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VARIATIONS IN THE SIZE OF CAMBIAL INITIALS AND THEIR DERIVATIVES IN *MADHUCA INDICA* LINN. AND *TERMINALIA ARJUNA* BEDD.

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Two tropical trees, viz. *Madhuca indica* (Sapotaceae), a deciduous and *Terminalia arjuna* (Combretaceae), an evergreen were investigated to find out size variations between cambial initials and their derivatives in the phloem and xylem. Both trees possess non-storeyed cambium and a diffuse porous wood. The fusiform initials are elongated with beaded tangential walls and abruptly tapering ends. The ray initials are rectangular and heterogeneous. Both fusiform and ray initials undergo variable dimensional changes due to intrusive growth and shifting of their end walls during differentiation and maturation into different elements of phloem and xylem. Vessel elements gain 7 and 9.5 times widening in *M. indica* and *T. arjuna* over their respective mother cells. The phloem and xylem fibres gain maximum elongation due to intrusive growth and become 2 to 3 times long as compared to their initials. The sieve tubes are slightly shorter whereas the companion cells are 1/3 to 1/2 the length of fusiform initials. Very little or no dimensional changes have been recorded in fusiform initials during their transformation into parenchyma strands of phloem and xylem. The ray cells in both the phloem and xylem region become lengthier whereas their width remains unaltered as compared to their initials in the cambium.

Keywords : Cambium; Phloem; Xylem.

Introduction

Size correlation studies between cambial initials and their derivatives have been the subject of considerable research particularly because of the interest of wood anatomists and paper technocrats. Such studies had been initiated in temperate trees[1-6]. However, this aspect is still little explored with reference to Indian tropical trees, especially the angiosperms. In recent years very fragmentary information is available on this aspect[7-12]. Thus it is desirable to know the extent of size variations and distribution pattern of the vascular elements especially the fibres in the wood and bark of tropical trees. The present investigation explores the size relationship between cambial initials and their derivatives - the phloem and xylem elements in two tropical trees viz. *Madhuca indica* Linn. and *Terminalia arjuna* Bedd..

Materials and Methods

The sample for the present investigation were drawn from the trees growing under natural climatic and edaphic conditions of Shikohabad, Uttar Pradesh. Two fully grown trees of *M. indica* Linn. (Sapotaceae) and *T. arjuna* Bedd. (Combretaceae) were marked out. Monthly collections were made from twigs (2 cm diameter) as well as the main trunks (6 cm^3) during 3rd week of each month for one complete year. Subsequently, at first these large pieces were cut into smaller ones and fixed in FAA for 24 hours and finally preserved in 70% ethyl alcohol for processing at a later date. Sections of the material from twigs as well as the main trunks were obtained in transverse and tangential longitudinal planes at 15-20 µm thickness on a sliding microtome. Staining was done following the method outlined by Cheadle *et al.*[13]. The dimensions of the fusiform initials, ray initials and their derivatives except the tracheary elements, phloem and xylem fibres were recorded from tangential and transverse sections. The measurements of tracheary elements and fibres were taken from the macerated materials. An average size of each element has been worked out and discussed in the text.

Results and Discussion

The vascular cambium in both the trees forms a continuous ring between secondary phloem and xylem. It is composed of radially elongated fusiform initials and heterogeneous ray initials which are in radial continuum to phloem and xylem rays. The fusiform initials are elongated having beaded tangential walls with abruptly tapering ends which on overlapping present a non-storeyed nature of cambium

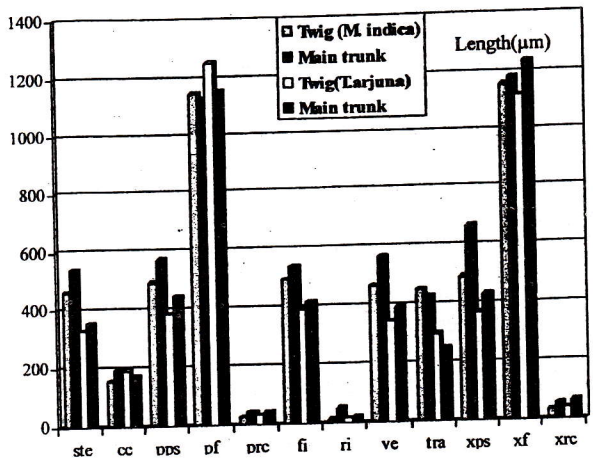

Fig. A.

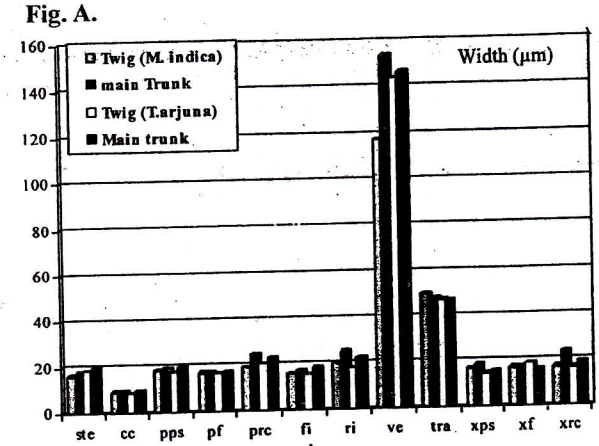

Fig. B.

Fig. 1 (A-B). *M. indica* and *T. arjuna* size correlations among cambial intitials and their derivativs. cc, companion cells; fi, fusiform initials, pf, phloem fibres; pps, phloem parenchyma strands; prc, phloem, ray cells; ri, ray initial; ste, sieve-tube elements; tra, tracheds ve, vessel elements; xf, xylem fibres; xps xylem parenchyma strands; xrc, xylem ray cells.

(Figs. 2A,B , 3A,B).

The average dimension of fusiform initial is 494.52 ± 57.51 X 15.96 ± 1.45 μm in the *M. indica* and 391.95 ± 22.03 X 15.12 ± 4.73 μm in *T. arjuna*. These grew by intrusive growth which is the characteristic of these initials. The ray initials are rectangular and heterogeneous (Fig. 2B). These were arranged in uni to multiseriate fashion in the twigs as well as in the main trunk of *M. indica* whereas these are mostly uniseriate in the twigs and uni- to multiseriate in the main trunk of *T. arjuna*. Starch and tanniniferous substance of brown to reddish brown colour have been observed in the cavity of ray initials. An average dimension of ray initial is 13.89 ± 2.91 X 20.24 ± 3.48μm in *M. indica* and 16.13 ± 1.36 X 17.93 ± 1.58 μm in *T. arjuna* (Table 1& Fig. 1).

The sieve tube elements are enucleate, generally devoid of dense contents except for the slime in their lumen. In the tangential plane the sieve tube elements are arranged in non-storeyed manner, bearing more oblique compound sieve plates with 3-6 sieve areas upon them in the twigs (Fig. 2C) and 3-4 sieve areas in the main trunk of *M. indica*. Short transverse or slightly inclined simple sieve plates with a single sieve area have been observed in the sieve-tubes of *T. arjuna*. (Fig. 3C). The dimension of sieve tube elements on an average is of 461.92 ± 30.38 X 16.15 ± 1.13 μm in *M. indica*. and 327.64 ± 21.99 X 18.28 ± 1.27 μm in *T. arjuna*. Single and rarely two to three companion cells are associated with each sieve tube element. The companion cells, being of common origin with sieve- tube element exhibit smaller dimension 154.28 ± 11.28 X 9.15 ± 2.21 μm in *M. indica*. and 192.66 ± 8.17 X 8.26 ± 1.42 μm in *T. arjuna* (Fig. 1). These are almost one third in length and one half in width as compared to their mother cells. The phloem fibres are elongated, aseptate, thick-walled, narrow lumened and with tapering apices in *M. indica*, whereas in *T. arjuna* these bear pointed apices. The average size of phloem fibres is 1145.84 ± 42.63 X 16.85 ± 0.98 μm in *M. indica* and 1252.41 ± 98.35 X 16.30 ± 1.13 μm in *T. arjuna*. Thus, these are 2.5 and 3 times longer as compared to their respective fusiform initials in both the tree species investigated here (Fig. 1). Axial parenchyma cells are rectangular to polygonal in cross section and occupied themselves in between sieve-tube elements. These form two types of strands. The first one with 3-8 rectangular cells has starch and tannin in their lumen as a storage matter and the second one is crystalliferous, having 10-25 compartment of isodiametric cells and each one of which has a single rhomboidal crystal in *M. indica*, and a star- shaped crystal in *T.arjuna*. Their average dimensions are 492.58 ± 72.04 X 18.05 ± 2.31 μm in *M. indica* and 385.75 ± 30.89 X 17.23 ± 1.15 μm in *T. arjuna*. These strands do not show any marked changes during metamorphosis from their mother cells. Phloem rays are heterogeneous, 2-5 cells wide with uniseriate tails at both apices in *M. indica* whereas these are exclusively uniseriate rarely biseriate in twigs and uni- to multiseriate in the main trunk of *T. arjuna*. The ray cells are filled with tannin, starch and other reserve eargastic substances. An average dimension of ray cells 27.35 ± 3.92 X 19.21 ± 2.64 μm in *M. indica* and 33.74 ± 3.99 X 20.21 ± 2.18 μm in *T. arjuna*

Table 1. *M. indica* and *T. arjuna* size correlations among cambial initials and their derivatives in the twigs and main trunk.

Tissues and their elements	*M. indica*						*T. arjuna*					
	Twig			Main trunk			Twig			Main trunk		
	Length (µm)	CV %	Width (µm)	Length (µm)	CV %	Width (µm)	Length (µm)	CV %	Width (µm)	Length (µm)	CV %	Width (µm)
PHIOEM												
Sieve-tube elements	461.92±30.38	6.58	16.15±1.13	540.42±15.97	2.9	17.54±1.56	327.64±21.99	6.72	18.38±1.27	355.05±15.12	4.26	19.47±0.89
Companion cells	154.28±11.28	7.31	9.15±2.21	195.17±11.74	6.01	9.22±0.84	192.66±8.17	4.29	8.26±1.42	169.45±23.30	13.76	9.37±0.52
Phloem parenchyma strands	492.58±72.04	14.62	18.05±2.31	571.24±30.63	5.36	19.15±0.52	385.75±3.80	8.01	17.23±1.05	447.05±15.99	3.58	19.68±1.07
Phloems fibres	1145.84±42.63	3.72	16.85±0.98	1125.92±18.39	1.64	17.19±1.82	1252.41±98.35	7.86	16.30±1.15	1153.45±11.62	1.01	17.30±0.16
Phloem ray cells	27.35±3.92	14.34	19.21±2.64	44.98±1.31	2.82	24.73±1.51	33.74±3.99	11.83		41.22±0.96	2.33	22.93±3.85
CAMBIUM												
Fusiform initials	494.52±57.51	11.62	15.96±1.45	539.41±21.61	4.00	17.05±1.54	391.95±22.03	5.62	15.12±4.73	416.76±26.05	6.26	17.95±0.89
Ray initials	13.89±2.91	14.48	20.24±3.48	25.43±5.07	19.94	25.06±2.63	16.13±1.36	8.44	17.93±1.58	21.91±1.06	4.84	22.38±2.07
XYLEM												
Vessel elements	468.34±33.94	7.25	117.21±26.51	567.80±13.95	2.46	153.53±21.36	346.11±36.75	10.62	143.70±18.69	392.31±22.99	5.86	146.40±23.50
Tracheids	452.65±54.58	12.06	49.64±9.39	425.62±45.22	10.62	47.83±2.89	297.63±36.08	12.13	46.71±2.85	251.70±21.82	8.67	46.56±1.77
Xylem parenchyma strands	492.84±54.39	11.04	77.28±1.77	667.53±58.82	8.82	18.15±0.52	369.69±45.92	15.42	14.35±0.54	432.19±12.17	2.82	15.28±0.38
Xylem Fibres	1158.08±71.91	6.21	16.79±1.16	1182.83.68	7.08	16.94±0.43	1117.18±75.85	6.79	18.23±1.42	1239.22±16.81	1.36	15.61±1.08
Xylem ray cells	33.72±3.83	11.36	16.84±1.86	55.68±10.62	23.76	23.51±7.56	36.87±3.61	9.79	16.22±0.95	62.24±3.11	4.99	18.97±0.91
Conductance	$3.439x10^{-4}$			$3.743x10^{-6}$			$5.542x10^{-6}$			$9.9025x10^{-6}$		
Mesorphy index	2516.98			7831.25			5262.89			5486.81		
Vulnerability	5.82			16.65			10.53			13.92		

CV - Coefficient of variability.

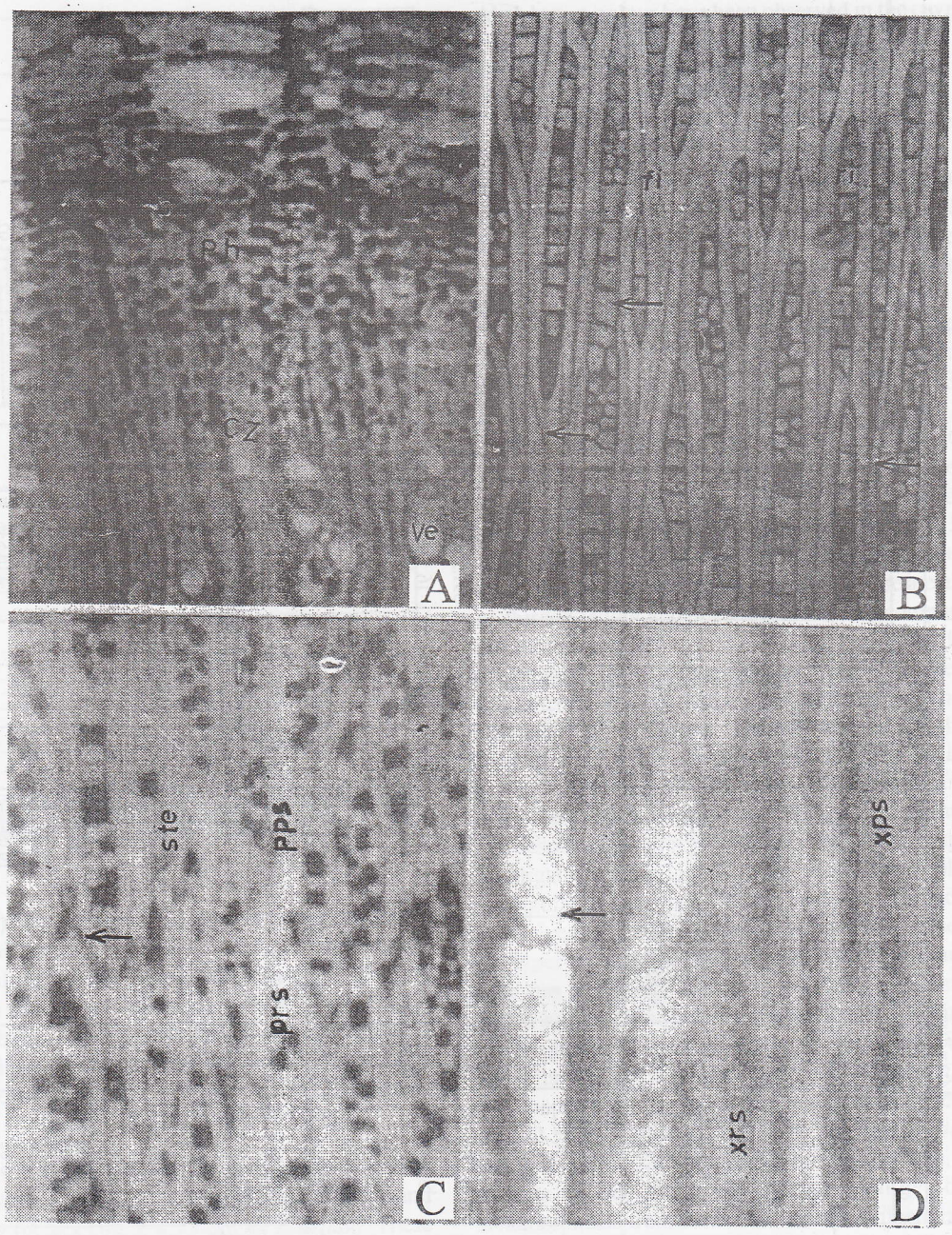

Fig. 2 (A-D). *Madhuca indica* Linn. Organization and structure of phloem, cambium and xylem.
(cz, cambial zone, fi, fusiform initials, ph, phloem, prs, phloem ray strand, pps, phloem parenchyma strand, ri, ray initial, ste, sieve-tube elements, ve, vessel elements, xrs, xylem ray strand, x, xylem)
(A) Microphotograph showing secondary structures of stem in a transactional view X 70.
(B) Microphotograph showing non-storeyed cambial organization and heterogeneous ray initials X 100.
(C) Microphotograph showing phloem organization and oblique compound sieve plate X 140.
(D) Microphotograph showing xylem organization, and vessels with tyloses X 100.

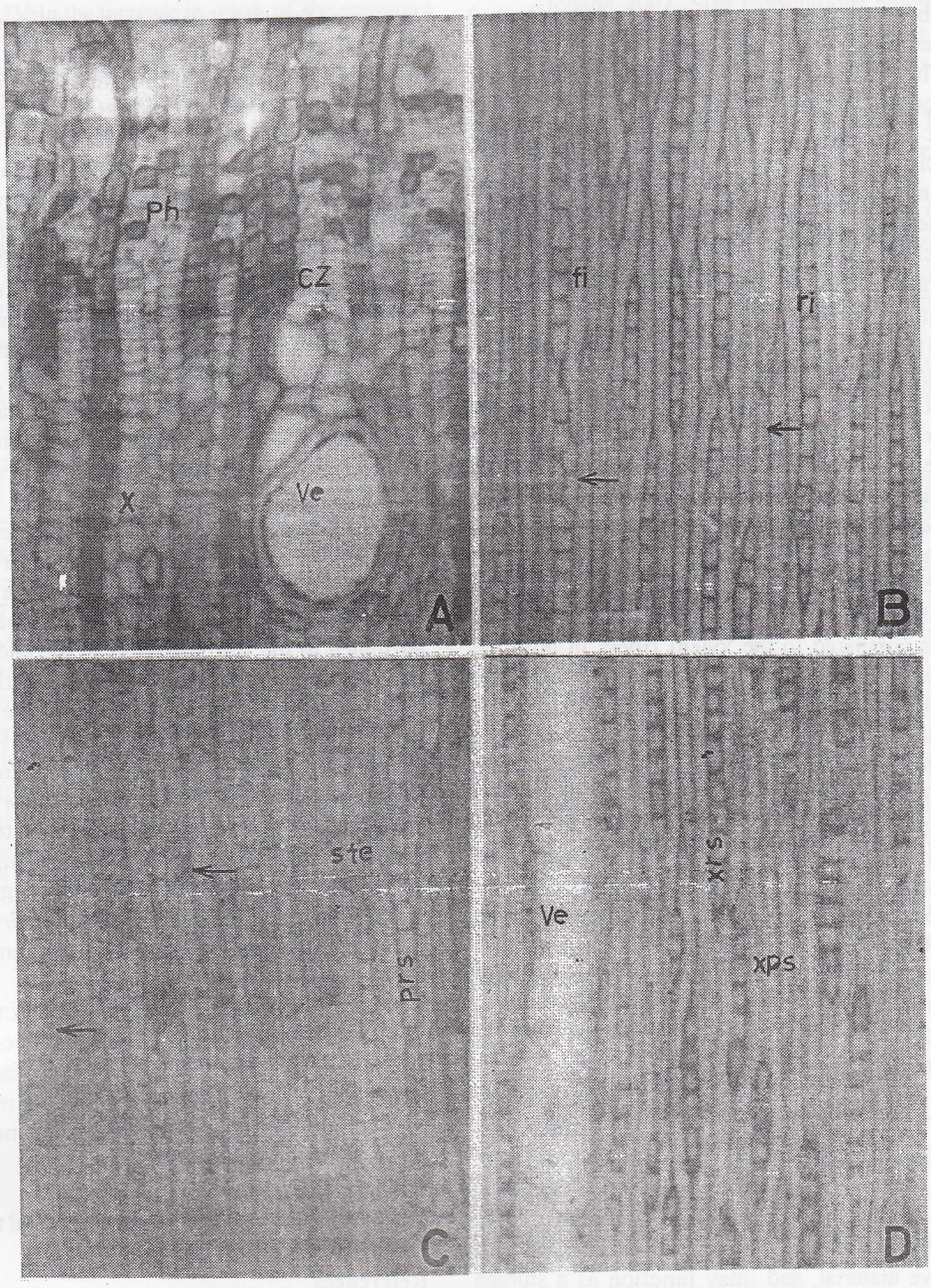

Fig. 3 (A-D). *Terminalia arjuna* Bedd. Organization and structure of phloem, cambium and xylem.
(cz, cambial zone, fi, fusiform initials, ph, phloem, prs, phloem ray strand, pps, phloem parenchyma strand, ri, ray initial, ste, sieve-tube elements, ve, vessel elements, xrs, xylem ray strand, x, xylem)
(A) Microphotograph showing secondary structures of stem in a transactional view X 180.
(B) Microphotograph showing non-storeyed cambial organization and heterogeneous ray initials X 140.
(C) Microphotograph showing phloem organization and a simple sieve plate X 150.
(D) Microphotograph showing xylem organization, small as well as large heterogeneous rays X 150.

has been observed. On elongation these become nearly 2 times the length of their mother cells.

The secondary xylem shows diffuse porous organization and indistinct growth rings in both the trees (Figs 2A & 3A). The vessel elements are of small to large diameter, circular to oval, and distributed solitarily or in radial pore multiples of 2-4 or, in small groups in *M. indica*, whereas these are solitary and round more frequently in pairs or in short radial pore multiples of 2-3 in *T. arjuna*. The perforation plates are oblique and inter vessel pits are opposite to alternate in *M. indica* whereas simple perforation plates and vestured inter- vessel pits have been recorded on tangential walls of *T. arjuna*. Presence of tyloses and a reddish brown gummy substance has also been noticed frequently in the lumen of vessel elements in both the taxa (Figs. 2D & 3D). The average size of vessel elements is 468.34 ± 33.94 X 117.21 ± 26.51 μm in *M. indica* and 346.11 ± 36.75 X 143.70 ± 18.69 μm in the twigs of *T. arjuna*. Thus these are 7 and 9.5 times wide to their progenitor fusiform initials. The tracheids are distributed in groups, being thick walled and broad lumened as compared to the xylem fibers in both the species. The average size of these has been observed to be 452.65 ± 54.58 X 49.64 ± 9.39 and 297.63 ± 36.08 X 46.71 ± 2.85 μm in *M. indica* and *T. arjuna*, respectively.

The axial parenchyma cells are apotracheal and diffuse. A narrow band of parenchyma (2-3 layers) has been observed at the end of growth ring in *M. indica*, whereas aliform and confluent paratracheal parenchyma occur in *T. arjuna*. The average size of xylem parenchyma strand is 492.84 ± 54.39 X 16.28 ± 1.77 μm in *M. indica* and 369.69 ± 45.92 X 14.35±0.54μm in *T.arjuna*. The xylem fibres are thick walled, aseptate narrow lumened, non libriform, and have pointed apices. Lignification is more pronounced in the fibres of latewood of *T. arjuna*. The average dimension of xylem fibres in the twigs is 1158.08 ± 71.91 X 16.79 ± 1.16 μm in *M. indica* and 1117.18 ± 75.85 X 18.23 ± 1.42 μm in *T. arjuna*. It is thus clear that in *M. indica* the fibres are 2 times larger whereas in *T. arjuna* these are 2.5 times larger than their precursors. The xylem ray cells are heterogeneous, II types or heterocellular and large. The ray cells were filled with some reserve material, and may function as a storage tissue. These are arranged in uni to multiseriate rays. The average size of xylem ray cells is 33.72 ± 3.83 X 16.84 ± 1.86μm in *M. indica* and 36.87 ± 3.61 X 16.22 ± 0.95 μm in *T. arjuna*. Marked changes have been observed in the dimension of ray initials during their transformation to xylem rays.

The cambium in both the species is of non-storeyed nature which is considered to be primitive[2]. It is evidenced from the data presented earlier and in Table 1, that all the derivatives of cambium experienced dimensional changes during their differentiation. For instance, the sieve-tube elements showed shortening and marginal broadening over the size of their progenitors in both trees. Phloem and xylem parenchyma strands either underwent slight shortening *(T. arjuna)* or remained more or less of the same length *(M.indica)* as compared to their initials. It suggests that these got differentiated directly from them without undergoing any further divisions. The phloem and xylem fibres grow by intrusive growth and gain maximum elongation amongst of all the derivatives of cambium. The fibres become 2.5 and 2 times in *M. indica* and 3 and 2-3 times long in T. *arjuna*, in the twigs and main trunk, respectively, as compared to their mother cells. These results are in conformity with those of others[2,3,8,9,11,14].

The length of vessel elements showed considerable variation during their differentiation and maturation in both the species. On an average, these exhibited slight decrease in length which might be attributed to the rearrangement of the end walls of the fusiform initials to form transverse or slightly oblique end walls of the mature vessel elements. These findings also corroborate the earlier reports of Bailey[2], Esau & Cheadle[15] as well as Sharma *et al*[16]. An appreciable broadening up to 7 and 9.5 times in the width of vessel elements has been observed, as compared to the width of fusiform initials in *M. indica* and *T. arjuna*, respectively. These observations are well within the range recorded by earlier workers such as 3-5 times *in Grewia optiva, Cedrella toona,and Shorea robusta*[17] and 7 times in *Albizzia lebbeck*[18].

The conductance, mesomorphy indices as well as vulnerability of xylem of both the trees were found moderately high. Broader vessels help in fast conduction of water and minerals besides providing more safety to cavitation. These characters make them more suited for the mesic habit of the area[19].

Acknowledgements

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