WOOD MICROSTRUCTURE OF LIGNEOUS SPECIES OF RHAMNACEAE FROM INDIA

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Received May 2010

GUPTA S & SAXENA V. 2011. Wood microstructure of ligneous species of Rhamnaceae from India. This study dealt with the wood microstructure of the family Rhamnaceae from India. The wood microstructure and salient diagnostic features of 22 species belonging to 8 genera were described. An identification key was developed for the 22 species. Perforated ray cells were reported for the first time in *Sageretia brandrethiana, Rhamnus purpurea, Rhamnus wightii, Zizyphus mauritiana, Z. oenoplia, Z. oxyphylla* and *Z. xylopyrus*. The study revealed a need for reclassification of the family as anatomically the family is quite heterogeneous at the generic level.

Keywords: Wood anatomy, perforated ray cell, identification key, systematic position, crystals

GUPTA S & SAXENA V. 2011. Mikrostruktur kayu spesies Rhamnaceae berlignin dari India. Kajian ini adalah tentang mikrostruktur kayu famili Rhamnaceae dari India. Mikrostruktur kayu dan ciri pengecaman penting bagi 22 spesies daripada 8 genus dihuraikan. Sel jejari berliang dilaporkan pertama kalinya dalam *Sageretia brandrethiana, Rhamnus purpurea, Rhamnus wightii, Zizyphus mauritiana, Z. oenoplia, Z. oxyphylla* and *Z. xylopyrus*. Kajian ini menunjukkan bahawa famili ini perlu dikelaskan semula memandangkan anatomi famili ini agak heterogen pada peringkat genus.

INTRODUCTION

The family Rhamnaceae comprises about 70 genera and 1500 species of erect or scandent shrubs and small- to medium-sized trees, distributed throughout the tropical and temperate regions of the world. A total of 12 genera and about 57 species occur in India (Bhandari & Bhansali 2000).

The family is of little significance from the point of view of timber but many of its members have medicinal value and some yield valuable dyes. Yellow and green dyes are obtained from several species of *Rhamnus*, which are used in the textile industry and for calico printing. *Gouania leptostachya, Ventilago madraspatana* and *Zizyphus jujuba* are used in native medicine (Anonymous 1963).

The wood microscopic features were studied but at the generic level (Metcalfe & Chalk 1950, Carlquist 1988). Schirarend (1991) gave a systematic wood anatomy of the Rhamnaceae. Inside Wood database (http://insidewood.lib.ncsu.edu/) dealt only with *Hovenia dulcis, Z. jujuba* and *Z. xylopyrus*.

On the Indian front, Gamble (1922) briefly described general features of the woods. Pearson and Brown (1932) described the wood microstructure of *Z. jujuba* and *Z. xylopyrus* Anonymous (1963) reported physical properties and gross structure of the wood.

A comprehensive study on the wood microstructure of the species of this family occurring in India is lacking. Thus, the present study was undertaken. The study was also aimed at developing a key for the identification of the species. The study also compared findings of earlier studies.

MATERIALS AND METHODS

The study examined 41 wood samples from 22 species belonging to 8 genera of the family Rhamnaceae, housed at the Forest Research Institute, Dehradun. Details of the specimens are given in Table 1 along with their accession number, specific gravity and locality. Data on specific gravity are as per Anonymous (1963).

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Table 1 Species of Rhamnaceae studied, their accession number, locality and specific gravity

Species	Accession number	Locality	Specific gravity
Berchemia floribunda (Wall.) Brongn.	DDw 2864	Darjeeling, West Bengal	0.52
Gouania leptostachya DC.	DDw 5369	Pilibhit, Uttar Pradesh	0.54
Hovenia dulcis Thunb	DDw 8398	Arunachal Pradesh	0.62
	DDw 3808	United States of America	0.58
Rhamnus nepalensis (Wall.) M. Lawson	DDw 3364	Darjeeling, West Bengal	0.62
	DDw 3346	West Bengal	0.65
R. persica Boiss.	DDw 5004	Dehradun,Uttaranchal	1.00
R. purpurea Edgew.	DDw 70	Himachal Pradesh	0.66
	DDw 4418	Jaunsar, Uttaranchal	0.63
	DDw 4707	Jaunsar, Uttaranchal	0.76
R. triquetra (Wall.) Brandis	DDw 4808	Jaunsar, Uttaranchal	0.93
R. virgata Roxb.	DDw 79	Simla, Himachal Pradesh	0.90
	DDw 2877	Simla, Himachal Pradesh	0.84
R. wightii W.&A.	DDw 3745	Nilgiri, Madras, Tamilnadu	0.89
Sageretia brandrethiana Aitch.	DDw 914	Simla, Himachal Pradesh	0.97
S. thea (Osbeck) Johnst.	DDw 2946	Simla, Himachal Pradesh	0.89
	DDw 2951	Simla, Himachal Pradesh	0.96
Scutia myrtina (Burm. F.) Kurz	DDw 5725	Tamil Nadu	0.89
Ventilago maderaspatana Gaertn.	DDw 3843	Madhya Pradesh	0.52
	DDw 6448	Myanmar	0.61
Ziziphus glabrata Heyne ex Roth.	DDw 5634	Madras, Tamilnadu	1.15
Z. incurva Roxb.	DDw 8067	Dehradun, Uttaranchal	0.68
Z. jujuba Mill.	DDw 885	Pakistan	0.69
Z. mauritiana Lam.	DDw 1128	Bombay, Maharashtra	0.85
	DDw 6273	Dehradun, Uttaranchal	0.62
	DDw 5314	Dehradun, Uttaranchal	0.56
	DDw 6066	Mysore, Karnataka	0.68
	DDw 4736	Uttar Pradesh	0.69
Z. nummularia W. & A.	DDw 3077	Punjab	0.61
	DDw 442	Ajmer, Rajasthan	0.70
	DDw 2931	Simla, Himachal Pradesh	0.63
Z. oenoplia (L.) Mill.	DDw2753	Maharashtra	0.56
Z. oxyphylla Edgew.	DDw4818	Jaunsar, Uttaranchal	0.64
	DDw2949	Punjab	0.58
Z. rugosa Lam.	DDw 2336	Darjeeling, West Bengal	0.69
	DDw 8343	Tamilnadu	0.78
Z. xylopyrus Willd.	DDw 4735	Uttar Pradesh	0.76
	DDw 6274	Dehradun, Uttaranchal	0.66
	DDw 8336	Tamil Nadu	0.77
	DDw 3559	Orissa	0.71
	DDw 6067	Mysore, Karnataka	0.78
	DDw 8469	Karnataka	0.75

For microscopic examination, 15–20 µm thick transverse, radial and tangential sections were obtained using a microtome. The sections were stained in Heidenhain's haematoxylin and safranin, and mounted on slides. For determination of fibre and vessel characteristics, small radial chips were macerated using 30% nitric acid and a pinch of potassium chlorate. The data on fibre and vessel characteristics as well as ray frequency (rays/mm) were means of 25, 10 and 10 counts respectively. Photomicrographs of diagnostic features were taken using microscope and image analyser. For microstructure, the terminology published by the International Association of Wood Anatomists (IAWA 1989) was used. The ratio between fibre length and vessel

element length (F/V ratio) was calculated for establishment of evolutionary trends (based on degree of intrusiveness) in the family (Carlquist 1977). The vulnerability and mesomorphy figures were calculated as per formula given by Carlquist (1977).

RESULTS

The quantitative and qualitative data collected are given in Tables 2 and 3.

Berchemia Neck. ex DC.

Species studied: *Berchemia floribunda* (Wall.) Brongn.
Microscopic features: Growth rings indistinct, wood diffuse porous, vessels exclusively solitary, rarely in radial multiples of 2–5 cells, round to oval shaped, perforation plate simple. Intervessel pits alternate, minute, rarely coalescent aperture present; vessel ray pits are similar to intervessel pits in shape and size. Fibres septate with simple pits. Axial parenchyma scanty paratracheal, in strands of 6–11 cells. Rays 1–8 seriate, rays of two distinct sizes, uniseriate ray height 5–20 celled, mean multiseriate ray height more than 1 mm. Body ray cells mixed throughout. Prismatic crystals present in ray cell, non-chambered, rarely chambered.

Gouania Jacq.

Species studied: *Gouania leptostachya* DC.
Microscopic features: Growth rings distinct due to fibrous tissue, wood diffuse porous, vessels solitary or in radial multiples of 2–6 cells, very rarely clustered, round to oval shaped, perforation plate simple. Intervessel pits alternate, large, vessel ray pits are smaller than intervessel pits with 8–11 µm diameter. Fibres non-septate with simple pits. Axial parenchyma in marginal or in seemingly marginal bands 4–7 cells wide, scanty paratracheal, in strands of 3–7 cells. Rays 1–7 seriate, ray of two distinct sizes, uniseriate ray height 13–41 celled, mean multiseriate ray height more than 1 mm. Body ray cells homogeneous consisting of procumbent cells. Prismatic crystals non-chambered, rarely chambered, present in ray and parenchyma cells. Druses present in ray cells (Figure 1).

Hovenia Thunb.

Species studied: *Hovenia dulcis* Thunb.
Microscopic features: Growth rings indistinct. Wood semi-ring to diffuse porous. Vessels solitary or in radial multiples of 2–3 cells, round to oval shaped, perforation plate simple. Intervessel pits alternate, small to medium, vessel ray pits smaller than intervessel pits with 4–6 µm diameter. Fibres non-septate with minutely bordered pits. Axial parenchyma scanty paratracheal rarely diffuse, in strands of 5–8 cells. Rays 1–5 seriate, uniseriate ray height 3–8 celled, multiseriate ray height 6–25 celled. Body ray cells procumbent with 1–2 rows of upright and square cells. Rays sometimes irregularly storied. Prismatic non-chambered crystals present in ray cells.

In the present study, two samples of *H. dulcis* were studied, of which one sample (DDw 8398) was from India and the other, (DDw 3808) from USA. The samples showed differences in ray seriation and parenchyma type (Table 4).

Rhamnus L.

Species studied: *Rhamnus nepalensis* (Wall.) M. Lawson, *R persica* Boiss., *R purpurea* Edgew., *R triquetra* (Wall.) Brandis, *R virgata* Roxb. & *R wightii* W. & A.
Microscopic features: Growth rings distinct due to fibrous tissue. Wood ring porous to semi-ring porous in *R. nepalensis*, *R. purpurea* (Figure 2), *R. virgata* and *R. wightii* while diffuse porous in *R. persica* and *R. triquetra* (Figure 3). Vessels arranged in dendritic pattern, round to oval shaped, perforation plate simple. Intervessel pits alternate, minute to large, coalescent aperture rarely present in *R. virgata*. Vessel ray pits are similar to intervessel pits in size and shape throughout the ray cells while rarely smaller to intervessel pits with 3–8 µm diameter in *R. pupurea* and *R. virgata*. Helical thickening present throughout body of vessel element (Figure 4). Fibres non-septate in *R. persica*, *R. purpurea*, *R. triquetra* and *R. virgata* while both septate and non-septate in *R. wightii* and *R. nepalensis* (Figure 5) with distinctly bordered pits and slit-like aperture. Axial parenchyma diffuse to scanty paratracheal in strands of 4–10 cells. Rays 1–6 seriate, rays of two types, uniseriate ray height 3–15 celled, multiseriate ray height 4–51 celled. Body ray cells procumbent with 1–3 rows of

Table 2 Wood anatomical characters of vessels and fibres in species of Rhamnaceae

Species	Type of plant	Vessel in dendritic pattern	Growth ring	Porosity	Mean vessel diameter (µm)	Vessel frequency per mm²	Mean vessel length (µm)	Intervessel pit (µm)	Helical thickening in vessel	Mean fibre length (µm)	Mean fibre diameter (µm)	Septation in fibre	Vulnerability	Mesomorphy	F/V ratio
Berchemia floribunda	C/SS	–	–	D	185 (± 51)	10–28	437 (± 72)	3–4	–	732 (± 70)	17 (± 1)	+	9.7	4239	1.67
Gouania leptostachya	C/SS	–	+	D	228 (± 84)	7–21	430 (± 105)	11–16	–	1106 (± 293)	17 (± 3)	–	16.2	6966	2.5
Hovenia dulcis	T	–	–	SR, D	106 (± 20)	3–7	399 (± 87)	5–9	–	1152 (± 208)	22 (± 6)	–	21.2	8459	2.8
Rhamnus nepalensis	S	+	+	Dd-SR	–	–	409 (± 83)	5–8	+, –	834 (± 143)	17/21 (± 3)	+, –	–	–	2.0
R. persica	S/ST	+	+	Dd-D	28 (± 6)	118–127	286 (± 47)	6–8	+	752 (± 116)	17 (± 5)	–	–	–	2.6
R. purpurea	S/ST	+	+	Dd-SR	–	–	299 (± 74)	5–10	+	815 (± 128)	16 (± 3)	–	–	–	2.7
R. triquetra	S/ST	+	+	Dd-D	55 (± 27)	98–121	339 (± 59)	5–8	+	1349 (± 219)	14 (± 3)	–	–	–	2.2
R. virgata	S/ST	+	+	Dd-SR	–	–	252 (± 25)	5–10	+	754 (± 279)	13 (± 6)	–	–	–	2.7
R. wightii	S	+	+	Dd-SR	–	–	360 (± 100)	3–8	+	834 (± 168)	14 (± 3)	+, –	–	–	2.3
Sageretia brandrethiana	S/ST	–	+	D	44 (± 11)	98–126	249 (± 44)	5–8	–	683 (± 165)	14 (± 23)	–	0.39	98	2.7
Sageretia thea	S/ST	–	+	D	43 (± 14)	37–83	243 (± 44)	2–3	–	578 (± 165)	11 (± 3)	–	0.75	132	2.4
Scutia myrtina	S	–	+	D	89 (± 30)	34–63	363 (± 76)	3–6	–	792 (± 95)	13 (± 2)	–	1.81	657	2.18
Ventilago maderaspatana	C/SS	–	+	D	213 (± 83)	5–15	344 (± 207)	8–12	–	918 (± 180)	14 (± 3)	–	22	17220	1.3
Ziziphus glabrata	ST	–	+	D	109 (± 17)	36–67	403 (± 90)	6–10	–	907 (±43)	14 (± 3)	–	2.2	756	2.67
Z. incurva	S	–	+	D	86 (± 24)	14–33	383 (± 23)	6–9	–	883 (±170)	15 (± 2)	+, –	3.58	1372	2.3
Z. jujuba	T	–	+	D	109 (± 26)	5–9	314 (± 82)	4–8	–	1018 (± 169)	17 (± 4)	–	15.6	4889	3.2
Z. mauritiana	T	–	+	D	142 (± 43)	4–28	352 (± 58)	5–10	–	1002 (± 171)	14 (± 18)	–	13	4551	2.84
Z. nummularia	S	–	+	D	114 (± 30)	3–22	404 (± 18)	5–10	–	917 (± 140)	15 (± 13)	–	8.5	3444	2.26
Z. oenoplia	C/SS	–	+	D	111 (± 22)	33–51	553 (± 92)	5–8	–	903 (± 155)	14 (± 34)	–	2.64	1462	1.6
Z. oxyphylla	S	–	+	SR	68 (± 21)	44–79	368 (± 62)	3–5	–	604 (± 76)	14 (± 3)	–	1.09	401	1.6
Z. rugosa	ST	–	+	D	145 (± 38)	9–15	577 (± 99)	5–11	–	941 (± 231)	17 (± 4)	–	12.08	6970	1.63
Z. xylopyrus	ST	–	+	D	122 (± 43)	5–20	411 (± 111)	5–13	–	969 (± 208)	16 (± 4)	–	8.76	3781	2.35

– = absent, + = present, ± = rarely present; D = diffuse porous, SR = semi-ring porous, R = ring porous, Dd = dendritic pattern; C/SS = large climber or scrambling shrub, S/ST = straggling shrub or small tree, T = tree; F/V = fibre length/ vessel length

Table 3 Wood anatomical characters of axial parenchyma and rays in the studied species of Rhamnaceae

Species	Parenchyma					Ray										
	Diffuse	Scanty paratracheal	Aliform to confluent	Vasicentric	Marginal	Seriation	Frequency/mm	Avg uniseriate ray width	Avg uniseriate ray height	Avg multiseriate ray width	Avg multiseriate ray height	Storied	Crystal	Druse	Pith fleck	Perforated ray cell
Berchemia floribunda	–	+	–	–	–	1–8	4–8	15 (± 3)	285 (± 108)	56 (± 26)	1092 ± 1011	–	+ R	–	–	–
Gouania leptostachya	–	±	–	–	+	1–7	5–8	11 (± 2)	347 (± 161)	57 (± 23)	1695 (± 835)	–	+ R, P	R	–	–
Hovenia dulcis	+	+	–	–	–	1–5	4–9	18 (± 3)	213 (± 61)	38 (± 8)	363 (± 164)	±	+ R	–	–	–
Rhamnus nepalensis	–	+	–	–	–	1–6	4–9	13 (± 2)	284 (± 112)	46 (± 11)	575 (± 186)	–	+ R	–	+	–
R. persica	+	–	–	–	–	2–4	5–8	–	–	19 (± 6)	202 (± 75)	–	–	–	–	–
R. purpurea	–	+	–	–	–	1–6	4–10	13 (± 3)	148 (± 14)	35 (± 11)	307 (± 112)	–	–	–	–	+
R. triquetra	–	+	–	–	–	1–6	4–7	13 (± 2)	178 (± 67)	51 (± 11)	337 (± 101)	–	–	–	–	–
R. virgata	–	+	–	–	–	1–4	4–9	11 (± 3)	140 (± 42)	23 (± 6)	260 (± 93)	–	–	–	–	–
R. wightii	+	+	–	–	–	1–5	4–9	14 (± 2)	246 (± 94)	27 (± 7)	395 (± 130)	–	–	–	+	+
Sageretia brandrethiana	+	±	–	–	+	1–4	13	13 (± 2)	248 (± 95)	29 (± 3)	367 (± 121)	±	+ R, P	–	–	+
Sageretia thea	+	±	–	±	+	1–4	6–12	12 (± 3)	223 (± 103)	22 (± 4)	364 (± 143)	–	+ R, P	–	–	+
Scutia myrtina	±	+	–	–	+	1–4	6–12	12 (± 3)	347 (± 120)	28 (± 5)	551 (± 208)	–	+ R, P	–	–	–
Ventilago maderaspatana	–	+	–	+	+	1–8	3–15	14 (± 3)	244 (± 104)	62 (± 23)	1075 (± 482)	–	+ R, P	–	–	–
Ziziphus glabrata	+	+	–	+	+	1–5	4–10	15 (± 2)	144 (± 39)	30 (± 11)	395 (± 114)	–	+ R, P	–	–	–
Z. incurva	–	+	±	+	+	1	6–12	13 (± 2)	318 (± 126)	–	–	–	+ R, P	R	–	–
Z. jujuba	±	–	+	+	+	1–3	6–10	23 (± 4)	289 (± 79)	43 (± 8)	385 (± 210)	–	+ R, ± P	–	–	+
Z. mauritiana	±	±	+	+	+	1–3	5–11	21 (± 6)	363 (± 202)	35 (± 13)	498 (± 239)	–	+ R	–	–	+
Z. nummularia	–	–	+	+	+	1–3	5–12	22 (± 6)	399 (± 205)	36 (± 8)	401 (± 163)	–	+ R	–	–	–
Z. oenoplia	–	+	–	–	–	1–2	7–12	15 (± 2)	635 (± 337)	20 (± 4)	841 (± 82)	–	+ R, P	–	–	+
Z. oxyphylla	±	+	–	±	±	1–2	5–10	14 (± 3)	544 (± 304)	19 (± 4)	590 (± 304)	–	+ R, ± P	–	–	+
Z. rugosa	±	–	±	+	+	1–2	5–16	19 (± 3)	678 (± 424)	27 (± 5)	529 (± 149)	–	+ R	–	–	+
Z. xylopyrus	+	–	+	+	+	1–3	4–15	15 (± 3)	342 (± 120)	29 (± 8)	391 (± 121)	–	+ R	–	+	+

– = absent, + = present, ± = rarely present; R = ray, P = parenchyma; Avg = average

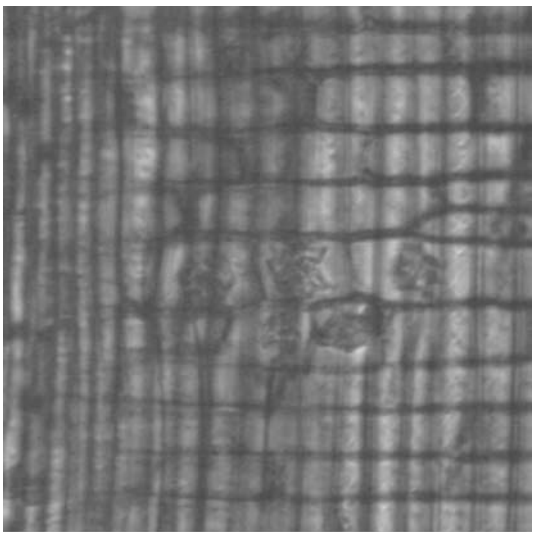

Figure 1 *Gouania leptostachya*. Radial section showing druses in ray cells (× 4000).

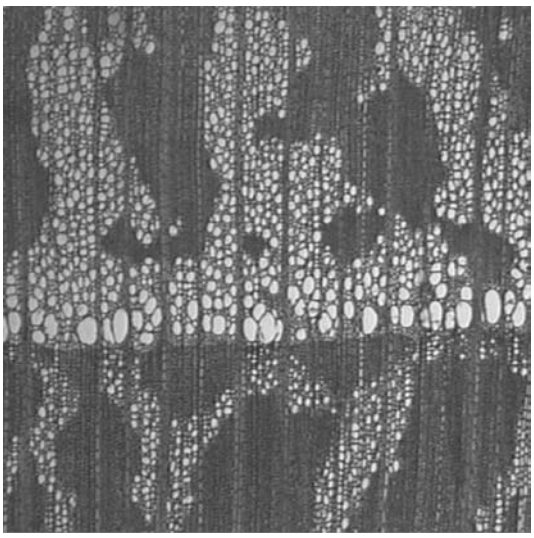

Figure 2 *Rhamnus purpurea*. Tangential section showing ring porosity with dendritic pattern (× 40).

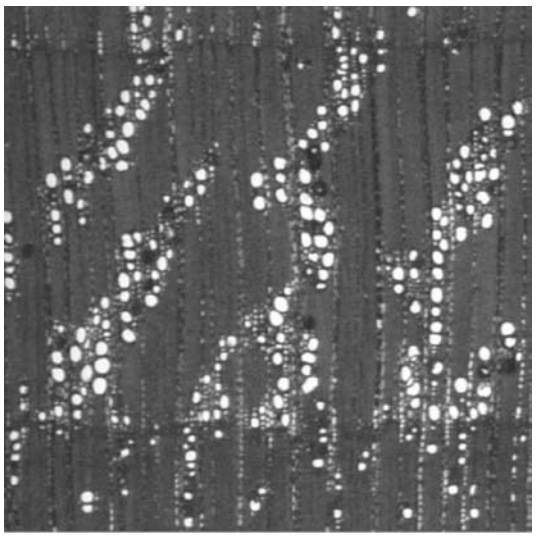

Figure 3 *Rhamnus triquetra*. Tangential section showing diffuse porosity with dendritic pattern (× 40).

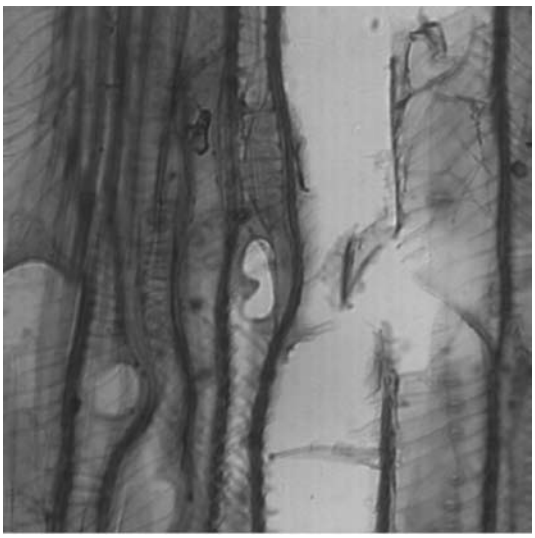

Figure 4 *Rhamnus purpurea*. Radial section showing helical thickening and simple perforation plate in vessels (× 100).

Table 4 Comparative account of the wood anatomical features of *Hovenia dulcis* from India and USA

Microscopic feature	DDw 8398, India	DDw 3808, USA
Porosity	Semi-ring porous	Ring porous
Ray seriation	1–5 (mostly 1–4)	1–7 (mostly 1–5)
Parenchyma	Sparse	Abundant
	Scanty paratracheal and diffuse	Scanty paratracheal, vasicentric aliform to confluent

upright and square cells (Figure 6). Perforated ray cells observed in *R. pupurea* (Figure 7) and *R. wightii*. Prismatic non-chambered crystals present in ray cells of *R. nepalensis*.

Sageretia Brongn.

Species studied: *Sageretia brandrethiana* Aitch., *S. thea* (Osbeck) Johnst. (syn. *S. theezans* Brongn.).

Microscopic features: Growth rings distinct due to parenchyma bands. Wood diffuse porous. Vessels solitary or in radial multiples of 2–6, round to oval shaped, perforation plate simple. Intervessel pits alternate, minute to medium, coalescent aperture present, vessel ray pits similar to intervessel pits in shape and size. Fibres non-septate with simple pits. Axial parenchyma marginal or in seemingly marginal bands 2–7 cells wide, diffuse, rarely vasicentric and scanty paratracheal, in strands of 2–4 cells. Rays 1–4 seriate, uniseriate ray height 4–19 celled, multiseriate ray height 8–37 celled. Body ray cells heterogeneous (procumbent, square and upright mixed in *S. thea* while procumbent and upright mixed in *S. brandrethiana*). Rays show storied tendency at few places in *S. brandrethiana*. Perforated ray cells observed in *S. brandrethiana* (Figure 8). Prismatic crystals, both chambered and non-chambered, present in ray and parenchyma cells. Two distinct sizes of crystals in same ray cells present in *S. thea*.

Scutia (DC.) Comm. ex Brongn.

Species studied: *Scutia myrtina* (Burm. F.) Kurz. (syn. *S. indica* Brongn.).

Microscopic features: Growth rings distinct due to fibrous tissue, wood diffuse porous, vessels solitary, clustered and in radial multiples of 2–8 cells, round to oval shaped, perforation plate simple. Intervessel pits alternate, minute to small, vessel ray pits similar to intervessel pits in shape and size. Fibres non-septate with simple pits.

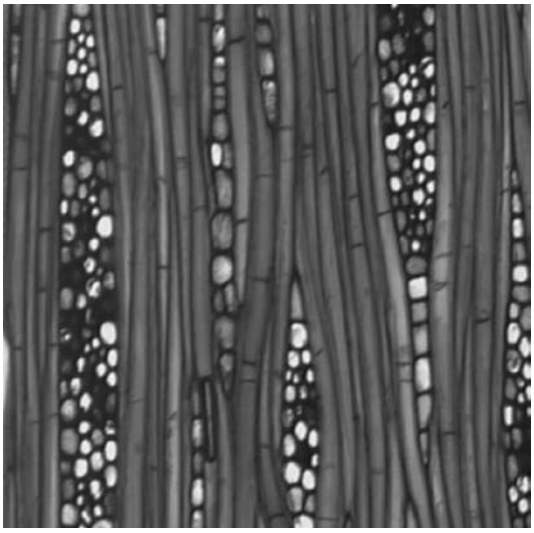

Figure 5 *Rhamnus nepalensis*. Tangential section showing septate fibres (× 125).

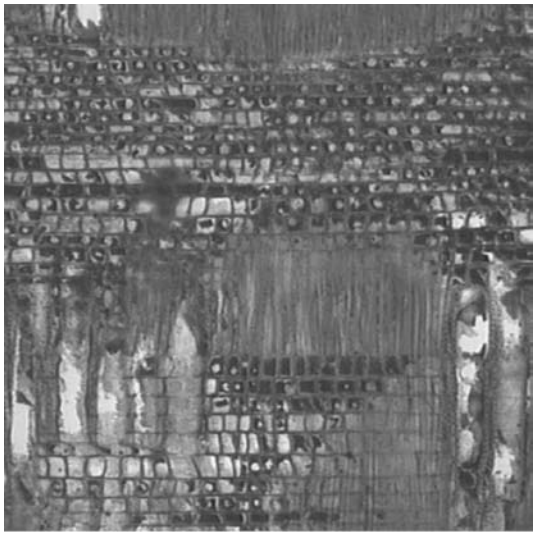

Figure 6 *Rhamnus triquetra*. Radial section showing heterogeneous rays (× 100).

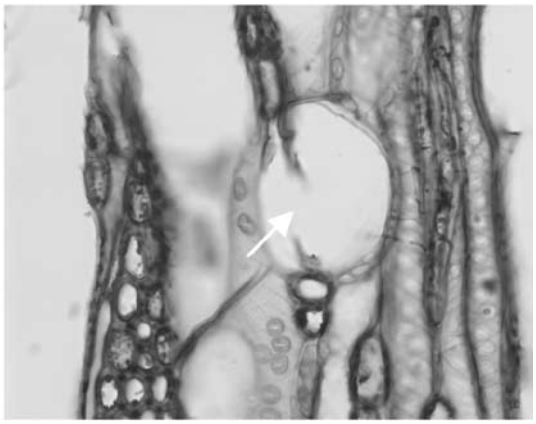

Figure 7 *Rhamnus purpurea*. Tangential section showing perforated ray cell (arrow) (× 400).

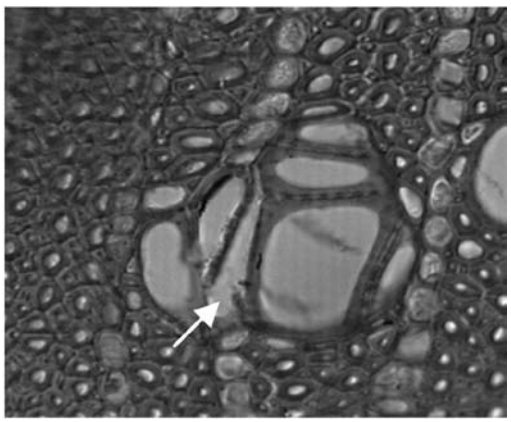

Figure 8 *Sageretia brandrethiana*. Tangential section showing perforated ray cell (arrow) (× 400).

Axial parenchyma in marginal (Figure 9) or in seemingly marginal bands 2–3 cells wide, also scanty paratracheal, rarely diffuse, in strands of 3–5 cells. Rays 1–4 seriate, uniseriate ray height 5–19 celled, multiseriate ray height 8–61 celled. Body ray cells both homogenous (procumbent cells) and heterogeneous (procumbent, square and upright mixed). Prismatic crystals, both chambered and non-chambered, present in rays and parenchyma cells.

Ventilago Gaertner

Species studied: *Ventilago maderaspatana* Gaertn.
Microscopic features: Growth rings distinct due to fibrous tissue. Wood diffuse porous, vessels solitary, clustered and in radial multiples of 2–6 cells, round to oval shaped, perforation plate simple. Intervessel pits alternate, medium to large (Figure 10), vessel ray pits smaller than intervessel pits in shape and size with 5–8 µm diameter. Fibres non-septate, with simple pits. Axial parenchyma in marginal or in seemingly marginal bands 1–3 cells wide, vasicentric and scanty paratracheal, in strand of 2–7 cells. Rays 1–8 seriate, rays of two distinct sizes, uniseriate ray height 6–28 celled, mean multiseriate ray height more than 1 mm. Body ray cells mainly homogeneous (procumbent cells) rarely heterogeneous (procumbent with 1–2 rows of upright and square cells and at places procumbent, square and upright mixed). Prismatic crystals, chambered and non-chambered, present in axial parenchyma and rays (Figure 10).

Ziziphus Tourn. ex Miller

Species studied: *Ziziphus glabrata* Heyne ex Roth (syn. *Z. trinervia* Roxb.), *Z. incurva* Roxb., *Z. jujuba* Mill. (syn. *Z. vulgaris* Lam.), *Z. mauritiana* Lam. (syn. *Z. jujuba* L.), *Z. nummularia* W. & A., *Z. oenoplia* (L.) Mill., *Z. oxyphylla* Edgew., *Z. rugosa* Lam. and *Z. xylopyrus* Willd.
Microscopic features: Growth rings distinct due to fibrous tissue, wood diffuse porous, while semi-ring porous in *Z. oxyphylla*. Vessels solitary, clustered and in radial multiples of 2–7 cells, round to oval shaped, perforation plate simple. Intervessel pits alternate, minute to large, vessel ray pits similar to intervessel pits in shape and size and rarely smaller to intervessel pits with 3–8 µm diameter. Coalescent aperture present in *Z. rugosa Z. nummularia Z. mauritiana* and *Z. glabrata*. Fibres non-septate with simple pits except for *Z. incurva* which has both septate and non-septate fibres. Axial parenchyma diffuse, scanty partatracheal, vasicentric, aliform to confluent (Figure 11) and marginal or in seemingly marginal bands 2–6 cells wide, in strands of 2–7 cells. Only scanty paratracheal in *Z. oenoplia*. Rays 1–3 seriate in all the species (Figure 12) except *Z. glabrata* having rays 1–5 seriate (Figure 13), uniseriate ray height 4–34 celled, multiseriate ray height 4–36 celled. Body ray cells

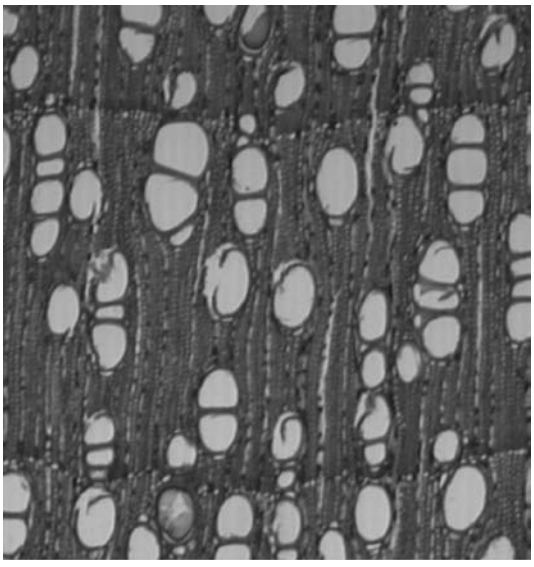

Figure 9 *Scutia myrtina*. Tangential section showing marginal parenchyma (× 40).

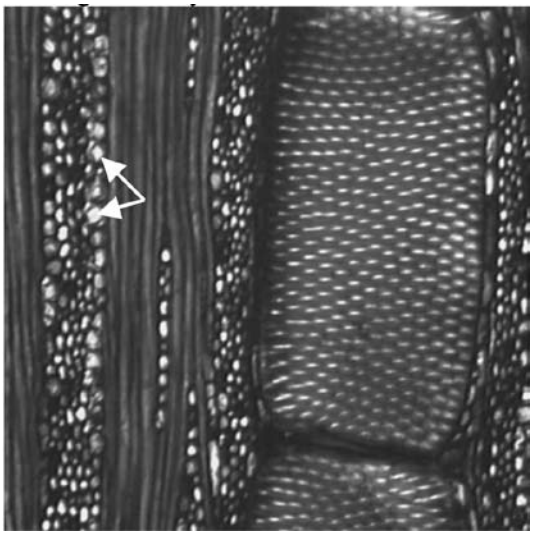

Figure 10 *Ventilago maderaspatana*. Tangential section showing large intervessel pits and crystals (arrows) in rays (× 125).

both homogeneous (procumbent cells) (Figure 14) and heterogeneous (procumbent with 1–2 rows of upright and square cells and procumbent, square and upright mixed). Perforated ray cells present in *Z. jujuba* (Figure 15), *Z. mauritiana, Z. oenoplia, Z. oxyphylla* and *Z. xylopyrus* (Figure 16). Prismatic crystals, both chambered and non-chambered, present in ray and parenchyma cells. Druses present in ray cells of *Z. incurva*.

Schiararend (1991) studied seven species (studied by us too) of *Ziziphus* viz. *Z. mauritiana* Lam. (syn. *Z. jujuba* Lam.), *Z. jujuba* Mill. (*Z. vulgaris* Lam.), *Z. oenoplia* (L.) Mill, *Z. rugosa* Lam., *Z. xylopyrus* Willd., *Z. nummularia* (Burm.) DC. and *Z. glabrata* Heyne ex Roth. A comparative account with the above data revealed differences in quantitative features, size of intervessel pits and mineral inclusions (Table 5).

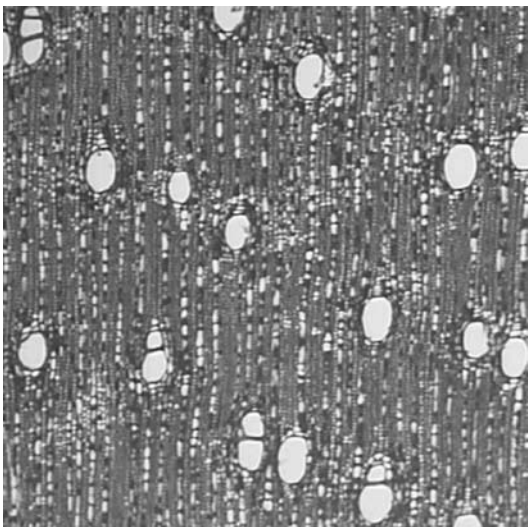

Figure 11 *Zizyphus vulgaris*. Tangential section showing diffuse, vasicentric, aliform to confluent parenchyma (× 40).

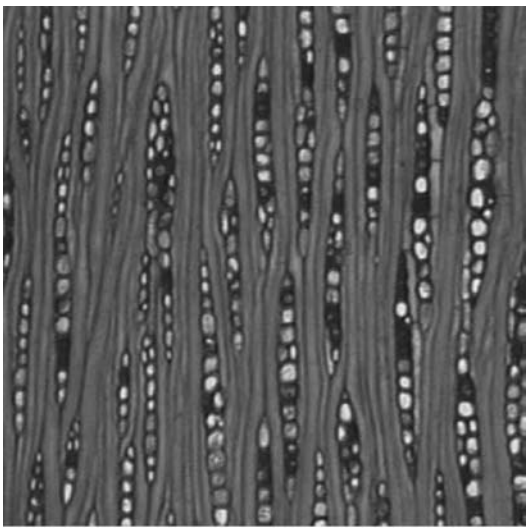

Figure 12 *Zizypus xylopyrus*. Tangential showing rays exclusively 1–2 seriate (× 100).

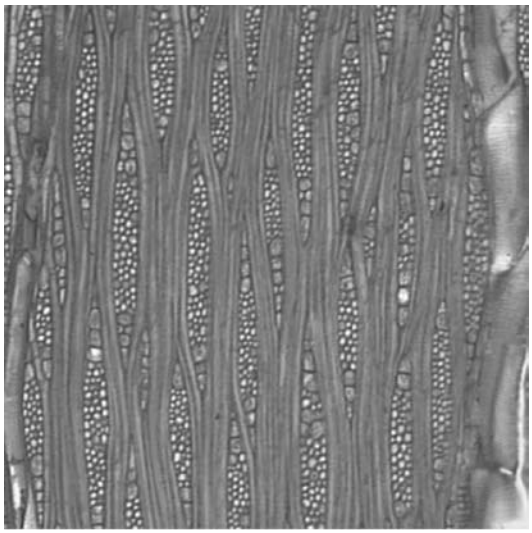

Figure 13 *Zizypus glabrata*. Tangential section showing rays 1–5 seriate (× 100).

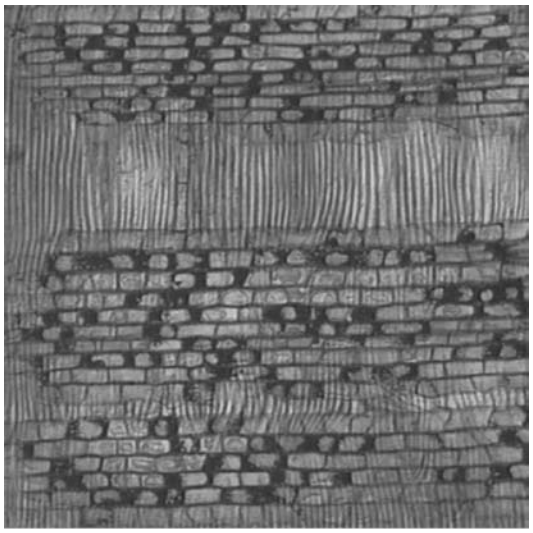

Figure 14 *Zizypus xylopyrus*. Radial section showing homogeneous rays with crystals (× 100).

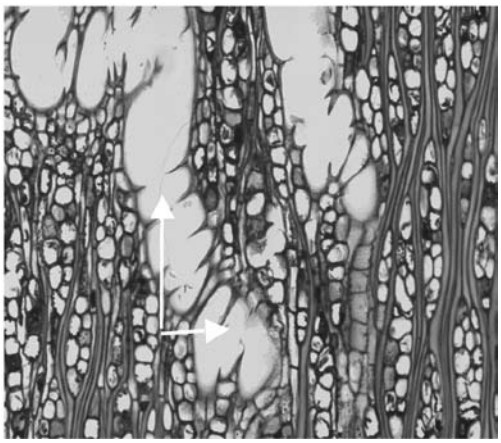

Figure 15 *Zizypus jujuba*. Tangential section showing perforated ray cell (arrows) (× 100).

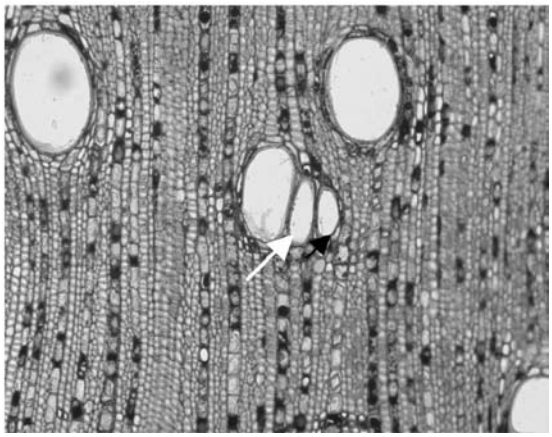

Figure 16 *Zizypus xylopyrus*. Tangential section showing perforated ray cell (arrow) (× 100).

Table 5 Comparative account of the wood anatomical features of *Ziziphus*

Species	Study	Mean vessel frequency	Mean vessel diameter (µm)	Mean vessel length (µm)	Mean fibre length (µm)	Ray seriation	Average ray height (µm)	Inter-vessel pit (µm)	Crystal in ray
Z. mauritiana	Schiararend (1991)	10/mm²	125	410	780	1–2	370	8–12	+
	Present	4–28/mm²	142	352	1002	1–3	498	5–10	+
Z. jujuba	Schiararend (1991)	33/mm²	90	360	750	1–2	480	8–12	NA
	Present	5–9/mm²	109	314	1018	1–3	385	4–8	+
Z. rugosa	Schiararend (1991)	14/mm²	145	590	935	1–3	440	8–14	–
	Present	9–15/mm²	145	577	941	1–3	529	5–11	+
Z. xylopyrus	Schiararend (1991)	10/mm²	110	405	860	1–2	500	8–14	+
	Present	5–20/mm²	122	411	969	1–3	391	5–13	+
Z. glabrata	Schiararend (1991)	37/mm²	95	425	870	1–5	340	4–8	NA
	Present	36–67/mm²	109	403	907	1–5	395	6–10	+
Z. oenoplia	Schiararend (1991)	33/mm²	110	500	750	NA	315	8–12	NA
	Present	33–51/mm²	111	553	903	1–3	841	5–8	+

NA = not available, + = present, – = absent

Species identification key of the family

1. Vessels in dendritic pattern, helical thickening present 2
1*. Vessels not arranged in dendritic pattern, helical thickening absent..... 7
2. Wood ring to semi-ring porous 3
2*. Wood diffuse to semi-ring porous 5
3. Vessels arranged in prominent dendritic pattern, fibre non-septate... *Rhamnus purpurea*
3*. Vessels show only a tendency of dendritic pattern, fibre both septate to non-septate... 4
4. Rays mostly 1–5 seriate, rarely 1–6 seriate and crystals in rays present .. *Rhamnus nepalensis*
4*. Rays mostly 1–3 seriate, rarely 1–5 seriate and crystals in rays absent ..... *Rhamnus wightii*
5. Rays 1–6 seriate ..... *Rhamnus triquetra*
5*. Rays 1–4 seriate 6
6. Intervessel pits 6–8 µm in diameter, ray vessel pits similar to intervessel pits ... *Rhamnus persica*
6*. Intervessel pits 5–10 µm in diameter, ray vessel pits smaller to intervessel pits (4–8 µm) .... *Rhamnus virgata*
7. Rays 1–8 seriate, mean vessel diameter > 150 µm 8
7*. Rays < 5 seriate, mean vessel diameter < 150 µm 10
8. Intervessel pits minute with 3–4 µm diameter, fibre septate to non-septate and crystals in rays only ..... *Berchemia floribunda*

8*. Intervessel pits medium to large with 8–16 µm diameter, fibre non-septate and crystals in rays and axial parenchyma 9
9. Druses in rays present, rays homogeneous, intervessel pits large (11–16µm) and axial parenchyma scanty paratracheal and marginal (4–7 cells wide)..... ..... *Gouania leptostachya*
9*. Druses in rays absent, rays heterogeneous, intervessel pits medium to large (8–12 µm) and parenchyma scanty paratracheal, vasicentric and marginal (2–7 cells)..... .....*Ventilago maderaspatana*
10. Marginal parenchyma absent. Wood semi-ring to diffuse porous 11
10*. Marginal parenchyma present. Wood diffuse porous 12
11. Rays 1–5 seriate, intervessel pits small to medium (5–9 µm diameter)... *Hovenia dulcis*
11*. Rays 1–2 seriate, intervessel pits small (3–5 µm diameter) ..... *Ziziphus oxyphylla*
12. Marginal parenchyma band 2–6 cells wide, mean vessel diameter < 50 µm 13
12*. Marginal parenchyma band 1–3 cells wide, mean vessel diameter > 50 µm 14
13. Intervessel pits minute with 2–3 µm diameter, rays not storied ..... *Sageretia thea*
13*. Intervessel pits small to medium with 5–8 µm diameter, rays storied at places .... S*ageretia brandrethiana*
14. Rays 1–5 seriate, wood very hard and very heavy 15
14*. Rays 1–3 seriate, wood hard and moderately heavy to heavy 16
15. Rays 1–4 seriate, intervessel pits < 6 µm, mean uniseriate ray height > 200 µm, mean multiseriate ray height > 400 µm .... *Scutia myrtina*
15*. Rays 1–5 seriate, intervessel pits > 6 µm, mean uniseriate ray height < 200 µm, mean multiseriate ray height < 400 µm .... *Ziziphus glabrata*
16. Vessel diameter < 70 µm, vessel frequency > 50 mm^2, wood semi-ring porous, parenchyma scanty paratracheal, rarely marginal, exclusively uniseriate rays .... *Ziziphus oxyphylla*
16*. Vessel diameter > 70 µm, vessel frequency < 50 mm^2, diffuse porous, parenchyma aliform and marginal, rays uni to biseriate, rarely triseriate 17
17. Druses present in rays, fibres both septate and non-septate ..... *Ziziphus incurva*
17*. Druses absent, fibres non-septate 18
18. Axial parenchyma scanty paratracheal, multiseriate ray height > 700 µm .... *Ziziphus oenoplia*
18*. Axial parenchyma scanty paratracheal, aliform, vasicentric and marginal (1–2 cells wide) multiseriate ray height < 700 µm 19
19. Intervessel pits 4–8µm diameter, vessel frequency < 8 mm^2, uniseriate ray height < 300 µm ..... *Ziziphus jujuba*
19*. Intervessel pits 5–10 µm (rarely 12 µm), vessel frequency > 8 mm^2, uniseriate ray height > 300 µm 20
20. Mean uniseriate ray height > 400 µm, axial parenchyma scanty paratracheal and narrow bands ..... *Ziziphus rugosa*
20*. Mean uniseriate ray height 300–400 µm, axial parenchyma vasicentric, aliform with short lateral extensions and narrow bands 21
21. Mean multiseriate ray height > 450 µm .... *Ziziphus mauritiana*
21*. Mean multiseriate ray height < 450 µm 22
22. Mean uniseriate ray height > 350 µm .... *Ziziphus nummularia*
22*.Mean uniseriate ray height < 350 µm .... *Ziziphus xylopyrus*

DISCUSSION

The study indicated that there was very little difference in anatomy within a genus and most of the species of a genus mainly differed from one another in a few quantitative features, some of which might be site dependent. *Gouania leptostachya* and *V. maderaspatana* are large climbers or scrambling shrubs showing quite similar anatomy with soft, usually light (specific gravity 0.44–0.66 air dry), coarse-textured wood containing large pores, large intervessel pits, marginal parenchyma, non-septate fibres and high rays. Although *B. floribunda* and *Z. oenoplia* are also climbers/scrambling shrubs, their anatomies differ from those of *Gouania* and *Ventilago* species. The F/V ratio (Table 2) suggested that *G. leptostachya, H. dulcis, R. persica, R. virgata, S. brandrethiana, Z. glabrata, Z. jujuba* and *Z. mauritiana* had a highly evolved mechanical system with a high degree of intrusiveness (F/V = ≥ 2.5), while *V. maderaspatana* showed a lower ratio

(F/V = 1.3) indicating primitive features and a low degree of intrusiveness. The vulnerability and mesomorphy figures calculated as per formula given by Carlquist (1977) indicated that all the species were mesic except for *S. brandrethiana* and *S. thea* which showed xeric values (Table 2).

The characters mentioned in the Inside Wood database for fossil wood of *Hovenia dulcis* were quite different while those of *Z. jujuba* and *Z. xylopyrus* matched the present study. The study of two samples of *H. dulcis* from India and USA showed differences in ray seriation and parenchyma type reflecting that within a species these features vary. Similarly, a comparative account of the present study with Schiararend's (1991) seven species of *Ziziphus* revealed differences in quantitative features, size of intervessel pits and mineral inclusions indicating that even feature like 'size of intervessel pits', which usually was considered to be a fixed character, varied greatly. Thus, it can be concluded that feature variation within a species is of much importance especially for the preparation of species identification key.

Rhamnaceae has been studied by a number of researchers but the presence of perforated ray cells has never been reported. In the present study this feature was observed in *S. brandrethiana, S. thea, R. purpurea, R. wightii, Z. jujuba, Z. mauritiana, Z. oenoplia, Z. oxyphylla, Z. rugosa* and *Z. xylopyrus*. Of the 41 wood samples studied, perforated ray cells were observed in 13 wood samples of the said species. These perforated ray cells occurred as uniseriate extensions of multiseriate rays. The perforation plates in the perforated ray cells were all simple. The ray cells having perforation plates were generally much larger than the surrounding ray cells and were of the same size as the vessel.

Systematic position of the family

Schiararend (1991) investigated the systematic wood anatomy of the Rhamnaceae (Rhamnales), tribe Zizipheae. He divided the genus *Ziziphus* into three group, namely, *Ziziphus*-A, *Ziziphus*-B and *Ziziphus*-C on the basis of ray width, parenchyma distribution and type of vessel perforation. The present study revealed that parenchyma type varied with site. All our samples were found to have simple perforation plate. Our study supports formation of two groups on the basis of ray seriation only: one with 1–3 seriate rays and the other with 1–5 seriate.

Suessenguth (1953) divided the family Rhamnaceae into five tribes, of which four, viz. Gouanieae, Rhamneae, Ventilagineae and Zizipheae, occurred in India. The present study showed that the tribes Rhamneae and Zizipheae were quite heterogeneous. Gouanieae and Ventilagineae had single genus and hence no comparison of these tribes could be done.

Richardson et al. (2000a) revised this classification and divided Rhamnaceae into 12 tribes, of which four tribes (Rhamneae, Ventilagineae, Paliureae and Gouanieae) were represented in India. Suessenguth (1953) placed *Hovenia, Rhamnus, Sageretia* and *Scutia* together in the tribe Rhamneae, and *Berchemia* and *Ziziphus* together in the tribe Ziziphae. Richardson et al. (2000a) placed *Berchemia* with *Rhamnus, Sageretia* and *Scutia* in the tribe Rhamneae and *Hovenia* and *Ziziphus* in different tribe Paliureae. This classification of Rhamnaceae was again revised by Richardson et al. (2000b) on the basis of DNA sequences-*rbcL* analysis. Our studied genera were placed in the same tribes as in his previous classification.

The present study revealed that the genera placed in the tribe Rhamneae and Ziziphae by Suessenguth (1953) and the tribes Rhamneae and Paliureae by Richardson et al. (2000a, b) are dissimilar (Tables 2 and 3) in their wood anatomy and hence need to be revised.

ACKNOWLEDGEMENTS

The authors are thankful to SS Negi, Director of the Forest Research Institute and S Nautiyal, Head of the Botany Division for administrative support. The financial support from the Indian Council of Forestry Research and Education, Dehradun is duly acknowledged.

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