DISCUSSION
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GROWTH RINGS

Growth rings are formed in the stem of Perennial plates. There is a belief that growth rings occur in the trees of temperate climate but not of tropics. This notion about the tropical trees is only partially true as 25 percent of the tropical trees exhibit demarcation of radial growth activity (Chowdhury, 1964). Studies on growth rings in tropical taxa happen to be only limited (Chowdhury, 1939, 1940a, b; 1964; Chowdhury and Rao, 1949; Chowdhury and Ghosh, 1946; Tomlinson and Craighead, 1972). In his paper on growth rings on tropical trees and taxonomy, Chowdhury (1964) described the anatomy of growth rings in Indian tropical trees and recognised five different types.

In the present study, 70 percent of the taxa investigated have been observed to produce distinct growth marks. Out of the 111 taxa, 8 main types of growth rings with several sub-types were recognised. Leaving aside the type I, all the other types recognised in the present study are of new types based on characters other than those employed by Chowdhury (1964).

In a recent communication Carlquist (1980) recognised thirteen types of growth ring in different hardwood species. In addition, he also described several sub-types and their functional aspects from ecological point of view.
VESSEL ELEMENT LENGTH

Vessel element length has been considered by Carlquist (1975) and Baas et al. (1983) to be a sensitive indicator of ecological strategy of a given taxon. Long vessel elements have been noticed to occur in mesomorphic conductive system and the short ones in mesomorphic woods, although, the length of vessel segments is almost independently controlled by the length of fusiform cambial initials (Bailey, 1923; Hejnowicz and Hejnowicz, 1958; Carlquist, 1962). The vessel length have also been reported to differ in different positions in a tree trunk (Swamy et al., 1960; Sastraspadja and Lamoureux, 1969; Sundrasivarao et al., 1973; Ghouse and Yunus, 1973; Ghouse and Iqbal, 1977; Khan and Ghouse, 1977; Sundrasivarao and Nazma, 1977; Iqbal and Ghouse, 1977, 1979; Bhat and Karkkainen, 1981a,b; Ghouse and Hashmi, 1981; Bhat et al., 1983; Ghouse et al., 1983, 1985).

Ecological considerations have demonstrated that short narrow vessels are adaptive in situations where periods of low soil moisture and low humidity create high tension in the water column (Carlquist, 1966a, 1975, 1982a,b). The larger vessels are on the other hand involved in better conduction as the conductivity in ideal capillaries is proportional to the fourth power of radius or diameter (Zimmermann, 1978b).
The present findings on vessel element length and diameter clearly indicate that the local flora invariably have vessels which are short and narrow in the majority at the taxa investigated, a condition which is essential to support a situation in which soil moisture and humidity are very low in major part of the year.

Webber (1936) in a survey of desert and chaparral shrubs found that vessel elements in these shrubs are much shorter and narrower than in dicotyledons at large. Novruzova (1968) and Baas (1973) also noted the same trend of vessel element length in dry sites. Carlquist (1966a) found a distinct decrease of both vessel diameter and vessel element length with increasing aridity in his survey of wood anatomy in Asteraceae. Many classical workers of the past (Scholander et al., 1965; Zimmermann and Brown, 1971; Anderson, 1972; Carlquist, 1977b, 1980; Horak, 1981; Zimmermann and Jeje, 1981; Zimmermann and Potter, 1982; Baas et al., 1983; Zimmermann, 1978b, 1982, 1983) also indicate that the short vessel length and narrow diameter of vessels go together with taxa exposed to arid environment.

Lianas, as an ecological group in the local flora, have shorter and broader vessel elements suited for rapid rate of flow (Scholander et al., 1955, 1961). Lianas do not experience strong negative tension in xylem, therefore the wider vessel elements would be of positive selective value as they offer less friction in conduction.
The succulents, on the other hand show longer and wider vessel elements (half of lianas in vessel diameter) which appears to be related to safer water conduction. The relatively uniform rates of transpiration provide low tension in the conductive system of succulents and, therefore, woods in these species would be expected to have longer and wider vessel elements as professed by Carlquist (1970, 1975).

PITS, PERFORATION PLATES AND END WALLS

Three types of pits have been observed in the present survey of local flora. About 75% of the species investigated have simple pits. In about 85% of the cases, simple pits have alternate arrangement, while the rest 15% have opposite pitting arrangement. Nearly, 21% of the species have bordered pits and about 4% scalariform pits (Table-8). Alternate lateral wall pittings offer maximal strength to the lateral walls of vessels especially the minute pittings (Metcalf and Chalk, 1985). Alternate pitting is invariably associated with simple perforation plates and short vessel elements in the presently investigated species as observed by Frost (1931).

Structure of perforation plate is highly variable in angiosperms as a whole (Frost, 1930a,b; Bailey, 1944, 1953; Cheadle, 1953; Bierhost and Zamora, 1965; Zamora, 1966; Meyer and Muhammad, 1971; Basset, 1976; Wagner, 1977; Butterfield and Meylan, 1980;
Mehra and Soni, 1984; Muhammad, 1973, 1984). Bailey (1944, 1953) has shown the long narrow-vessel elements with scalariform perforation plates to be primitive, short and wide vessel elements with simple perforation plates as specialized. Elements having scalariform perforation plates with fewer bars or with transitional perforation plates are considered to be intermediate in specialization. This trend of vessel specialization is unidirectional and irreversible according to Bailey (1944). Recent findings on the basis of ecological studies, however, have challenged this generalization (Baas, 1973; Van der Graaff and Baas, 1974; Metcalfe and Chalk, 1983). Parameswaran and Liese (1973) have also shown that the phylogenetic specialisation trend proposed by Bailey (1944, 1953) fails to explain the development of complex multiperforate plates from the scalariform type. The present investigation indicates that the simple perforation plate may occur even in structurally unspecialized family of dicotyledons, a situation which is difficult to explain from phylogenetic point of view held by Bailey (1944, 1953).

The present study further indicates that the local flora is essentially with simple perforation type as 97.3% of the members bear simple perforation plates. The flora of South California (Adams, 1949), Hawaiian Islands (Brown, 1922), Lowland tropics (Baas, 1973) and South Africa (Carlquist, 1975) have also been reported to have simple perforation plates, as a means of adaptation.
to the dry arid climate in which they thrive, though the actual relationship between the perforation plate and the environment of different taxa is yet to be established. A number of workers have also made survey of perforation plates in different taxa belonging to different parts of the world and have tried to correlate it with their ecologies (Brown, 1922; Kanehira, 1921a,b; 1924; Bailey, 1944; Adams, 1949; Bailey and Swamy, 1949; Cheadle, 1953; Wilson, 1960; Carlquist, 1961a, 1962; Bierhorst and Zamora, 1965; Zamora, 1966; Versteegh, 1968; Baas, 1973; Metcalfe and Chalk, 1983; Muhammad, 1984; Bisen and Sharma, 1985). Baas (1976) has shown that the occurrence of scalariform perforation plates is far more frequent in montane flora than in everwet tropical lowland or in arid regions. Reduction of bar number in more xeric condition has been noticed by various workers (Carlquist, 1975; Dickison et al., 1978; Dickison, 1979).

**VESSEL DIAMETER AND FREQUENCY**

It is a well established fact that the vessel diameter and its frequency per unit area of wood vary to a great extent in different species, especially in trees, depending on the position across the tree at a given height, as well as at different level of the tree trunk (Priestley et al., 1935; Kujala, 1946; Fahn, 1958a,b; 1959; Taylor, 1968; Zasada and Zahner, 1969; Taylor and Wooten, 1973; Datta et al., 1976; Ezell, 1979; Vurdu and Bensend,
1980; Bhat and Karkkainen, 1980, 1981b; Pukazawa and Ohtani, 1982; Cumbie, 1983; Iqbal and Ghouse, 1977, 1979, 1983; Carlquist, 1984a, c; Dodd, 1982, 1984; Ghouse et al., 1983, 1985). However, not much has been done to correlate the vessel diameter and the vessel frequency with the ecological conditions of the habitat.

Narrow vessels are positively correlated with xeromorphy in any given group of dicotyledons (Carlquist, 1966). The area of vessels in such xeromorphic woods is invariably compensated by greater vessel number per sq./mm of transections (Carlquist, 1977a, 1980, 1982a,b, 1984d; Danin, 1983). The narrow vessel elements have been frequently come across in taxa which grow in such ecological situations where periods of low soil moisture and low humidity create high tension in vessel water columns (Jeje and Zimmermann, 1979; Zimmermann, 1978a, 1982, 1983). In the present investigation it has been found that in the majority of taxa the vessel segments are narrow and short, and this is coupled with high frequency of vessels per unit area of wood transection. In some cases of this sort, the vessel frequency goes as high as hundred and even more per mm$^2$. In shrubs the vessel diameter and frequency are almost the same as in xeromorphic taxa. Thus, the xeromorphic trees and shrubs appear to manage for their survival by virtue of these narrow and numerous vessels which can be attributed to offer a high degree of safety under water stress condition by resisting tension in water columns better than wider vessels (Fahn, 1964; Scholander, et al.,
1965; Baas, 1976; Zimmermann, 1978a, 1982, 1983; Baas et al., 1983). Therefore, these species with narrow and numerous vessels form a distinct ecological group which could be designated as xeromorphic species having a trait for drought resistance and capable of surviving under high water stress condition (Baas, 1976; Carlquist, 1977a, 1980; Baas et al., 1983).

In mesomorphic trees of the region, the vessel diameter is comparatively large (more than xeromorphic group) and the frequency shows a significant fall e.g. 13.25-36.25 per mm² (Table 7). These species survive in the garden and are cultivated with sufficient irrigation facilities. According to Carlquist (1975), long and wide vessel elements are of adaptive value where soil moisture is abundant and transpiration is relatively uniform.

In case of lianas it has been found that the conductive area per mm² of wood transection is lower and the diameter is five times more than in xeromorphic species. The wide vessels of lianas have minimal friction to water movement and are, therefore, far more efficient than the conductive areas alone would suggest (Carlquist, 1975). The selective value of wide vessels is positive only where high negative tension in water column does not exist. Presence of numerous, wide vessels with relatively little mechanical tissues characterises the lianas but would be an unsatisfactory xylary formula for a tree (Baas, 1982; Baas et al., 1983).
Stem succulents seem to fall appreciably below the mesic woody species in conductive areas per unit transection (Table 7). They have an average vessel diameter more than double the size of xeromorphic trees and shrubs but have lesser number of vessels per unit area than the xeromorphic group. This is exactly what one can expect, because succulents have low transpiration rate yet moderate negative pressure. A succulent has a system for rapid absorption of water on a seasonal basis, but with a slow but steady rate of transpiration. The low conductive area per unit transection seems directly related to low transpiration (Zimmermann, 1978a, 1982, 1983).

VESSEL GROUPING

Vessels are found solitary as well as in groups in the different taxa investigated. Grouping varies from 2.48 to 6.78 in different species. Sometimes they are found in clusters or in chains of radial multiples. This grouping of vessels seems strategic from functional point of view (Carlquist, 1975, 1977a, 1980, 1984b). To face the fluctuating temperature, plants develop grouping systems of vessels which consist of both broad and narrow ones. There are many narrow vessels around a broad vessel and they function according to the need to meet a particular situation. The broad vessels prove efficient to maintain water column, while the narrow vessels are useful from safety point of view (Carlquist, 1977a, 1980; Zimmermann, 1982, 1983).
VULNERABILITY AND MESOMORPHY RATIO

Carlquist (1977a) coined the terms vulnerability and mesomorphy for wood ecology. Vulnerability ratio indicates the mean vessel diameter divided by the mean number of vessels per mm$^2$ of wood transection. Although vessel diameter and vessel number per mm$^2$ are roughly inversely proportional for mesophytes (Carlquist, 1977a), the vulnerability ratio varies in different taxa (Carlquist and De Buhr, 1977). The xerophytes tend to have narrow and more numerous vessels per mm$^2$ than mesomorphic woods. The low values of "vulnerability" offers high degree of "safety" under water stress conditions. If the ratio of vulnerability is far less (0.1-0.5) the greater would be the degree of xeromorphy (Carlquist, 1975, 1977a, 1980). This situation leads to "redundancy" of vessels, where air embolism formed under water stress would disable the conductive ability of some vessels, while many other vessels would probably remain unaffected, impairing the total conductive ability only slightly.

Another index can be formulated by multiplying vulnerability ratio with vessel element length. This value is termed as mesomorphy (Carlquist, 1977a). The lower the value for this index, the greater the degree of xeromorphy (Carlquist and De Buhr, 1977). If the ratio of vulnerability is high the degree of mesomorphy grows greater in the species.
After working out vulnerability and mesomorphy ratio of all the 111 species in the present study, it has been found that 77.48% species of trees and shrubs fall under xeromorphic group as their vulnerability ratio is below one. About 13.51% of the species of trees have a high vulnerability ratio and hence fall under mesomorphic group. In other words, 77.48% of species have developed structural means to withstand high water stress by evolving short, narrow and numerous vessels. On the other hand, the species of mesomorphic group amount to be about 22.62% in which vessels are broad and few in number per mm$^2$ and have highly vulnerable wood structure.

Lianas have vulnerability ratio as more than two, and, hence, do not fall under xeromorphic group. Succulents also have a few but narrow vessels per mm$^2$ and abundant parenchyma. The succulents have a system for rapid absorption of water on a seasonal basis but with a slow and steady rate of transpiration. The low conductive area per unit transection seems directly related to low transpiration.

**FIBRE LENGTH**

Considerable amount of work exists to the literature regarding wood fibre length in dicotyledons and gymnosperms (for review Dinwoodie, 1961; Ghous and Iqbal, 1981).

Studies on variation of wood fibre length invariably indicate that the length varies considerably in different taxa as well as in the same taxon depending on the position across the tree
trunk or along the tree axis (Bailey and Shepard, 1915; Bethal, 1941; Fegel, 1941; Gleaton and Saydah, 1956; Kujala, 1946; Ollinmaa, 1958; Pattanath, 1972; Purkayastha et al., 1974; Khan, et al., 1979b,c; Vurdu and Bensend, 1979; Bhat, 1980; Bhat and Karkkainen, 1981a; Ghouse and Iqbal, 1981; Ghouse et al., 1983; Dodd, 1984).

In the present study xeromorphic and mesomorphic trees have an average fibre length as 1154.70 um and 1162.69 um respectively (Table 47). Shrubs have comparatively shorter fibres (mean fibre length = 907.71 um). Relatively long libriform fibres in any species appear to connote greater mechanical strength (Carlquist, 1975). Longer fibres in xeromorphic and mesomorphic trees indicate that these trees need more mechanical support than shrubs. Mostly the trees presently investigated are of large size with fairly big crown. As reported earlier by a number of workers there appears to be a fairly close association between the wood structure and the crown of the tree in the local flora (Richardson, 1961; Larson, 1969; Denne and Dodd, 1980). Further, the local trees face stormy winds especially in summer months. To face these difficult situations with their huge crown, it is necessary for these trees to develop sufficient mechanical support by possessing longer fibres.
Lianas as a group have the shortest fibre length (560.28 um), as they require very less mechanical support. The succulents have longer fibre length (Table 52) than as they face extreme external forces.

The present study shows that about 18% of the investigated species have septate fibres; 10% species have both septate and non-septate and 72% have only non septate fibres (Table 42). The presence of either septa or nuclei or both are indicative of the longevity ofoplasts. In other words septate fibres have some of the features of parenchyma (Carlquist, 1975). They may be considered libriform fibres functioning as parenchyma, in essence. Living fibres are not only a substitute for axial parenchyma, they occur precisely where axial parenchyma is absent (Wolkinger, 1969, 1970, 1971).

**RAYS**

Rays constitute a vital portion of wood and bark. The origin and development of ray initials have been worked out in detail by Barghoorn (1940a, b; 1941a, b) and Braun (1955) in conifera and dicotyledons. Some other pertinent works related to the ray initial formation include those of Klinken, 1914; Chattaway, 1933, 1938; Bannan, 1950, 1951, 1953; Boureau, 1957; Evert, 1959, 1961; Cumbie, 1963, 1967, 1969a, b; Srivastava, 1963; Ghouse and Yunus, 1973; Ghouse and Iqbal, 1977; Ghouse and Hashmi, 1980.
The proportion of ray initials in a number of tropical trees varies from 15-40% depending on the genetic make up as well as on the age and size of the tree (Paliwal and Srivastava, 1969; Ghouse and Yunus, 1973, 1974, 1976; Ghouse and Iqbal, 1973, 1977; Khan et al., 1979a, Ghouse and Hashmi, 1977; Ghouse et al., 1975a, b, 1976, 1980, 1982; Bartwal et al., 1983). However, the earlier findings on this aspect show that the ray elements hardly constitute over 10% of the wood, particularly in conifers and hard woods of temperate world.

In contrast to the extremely low content of ray elements in the temperate taxa, the rich quantity of rays in tropical trees of India appears to be characteristic of its own.

In the present study, the qualitative as well as the quantitative estimation of ray system has indicated that most of the species have predominantly multiseriate rays (93% species). In only 7% species, multiseriate rays are absent. The balance between multiseriate and uniseriate rays varies in different species.

The past work on wood rays shows that the ray height decreases with higher latitude and altitudes (Carlquist, 1966; Baas, 1973; Van der Graaff and Baas, 1974; Van den Oever et al., 1981) and a similar correlation has been found to hold true for increased drought condition in case of some compositae (Carlquist, 1966a). In the present investigation, it has been found that the majority of the members of the regional flora of Aligarh also have short rays. This short ray system so common in the regional flora
appears to have been developed as a means to combat the local arid condition of the region as noticed by Carlquist (1966a) in case of some Compositae. The analysis of ray height in the different ecological categories investigated, has also revealed the same. The mesomorphic trees have the largest height value average while the xeromorphic shrubs the lowest, the xeromorphic trees falling in between.

There appears to be a strong tendency for procumbency in temperate species than in tropical ones (Carlquist, 1980). In the present investigation it has been found that in 98% species which are dominated by multiseriate, and 60% species dominated by uniseriate rays, have procumbent cells in a predominating position. Further, the regional flora comprises 90% species with heterogeneous rays, the rest having homogeneous ray systems. A survey of literature in this regard (Moll and Janssonius, 1906-1938; Kanehira, 1921c; Hayashi et al., 1973; Normand and Paquis, 1976; Grosser, 1977; Schweingruber, 1978; Meylan and Butterfield, 1978), indicates that the temperate flora of New Zealand has a low percentage of genera with homogeneous rays while the floras of Formosa, Java and New Guinea are characterised with high percentage of genera with homogeneous rays. New Zealand follows the common trends for temperate and sub-tropical flora (Van der Graaff and Baas, 1974; Baas, 1976; Meyland and Butterfield, 1978). The extremely low percentage of genera (10%) with homogeneous ray system in the local vegetation as a whole, appears to be an ecological adaptation to the arid conditions of the region.
LENGTH RATIO OF FIBRES TO VESSEL ELEMENTS

The ratio for length of libriform fibres to those of vessel elements is more than one in all categories of plants investigated (Table 2). On the basis of this ratio, if the different ecological categories are arranged in descending order the following picture would arise: xeromorphic trees (4.60), mesomorphic trees (5.40), lianas (4.07), shrubs (3.30) and the succulents (2.17) (table 53). Similarly, the regional species are followed by introduced and exotic species in the order of fibre vessel length ratio (table 52).

Carlquist (1975) is of the opinion that if the family is predominantly woody, one would expect that the ratio of libriform fibre length to that of vessel elements would exceed 2.0. Carlquist (1975) is also of the opinion that if mechanical strength is related to relatively long fibres, one would expect a high ratio in tree species. The present investigation also reveals the same. The investigated species are predominantly woody, the average ratio for the different ecological categories investigated exceed 2.0. This is obviously due to the much needed mechanical strength in habitats like the one present at Aligarh, a semi-arid zone.

AXIAL PARENCHYMA

Functions of parenchyma in xylem have been understood tardily, and even today we need clarification. They are probably
more complex and subtle than those of tracheary elements.

By means of staining reaction Braun (1970), Braun and Wolkinger (1970) have demonstrated that axial parenchyma cells are the sites of photosynthates mobilization and translocation, storage and deposition. Although this is most obvious in some temperate trees, it has been demonstrated for some tropical woods as well.

In the present investigation, it has been found that in about 80% species, parenchyma surrounds the vessel completely or partially (table-28). The possible significance of this type of distribution of parenchyma is the lateral movement of ions from xylem vessels into the surrounding tissues (Lauchli, 1972). Rest 20% of the species have axial parenchyma in diffuse form.
Type of Growth Rings

CR = Growth Range

Fig. CR-1

Percentage

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30