravity and greater vessel wall thickness than the species from the rain forest (Josefina, 1985).

Wood anatomical variation of *Acacia melanoxylon* in relation to latitude was reported (Wilkins and Papassotiriou, 1989). Samples from various locations in eastern Australia were examined and a number of characteristics were found to be significantly related to latitude. Vessel member length, proportion of fibers and proportion of multiseriate rays were positively related to latitude. Vessel frequency, vessel diameter and the abundance of crystals were negatively related to latitude as were the proportion of uniseriate rays, vessels and axial parenchyma. Total proportion of any ray tissue and basic density was not found to be associated with latitude.

### 2.4 Variations in micro fibril angle (MFA)

Fibril angle were studied on the Douglas-fir trees and it was reported that fibril angle decreased with age from over 30 degrees to about age 30. Tracheid length was highly correlated with fibril angle (Erickson and Arima, 1974).

McMillan (1973) described fibril angle of loblolly pine wood as related to specific gravity, growth rate and distance from pith. It was observed that fibril angles were greater for
early-wood (avg. 33.4°) than for the latewood tracheids (avg. 29.6°). For early-wood, fibril angle did not differ between growth rates when the specific gravity was low (avg. 33.3°). When the specific gravity was high, wood of fast growth had a higher fibril angle (avg. 35.1°) than the wood of slow growth (avg. 32.0°). No differences were detected between core, middle and outer wood. In latewood tracheids, fibril angles were greater in core wood (avg. 28.0°) than in middle or outer wood (avg. 26.3°). For whole wood, fibril angle averaged 30.7° and was greater in core wood (avg. 32.2°) than in middle or outer wood (avg. 29.9°).

The variation in wall thickness and its correlation with the inclination of the microfibrils in the cell wall of southern pine at the U. S. Forest Products Laboratory. In one loblolly pine (Pinus taeda L.) two annual increment sheaths were studied and a very high degree of correlation was found between the two variables at all positions from the apex to the base of the sheaths. In a similar study, twelve slash pines (Pinus elliottii Engelm.) were sampled at breast height and the annual rings from pith to bark were segregated into three age classes. The correlation between wall thickness and fibril angle, within and among age classes, in slash pine was high as that obtained for the loblolly pine. Variations in wall thickness in both species accounted for 6 to 81% of the overall variations in fibril angle (Hiller, 1964).

In a study on the variation of tracheid length and microfibril angle of slash pine (Pinus elliottii) wood samples were taken from 15 trees (17 yr old) at 3 locations in Guangdong, China. Results showed that location index had a significant effect on both tracheid length and microfibril angle. In the radial direction, the tracheid length increased while the microfibril angle decreased from pith outwards. However both tracheid length and microfibril angle were linearly, negatively and significantly correlated with each other within a tree, although there was no significant correlation between tracheid length and microfibril angle among stands on the same location (Xu et al., 1999).

2.5 Variation in Populus

Within-ramet and intra- and inter-clonal variations in wood traits in the genus Populus were studied by many workers. Some reports are available on wood quality parameters in the clones of Populus spp. (Phelps et al. 1982; Kauba et al. 1998; Chauhan et
Fiber length showed a constant decrease in the upward direction of *Populus japonogigas* was reported by Inokuma *et al.* (1956).

Natural variation in *Populus tremuloides* Michx was reported. The variation within clone is environmentally caused. The variation between clones is caused by differences in environment as well as in genetic constitution. Diameter growth, volume growth and specific gravity showed wide differences in one and the same clone as compared to between-clone differences, whereas fiber length showed less pronounced within-clone variation (Van Buijtenen, 1962).

Knigge and Koltzenburg (1965) found a rapid increase in cell length during the first 10 to 20 years in hardwoods, followed by a leveling off. This pattern was also present in poplars (Jayme *et al.* 1943; Scaramuzzi, 1955; Boyce and Kaiser, 1961).

Murphy *et al.* (1979) studied the selected wood properties of young *Populus* hybrids NE-49, -252, and -388 were grown for 4 years in central Pennsylvania at planting densities of 0.09 to 0.46 m$^2$ per tree. Specific gravity, chemical constituents and fiber length of the three hybrids were unaffected by the amount of growing space per tree. Within clones, fiber length increased each year for all three clones and hybrid NE-388 had significantly greater fiber length among clones for each of the 2, 3, 4 years.

Genetic variation in wood properties among and within 3 provenances of balsam poplar was investigated. Thirty clones from each provenance, with 4 ramets per clone were measured for growth characteristics, and specimen disks were cut at tree base. The results showed significant differences among the 3 provenances in growth rate and cell length. Growth rate, relative density and fiber length as dependent variable showed differences between the southern and northern provenance with the local source in an intermediate position. Both genetic and environmental variances for a certain trait differed from provenance to provenance (Ivkovich, 1996).

Anatomical variations in *Populus deltoides* were examined, in 8 year old trees of six different clones (Chauhan *et al.* 1999). The analysis indicated that significant clonal variation in specific gravity, fiber length, vessel length, fiber diameter, lumen diameter, vessel frequency and vessel diameter. The specific gravity, fiber length and vessel length also showed an increase with age. The variation in wood parameters offers possibility for selection of breeding stock with desirable wood quality.
Inter-clonal variations in *Populus deltoides* in specific gravity and wood parameters of 18 clones in 10 year old trees observed. The inter-clonal differences were significant in anatomical parameters and specific gravity while, within clones showed no significant effect. It also showed that specific gravity reached maximum at 50% tree height and fiber length at 25% of tree height showing decrease trend upwards (Chauhan *et al.* 2001).

Fiber length in young *Populus* stems, relation to clone, age, growth rate, and pruning was studied by (Debell *et al.* 2002). Averaged over all trees, fiber length increased from 0.57 mm at age 1 to nearly 1.0 mm at age 9. Averaged over all disks at 1.5 m, clones differed significantly in ring width, and fiber length. Mean values for two wood properties at 3.0 m were slightly lower than those at 1.5 m and did not differ significantly among clones. Within clone correlations between ring width and fiber length or between wood properties were low, and generally non-significant.

Variation of fiber length and fiber width for seven poplar clones was reported by Yang and Fang Shen Zuo (2003). Results were presented for the study investigating the variation of fiber length and width of seven poplar (*Populus*) clones. The increase in fiber length and width from pith to bark, and from base of trees to peak were observed.

Radial variation of fiber morphology of five different poplar clones, were selected to study the radial variation of fiber length, fiber width, lumen diameter, double cell wall thickness, the ratio of fiber length to width. Results showed that from pith outward, the fiber length, the fiber width and the ratio of fiber length to fiber width of five poplar clones all increased with the increase of growth rings; reached a maximum in a certain year and then decrease or level off (Zha *et al.* 2005).

Wood characteristics of twenty poplar clones grown under short rotation intensive culture was studied by Venkaiah *et al.* (2007). The average number of vessels/mm² and diameter of vessel cross sectional area in earlywood and latewood, height and width of ray, specific gravity and fiber length were compared. The maximum numbers of 80.55 vessels/ mm² were found in clone 6-5 while minimum were observed in 6-17 (30.08). Clone 6-18 (0.427) showed maximum specific gravity and minimum by clone 6C (181 (0.333). The longest fibers were found in the clone 6C (1.236 mm), closely followed by 6A-238 (1.222 mm) and shortest fibers in 6-17 (0.952 mm).
Clonal variation in poplar wood for making match splints of 8 poplar clones viz. S7C15, Wimco-22, L-34, Bahar, Udaï and Kranti was studied by (Dhiman and Gandhi, 2007). The results indicated that wood of clones G-48 and Bahar produced match splints with low wood defects parameters i.e. crookedness and cross grain splints and these clones are considered ideal for making splints. Total splint defects were more in S7C15, Wimco-22, L-34, L-49 and Udaï clones.

Intra- and inter-ramet variation in wood traits of micro propagated L-34 clone plantation of *Populus deltoides* was studied (Gautam et al. 2008). Fiber diameter and vessel diameter significantly vary for different ramets, whereas variations were non significant for fiber length, wall thickness and vessel element length (\(\bar{U}=5\)). Non significant differences in most of the wood element dimensions for height, direction and location showed homogeneous wood properties within the ramet of L-34 clone. Significant intra-clonal variations for vessel element diameter and fiber diameter showed that these characters were not controlled in micro-propagated plantation wood of L-34 clone, while, important characters like fiber length, wall thickness and specific gravity were well controlled in L-34 clone.

2.6 Variation in pulp and paper making properties

The basic raw material for paper making is cellulose which occurs in the form of fibers in a wide variety of plants ranging from common grasses to the large trees. Pulp and paper can be made from different plants, but the suitability of a plant for this purpose depends largely on the shape of its cells. Cells are hollow structural units of plants consisting of a cell-wall enclosing a cavity. In the early stages of growth, the cell cavities contain protoplasm but soon after the cell-wall are fully formed, this disappears from the cells that are of value for paper making leaving only the hollow, tubular or quill shaped structure. These narrow, elongated plant cells with tapering ends which resemble minute threads in shape are known as fibers. In pulp and paper technology a cellulose fiber is an elongated cell with a length much greater than the diameter.

Due to widespread interest in paper making, majority of the work done in the area of wood variation was confined to tracheid length (Zobel and Van Buijtenen, 1989).
Dimensional variation in fiber both along vertical and horizontal axis of 28 years old *Daniellia oliveria* (Rolfe) Hutch and Dalz was carried out by Idu and Ijomah (2000). Variation in lumen diameter, fiber wall thickness, Runkel Ratio, flexibilityco-efficient plant height and distance from the pith were non-significant. The variation were non-significant along radial axis of the plant.

Variation in clonal wood quality of *Eucalyptus tereticornis* and its role in paper and pulp production were studied (Shashikala and Rao, 2005). A number of correlations both positive and negative between anatomical properties were also observed. Runkel Ratio, shape factor, fiber length along with basic density suggests the usefulness of some clones for the production of pulp and paper.

Variability in pulping and fiber characteristics of hybrid poplar trees due to their genetic make up, environmental factors and tree age was studied (Gopal et al., 1999). Specific gravity varied from 0.30-0.36. Pulp yield varied significantly (49-57%). Fiber length and pulp yield increased with age.

Wood species, age and density control the length, diameter and wall thickness of the fibers. These parameters influence the performance of the product (Rudie, 1998).

Within tree, intra- and inter-clonal variations in wood anatomical properties of 4 years old clonal ramets of *Eucalyptus tereticornis* Sm. were investigated (Pande and Singh 2009). The values of Runkel Ratio, shape factor and fiber-length to diameter ratio of the selected clones from Lalkuan were well within the permissible limits for producing better pulp. The wood properties of the clones were comparable with the clones of ITC-Bhadrachalam grown in South India except for fiber-length, Runkel Ratio and shape factor which were significantly higher in South India. ITC-Bhadrachalam clones grown in Bannakhera and Lalkuan clones were not different from each other on the basis of wood anatomical properties. They grouped differently for wood anatomical characters. Fiber-length of different clones was compared with the 8-10 year old seedling seed-raised plantation of the same species. Clone raised plantation wood showed better paper making wood properties than of the seedling seed raised trees even at the early age.

The fiber length affects the sheet formation or uniformity of fiber distribution. The shorter fibers form closer and more uniform sheets. The approximate limit or Runkel Ratio was 0.25 to 1.5, which produces the pulp of reasonable quality (Singh et al. 1991). The wall
fraction affects fiber flexibility. The fibers having low wall fraction and Runkel Ratio produces stronger paper.

2.7 Inheritance patterns of wood anatomical traits and specific gravity

Hereditity is the transmission of traits from one to following generations. Variation in hereditity is found in sexually produced hybrids but not in asexually produced clones unless and until mutation occurs. Studies made on mature juvenile wood characteristics have indicated that parent with high or low wood density produce progeny with juvenile wood similar to that of the parent (Zobel, 1964, 1973, Nicholls, 1967). It is also observed that based on selection of wood properties at younger age, gives fairly accurate results, on that basis wood properties of mature age can also be predicted.

Inheritance pattern of wood anatomical characters and specific gravity from parents to the F1 offspring of *Populus deltoides* was reported by Aziz et al. (2008). Results indicated that within ramet variations were significant for fiber length, vessel element length and diameter, specific gravity and Runkel Ratio and non-significant for fiber diameter. Fiber length was highest in female offspring (Bahar) followed by male offspring, female parent (G48) and male parent (G3). The variations were significant for wall thickness and were found to be highest in offspring than parents. Characters like fiber length, wall thickness and vessel element length were higher in offspring followed by parents whereas fiber diameter, vessel element diameter, specific gravity and Runkel ratio were higher in parents followed by offspring. Vessel element diameter and specific gravity were higher in male group followed by female group.

Surendran and Chandrasekharan (1984) also found high heritability in number of branches in *Eucalyptus tereticornis*. This indicates that these parameters are under strong genetic control and contain good amount of heritable additive genetic components. Heritability has an important place in tree improvement programmes as it provides an index of the relative strength of heredity versus environments. It is also useful for ranking importance of each trait in cross breeding programmes. Gains from tree breeding programmes depend on type and extent of genetic variability. The best gains are for characteristics that are strongly under genetic control and have a wide range of variability (Zobel, 1971). Johanson et al. (1955) reported that heritability estimates along with expected
genetic gain is more useful and realistic than the heritability alone in predicting the resultant effect for the best genotypes. Similar findings were also reported by Wilcox and Farmer (1967) and Singh et al. (2001) in *Populus delotides*.

The specific gravity of the branch wood exhibited highest heritability on a half-sib family basis (60.5%) whereas tracheid length exhibited highest heritability on a within-family and tree basis followed by height of the plant. It has reported that specific gravity and tracheid length in conifers are under strong genetic control (Jackson and Greene, 1958; Zobel, 1961, 1964; Byram and Lowe, 1984), therefore such variation and a high estimated value of heritability indicated that genetic improvement can be made by selection for specific gravity, tracheid length and height of the plant. The heritability estimates, however, indicate only the effectiveness with which selection of genotype can be based on the phenotypic performance, but fails to indicate the real genetic progress (Johnson et al. 1995). Therefore, high heritability need not always be accompanied by greater progress. Specific gravity, tracheid length and height of the plant recorded high heritability estimates but showed only moderate genetic gain.

The estimate of genetic variation can be made either through controlled pollination (full sib) or open pollination (half sib) tests. The latter are less precise and give information only on the additive component of variance (Zobel, 1964).

Variations observed in specific gravity of wood in segregating populations of F₂ and F₃ hybrids of *Eucalyptus citriodora* and *Eucalyptus torelliana* in 10-year-old plants (Verma et al. 2001). A subtle range in variation in specific gravity of wood was observed due to segregation, a wide spectrum of variation has been observed in individual tree specific gravity of wood belonging to F₂ and F₃ generation hybrids.

Zobel and Rhodes (1957) studied progenies of several 12-years old selfed trees, as well as open-pollinated progenies of *Pinus taeda*. In every instance, high specific gravities of the progenies were associated with high parental specific gravities. Brown and Klein (1961) found that when high specific gravity of *Pinus taeda* parents were crossed, the 2-year-old progeny had a specific gravity of 0.39, while the progeny of high × low specific gravity parents averaged 0.35. They concluded that progeny groups did inherit specific gravity differences from the parent trees. Fielding and Brown (1960) determined variance components in *Pinus radiata* from Australia, (age 6 years) in open-pollinated progeny test
and obtained a heritability estimate of 0.20. In a somewhat more comprehensive study, Squillace et al. (1962) estimated heritabilities for specific gravity and summerwood percent of both 14-year-old control- and open-pollinated progenies of *Pinus elliottii*, obtaining a narrow-sense heritability of 0.21 from the open-pollinated and 0.56 from control pollinated progeny, similar to that found by Stonecypher et al. (1963) who obtained a heritability of 0.55 from progenies of 100 open-pollinated mother trees of *Pinus taeda*. Another report of *Pinus taeda* from Texas showed heritabilities of 0.37 and 0.49 for 2-year-old control pollinated progeny (van Buijtenen, 1962), comparable to the high values obtained by Stonecypher et al. (1963).

An important recent contribution dealing with inheritance of a number of wood properties is by Goggans (1962) who determined variance components for specific gravity of springwood and summerwood separately. He also studied percentage summerwood, length, width, wall thickness and various ratios of springwood and summerwood tracheids for 5-year-old open-pollinated *Pinus taeda*, both from Louisiana and Georgia. The strong genetic control of tracheid length, tracheid width, and specific gravity (except spring wood specific gravity). Results from young progenies of *Pinus taeda* make it appear that with moderate to intense selection it should be possible to obtain an increase in specific gravity of 2 to 6 percent, based on overall specific gravity, while on the basis of the existing variation, it will be possible to gain from 8 to 15 percent of the possible improvement.

The inheritance of specific gravity in *Swietenia* and teak (*Tectona Grandis*) is somewhat weaker, but results are based on fewer studies. There is a current upsurge of interest in inheritance of wood properties in hardwoods, and soon many results will be available for trees beyond the juvenile stage (Zobel and Buijtenen, 1989).

The available evidence indicates that the inheritance of wood properties other than specific gravity is also very strong. This even includes such factor as pulp yield, tear factor and stretch of paper, which were found to differ greatly among families of the *Pinus elliottii* × *Pinus Caribaea* var. *hondurensis* hybrid, *Pinus caribaea* var. *bahamensis*, and *Pinus cubensis* families (Wright, 1987). Calculating the genetics of pulping and paper making traits is recommended by Wright, who reports that it can be done using micropulping. Such information integrates both morphological and chemical properties of wood.
**Cell Length:** Cell length differences among stands are sometimes considerable and nearly always large among trees within stands. Cell length is strongly inherited. A number of reviews related to the inheritance of cell length appeared in the 1960s (Dinwoodie 1961; van Buijtenen 1965; Smith 1967).

**Fiber dimensions:** The inheritance of fiber characteristics in hardwoods was reviewed by Zobel (1965) but there has been a great deal of information developed since then, especially for the genera *Eucalyptus* and *populus*. Evidence for hardwood is somewhat scant, but those studies reported indicate that there is a moderate genetic control of cell length. A striking example of a large increase in fiber length was that obtained through polyploidy in *Populus* spp., where van Buijtenen *et al.* (1958) found fiber length to be increased by 21-26%.

Otegebye and Kelson (1980) found family heritability of 0.82 and 0.94 for fiber diameter and fiber wall thickness in young *Eucalyptus viminalis*. These represent some of the highest values reported related to inheritance of fiber dimensions. Fiber wall thickness and specific gravity were two important wood traits showed 0.515 and 0.297 broad sense heritability. The heritability values reported for different species of *Populus* are in the range of 0.56 to 0.70 (Farmer and Wilcox 1966; Farmer and Wilcox 1968; Reck 1974. The heritability values for fiber length for *Populus deltoides* was reported as 0.36 (Farmer and Wilcox 1968); for *Populus* polyploids was 0.50 (Einspahr *et al.* 1963) and for *Populus trichocarpa* was 0.71 (Reck, 1974). Though, evidences on heritability for hardwoods are somewhat scant, yet those studies indicate that there is moderate genetic control of cell length (Zobel and Buijtenen, 1989).

There are scattered reports on inheritance of other morphological wood characters but very few indicate more than a tendency towards inheritance, usually towards intermediacy between parents. Typical is the study by Pryor *et al.* (1956), who reported that wood properties of most *Eucalyptus* hybrid were intermediate or the same as the parents, and seemed to be under multiple factor control.