

CHANGES IN ANATOMICAL FEATURES ALONG THE ALTITUDINAL AND RAINFALL GRADIENTS IN PAKISTAN

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ABSTRACT

Altitude causes changes in the environmental factors thus alter the anatomy of plants greatly. Anatomical modifications of plants under broad environmental changes concerning global climate changes along the altitudinal gradient are lacking. Therefore, the present investigation was conducted to find out the structural modifications of a wide range of species growing in contrasting habitat along the altitudinal and rainfall gradients in Pakistan. For such perspectives, perennial shrubs were collected along the altitudinal transect ranges 410-2941m (a.s.l). The transect was passed through five climatic forest types of Pakistan during 2018. The wood parameters were measured from the macerated wood materials included length of vessel element, vessel element diameter, fiber length, fiber diameter, fiber lumen diameter; wall thickness, slenderness ratio (SR), Runkel ratio (RR) and coefficient of suppleness (CS). Analysis of variance and cluster analyses were used for data simplification. Alpine flora exhibited the shortest vessel and fibers while the longest vessels were recorded in montane Sub-tropical plateau forest. However, no changes were recorded in-wall diameter, Runkel ratio and coefficient of suppleness were observed with the changes in altitude and climatic factors.

Keywords: Anatomy, Altitude, Rain-fall gradient, Pakistan.

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INTRODUCTION

Altitude is an easily measurable surrogate for a number of environmental factors and thus is often used to measure changes including anatomical and morphological characteristics. Variations in morphoanatomical features at different altitudes are due to the associated variations in light intensity, temperature, rainfall, differences in availability of nutrients, wind, humidity and soil chemistry (Hunter, 2015). Increasing altitude changes the climate that has the strongest and wider impact and can alter the morphology, size and proportion of wood anatomical elements in plants (Usta *et al.*, 2014; Topaloglu *et al.*, 2016; Kaygin *et al.*, 2016). Various studies had shown that ecological factors strongly influenced properties of wood i.e. in *Alnus* by Noshiro *et al.* (1994), *Rhododendron* by Noshiro *et al.* (1995), *Origanum vulgare* by Kofidis *et al.* (2003), *Quercus pontica* by Yilmaz *et al.* (2008), Hornbeam by Kiaei *et al.* (2011, 2012), *Chromolaena odorata* by Jimoh and Saheed (2014) and *Carpinus betulus* by Kiaei *et al.* (2019). Although these studies showed important relationship between ecological factors and anatomical characteristics of wood, however the way, however, the method in which broad altitudinal gradient altered the anatomical characteristics of wood under diverse climatic factors is still lacking in details among diverse plants.

There are variety of structural modification in plants occurring in different environments (hydrophytes to

xerophytes) along the altitudinal gradient. Typical plant structure develops in the region of average or optimum water supply such as mesophytic environment that is located at median altitudes (Jimenez-Noriega *et al.*, 2017). The most common modifications are found in desert flora and the plants growing in other extreme habitats like high mountain ecosystems. These stressful environments provide an ideal setting for experiments to explore alteration in diverse species, as change of climate along the ecological gradients cause selection pressure (Bresson *et al.*, 2010). The elaborated structural modifications ensure their survival in such habitats. Knowing how plant fitness and anatomical traits change along altitudinal/ rainfall gradients, is essential for understanding the response of plants to global change drivers (Pescador *et al.*, 2015). Shifts in plant anatomical traits within or between sites and/or species across altitudinal gradient may also reflect deterministic processes of survival of fittest. Environmental gradients like altitude have been suggested to explain the shift of anatomical trait at diverse biological levels (Pourtahmasi *et al.*, 2011). Due to its important function of water conduction and storage, vessel has been the main focus in research among different types of cells in the wood. Freezing or drought can disrupt the xylem stream, hence on average vessels are narrow in plants of cold or dry regions as compared to vessels of plants growing in warm and moist regions. Ecotaxonomists have suggested narrow vessels as key adaptations to these extreme environmental conditions, as the climate is the

main driver of variations in vessels diameter (Pfautsch *et al.*, 2016; Hacke *et al.*, 2017). Selection also favors narrow distal vessels, because diffusion of water is vital in driving the conduction stream, and it is highest when vessels are narrow (Olsona *et al.*, 2018).

The influences of environmental factors on wood fiber length and diameter and their derived values (Runkel ratio, coefficient of suppleness and Slenderness ratio) are well defined on mechanical properties of paper and pulp. For production of fiberboards, paper and pulp, wood fibers are very important. Kiaei *et al.* (2019) also demonstrated that fibers are very important in predicting the mechanical properties of wood pulp. Before production the fibers determine the suitability of lignocellulosic materials, therefore the importance of morphological characteristics of fibers are already depicted (Ona *et al.*, 2001; Ververis *et al.*, 2004). With increase of altitude, the average length and diameter of fiber decreased. Similar results had been shown by many studies i.e. Noshiro *et al.* (1994) for *Alnus nepalensis*, Noshiro *et al.* (1995) for *Rhododendron*, Yilmaz *et al.* (2008) for *Quercus pontica* and San *et al.* (2016) for *Paulownia*. Slenderness coefficient (SC) that is obtained from the fiber length divided by fiber diameter shows the quality of paper. According to Ashori and Nourbakhsh (2009) high value to SC delivers well bonded and better forming paper. This characteristic is a crucial factor as it has a significant influence of double folding resistance, tear, breaking off, burst and strength, shown by paper test in physical properties of paper (Kiaei *et al.*, 2014).

Therefore, the present investigation was planned with the objective to contribute to the knowledge of

ecological anatomy and to investigate the structural modifications/adaptations of a wide range of species growing in contrasting habitat along the altitudinal and rainfall gradients.

MATERIALS AND METHODS

The study sites were in four areas in Pakistan (latitude). The sites represent a range of habitats along the altitudinal and rainfall gradient. In the beginning, there lies the tropical thorn forest. This includes low land arid tract which has been described in detailed by Dasti and Agnew (1994) while the middle of transect is occupied by Montane sub-tropical plateau. The transect was terminated at Montane temperate forest followed by Alpine pastures and Sub Alpine dry temperate forest during 2018.

Only woody perennial dicot bushes were investigated for wood parameters. All the wood samples were collected from May to August, 2018 to avoid seasonal impact on wood morphology. Ten wood samples were collected randomly at each site from ten different species of bushes. A 2 cm thick piece of wood was cut 15-cm below the tip from the main branch. The altitude was measured by using an altimeter. Rainfall and temperature data were gathered from the literature and/or local forest department (Table 1). Plants were identified in the field whenever possible, and the vouchers of the remaining plants were identified according to the flora of Pakistan (Stewart, 1972).

Table 1. Habitat types with environmental data.

Habitat types	Temperature (°C)	Altitude (m)	Rainfall (cm)
Tropical thorn forest (desert forest)	24.5°C	410	9.1
Montane sub tropical plateau forest	21.5°C	915	36.6
Montane temperate forest	10.27°C	1925	59.3
Alpine pastures (desert habitat)	1.6°C	2100	30.0
Sub Alpine dry temperate scrub	16.7°C	2941	5.4

Table 1S: The scientific names of plants with their families used in present investigation.

Tropical Thorn Forest (Desert Forest)	
<i>Abutilon indicum</i> (L.) Sweet	Malvaceae
<i>Tamarix aphylla</i> (L) Karst.	Tamaricaceae
<i>Suaeda fruticosa</i> (L) Forssk.	Chenopodiaceae
<i>Prosopis cineraria</i> (Linn) Druce.	Fabaceae
<i>Capparis aphylla</i> Roth.	Capparaceae
<i>Acacia nilotica</i> (Linn) Delile	Leguminosae
<i>Prosopis juliflora</i> Swartz	Fabaceae
<i>Zizyphus jujuba</i> Lam. non-Mill.	Rhamnaceae
<i>Achyranthus asper</i> L.	Amaranthaceae
<i>Atriplex aphylla</i> Iljin	Chenopodiaceae
Montane Subtropical Plateau Forest	

<i>Cresc. cretica</i> L.	Convolvulaceae
<i>Adhatoda vasica</i> Nees	Acanthaceae
<i>Olea europaea</i> L.	Oleaceae
<i>Nerium indicum</i> Mill.	Apocynaceae
<i>Berberis aristata</i> DC.	Berberidaceae
<i>Zizyphus nummularia</i> (Burm.f) Wight.	Rhamnaceae
<i>Acacia modesta</i> Wall.	Leguminosae
<i>Olea cuspidata</i> Wall. ex DC.	Oleaceae
<i>Debregeasia salicifolia</i> (D.Don) Rendle	Urticaceae
<i>Ficus palmata</i> Forssk.	Moraceae
Montane temperate forest	
<i>Plectranthus rugosus</i> Wall	Lamiaceae
<i>Rosa macrophylla</i> Lindle	Rosaceae
<i>Salix acmophylla</i> Boiss	Salicaceae
<i>Rubus gracillus</i> Roxb.	Rosaceae
<i>Indigofera gerardiana</i> Wall.	Fabaceae
<i>Spirea vacciniifolia</i> D.Don.	Rosaceae
Sample	Unidentified
<i>Rumex nepalensis</i> Spreng	Polygonaceae
<i>Sageretia theezans</i> (L.) Brongn	Rhamnaceae
<i>Otostegia lumbata</i> (Bth) Boiss.	Lamiaceae
Alpine Pastures	
<i>Rhamnus purpurea</i> Edgew.	Rhamnaceae
<i>Eremostachys viceryi</i> Bth.	Lamiaceae
<i>Achyranthes bidentata</i> Blume	Amaranthaceae
<i>Cotoneaster acuminata</i> Lindl.	Rosaceae
<i>Rubus paniculatus</i> Sm.	Rosaceae
<i>Artemisia parviflora</i> Roxb.	Asteraceae
<i>Zizyphus sativus</i> Gaertn.	Rhamnaceae
<i>Quercus dilatata</i> Lindl.	Corycaceae
<i>Skimmia laureola</i> (DC) Sieb and Zacc.	Rutaceae
Sample	Unidentified
Subalpine dry temperate forest	
<i>Hippophae salicifolia</i> D. Don	Elaeagnaceae
<i>Centaurea</i> sp. L.	Asteraceae
<i>Haloxylon griffithii</i> (Moq) Bunge	Chenopodiaceae
<i>Myricaria dahurica</i> (Wild) Ehrenb	Tamaricaceae
<i>Tamarix</i> sp. (L) Karst	Tamaricaceae
<i>Atriplex</i> sp.	Chenopodiaceae
<i>Capparis spinosa</i> L.	Capparaceae
<i>Juniperus</i> sp. L.	Cupressaceae
<i>Capparis parviflora</i> L.	Capparaceae
<i>Rosa webbiana</i> Wall	Rosaceae

Maceration of wood material: The outer portion of the stem toward the epidermis was peeled off to remove epidermal tissues. The remaining part of the wood was cut into pieces before being macerated. Maceration of wood material was performed by Jeffery's method. Small wood pieces were placed in 10% aqueous nitric acid and 10% aqueous chromic acid. The solution was heated for fifteen minutes. A thick glass rod with rounded ends was used for crushing the material very gently. The material was washed thoroughly with water to remove the acid and then washed with 0.5N NaOH solution to remove acid crystals and after that stained with 1% Safranin. Three slides were

prepared for each specimen, and three observations were taken from each slide. Thus, a total of 90 observations were made for each habitat. Length of vessel element, the diameter of vessel element, fiber length, fiber diameter, fiber lumen diameter and wall thickness were measured by following (Rasheed, 1999).

Data obtained from the above parameters were used to calculate the following derived parameters.

1. Slenderness ratio (SR) or felting power which is the measure of the tear property of pulp in paper production was calculated from

$$SR = L/D$$

- (L= Fiber length, D= Fiber diameter).
- Runkel ratio (RR), which is the measure of the suitability of fiber for paper production was calculated from
 $RR = 2w/k$
 (w= fiber wall thickness, K= fiber lumen diameter).
 - Coefficient of suppleness (CS) or flexibility coefficient, which is the measure of strength properties of paper was calculated from
 $CS = K/D$

Data analysis: The data for each parameter was subjected to one-way analysis of variance (ANOVA), using STATISTICA (version 5.5 a) at 0.05 level of significance. The significant differences between the species were derived from Duncan's (1955) Multiple Range Test. Cluster analysis of the whole data set was made by using a Multivariate Statistical Package (Warren C. Kach 1986-1993, Value U.K). The similarity among the plant groups was established by specifying three levels of divisions in the hierarchical diagram obtained from Cluster analysis.

Cluster analysis: Cluster Analysis was used to identify whether the anatomical attributes would cause species to sort according to habitat, taxonomic group or otherwise. Four plant groups were delineated at three levels of division of the hierarchical diagram (Fig. 1). These groups were not arbitrary but related to environmental conditions. The application of hierarchical cluster analysis to all the data set revealed that species belonging to low land (Group 1) were separated from those of high at the first hierarchical level. At the second hierarchical level, low altitude mountain forests were separated from high land alpine scrubs. The third hierarchical level separated species belonging to wet montane temperate (Group 3) forest from the species belonging to plateau (Group 4) were separated from the low altitude scrub pastures (Group 5). It is interesting to note that species belonging to each group exhibited about 80% homology. The variability (standard deviation) among the species belonging to a particular group was exhibited.

RESULTS

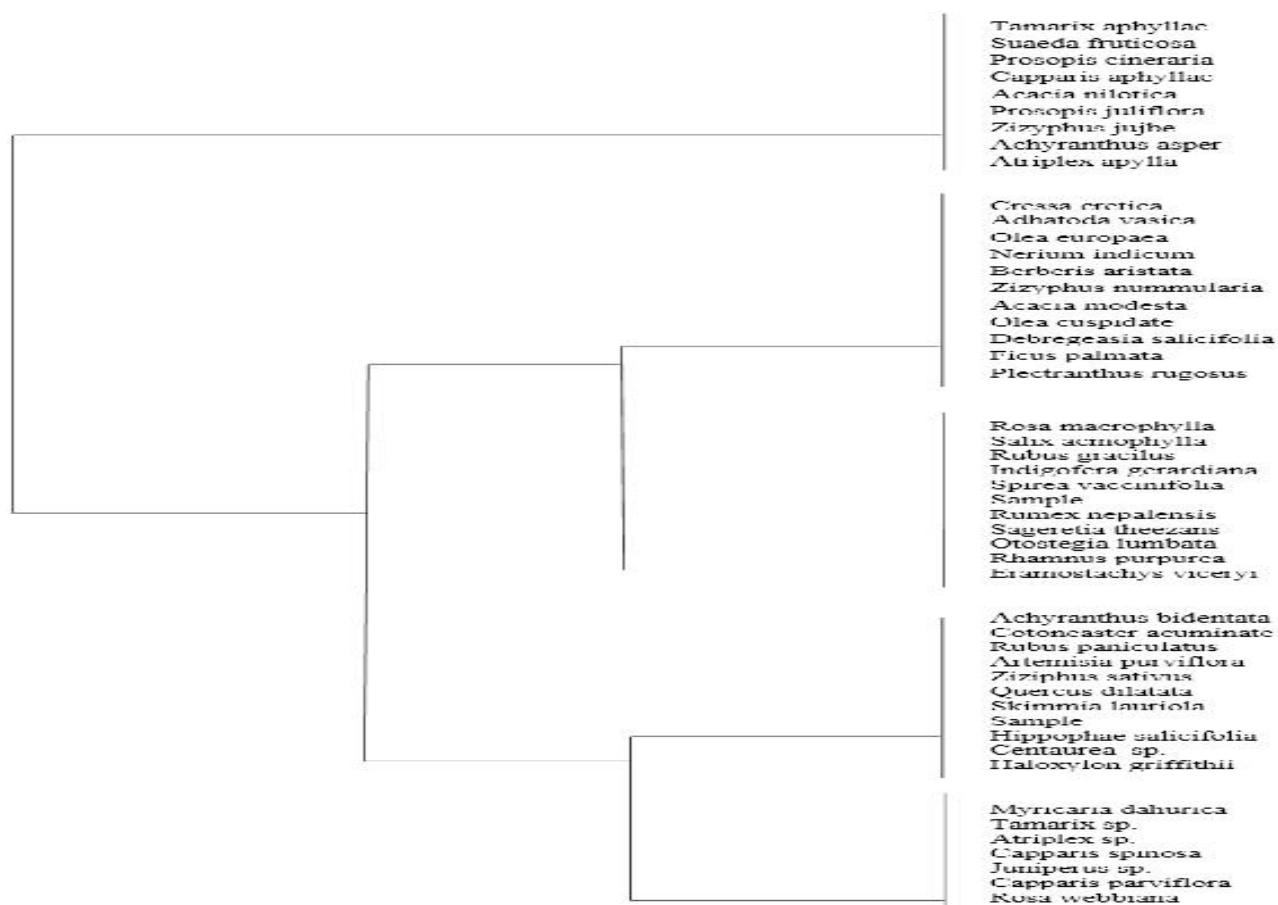


Fig. 1. Hierarchical diagram of cluster analysis.

Structural diversity: Vessel length differed significantly (Table 2) between the plant groups belonging to different forest types ($F= 148.48$, $P= 0.000$). The shortest vessels (43.74m) were found in plants growing on sub alpine habitats. The longest vessels (122.61m) are the characteristic of the component species of subtropical plateau vegetation. Bushes belonging to high or low wet temperate forests showed the intermediate vessel length. ANOVA detected significant differences in vessel

diameter ($F=16.04$, $P=0.000$). Plant species growing at high altitudes (subalpine habitats) had narrow (16.6–17.8 m) vessels than the species occur at relatively low altitudes and belonging to either tropical or temperate habitats. Wider vessels (24.589–22.022m) are found in plants growing either in drought-prone areas (Tropical thorn forest) or on rocks which generate runoff (mountain wet temperate forest), but little water is available for plants.

Table 2: Analysis of variance of vessel length, vessel diameter, fiber length and diameter, lumen width, wall width, Slenderness ratio (SR), Runkel ratio (RR) and Coefficient of suppleness (CS) from five different altitudes.

Source	DF	Mean Square	F value	P-value
Vessel length	4	95020	148.8	0.000
Vessel diameter	4	976.9	16.04	0.000
Fiber length	4	111834	72.39	0.000
Fiber diameter	4	28.75	3.20	0.013
Lumen width	4	10.12	9.51	0.000
Wall width	4	2.05	0.99	0.413
Slenderness ratio (SR)	4	2668.07	122.67	0.000
Runkel ratio (RR)	4	1.896	1.83	0.121
Coefficient of suppleness (CS)	4	0.088	18.50	0.000

Table 2S: Percent variability of vessel length, vessel diameter, fiber length, fiber diameter, lumen diameter, wall diameter, Slenderness ratio (SR), Runkel ratio (RR) and Coefficient of suppleness (CS) from five different altitudes.

Characters	Altitude (m)				
	410	915	1925	2100	2941
Vessel length	25%	24%	16%	23%	11%
Vessel diameter	27%	19%	15%	17%	18%
Fiber length	27%	22%	16%	17%	14%
Fiber diameter	8%	14%	62%	8%	13%
Lumen diameter	16%	26%	20%	15%	22%
Wall diameter	4%	11%	79%	2%	8%
Slenderness ratio (SR)	19%	24%	20%	21%	14%
Runkel ratio (RR)	19%	21%	19%	17%	22%
Coefficient of suppleness (CS)	19%	19%	21%	21%	19%

Significant differences (Table3) in fiber length were found in plants belonging to different forest types (habitats). The maximum length of fiber (202.74m) was observed in species growing on mountain subtropical forest while minimum fiber length (111.21 m) was found in those belonging to tropical thorn forest. The remaining habitats (forest types) showed the intermediate values of fiber length. Not only the fiber length, fiber diameter was significantly influenced by main habitat effect ($F= 72.39$, $P= 0.000$, $F= 3.20$, $P= 0.013$). Plants growing in wet temperate forests showed significantly wider fibers (6.8m) than other forest types which do not differ significantly between themselves. Similar comments can be made for lumen diameter. While cell wall thickness was similar, the slenderness ratio showed significant differences in species sampled across the forest types. Plant species belonging to

plateau (montane subtropical forest) showed higher values than those of other forest types which do not differ between the species. Similar comments can be made for coefficient of suppleness.

Correlation with environmental factors: All the anatomical features under consideration were significantly correlated with various climate factors. However, the extent and magnitude of correlation were specific for a specific attribute. vessel diameter, fiber length, and fiber slenderness ratio were negatively correlated ($r > 0.4$) with the altitude. Temperature played an important role in shaping the anatomy of the wood. Although temperature played a positive role in determining the diameter of the vessel, wall thickness and Runkel ratio of the fibers but was correlated negatively with vessel length, fiber length,

fiber diameter, lumen width, fiber slenderness ratio, coefficient of suppleness. Besides altitude and temperature, rainfall is another important climatic factor that was closely linked with the anatomical characteristic of the wood. Vessel length, fiber length, fiber diameter, lumen width, wall thickness, slenderness ratio and coefficient of suppleness were positively correlated with rainfall. The wood parameters change not only with the environment but also with the plant height. The characters

such as vessel diameter, fiber length and slenderness ratio were positively correlated while the coefficient of suppleness showed a negative correlation with plant height. The wood samples drawn from thorn forests showed wider vessel, long fiber, higher slenderness than those found in all other forest types. A close look at the results (Table 4) suggested that most of the anatomical characteristics were negatively or positively correlated with the height of the plants.

Table 3: Mean values of anatomical features from five different altitudes. Similar super script letters indicate no significant difference among the values at $P < 0.05$.

Characters	Forest types					LSD
	TTF	MSTPF	MTF	AP	SADTS	
Vessel length	63.86 ^b	122.61 ^c	96.99 ^c	108.18 ^d	43.74 ^a	7.81
Vessel diameter	24.589 ^{de}	18.567 ^{abc}	22.022 ^d	16.622 ^a	17.8 ^{ab}	2.48
Fiber length	161.11 ^b	202.74 ^c	185.89 ^{cd}	181.1 ^c	111.21 ^a	12.51
Fiber diameter	5.544 ^{ab}	5.911 ^{cd}	6.833 ^c	5.722 ^{abc}	5.40 ^a	0.39
Lumen diameter	3.478 ^{ab}	3.522 ^{bc}	4.1 ^e	3.7 ^{bcd}	3.189 ^a	0.326
Wall diameter	2.033 ^{ab}	2.233 ^{abcd}	2.378 ^{abcde}	2.011 ^a	2.144 ^{abc}	4.36
Slenderness ratio (SR)	29.29 ^{ab}	36.33 ^{de}	30.59 ^{abc}	32.49 ^{abcd}	21.56 ^a	4.97
Runkel ratio (RR)	1.26 ^{ab}	1.46 ^{abcd}	1.29 ^{abc}	1.14 ^a	1.49 ^{abcde}	1.08
Coefficient of suppleness (CS)	0.61 ^{abc}	0.58 ^a	0.65 ^{abcde}	0.64 ^{abcd}	0.58 ^{ab}	0.073
Plant height	394.7 ^d	357.8 ^c	124.4 ^{ab}	107.5 ^a	101.7 ^a	282.7

TTF = Tropical Thorn Forest, MSTPF = Montane Subtropical Plateau Forest, MTF = Montane Temperate Forest, AP = Alpine Pastures, SADTS = Sub-alpine Dry Temperate Scrub.

Table 4: Pearson correlation between anatomical features with plant height and environmental factors (altitude, temperature, rainfall).

Anatomical features	Altitude	Temperature	Rainfall	Plant height
Vessel length	-0.515	-0.328	0.728	0.260
Vessel diameter	-0.693	0.545	0.025	0.438
Fiber length	-0.562	-0.150	0.743	0.427
Fiber diameter	-0.015	-0.300	0.947	-0.128
Lumen width	-0.104	-0.494	0.910	-0.188
Wall width	0.125	0.036	0.747	-0.009
Slenderness ratio (SR)	-0.614	-0.079	0.591	0.523
Runkel ratio (RR)	0.173	0.595	-0.219	0.273
Coefficient of suppleness (CS)	0.059	-0.697	0.603	-0.473

DISCUSSION

Large-scale geographic and climatic changes are known to affect plant existences directly through impacts on plants adaptive strategies (Chaves *et al.*, 2003; Chown *et al.*, 2004). During the last couple of decades, most of the studies were conducted on adaptive strategies mainly focused on plant biochemical and physiological responses in controlled stresses (Pen˜a-Rojas *et al.*, 2003; Wang *et al.*, 2011). The knowledge of plasticity of anatomical traits is also vital for prediction of the fate of natural ecosystems under the long term global climatic changes. In the present investigation, an all-species analysis of average anatomical traits against altitudinal/climatic gradient

indicated maximum homology (75% to 90%) between plant species belonging to a particular habitat for various anatomical features. The low variability in anatomical make-up of the species belonging to a specific climate agrees with the well-known fact that plant species can live together in a community because of the physiological balance between them. This balance depends on the morphological and anatomical characteristics of the plants (Table 3).

The plants growing in wet habitat (montane temperate forest) showed longer and narrow vessels compared to the plants growing in dry thorn forest or dry temperate alpine meadows. At higher elevations, due to harsh environment, the duration and rate of elongation of

these cells might be below that leads to shorter vessel elements in plant growth at higher altitudes (Korner, 2003; Pathak *et al.*, 2011). Thus, the shape of the vessel's element may be linked with climatic factors such as moisture availability, altitude and temperature (Hacke and Sperry, 2001; Sperry *et al.*, 2006; Ziaco *et al.*, 2014). Reduction in vessel length has also been reported for *Iresine latifolia* (Zumaya-Mendoza and Terrazas, 2016). The narrow vessels are important to prevent cavitation while shorter elements are advantageous to minimize the damage if whatever cavitation does occur. The narrow vessel noted in wet temperate flora may be attributed to the low activity of cambium. In temperate dicotyledonous species, the period of radial growth is generally shorter than the plants growing in the regions of tropical climate (Studhalter and Glock, 1963). Altitude appears to be a significant factor prevailing the anatomical variation in vessels. In tropical woody species, the cambium has either no dormant period or have a short dormancy of a month or so (Fahn, 1989). The decrease in size of the vessels noted in thorn forest elements may be attributed either to the climatic factors or to the phylogenetic advancement in the cambial structure. Phylogenetically the shorter vessels are considered an advance (Fahn, 1989). If it is true, then the flora belonging to either thorn forest or subalpine meadows (dry habitats) may be considered as advance than that of wet temperate forest of either high or low altitudes.

The diameter of the vessel element is another characteristic of phylogenetic and physiological importance. The vessels of angiosperms with large diameter produced in spring (moist season) as vessels with the narrow diameter in summer. Dry, warm weather may reduce it (Bryukhanova and Fonti, 2013; Ziaco *et al.*, 2014), whereas growth at lower altitude with the application of fertilizers (Bhagwat, 1968) may increase it. Thus, the water stress occurring at lower elevations during the summer may be associated with the formation of wider cells (Panayotov *et al.*, 2013). It can also be assumed that the woody flora of the thorn forests has developed from the woody plants of the temperate region through the reduction in fusiform initials of the cambium, as the length of cambial initial is significantly related with the length of the vessel (Madcaff and Chaugh, 1983). Compounding direct and indirect effects of elevation could explain the larger diameter of vessels in temperate forests as average April–June maximum temperature is 19°C and July–September rainfall accounts for about 40% of total annual precipitation. This higher spring temperature should anticipate snowmelt and the onset of xylem production (Rossi *et al.*, 2011). Summer precipitation could also extend the positive growth effects of the post melting period further into the growing season, allowing the formation of larger cells. This particular climatic combination (warmer spring and moister summer) would create better-growing conditions for woody flora of temperate region (Ziaco *et al.*, 2014). Gullo *et al.*, (1995).

Working with other genera found that the vessel diameter in highland species is smaller than those of low land temperate species. Wang *et al.*, (2011) found a similar trend in water-conducting tissues. These observations suggested that vessel diameter is linked with conditions of growth rather than the phylogeny.

Like vessels, other related tissues such as fibers showed significant differences among the plant species belonging to different habitats. The habitats that promote vessel length also facilitate the growth of fibers. This correlation ship between vessel and fibers is well documented in the literature (Fahn, 1989; Rajput and Rao, 2003; Zumaya-Mendoza and Terrazas, 2016) and it is assumed that fiber have developed from the tracheary elements during the course of evolution. The shorter fibers are considered more advanced than, the longer ones. If this is true than the flora of dry habitats (either thorn forest or alpine pastures) is advance than any other habitat included in the present investigation. Wood cellular parameters varied in response to seasonal climate reflecting physiological adjustments to environmental constraints. In correlation analysis of average anatomical parameters against climate indicated significant relationships of precipitation, altitude and temperature with wood anatomy. Possibly many ecological factors (e.g., snowpack dynamics, radiative balance and soil properties) might have indirect or direct effects on growth and physiological processes that produce wood anatomy (Ziaco *et al.*, 2014). However, these variations in anatomical features have been attributed to the adaptive strategies of the plant at different elevations in the hostile environment (Noshiro and Suzuki, 2001; Pathak *et al.*, 2011).

From the discussion given above it is evident that in the studies of ecological anatomy, the structural diversity and the environmental queues go hand to hand. When the habitat is narrow the structural differences among species are only minor. Generally different species belonging to different families attain harmony with the environment. Infact, anatomical structures are the results of the impress of two different categories of forces: environmental and hereditary. Thus, at present one cannot establish precise links between particular climatic conditions and particular modes of anatomical structures in angiosperms at large (Mortenson, 1973; Rehman and Brauning, 2018). Probably each group of species (delineated by cluster analysis) has solved its adaptive problems within the scope of its own genetically fixed possibilities of variation. From the results of present investigation, it is concluded that the comparison of different species with respect to the adaptation problem is meaningful only within the confines of a particular taxonomic such as genus or species.

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