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Research Article

Ecological Wood Anatomy of Turkish *Rhododendron* L. (*Ericaceae*). Intraspecific Variation

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Abstract : The intraspecific relationships of selected wood anatomical characters such as altitude, stem diameter, stem age and average annual ring width were investigated in five different Turkish *Rhododendron* L. species. *Rhododendron luteum* Sweet. grows at an altitude of 110 to 2230 m, *R. ungernii* Trautv. 900 to 2020 m, *R. smirnovii* Trautv. 1600 to 2230 m, *R. caucasicum* Pallas 1900 to 3100 m, and *R. ponticum* L. from sea level to 2230 m in the Eastern Black Sea Region. Although the degree of significance varies between species, correlation and multiple regression analysis indicated a significant correlation between wood anatomical characters and non-anatomical factors.

Key Words: Intraspecific variation, wood anatomy, altitude, *Rhododendron,* Turkey.

Türkiye Orman Güllerinin (*Rhododendron* L.) Ekolojik Odun Anatomisi (*Ericaceae*). Tür Düzeyinde Varyasyonlar

Özet : Türkiye'deki beş *Rhododendron* L. türünün bazı anatomik özellikleri ile rakım, gövde çapı, yaş ve ortalama yıllık halka genişliği ilişkileri tür düzeyinde araştırılmıştır. Doğu Karadeniz Bölgesi'nde; *R. luteum* Sweet. 110-2230 m, *R. ungernii* Trautv. 900-2020 m, *R. smirnovii* Trautv. 1600-2230 m, *R. caucasicum* Pallas 1900-3100 m, *R. ponticum* L. ise deniz seviyesinden 2230 m yükseklikler arasında yetişmektedir. Korelasyon ve çoğul regresyon analizleri sonucunda; türlere göre önem düzeyleri değişmekle birlikte, bazı anatomik özellikler ile anatomik olmayan faktörler arasında anlamlı ilişkiler saptanmıştır.

Anahtar Sözcükler: Tür düzeyinde varyasyon, odun anatomisi, rakım, *Rhododendron*, Türkiye

Introduction

According to Metcalfe and Chalk (1) *Ericaceae*, particularly *Rhododendron* L. is widely distributed, but species are numerous especially in China and South Africa. *Rhododendron* species are distributed in China, Tibet, Burma, Nepal, New Guinea, Tropical Asia, Europe and North America. There are about 700 species in these regions (2, 3). According to Suzuki (4), the habitats of *Rhododendron* species show a wide range, from low-montane forests to alpine regions more than 4000 m high. These species are usually shrubs and tall trees about 30 m high and 100 cm in diameter in Nepal. In Turkey, the ones distributed from sea level to about 3200 m, are usually large shrubs (*R. ponticum* L., *R. ungernii* Trautv.), shrubs (*R. smirnovii* Trautv., *R. luteum* Sweet.) or dwarf shrubs (*R. caucasicum* Pallas). *R. luteum* is deciduous, and the others are evergreen shrubs. *R. caucasicum* is alpine type, and the others are forest type.

Studies on wood anatomical variation within species are few, and usually did not succeed in finding a correlation between wood structure and non-anatomical factors (5, 6). A significant correlation was found only in studies carried out in a small region, and showed that wood anatomical characters are significantly related with non-anatomical factors (NAF), especially in relation to the altitude (7-9). There are very few studies of intraspecific variation compared with interspecific ones in ecological wood anatomy.

The objective of this study was to examine the intraspecific variation of the wood anatomy of Turkish *Rhododendron*.

Materials and Methods

Wood samples of *Rhododendron* species were collected in the Eastern Black Sea Region (Artvin and the Fırtına Valley) at an altitude of sea level up to 3100 m, with 50 m intervals. The material was sectioned in the usual way, and sections were stained with safranin. Maceration was prepared using Schultze's method (nitric acid and potassium chlorate). The length of libriform fibres, fibre-tracheids and vessel members, and fibre diameters were measured using macerations. The other quantitative data were measured and counted in sections. One sample was studied for a particular altitude at 50 m intervals for 5 species making a total of 176 samples. Each average value is based on 50 measurements and counts. Results of all individuals are compared in relation to different non-anatomical factors (altitude, stem age, stem diameter, ring width). Correlation among these four factors and 26 wood anatomical characters are assessed, and anatomical characters are then evaluated by multiple regression analysis using non-anatomical factors as independent variables. The software used is multivariate general linear hypothesis in SPSS on a IBM PC. All wood terms used conform to the usage of the IAWA Committee on Nomenclature (10).

Voucher number of samples: *Rhododendron* ungernii; Artvin-Murgul 900 m, KATO 13362 (n. merev [abbreviated as nm from now on] 184); 950 m, KATO 13363 (nm 11); 1000 m, KATO 13364 (nm 186); 1150 m, KATO 13365 (nm 180); 1200 m, KATO 13366 (nm 80); 1300 m, KATO 13367 (nm 179); 1350m, KATO 13368 (nm 178); 1400 m, KATO 13369 (nm 20); 1450 m, KATO 13370 (nm 177); 1550 m, KATO 13371 (nm 174); 1600m, KATO 13372 (nm 172); 1650 m, KATO 13373 (nm 98); 1700 m, KATO 13374 (nm 170); 1770 m, KATO 13375 (nm 85); 1790 m, KATO 13376 (nm 165); 1800 m, KATO 13377 (nm 36); 1900 m, KATO 13378 (nm 166); 2000 m, KATO 13379 (nm 110). *R. smirnowii*; Artvin-Murgul 1350 m, KATO 13380 (nm 176); 1600 m, KATO 13381 (nm 173); 1620 m, KATO 13382 (nm 163); 1660 m, KATO 13383 (nm 93); 1680 m, KATO 13384 (nm 36); 1700 m, KATO 13385 (nm 83); 1730 m, KATO 13386 (nm 168); 1750 m, KATO 13387 (nm 86); 1770 m, KATO 13388 (nm 84); 1850 m, KATO 13389 (nm 167); 1900 m, KATO 13390 (nm 185); 1970 m, KATO 13391 (nm 108); 2020 m, KATO 13392 (nm 109); 2060 m, KATO 13393 (nm 111); 2230 m, KATO 13394 (nm 112). *R. caucasicum*; Artvin-Melo 1900 m, KATO 13395 (nm 38), 1950 m, KATO 13396 (nm 37); 2000 m, KATO 13397 (nm 39); 2050 m, KATO 13398 (nm 199); 2100 m, KATO 13399 (nm 190); 2150 m, KATO 13400 (nm 198); 2200 m, KATO 13401 (nm 188), 2230 m, KATO 13402 (nm 117); 2310 m, KATO 13403 (nm 118); Artvin-Atilla vadisi 2320 m, KATO 13404 (nm 119); 2350 m, KATO 13405 (nm 133); 2380 m, KATO 13406 (nm 120); 2400 m, KATO 13407 (nm 200); 2450 m, KATO 13408 (nm 121), 2500 m, KATO 13409 (nm 46), 2550 m, KATO 13409 (nm 193), 2600 m, KATO 13410 (nm 194); 2650 m, KATO 13411 (nm 192); 2700m, KATO 13412 (nm 135); 2750 m, KATO 13413 (nm 197); 2850 m, KATO 13414 (nm 191), 2950 m, KATO 13415 (nm 195); Kaçkar- Öküz yaylası 3000 m, KATO 13416 (nm 138); 3050 m, KATO 13417 (nm 136); 3100 m, Kato 13418 (nm 137). *R. ponticum*; Hemşin-Fırtına deresi 5 m, KATO 13419 (nm 139); 50 m, KATO 13420 (nm 141); 100 m, KATO 13421 (nm 142); 140 m, KATO 13422 (nm 47); 250 m, KATO 13423 (nm 145); 380 m, KATO 13424 (nm 150); 450 m, KATO 13425 (nm 151); 490 m, KATO 13426 (nm 153); 550 m, KATO 13427 (nm 62); 600 m, KATO 13428 (nm 63); 650 m, KATO 13429 (nm 64); 750 m, KATO 13430 (nm 43); 800 m, KATO 13431 (nm 49); 850 m, KATO 13432 (nm 66); 900 m, KATO 13433 (nm 67); 980 m, KATO 13434 (nm 68); Artvin-Murgul 1000 m, KATO 13435 (nm 4); 1060 m, KATO 13436 (nm 50); 1080 m, KATO 13437 (nm 69); 1100 m, KATO 13438 (nm 41); 1150 m, KATO 13439 (nm 27); 1200 m, KATO 13440 (nm 90); 1250 m, KATO 13441 (nm 91); 1300 m, KATO 13442 (nm 101); 1370 m, KATO 13443 (nm 72); 1450 m, KATO 13444 (nm 74); 1500 m, KATO 13445 (nm 53); 1650 m, KATO 13446 (nm 159); 1700 m, KATO 13447 (nm 171); 1730 m, KATO 13448 (nm 169);1850 m, KATO 13449 (nm 164); 1970 m, KATO 13450 (nm 107); 2100 m, KATO 13451 (nm 123); 2230 m, KATO 13452 (nm 113).

Results

Wood Anatomical Description

Rhododendron: Wood diffuse-porous (11) (Figure 1), with distinct or indistinct growth rings. Pores evenly distributed without any tendency to a specific pattern, many to numerous (pores/sq. mm), very small to small (tangential diameters); angular, solitary and sometimes in small radial and tangential multiples (2-5 pores) in cross-section. Vessel elements short with thin walls (1-1.25 µm), perforation plates mostly scalariform (Figure 5) and sometimes both simple and scalariform (exclusively in *R. luteum*). Spiral thickening present on the walls of the vessel elements but inconspicuous, usually restricted to ligulate ends. Imperforate tracheary elements intermediate or libriform fibres (few), fibre-tracheids (abundant) and vascular tracheids. Libriform fibres with simple pits (sometimes extremely minute vestige of border observed on pits, sometimes inpitted). Fibre-tracheids with distinctly bordered pits on the radial and tangential walls. Tracheids, here defined as tracheary elements, resemble narrow vessel elements but lack perforation or only have a single perforation or very reduced perforation. Parenchyma apotracheal-diffuse, very sparse, fusiform and strands of 2-4 cells. Rays heterogeneous I, II (Figure 3) or I (Figure 2), uniseriate and multiseriate. Crystals not observed in ray cells and parenchyma cells.

R. luteum Sweet.: Pores 288-558-1072 /sq. mm, mostly solitary (56-88 %), tangential diameter 17-27-43 µm, vessel elements 198-449-764 µm long, perforation plates scalariform with 2-12 bars and simple in oblique end walls, intervessel pits opposite to diffuse, rounded to oval, 2-6 µm in diameter. Libriform fibres 573-774-1176 µm long, 15-20-28 µm wide, 2-7 µm wall thickness; fibre-tracheids 573-627-1123 µm long, 9-18-34 µm wide, 2-5 µm wall thickness, tracheids average 480 µm long. Rays heterogeneous I (uniseriate rays composed of upright cells, multiseriate rays composed of a multiseriate central core of procumbent cells, uniseriate wings upright and square cells), uniseriate rays abundant, 9-19-29 rays/mm, average height 517 µm, multiseriate rays few 1-4-9 rays/mm, 2-8 cells wide and 24-75 µm wide, average height 673 µm. Vessel-ray pits half-bordered, numerous, and alternate a little smaller than intervessel pits.

R. ungernii Trautv.: Pores 176-424-704 /sq. mm, mostly solitary (57-88 %), tangential diameters 15-27-45 µm, vessel elements 237-521-840 µm long, perforation plates with 10-17-30 bars, intervessel pits opposite to diffuse. Libriform fibres 596-800-1123 µm long, 13-20-28 µm wide, 3-7 µm wall thickness. Fibre-tracheids 446-657-955 µm long, 13-19-28 µm wide, 2-5 µm wall thickness. Tracheids average 483 µm long. Ray heterogeneous I and II (heterogeneous II rays: uniseriate rays composed of upright, square and procumbent cells, wings of multiseriate rays short, of square cells), uniseriate rays abundant, 8-17-25 rays/mm, average 409 µm height, multiseriate rays few 1-4-11 rays/mm, 2-6 cells wide and 30-78 µm wide, average 534 µm height (Table 1).

R. smirnovii Trautv.: Pores 224-472-960 /sq. mm, mostly solitary (48-80 %), tangential diameter 11-26-37 µm, vessel elements 252-490-756 µm long, perforation plates with 10-17-25 bars, intervessel pits opposite to alternate and sometimes sparse. Libriform fibres 497-743-1054 µm long, 13-19-24 µm wide, 3-7 µm wall thickness. Fibre-tracheids 382-614-886 µm long, 11-17-21 µm wide, 2-5 µm wall thickness. Tracheids average 459 µm long. Rays heterogeneous I-II, uniseriate ray 10-17-29 rays/mm, average 383 µm height, multiserate rays 1-3-7 rays/mm, 2-9 cells wide, 15-88 (m wide and average 485 µm height (Table 2).

R. caucasicum Pallas: Pores 416-781-1244 /sq. mm, mostly solitary (47-77 %), tangential diameters 7-19-37 µm, vessel elements 175-326-580 µm long, perforation plates with 6-12-22 bars, intervessel pits opposite to alternate. Libriform fibres decreased, fibre-tracheids increased with altitude (about 2300-3100 m), and 405-532-745 µm long at low altitude (not observed at high altitude), 13-16-22 µm wide, 3-6 µm wall thickness. Fibre tracheids 244-414-764 µm long, 9-14-22 µm wide, 2-5 µm wall thickness. Tracheids average 318 (m long. Rays heterogeneous I, uniseriate rays 16-23-30 rays/mm, average 423 µm height, multiseriate rays 1-4-14 rays/mm, 2-6 cells wide, 15-50 µm wide, average 547 µm height, pits to vessels (vessel-ray), numerous and alternate (Table 3).

R. ponticum L.: Pores 176-486-1008 /sq. mm, mostly solitary (48-85 %), tangential diameters 13-26-47 µm, vessel elements 191-553-802 µm long, perforations plates with 8-17-27 bars, intervessel pits opposite to diffuse, rounded to oval, sometimes long in horizontal (3-6 µm). Libriform fibres 519-842-1130 µm long, 13-19-24 µm wide, 2-6 µm wall thickness, fibre-tracheids 366-678-993 µm long, 11-18-22 µm wide, 2-5 µm wall thickness. Tracheids average 511 µm long. Rays heterogeneous I, uniseriate rays 11-20-28 rays/mm, average 433 µm height, multiseriate rays 0-3-8 rays/mm, 2-8 cells wide, average 603 µm height (Table 4).

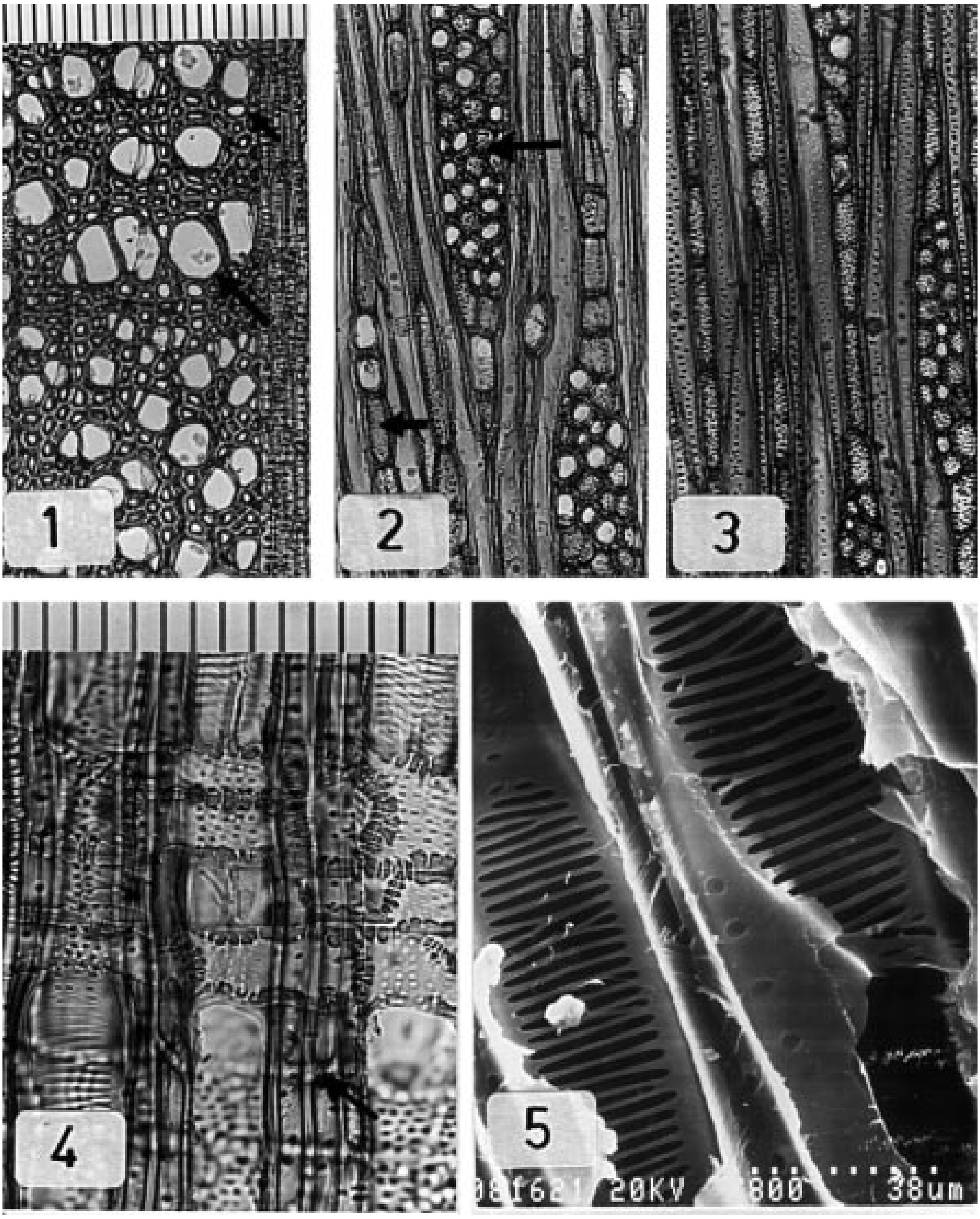

Figure 1-5. *Rhododendron*. -1: cross section, *R. smirnovii*, axial parenchyma (short arrow), vessel (long arrow) (KATO 13380). -2: tangential section, *R. ungernii*, uniseriate ray (short arrow) and multiseriate ray (long arrow), heterogeneous type I, II (KATO 13373). -3: TLS, *R. luteum*, rays heterogeneous type I (KATO 13453). -4: radial section, *R. smirnovii*, vessel-ray pits, procumbent cells in ray tissue and longitudinal view axial parenchyma. -5: RLS (SEM) *R. ponticum*, scalariform perforation plates (KATO 13424). (Figure 1-3: 1 scale bare = 10 (m (Fig 1-3, magnifications are the same.) Fig 4: 1 scale bare = 10 (m, Fig 5: 10 square = 38 (m).

Wood anatomical characters were found to be significantly correlated with one non-anatomical factor (altitude), but the degree of significance varies between species: one for *R. ungernii*, six for *R. smirnovii*, nine for *R. caucasicum*, five for *R. ponticum*. In *R. luteum*, it is found that there is no significant correlation between anatomical characters and altitude.

Generally, intraspecific variation of wood anatomical characters tends to be large for species having a large altitudinal range, but *R. ponticum* shows smaller variation, although it has a larger altitudinal range. The largest variation is observed between some wood anatomical characters and altitude in *R. caucasicum* and *R. smirnovii*.

There is a strong negative correlation between altitude and stem diameter, tangential pore diameter, perforation plates length, multiseriate ray width (in cell and in micron), fibre-tracheid length and wall thickness, vascular tracheid length and lumen width, and a strong positive correlation pore density in *R. caucasicum*. In *R. ponticum*, tangential pore diameter, perforation plate length, vessel element length, fibre-tracheid length, libriform fibre length show a strongly negative correlation with altitude. There is only a positive correlation between altitude and tangential pore diameter and perforation plate length in *R. smirnovii*. The other characters (multiseriate ray width, libriform fibre and tracheid length) have a negative correlation with altitude.

Against stem diameter (NAF), multiseriate ray width, fibre width (FW, LW, TW) increased strongly, and tangential pore diameter, fibre length and lumen width increased moderately in *R. luteum*. Pore diameter, PPL length, multiseriate ray width, fibre wall thickness (FWT, LWT, TWT) and libriform fibre length increased strongly in *R. ungernii*. Uniserate ray height and fibre lumen width decreased moderately, multiseriate ray width, and fibre wall thickness (FWT, TWT) increased moderately in R. smirnovii. Some characters of vessel (TD, PPL, VEL) and fibre (FL, FW, FWT, TL, TLW, TWT) increased, and pore density and multiseriate rays in mm decreased with stem diameter in *R. caucasicum*. In *R. ponticum*, pore diameter, multiseriate ray width, fibre-tracheid length and width, and libriform fibre length are significantly correlated (positive) with stem diameter.

In *Rhododendron* species, stem age has a positive relation with rays width, fibre wall thickness and pore diameter, but it has a negative correlation with bar number. In addition, vessel element length, bar number, perforation plate length, pore diameter and fibre length are mutually and strongly positively correlated with each other. Uniseriate ray ratio is strongly correlated with uniseriate and multiseriate rays in mm and in mm^2, which differ within species.

Uniseriate ray in mm is strongly correlated (negative) with annual ring width, and positively correlated with pore diameter (*R. luteum* and *R. ungernii*). Pore diameter, PP length, vessel element length, fibre length and lumen width (FL, LL, T) is positively, and pore density is negatively correlated with WAR in *R. caucasicum*. Pore diameter, solitary pore ratio, and tracheid length is positively correlated with WAR in *R. ponticum*.

Altitude also influences stem diameter and width of annual rings. There is a strong negative correlation between altitude, stem diameter and annual ring width. At the same time, no correlation is found between altitude and bar number per perforation plates, multiseriate rays height and density, multiseriate and uniseriate rays in mm, fibre width, percentage of solitary pore and uniseriate rays which differ within species.

According to the results of the multiple regression analysis, five anatomical characters are significantly negatively correlated with altitude in *R. ponticum* and *R. caucasicum*. Tangential pore diameter, perforation plate length, vessel element length and fibre length, and multiseriate ray width have a stronger correlation with altitude compared to with stem diameter, stem age, and annual ring width. Pore density has an equal relationship with altitude, stem diameter and stem age. Annual ring width has a direct influence on pore density compared to altitude, stem diameter, and stem age (Table 5).

Discussion

Wood anatomical variation of Nepalese *Rhododendron* was studied by Noshiro et al. (8) and Noshiro et al. (12) in 26 different species, indicating that the wood structure of *Rhododendron* species is rather homogeneous, and intraspecific (species level) variation is less pronounced than the interspecific (genus level) variation (8, 12).

Intraspecific studies on wood anatomy have so far been carried out on *R. antropogen* D. Don, *R.*

Table 1. Non-anatomical data and wood anatomical characters of *Rhododendron ungernii*.

ALT (m)	SD (cm)	SA (year)	WAR (mm)	TD (μm)	BAR	PPL (μm)	MRH1 (μm)	MRW2 (cell)	MRW (μm)	PD	MRD	MRmm
900	4.0	23	0.8	29	17	70	559	3.6	39	526	5.5	3.2
950	6.6	22	1.9	32	19	79	458	3.4	36	457	7.9	3.2
1000	4.0	17	1.8	28	19	76	505	3.5	41	385	10.6	4.6
1150	4.9	23	1.3	27	18	73	610	3.7	37	421	7.2	3.7
1200	5.2	23	1.0	29	19	71	517	4.5	52	402	6.0	2.7
1300	3.6	25	1.0	31	18	72	591	3.5	46	379	9.6	5.0
1350	4.0	18	1.2	32	18	64	447	3.9	41	403	7.6	2.7
1400	10.9	72	1.3	34	20	81	592	5.8	59	354	5.8	3.1
1450	4.0	16	1.2	28	19	73	518	3.1	37	359	9.3	4.0
1490	5.0	35	0.6	25	15	59	449	4.8	55	438	5.2	2.2
1550	3.1	28	0.7	26	17	66	652	3.8	47	378	4.2	2.3
1600	5.1	44	0.4	28	18	71	639	3.3	37	462	5.9	3.4
1650	2.4	25	0.6	26	18	68	602	3.3	41	400	13.9	5.9
1700	2.0	10	1.2	23	15	61	458	2.6	28	414	20.7	8.7
1770	6.4	61	0.7	25	20	68	538	3.8	45	466	5.9	2.9
1790	2.8	20	0.9	23	18	66	645	4.2	47	390	9.5	5.2
1800	5.0	50	0.4	24	19	73	567	4.4	54	436	5.8	3.1
1900	2.7	11	0.7	23	18	64	584	3.4	41	378	6.1	2.8
2020	2.0	18	0.4	24	17	62	495	4.6	48	471	11.0	4.7

Table 1. Continued

Urmm	VEL (μm)	FL (μm)	FW (μm)	FWT (μm)	LL (μm)	LW (μm)	LWT (μm)	SP %	UR %	TL (μm)	TW (μm)	TWT (μm)
21	595	674	18	3.4	796	19	3.5	72	72	505	23	2.6
17	462	629	20	3.6	792	21	4.0	62	72	388	27	3.1
14	631	698	19	3.2	869	20	3.5	77	56	550	27	2.9
20	515	610	19	3.12	778	20	3.5	76	70	463	27	3.1
17	474	666	18	3.49	766	20	3.7	76	71	441	25	3.6
15	518	635	19	3.40	757	21	3.8	88	53	467	25	2.8
18	486	643	20	3.82	770	22	3.7	72	76	473	27	3.4
18	549	732	21	4.24	907	21	4.2	61	64	524	28	3.6
16	549	651	19	3.42	826	21	3.6	62	66	542	26	2.8
17	486	612	19	3.51	755	20	3.5	63	69	441	26	2.9
21	499	583	20	2.79	781	22	3.2	72	77	420	26	2.8
21	567	682	18	2.79	799	19	2.8	71	73	539	23	2.6
-	537	702	17	3.21	815	17	3.3	64	-	516	23	3.0
14	476	588	17	3.17	720	19	3.6	75	48	452	22	2.8
18	510	665	17	3.73	791	19	3.8	57	71	479	24	3.5
14	529	641	18	3.59	782	22	3.2	74	51	512	25	3.1
18	494	635	20	3.77	764	20	3.5	70	67	461	25	3.2
19	464	603	19	3.17	774	19	3.0	64	75	464	27	2.8
15	553	669	17	2.79	792	20	3.0	63	55	499	22	2.9

Table 2. Non-anatomical data and wood anatomical characters of *Rhododendron* smirnovii.

ALT (m)	SD (cm)	SA (year)	WAR (mm)	TD (µm)	BAR	PPL (µm)	MRH1 (µm)	MRW2 (cell)	MRW (µm)	PD	MRD	MRmm
1350	4.0	25	0.8	29	15	62	357	4.1	39	494	7.4	2.9
1600	4.0	38	0.5	26	19	74	582	3.8	45	485	5.2	2.8
1620	5.0	33	0.9	29	17	64	477	4.1	43	510	5.1	2.2
1660	2.5	22	0.5	28	19	68	514	3.5	42	522	7.1	3.1
1680	5.7	38	0.9	28	21	69	501	4.0	53	387	8.1	3.2
1700	4.6	40	0.6	25	18	61	480	4.3	42	338	3.5	1.8
1730	2.6	32	0.6	25	15	57	439	3.3	30	455	8.1	3.5
1750	3.9	32	0.6	29	18	64	494	3.6	37	437	7.2	2.8
1770	2.7	27	0.5	25	17	63	530	3.4	39	501	6.2	3.0
1850	2.2	11	0.8	28	15	56	553	3.9	54	283	8.1	4.1
1900	6.0	50	0.3	24	16	68	398	3.7	37	432	10.0	3.4
1970	1.2	12	0.4	24	15	56	497	3.2	40	492	7.5	3.5
2020	7.0	75	0.3	24	15	57	446	3.8	32	507	7.9	3.3
2060	3.8	35	0.5	23	15	57	488	2.9	26	577	9.2	4.4
2230	2.5	22	0.6	20	15	54	465	2.8	26	531	6.4	2.9

Table 2. Continued

Urmm	VEL (µm)	FL (µm)	FW (µm)	FWT (µm)	LL (µm)	LW (µm)	LWT (µm)	SP %	UR %	TL (µm)	TW (µm)	TWT (µm)
18	461	592	18	3.3	719	20	3.5	67	69	415	25	2.9
19	534	649	18	3.8	821	19	3.4	70	73	471	25	3.0
19	500	652	16	3.1	776	19	3.1	58	74	493	24	2.9
18	482	667	18	4.8	776	21	4.3	80	67	452	24	4.3
19	561	610	19	3.6	795	20	3.7	65	67	445	21	2.5
25	427	512	18	3.2	632	19	3.0	62	67	400	22	2.5
17	509	659	18	3.5	753	20	3.7	50	75	467	22	3.2
17	529	653	17	2.8	770	18	3.2	63	72	446	23	2.6
14	461	569	19	3.2	722	21	3.2	65	57	456	26	2.9
20	452	644	17	2.4	770	19	3.9	66	70	438	23	3.3
18	517	588	16	2.6	727	18	2.8	61	66	461	24	3.1
17	492	612	16	3.5	708	19	3.5	66	68	500	22	3.3
19	418	53	15	3.0	643	17	3.5	67	66	426	21	2.7
24	435	524	17	3.5	637	17	3.3	69	79	410	22	3.0

Table 3. Non-anatomical data and wood anatomical characters of *Rhododendron* caucasicum.

ALT (m)	SD (cm)	SA (year)	WAR (mm)	TD (µm)	BAR	PPL (µm)	MRH1 (µm)	MRW2 (cell)	MRW (µm)	PD	MRD	MRmm
1900	2.0	31	0.5	25	15	57	542	3.3	36	576	5.7	2.8
1950	1.8	24	0.4	23	13	43	513	3.0	29	635	6.5	3.1
2000	1.4	16	0.4	22	13	50	639	3.3	34	760	3.9	2.3
2050	1.0	11	0.4	21	13	48	502	4.1	38	778	6.7	3.6
2100	1.0	14	0.3	20	12	49	545	2.8	25	691	5.4	3.0
2150	1.7	13	0.4	21	11	47	522	3.1	30	643	4.2	2.0
2200	1.8	27	0.3	22	22	45	554	4.2	40	636	4.2	2.4
2230	1.0	13	0.3	21	13	51	571	2.7	24	716	10.1	4.2
2310	1.8	20	0.4	21	11	39	466	2.2	21	818	10.3	3.8
2320	0.7	8	0.2	20	13	48	562	2.8	26	818	7.4	3.9
2350	0.9	11	0.3	19	13	49	533	2.9	29	898	6.5	3.4
2380	1.6	31	0.3	22	13	46	640	3.0	27	807	10.1	5.4
2400	0.9	16	0.2	20	11	41	527	3.0	31	951	6.2	3.7
2450	0.8	16	0.2	17	13	43	555	3.0	26	962	6.9	4.0
2500	0.8	14	0.2	19	11	39	555	3.3	33	744	4.9	2.7
2550	1.1	11	0.3	19	10	43	574	2.2	20	757	20.2	10.2
2600	1.0	18	0.3	18	14	49	538	2.7	23	757	11.1	6.1
2650	1.1	23	0.2	19	12	46	553	3.5	33	740	5.1	3.0
2700	0.8	5	0.4	16	11	40	551	2.4	23	731	10.9	6.3
2750	0.5	12	0.2	17	10	34	559	2.5	23	817	13.0	7.2
2850	0.7	15	0.2	17	11	42	396	2.8	24	840	11.0	7.0
2950	0.6	16	0.2	17	11	42	425	2.8	25	896	12.2	5.9
3000	0.5	16	0.1	16	10	36	528	2.8	26	899	11.3	6.2
3050	0.6	14	0.2	16	10	35	577	2.9	25	828	5.4	3.5
3100	0.7	10	0.2	15	11	38	745	2.5	23	1018	6.2	4.3

Table 3. Continued

URmm	VEL (µm)	FL (µm)	FW (µm)	FWT (µm)	SP %	UR %	TL (µm)	TW (µm)	TWT (µm)
20	424	535	15	3.1	67	72	-	-	-
21	359	479	14	3.0	66	74	347	21	2.5
22	387	505	15	3.2	47	78	385	23	2.8
22	335	445	15	2.8	71	70	350	21	2.2
25	342	428	15	3.2	77	81	333	21	2.6
24	348	427	15	3.2	60	85	351	21	2.5
25	349	412	16	3.0	72	79	340	24	2.8
21	328	407	15	2.8	73	74	325	21	2.6
21	345	417	15	2.8	68	75	299	23	2.7
23	304	351	13	2.2	64	76	233	21	2.7
27	293	397	13	2.3	62	80	233	20	2.1
22	361	413	15	3.5	68	70	331	20	2.8
23	310	387	14	2.8	65	74	310	18	2.2
26	322	427	13	2.2	56	75	288	20	2.8
26	334	441	13	2.5	57	80	-	-	-
17	385	442	14	2.8	63	50	383	22	17.5
21	335	412	16	2.7	62	61	311	22	2.7
26	308	421	16	2.8	60	77	320	22	2.7
22	293	413	16	2.7	64	65	-	-	-
21	261	336	14	2.6	60	63	254	19	2.2
21	245	350	13	2.5	55	-	-	-	-
22	240	341	13	2.0	60	-	-	-	-
24	242	332	14	2.0	53	63	-	-	-
26	240	326	14	2.3	73	78	280	18	2.2
25	288	363	12	2.2	58	72	308	18	2.3

Table 4. Non-anatomical data and wood anatomical characters of *Rhododendron* ponticum.

ALT (m)	SD (cm)	SA (year)	WAR (mm)	TD (µm)	BAR	PPL (µm)	MRH1 (µm)	MRW2 (cell)	MRW (µm)	PD	MRD	MRmm
5	4.4	10	2.1	30	18	71	657	3.3	39	462	5.8	3.7
50	3.9	13	1.7	29	16	66	480	3.5	41	510	14.6	6.4
100	4.0	34	0.9	27	21	82	767	5.2	65	559	2.8	2.3
140	7.3	30	1.8	30	17	65	541	4.5	54	414	4.6	2.4
250	3.5	11	1.7	31	18	67	687	3.5	46	476	3.8	2.2
380	6.8	40	1.1	28	18	72	797	5.4	54	640	4.5	3.5
450	3.9	10	1.8	33	15	59	526	3.7	44	343	10.3	3.8
490	3.7	14	1.2	31	18	68	622	4.3	52	521	7.7	3.9
550	3.7	13	1.5	30	13	57	413	3.1	40	365	9.7	3.8
600	2.3	21	0.7	28	15	63	568	3.2	40	478	4.1	1.8
650	2.5	13	0.9	28	16	63	572	3.8	42	501	5.2	2.9
750	2.4	26	0.6	27	16	62	492	4.1	43	539	4.2	2.1
800	3.7	32	0.8	28	17	69	538	3.4	38	495	9.9	4.4
850	2.3	17	0.9	23	18	66	557	3.4	38	501	4.7	2.5
900	1.9	15	0.6	23	14	60	742	3.3	37	565	4.4	2.9
980	2.0	11	1.4	24	17	67	503	3.6	43	408	6.0	3.1
1000	3.3	21	1.2	27	16	58	553	4.6	56	339	5.1	2.7
1060	2.3	12	1.1	26	16	61	509	3.8	43	461	4.2	1.8
1080	1.7	26	0.5	22	17	66	567	3.1	36	466	3.4	2.0
1100	11.9	149	0.5	30	18	72	545	3.7	45	348	4.9	2.6
1150	4.1	37	0.4	25	15	64	554	3.6	60	896	11.9	5.1
1200	1.8	14	0.7	28	16	68	515	3.3	41	429	5.5	3.1
1250	2.2	19	0.5	23	16	66	607	3.2	33	485	4.3	2.5
1300	1.0	5	0.5	22	15	60	728	3.0	34	505	6.5	3.8
1370	0.8	4	0.7	22	15	63	775	3.0	35	551	2.7	1.4
1450	1.5	10	0.7	21	17	67	779	3.5	39	583	5.3	3.4
1500	2.8	29	0.4	26	15	53	493	3.2	42	468	7.8	3.1
1650	1.5	10	0.6	26	17	66	581	3.5	47	531	6.1	3.3
1700	1.5	11	0.6	26	18	67	798	3.4	50	406	6.9	4.3
1730	1.7	25	0.3	22	17	66	557	2.6	35	488	12.2	5.8
1850	1.5	18	0.5	21	15	62	552	2.9	29	623	8.3	4.4
1970	2.8	33	0.5	22	14	57	559	3.3	38	701	8.2	4.1
2100	1.3	18	0.4	22	13	48	684	3.3	38	515	9.7	5.6
2230	3.1	53	0.3	26	14	54	554	5.3	51	531	6.3	3.5

Table 4. Continued

Urmm	VEL (µm)	FL (µm)	FW (µm)	FWT (µm)	LL (µm)	LW (µm)	LWT (µm)	SP %	UR %	TL (µm)	TW (µm)	TWT (µm)
19	632	750	18	3.9	862	20	4.3	66	67	563	26	3.7
15	644	749	18	3.8	855	19	857	73	47	426	24	3.2
20	647	722	19	3.8	928	19	4.2	85	71	519	27	3.2
19	603	761	18	4.2	963	19	4.2	83	73	542	23	3.3
23	537	747	20	3.4	910	21	3.7	74	78	501	26	3.1
21	638	761	19	3.6	911	20	3.9	62	63	637	24	2.8
17	473	622	21	3.5	851	20	4.0	79	64	424	28	3.5
17	517	676	19	3.1	858	20	2.8	74	59	485	24	2.8
19	520	614	19	3.1	832	20	3.5	75	67	461	26	3.1
22	539	648	17	3.4	842	17	3.6	81	88	541	21	2.9
19	617	678	18	2.8	885	21	3.3	83	73	543	24	2.8
19	636	722	19	3.6	919	19	4.3	65	77	576	23	3.0
16	623	735	19	3.5	918	18	4.3	67	59	557	25	3.3
22	573	647	17	3.5	837	17	3.5	69	79	508	24	3.4
19	585	680	17	3.4	868	18	3.6	58	73	527	21	2.5
18	546	688	18	3.7	862	17	3.9	82	69	509	24	3.3
19	531	722	19	4.2	892	21	4.7	73	69	531	26	3.7
24	533	667	17	4.0	785	20	4.2	67	88	494	23	2.9
23	683	713	17	3.4	887	18	3.7	75	83	582	21	3.1
20	576	715	21	3.7	870	20	3.9	67	74	505	27	3.4
17	598	735	17	4.3	895	19	4.4	68	52	555	24	3.6
19	538	675	18	3.6	827	22	4.2	64	72	508	24	3.2
24	570	691	17	3.5	850	20	4.2	82	81	510	23	4.1
19	480	607	15	3.2	730	15	3.7	71	66	449	22	2.8
23	536	626	17	3.0	755	16	3.0	77	88	478	23	2.8
17	588	645	17	3.4	830	18	3.9	58	67	563	23	2.9
18	553	671	19	3.5	791	18	3.6	70	71	514	23	3.4
18	469	634	18	3.6	796	20	4.1	67	67	465	25	3.3
13	546	676	20	3.6	795	22	3.5	72	53	524	28	2.9
19	511	679	18	3.4	804	18	3.7	64	59	481	24	3.1
21	490	544	16	3.0	731	16	2.9	59	68	458	22	2.8
23	524	652	18	3.5	750	18	3.5	62	71	442	22	2.7
17	410	553	16	3.1	650	18	3.4	75	54	384	21	2.7
24	472	593	17	3.3	721	19	3.6	79	67	425	24	2.9

Table 5. Multiple Regression Analysis of Significant Wood Anatomical Characters of *R. ponticum* and *caucasicum*.

				Partial Regression Coefficient				Standard Reg. Coefficient			
Character	CD	F-ratio	Cons.	ALT	SD	SA	WAR	ALT	SD	SA	WAR
R. ponticum											
TD	0.50	13.6 ***	25.7 ***	-0.002 **	0.412	0.048	1.06	-0.45	23	0.17	0.17
PPL	0.22	3.9 **	67.4 ***	-0.005 *	0.605	0.067	-1.49	-0.44	0.17	0.12	-0.12
VEL	0.30	5.6 ***	601.3 ***	-0.067 ***	-4.46	2.43 *	-21.6	-0.61	-0.12	0.42	-0.17
FL	0.26	4.8 **	677.8 ***	-0.047 *	-1.68	2.45 *	2.69	-0.44	-0.05	0.43	0.02
LL	0.49	12.8 ***	885.0 ***	-0.083 ***	-0.44	2.37 *	-10.7	-0.73	-0.01	0.39	-0.08
R. caucasicum											
TD	0.92	73.5 ***	28.5 ***	-0.005 ***	1.20	0.087 *	1.02	-0.66	0.21	0.22	0.05
PPL	0.60	9.2 ***	65.2 ***	-0.0109 *	-6.19	0.405	22.0	-0.63	-0.46	0.44	0.40
MRW	0.32	3.0 *	5.2 ***	-0.0009 *	-0.47	0.031	-0.00	-0.69	-0.46	0.45	0.00
PD	0.53	7.1 ***	1022 ***	0.0066	-26.5	-3.641	591 *	0.02	-0.11	-0.21	-0.59
FL	0.67	12.9 ***	464.8 ***	-0.059 *	22.10	1.682	155	-0.36	0.17	0.19	0.30
FWT	0.62	10.0 ***	3.4 ***	-0.0004 *	0.39	0.003	-0.18	-0.34	0.37	0.06	-0.05
TL	0.46	3.6 *	146.5 ***	0.022	20.5	1.387	265	0.14	0.25	0.18	0.61

*: Significant at 5 % level, **: significant at 1 % level, and ***: significant at 0.1 % level.

Legends for Table 1, 2, 3, 4, 5.

ALT: altitude, SD: stem diameter, SA: stem age, WAR: width of annual rings, TD: tangential pore diameter, BAR: bar number per perforation plates, PPL: perforation plates length, MRH: multiseriate ray height, MRW1: multiseriate ray width (cell), MRW2: multiseriate ray width (micron), PD: pore density, MRD: multiseriate rays density, MRmm: multiseriate rays in mm, URmm: uniseriate rays in mm, VEL: vessel elements length, FL: fibre-tracheids length, FW: fibre-tracheids width, FWT: wall thickness of fibre-tracheids, LL: libriform fibre length, LW: libriform fibre width, LWT: wall thickness of libriform fibre, SP: percentage of solitary pore, UR: percentage of uniseriate rays, TL: tracheids length, TW: tracheids width, TWT: wall thickness of tracheids (Due to no variation with altitude, the table for *R. luteum* is not given).

campanulatum D. Don, *R. lepidotum* Wall., *R. arboreum* Smith. (8), on *Alnus nepalensis* D. Don (7) in East Nepal, and on *Syringa oblata* Lindl. var. *giraldii* (9) in Northwestern China. The intraspecific ecological trend in the anatomy of Turkish *Rhododendron* species conform to those in the four Nepalese *Rhododendron* and *A. nepalensis*. In those studies, there is a strong negative correlation between altitude and ring width, stem diameter, vessel member, fibre length, pore diameter, and ray dimensions. At the same time vessel density has a positive correlation with altitude in contrast to the former features. However, the results of *Syringa oblata* var. *giraldii* run counter to the altitudinal trend in wood structure reported for four Nepalese *Rhododendron*, *A. nepalensis* and Turkish *Rhododendron* species. While most of the quantitative wood anatomical characters decreased with altitude in the temperate regions, they increased with altitude in the rainfall regions (in *Syringa oblata* var. *giraldii*). In the rainfall region, average ring width, vessel frequency, percentages of solitary vessels, vessel member length, vessel diameter, fibre length and diameter, ray height and frequency (per square tangential mm) increase with altitude. There is a strong positive correlation between altitude and ring width, percentage of solitary vessels, vessel member length, fibre length and ray dimensions; at the same time vessel frequency and ray frequency are inversely related to altitude (9).

The wood structure does not vary directly according to habit, but to the ecological factors related to altitude. Although the shrubby species are most abundant at high altitude, there are several shrubby species at low altitude, for example *R. luteum*, which is a deciduous shrub growing on both low and high altitudes from 110 to 2200 m. Stem diameter does not vary with altitude. Therefore, its wood anatomical characters are not influenced by non-anatomical factors, especially with altitude. In *Pittosporum ferrugineum* Ait. f., Van der Graaff and Baas (13) noticed that there was no correlation between altitude and the wood anatomical characters analyzed and that the variation was quite small for altitude, between sea level and 2667 m. Climatic factors, such as temperature and water supply play an important role in the xylem element size.

Baas (14) stresses that, in both the northern and southern hemispheres and the Old and New Worlds, temperate and subtropical species are characterized with narrow vessels, relatively short vessel members and few bars, and conspicuous spiral thickenings on both vessel and fibre walls. In tropical lowland species, growth rings are absent or less marked, and the vessels are scanty and wide. The vessel members are long and the number of bars is high, spirals are lacking, and the fibre-tracheids usually have few pits. Tropical montane species resemble the temperate ones.

Seeing that the role of wood is conducting water and mechanical support, wood anatomy will differ with ecological conditions and plant habit.

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