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Physico-anatomical properties of *Rhododendron arboreum* Sm. subspecies of Arunachal Pradesh, India

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ABSTRACT

Rhododendron arboreum, a flowering plant found in higher altitude is used for medicinal, social and cultural purposes by various local communities. 3 subspecies of *R. arboreum* viz. subsp. arboreum, subsp. cinnamomeum and subsp. delavayi found in West Kameng, Arunachal Pradesh were selected. Wood samples of 5 randomly selected trees of each subspecies were collected at breast height. The objectives of the study were to investigate anatomical and physical characteristics of selected subspecies and to see their potential use in pulp and paper making. All the selected subspecies shared common qualitative anatomical features like diffuse-porous wood with distinct growth rings, solitary, angular, barrel-shaped vessels with spiral thickening throughout the body, scalariform perforation plate, tyloses present, opposite inter-vessel pits, vessel-ray pits with distinct borders, small thin-walled occasionally septate fibres with bordered-pit, paratracheal scanty parenchyma, uniseriate, biseriate and multiseriate rays without/with uniseriate wings, except absence of tyloses and pith flecks in subsp. cinnamomeum. However, significant variations were observed in quantitative anatomical characteristics of vessel, fibre, parenchyma and rays. Ecological indices showed all the selected subspecies are adapted to xeric environment. The range of derived indices fulfilled the criteria for pulp and paper making in all subspecies. Wood specific gravity was the highest in subsp. delavayi (0.47) followed by subsp. cinnamomeum (0.44) and subsp. arboreum (0.43) whereas, subsp. arboreum (134.36%) has the highest moisture content followed by subsp. cinnamomeum (128.49%) and subsp. delavayi (114.78%). The present study reveals that anatomical traits can be used to distinguish subspecies of *R. arboreum* and have potential for utilization in pulp and paper making.

1. Introduction

Rhododendron arboreum Sm., belonging to the family Ericaceae under the genus *Rhododendron*, is a large evergreen tree with distinct bright red flowers that grows with a well-developed trunk up to a height of 30 m (Mao *et al*. 2017). The species holds the Guinness Record for the World's Largest Rhododendron measuring 20 m discovered in 1993 at Mount Japfü in the Kohima District of Nagaland, India. (“Largest Rhododendron". Guinness Book of World Records.). The species was discovered by Captain Hardwick in the Siwalik Mountains of Srinagar, Kashmir in 1796 and described for the first time by Sir James Smith in Exotic Botany in 1805 (Hooker 1849).

R. arboreum Sm. is restrictedly found in a few South Eastern Asian countries viz. India, Nepal, Bhutan, Sri Lanka, South Western China, Northern Myanmar, Northern Thailand and Northern Vietnam. In India, the species is distributed at higher altitudes of the Himalayas, North Eastern India and the hilltops of South Western Ghats (Tamil Nadu & Kerala) (Panda and Kritania 2016). The IUCN red list of threatened species (2021) has listed *Rhododendron arboreum* under least concern category.

The subspecies of *R. arboreum* shows a great variation in its morphological characteristics. There are about 5 subspecies discovered so far out of which 3 subspecies and 2 varieties are found in Northeast India (Srivastava 2012; Mao *et al*. 2017**;** Verma *et al*. 2020**).**

From utilization point of view, the species is useful for medicinal, social and cultural purposes by various local communities. Various bioactive compounds present in

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different plant parts such as leaves, flowers, bark, roots, etc., phytochemical and pharmacological activities along with their traditional uses by various ethnic communities have been well documented by several authors (Srivastava 2012; Purohit 2014; Rawat *et al*. 2017; Madhvi *et al*. 2019; Verma *et al*. 2020; Nikita *et al*. 2021; Sharma *et al*. 2022). Chauhan *et al*. (2021) studied the livelihood and rural income generation from *R. arboreum* flowers in Garhwal region of Western Himalaya, India. Shrestha and Budhathoki (2012) conducted a detailed investigation of chemical and fatty acids composition of Nepalese *R. arboreum*.

Panda and Kirtania (2016) reported qualitative leaf anatomical and pollen morphology variations of 5 subspecies and 2 varieties of *R. arboreum*. Tewari *et al*. (2016) investigated on the influence of tree water potential and its importance in inducing *R. arboreum* flowering in the central Himalayan region. Some authors have studied variations in wood anatomical characteristics of *R. arboreum* and other *Rhododendron* species of Nepal (Noshiro and Suzuki 1955; Suzuki and Ohba 1988; Suzuki and Noshiro 1988; Noshiro *et al*. 1995; Noshiro and Suzuki 2001). Khaing *et al*. (2015) also studied on wood anatomical characteristics of *R. arboreum* in Myanmar. Noshiro *et al*. (2010) documented reduction in the size of vessel elements, fibre and multiseriate rays with increase in altitude of *R. arboreum* in Nepal.

Since there is no study on the wood anatomical characteristics of *R. arboreum* subspecies, therefore, the present study aims to investigate anatomical and physical characteristics of wood in *R. arboreum* subspecies found in West Kameng district, Arunachal Pradesh and to see its potential for use in pulp and paper making.

2. Materials and Methods

Three subspecies of *Rhododendron arboreum* Sm. viz., *Rhododendron arboreum* Sm. subsp. arboreum, *Rhododendron arboreum* Sm. subsp. cinnamomeum Tagg and *Rhododendron arboreum* Sm. subsp. delavayi (France) D.F. Chamb. (Plate 1) were collected from Dirang, Mandala and Shergoan areas of West Kameng district, Arunachal Pradesh. For each subspecies, five trees of 25 – 40 cm diameter and having straight bole with no visible defects were selected randomly. Wood samples of 5 × 5 × 3 cm^3 size were collected at breast height with the help of a hammer and chisel. The samples were processed by keeping them in FAA (Formalin-aceto-alcohol) for 24-48 hrs and preserved in 50% alcohol for further anatomical studies.

Sections of three planes, namely Cross Section (C.S.), Tangential Longitudinal Section (T.L.S.) and Radial Longitudinal Section (R.L.S.) of preserved blocks were cut using sliding microtome and permanent slides were made using standard methods. Maceration of wood samples was done using Franklin's solution at 60˚C for 24 hours.

Quantitative and qualitative anatomical characteristics were studied as per IAWA Bulletin (1989). Identification of vessel shape was done as given by Helmling *et al*. (2018). Determination of mesomorphy and vulnerability indices was done according to Carlquist (1977, 2001).

Physical properties of selected woods such as wood density and moisture content were determined using Water displacement method (Smith 1955) and Panshin and deZeeuw (1980) method respectively.

Various indices for pulp and paper making were determined as given below:

- Runkel ratio = (2×FWT)/FLD (Runkel 1949)
- Luce's shape factor = $(FD^2 - FLD^2)/(FD^2 + FLD^2)$ (Luce 1970)
- Flexibility coefficient = (FLD/FD)×100 (Malan and Gerisher 1987)
- Slenderness ratio = FL/FD (Malan and Gerisher 1987; Ona *et al*. 2001)
- Rigidity coefficient = 2FWT/FD (Hudson *et al*. 1998)

Statistical analysis was carried out with MS excel 2016 and SPSS 16.0 software.

3. Results

1. *Rhododendron arboreum* Sm. subsp. arboreum

Description of wood (Plate 2: A-I)

Anatomical features – A diffuse porous wood.

Growth rings – Distinct due to radially flattened fibres.

Vessels – Mostly solitary in radial multiple of 2-3, angular in outline, tube shape without tail and with small tail of abrupt transition at one and/or both ends with spiral thickening throughout the vessels, 416.80 – 812.76 µm (553.44 ± 82.44 µm) in length, 24.38 – 42.66 µm (32.78 ± 3.61 µm) in diameter, vessel frequency 157 - 249 (199.28 ± 19.45) per mm^2, scalariform perforation plate 9 – 21 (13.67 ± 2.57) bars, inter-vessel pits opposite, small 4.29 – 5.95 µm (5.27 ± 0.35 µm) in size, vessel-ray pits with distinct borders similar to inter-vessel pits, tyloses present, vessel percentage 26.73 %.

Fibres – Thin-walled, 427.22 – 1146.20 µm (829.00 ± 114.15 µm) long, 21.30 – 33.28 µm (25.39 ± 2.19 µm) and 12.01 – 22.01 µm (16.40 ± 2.03 µm) in diameter and lumen diameter, 3.50 – 6.04 µm (4.49 ± 0.53 µm) in wall thickness, bordered pit, septate fibre rarely present, fibre percentage 22.91 %.

Parenchyma – Paratracheal, scanty, 2 - 5 celled per parenchyma strand, simple pits present in parenchyma, parenchyma percentage 20.00 %.

Ray – Uniseriate, biseriate and multiseriate. Uniseriate rays 277.50 – 1082.79 µm (469.66 ± 138.73 µm) in height, 9 – 18 (12.9 ± 1.85) rays per mm^2. Multiseriate rays have uniseriate wings on one or both ends, 350.65 – 1163.63 µm (685.17 ± 195.65 µm) in height, 2 – 7 cells wide, 2 – 7 (4.24 ± 1.17) rays per mm^2. Both homocellular and heterocellular, all homocellular rays of upright/square cells, heterocellular rays of body ray cells procumbent with 2 - 6 rows of upright and/or square marginal cells; disjunctive ray parenchyma cells present, ray percentage 30.36 %. Crystals in ray cells absent.

2. *Rhododendron arboreum* Sm. subsp. cinnamomeum Tagg

Description of wood (Plate 3: A-I)

Anatomical features – A diffuse porous wood.

Growth rings –Distinct.

Vessels – Mostly solitary, rarely in tangential multiple of 3, angular in outline, tube shape without tail and with small tail of abrupt transition at one and/or both ends with spiral thickening throughout the vessels, 250.08 – 593.94 µm (412.91 ± 72.30 µm) in length, 23.27 – 42.11 µm (31.12 ± 3.63 µm) in diameter, vessel frequency 120 - 253 (188.20 ± 31.61) per mm^2, pith flecks present, scalariform perforation plate 12 – 26 (16.36 ± 3.32) bars, inter-vessel pits opposite, minute-small 2.89 – 4.00 µm (3.37 ± 0.25 µm) in size, vessel-ray pits with distinct borders similar to inter-vessel pits, tyloses absent, vessel percentage 21.17 %.

Fibres – Thin-walled, 427.22 – 979.48 µm (686.75 ± 90.07 µm) long, 14.7 – 25.87 µm (20.88 ± 1.86 µm) and 9.35 – 19.52 µm (14.17 ± 1.69 µm) in diameter and lumen diameter, 2.68 – 4.46 µm (3.35 ± 0.35 µm) in wall thickness, bordered pit, septate fibres present, fibre percentage 32.48 %.

Parenchyma – Apotracheal, diffuse, 2 - 4 celled per parenchyma strand, simple pits present in parenchyma, parenchyma percentage 18.25 %.

Ray – Uniseriate, biseriate and multiseriate. Uniseriate rays 197.92 – 548.94 µm (312.76 ± 69.07 µm) in height, 8 – 18 (12.62 ± 2.42) rays per mm^2. Multiseriate rays have uniseriate wings on one or both ends, 250.03 – 706.31 µm (403.73 ± 85.20 µm) in height, 2 – 4 cells wide, 2 – 6 (4.12 ± 0.98) rays per mm^2. Both homocellular and heterocellular, all homocellular rays of upright/square cells, heterocellular rays of body ray cells procumbent with 3 - 6 rows of upright and/or square marginal cells; disjunctive ray parenchyma cells present, ray percentage 28.10 %. Crystals in ray cells absent.

3. *Rhododendron arboreum* Sm. subsp. delavayi (France) D.F. Chamb

Description of wood (Plate 4: A-I)

Anatomical features – A diffuse porous wood.

Growth rings – Distinct.

Vessels – Mostly solitary, angular in outline, tube shape without tail and with small tail of abrupt transition at one and/or both ends with spiral thickening throughout the vessels, 249.60 – 707.20 µm (491.23 ± 100.24 µm) in length, 28.83 – 49.42 µm (39.36 ± 4.31 µm) in diameter, vessel frequency 118 - 176 (146.02 ± 18.23) per mm^2, scalariform perforation plate 10 – 20 (14.29 ± 2.99) bars, inter-vessel pits opposite, minute-small 3.51 – 5.04 µm (4.14 ± 0.30 µm) in size, vessel-ray pits with distinct borders similar to inter-vessel pits, tyloses present, vessel percentage 26.14 %.

Fibres – Thin-walled, 621.00 – 1188.00 µm (966.24 ± 91.87 µm) long, 20.51 – 36.96 µm (29.20 ± 3.20 µm) and 12.75 – 26.55 µm (18.45 ± 2.66 µm) in diameter and lumen diameter, 3.61 – 7.31 µm (5.38 ± 0.91 µm) in wall thickness, bordered pit, septate fibres present, fibre percentage 22.80 %.

Parenchyma – Paratracheal, scanty, 2 - 5 celled per parenchyma strand, simple pits present in parenchyma, parenchyma percentage 21.58 %.

Ray – Uniseriate, biseriate and multiseriate. Uniseriate rays 310.44 – 752.09 µm (456.45 ± 96.01 µm) in height, 6 – 14 (10.30 ± 2.27) rays per mm^2. Multiseriate rays have uniseriate wings on one or both ends, 405.23 – 1049.59 µm (677.19 ± 151.04 µm) in height, 2 – 7 cells wide, 2 – 6 (3.66 ± 0.85) rays per mm^2. Both homocellular and heterocellular, all homocellular rays of upright/square cells, heterocellular rays of body ray cells procumbent with 3 - 7 rows of upright and/or square marginal cells; disjunctive ray parenchyma cells present, ray percentage 29.48 %. Crystals in ray cells absent.

The Analysis of Variance of quantitative anatomical parameters showed significant variation at 0.05 level within the selected subspecies. However, fibre length and multiseriate ray height in subsp. arboreum; vessel length, vessel frequency, fibre length and multiseriate ray per mm in subsp. cinnamomeum and vessel diameter, inter vessel pit size, vessel frequency, fibre lumen diameter and multiseriate ray per mm in subsp. delavayi showed non-significant variation within the subspecies.

Tukey's test given in Tables 1 showed significant variations among three subspecies of *Rhododendron arboreum*. Vessel length, inter-vessel pit size and vessel frequency were significantly larger in subsp. arboreum whereas vessel diameter was larger in subsp. delavayi than in other subspecies. There was significantly larger fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness in subsp. delavayi. Both multiseriate and uniseriate rays height and ray per mm were significantly larger in subsp. arboreum. However, subsp. delavayi has significantly wider rays compared to other subspecies. Number of cells per strand was larger in subsp. arboreum and specific gravity were larger in subsp. delavayi than others.

Specific gravity was maximum in subsp. delavayi and minimum in subsp. arboreum and vice-versa in the case of moisture content (Fig. 1 and 2).

The result of ecological indices in Table 2 showed maximum value of mesomorphy, conductance and vulnerability index in subsp. delavayi while subsp. cinnamomeum has the least values.

Principal component analysis was performed using quantitative anatomical parameters among the selected subspecies. The results presented in Fig. 3 indicated a close relationship between subsp. arboreum and delavayi in comparison with subsp. cinnamomeum.

The result in Fig. 4 showed the tissue proportions of selected *R. arboreum* subspecies. Vessel and ray percentage was the highest in subsp. arboreum. However, fibre percentage was the highest in subsp. cinnamomeum and the lowest in subsp. delavayi whereas parenchyma percentage was the highest in subsp. delavayi and the lowest in subsp. cinnamomeum.

The result given in Table 3 depicted the derived indices values such as Runkel ratio, Luce's shape factor, flexibility coefficient, slenderness ratio and rigidity coefficient values of selected subspecies and other commonly used species in paper and pulp industries.

4. Discussion

The wood anatomical traits of *Rhododendron arboreum* subspecies are found to be comparable with earlier findings within the related genus and species (Suzuki and Noshiro 1988). Diffuse porous wood with distinct growth rings was observed in the selected subspecies. However, the presence of semi-ring porous wood was reported by Khaing *et al*. (2015).

Vessels were mostly solitary, angular in outline, barrel shape without or with tail at one and/or both ends. Presence of spiral thickening throughout the body of vessel, scaraliform perforation plate, small inter vessel pits with opposite arrangement, vessel ray pits with distinct borders similar to inter-vessel pits and tyloses were common in selected subspecies whereas, tyloses were absent and pith flecks were spotted in subsp. cinnamomeum. In the same species, Khaing *et al*. (2015) and Suzuki and Noshiro (1988) reported similar characteristics. However, Khaing *et al*. (2015) observed reticulate perforation plate in vessel of Burmese *R. arboreum.*

The fibres were all small, thin-walled, pit-bordered, septate, and rarely bifurcated at one end for the subspecies that were studied. On the contrary, Khaing *et al*. (2015) reported thick wall and septate fibres. The presence of septate fibres in subsp. cinnamomeum may be due to lower percentage of parenchyma than other species (Evert 2006) as septate fibres are responsible for the delivery and storage of photo-assimilates in plants with less parenchyma.

Both subsp. arboreum and delavayi had paratracheal, scanty axial parenchyma with simple pits and confirms the findings of Suzuki and Noshiro (1988).) However, parenchyma was apotracheal and diffuse in subsp. cinnamomeum. In the current study, all of the selected subspecies have disjunctive ray parenchyma cells and uniseriate, biseriate and multiseriate rays without or with uniseriate wings on both or one end, which collaborate the findings of Suzuki and Noshiro (1988) and Khaing *et al*. (2015). Both homocellular and heterocellular rays of body ray cells procumbent with rows of upright and/or square marginal cells were observed as common features. It was found that the multiseriate rays in subsp. cinnamomeum were significantly narrower than those in the other two subspecies.

Carlquist (1977) considered value of vulnerability index below 3 and mesomorphy index below 200 as xeromorphy. The vulnerability index and mesomorphy index in the selected subspecies had values below 3 and 200, respectively indicating their adaptation to xerophytic conditions.

The specific gravity of selected subspecies was subsp. arboreum (0.43), subsp. cinnamomeum (0.44) and subsp. delavayi (0.47) which were lesser than the specific gravity of *R. arboreum* reported by Rajput *et al*. (1985) (0.512) and Sheikh *et al*. (2011) (0.628). The moisture content of the subspecies was subsp. arboreum (134.36%), subsp. cinnamomeum (128.49%) and subsp. delavayi (114.78%).

The results of principal component analysis revealed close relationship among subsp. arboreum and subsp. delavayi forming a separate group in comparison with subsp. cinnamomeum. On contrary, Panda and Kirtania (2016) reported similar relationship between subsp. cinnamomeum and subsp. delavayi on basis of exomorphology, leaf anatomy and pollen morphological data.

Pulp and paper making quality for a species were determined using indices such as Runkel ratio, Luce's shape factor, flexibility coefficient, slenderness ratio, solid factor and rigidity coefficient from data of fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness. For good pulp and paper making, Runkel ratio less than 1 is preferable as the fibres are flexible, provide large surface area for bonding and good mechanical properties (Ezeibekwe *et al*. 2009). Runkel ratio of the selected subspecies ranges from 0.48 – 0.59 which were comparable with *E. globolus* (0.54 – 0.67), lesser than *B. tulda* (1.18) and greater than *P. kesiya* (0.22) (Sharma *et al*. 2015). As per Bektas *et al*. (1999) classifications of fibre flexibility coefficient into four categories - highly elastic (greater than 75), elastic (50–70), rigid (30–50), and highly rigid (less than 30). Fibre flexibility improves all mechanical properties, such as burst index, tensile index, and double fold numbers, and increases the area for bonding of fibres as a result of better fibre collapse (Monga *et al*. 2017). The fibres of the selected subspecies were flexible and their flexibility coefficient ranged from 63.13 to 67.75 which was greater than *B. tulda* (48.52).

Luce's shape factor is related to pulp beating resistance, paper sheet density, and breaking length of paper and a higher value in this index indicates increased beating resistance in paper making (Luce 1970; Ona *et al*. 2001). The value of the selected subspecies (0.37 – 0.44) were comparable to that of *Eucalyptus globolus* (0.39 – 0.44) indicating reasonable breaking length (Ohshima *et al*. 2005). Slenderness ratio is related to tearing property of paper and high value (more than 33) were preferable as good paper with well-bonded fibre (Xu *et al*. 2006; Ashori and Nourbakhsh 2009). In the selected subspecies, Slenderness ratio was low (32.94 – 33.55) which may be result of its short fibres. Rigidity coefficient determines the bending resistance of paper and value less than 0.4 is regarded good for paper making (Hudson *et al*. 1998). In the present study, the rigidity value for selected subspecies was 0.32 – 0.37 which was lower than *B. tulda* (0.51) and *E. globolus* (0.46) (Sharma *et al*. 2015; Hudson *et al*. 1998). Shrestha and Budhathoki (2012) also suggested use of *R. arboreum* wood for paper making as per their findings on α-cellulose percentage. Therefore, the above derived indices of selected subspecies revealed the suitability of utilizing its wood for pulp and paper making.

The results of the current study show that there was significant variation in physical and quantitative anatomical characteristics within subspecies, which may attribute to the collection of samples from various altitudes and unknown ages of the selected trees. Highly significant variations in anatomical characteristics among subspecies support the findings of Noshiro and Suzuki (1995) and Noshiro *et al*. (1995), who reported similar variations in other *Rhododendron* species.

All the selected subspecies have diffuse-porous with distinct growth rings, solitary, angular, barrel-shaped vessel with spiral thickening throughout the body, scalariform perforation plate, tyloses, opposite inter-vessel pit, vessel-ray pit with distinct borders, small thin-walled occasionally septate fibre with bordered-pit, paratracheal scanty parenchyma and uniseriate, biseriate and multiseriate rays without/with uniseriate wings, except absence of tyloses and pith flecks in subsp. cinnamomeum. However, significant variations were observed in quantitative anatomical features. Ecological indices showed that all the selected subspecies were xerophytes. Wood specific gravity was maximum in subsp. delavayi and minimum subsp. arboreum. Subsp. arboreum has the highest moisture content and lowest in delavayi. All the selected subspecies had derived indices suitable for pulp and paper making. Thus, the results of the current study suggest that anatomical traits can be used to distinguish between *Rhododendron arboreum* subspecies and have potential for utilization in pulp and paper making.

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Table 1. Variation in anatomical characteristics among *Rhododendron arboreum* subspecies

PARAMETERS	Subsp. arboreum (Mean ± SD)	Subsp. cinnamomeum (Mean ± SD)	Subsp. delavayi (Mean ± SD)
Vessel length (µm)	553.44 ± 82.44^c	412.91 ± 72.30^a	491.23 ± 100.24^b
Vessel diameter (µm)	32.78 ± 3.61^b	31.12 ± 3.63^a	39.36 ± 4.31^c
Inter-vessel pit (µm)	5.27 ± 0.35^c	3.37 ± 0.25^a	4.14 ± 0.30^b
Vessel per mm^2 (no./mm^2)	199.28 ± 19.45^b	188.20 ± 31.61^b	146.02 ± 18.23^a
Fibre length (µm)	829.00 ± 114.15^b	656.75 ± 90.07^a	966.24 ± 91.87^c
Fibre diameter (µm)	25.39 ± 2.19^b	20.88 ± 1.86^a	29.20 ± 3.20^c
Fibre lumen diameter (µm)	16.40 ± 2.03^b	14.17 ± 1.69^a	18.45 ± 2.66^c
Fibre wall thickness (µm)	4.49 ± 0.53^b	3.35 ± 0.35^a	5.38 ± 0.91^c
Multiseriate ray height (µm)	685.17 ± 195.65^b	403.73 ± 85.20^a	677.19 ± 151.04^b
Ray width in number	4.14 ± 1.24^b	2.91 ± 0.72^a	5.17 ± 0.97^c
Multiseriate ray/mm	4.24 ± 1.17^b	4.12 ± 0.98^{ab}	3.66 ± 0.85^a
Uniseriate ray height (µm)	469.66 ± 138.73^b	312.76 ± 69.76^a	456.45 ± 96.01^b
Uniseriate ray /mm	12.90 ± 1.85^b	12.62 ± 2.42^b	10.30 ± 2.27^a
Parenchyma strand	3.80 ± 0.81^c	3.00 ± 0.78^a	3.40 ± 0.86^b

Values with same letter in the same row are not significantly different at 0.05 probability level

Table 2. Ecological indices of the selected *R. arboreum* subspecies

Subspecies	Mesomorphy index	Conductance	Vulnerability index
Subsp. arboreum	91.05	0.58	0.16
Subsp. cinnamomeum	68.28	0.50	0.17
Subsp. delavayi	132.43	1.64	0.27

Table 3. Comparison of derived indices among selected subspecies and other commonly used species in paper and pulp industries

Particulars	Subsp. arboreum	Subsp. cinnamomeum	Subsp. delavayi	***Eucalyptus globolus****	***Bambusa tulda*****	***Pinus kesiya*****
Runkel ratio	0.56	0.48	0.59	0.54-0.67	1.18	0.22
Luce's shape factor	0.41	0.37	0.43	0.39-0.44	0.62	0.19
Flexibility coefficient	64.49	67.75	63.13	-	48.52	81.74
Slenderness ratio	32.94	33.16	33.55	57.7-59.9	105.27	49.04
Rigidity coefficient	0.36	0.32	0.37	-	0.51	0.18

*Ohshima *et al*. (2005) and **Sharma *et al*. (2015)

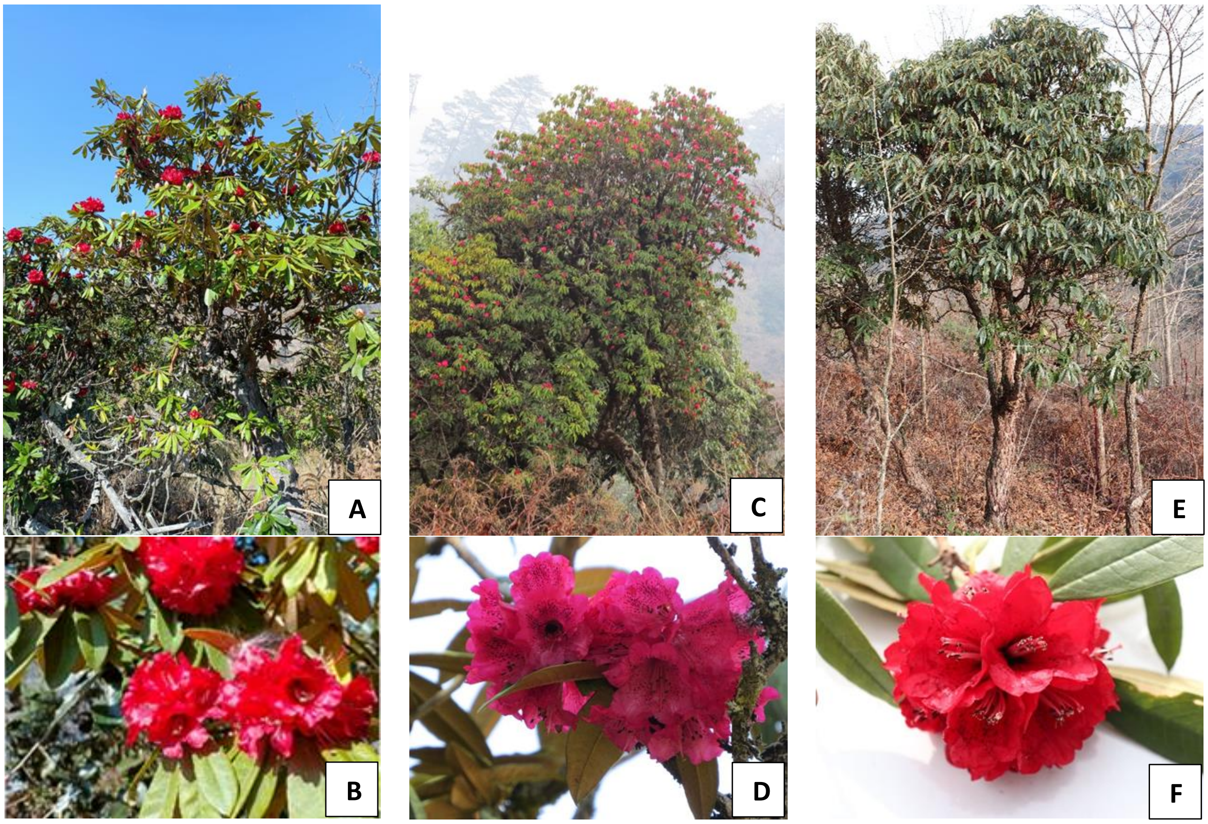


Plate 1. Tree and flower: *R. arboreum* subsp. arboreum (A & B); *R. arboreum* subsp. cinnamomeum (C & D); *R. arboreum* subsp. delavayi (E & F)

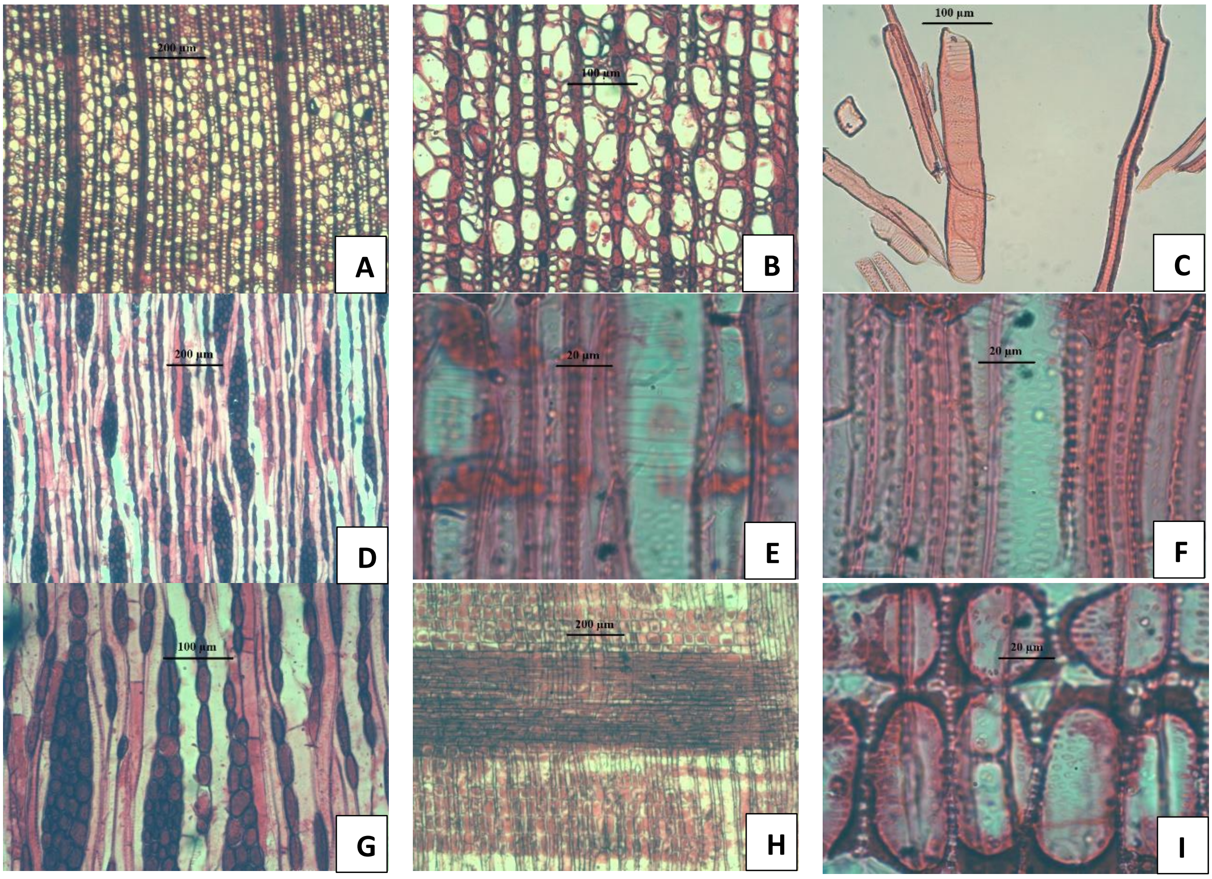
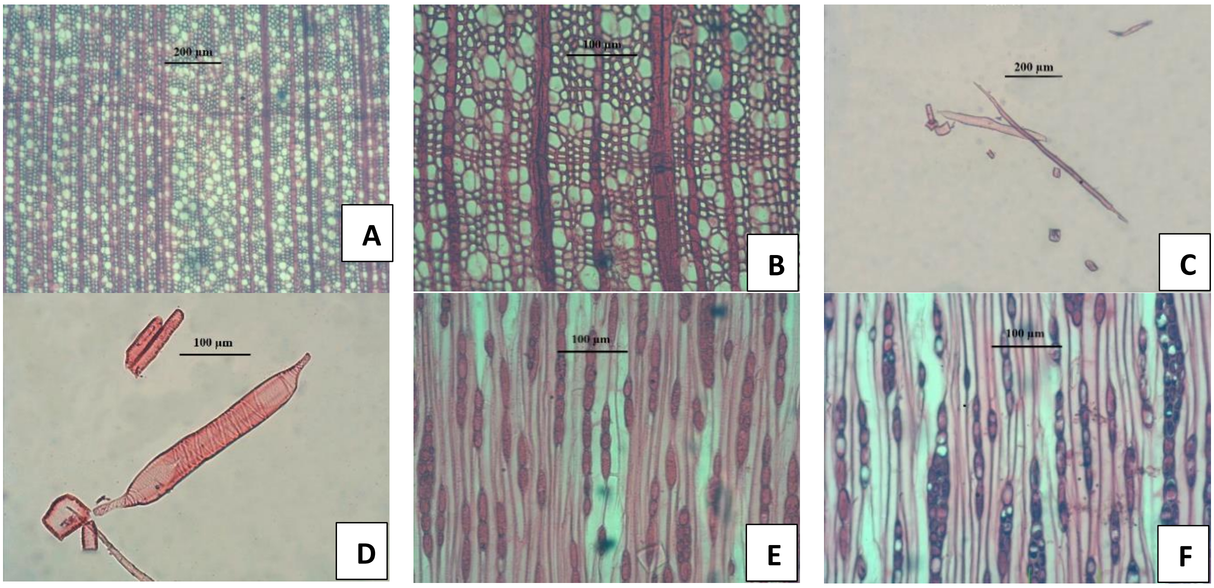


Plate 2. ***Rhododendron arboreum*** **subsp. arboreum: C.S. – diffuse-porous wood with distinct growth ring, vessel angular outline, apotracheal diffuse axial parenchyma (A & B); barrel shaped vessel without tail, fibre and parenchyma (C); T.L.S. – rays: uniseriate, biseriate and multiseriate (D); scalariform perforation plate (E); opposite inter-vessel pits (F); parenchyma strand (G); R. L. S. - Heterocellular ray of procumbent and upright and/or square marginal cells (H); vessel-ray pit (I)**



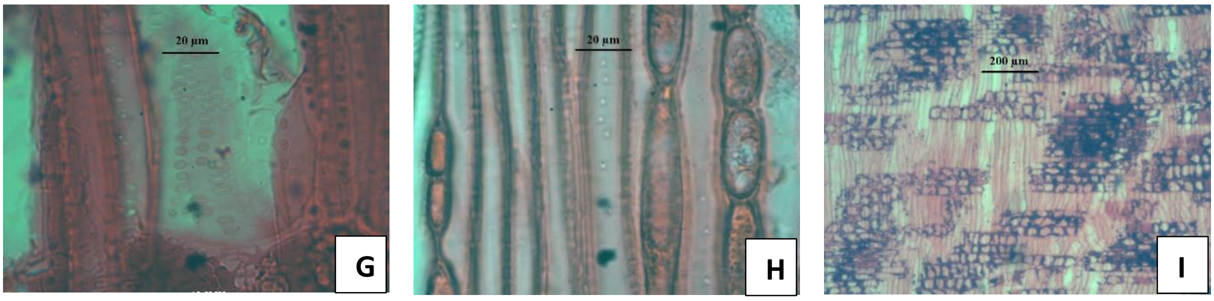


Plate 3. ***Rhododendron arboreum*** **subsp. cinnamomeum: C.S. – diffuse porous wood, solitary vessel angular in outline (A & B); maceration showing vessel, fibre and parenchyma (C); barrel shaped vessel with tails at both ends, spiral thickening throughout vessel body (D); T.L.S. - parenchyma strandseptate fibre, opposite inter-vessel pits, bordered-pits fibre (E, F, G & H); R. L. S. - Heterocellular ray of procumbent and upright and/or square marginal cells, homocellular ray of upright cells (I)**

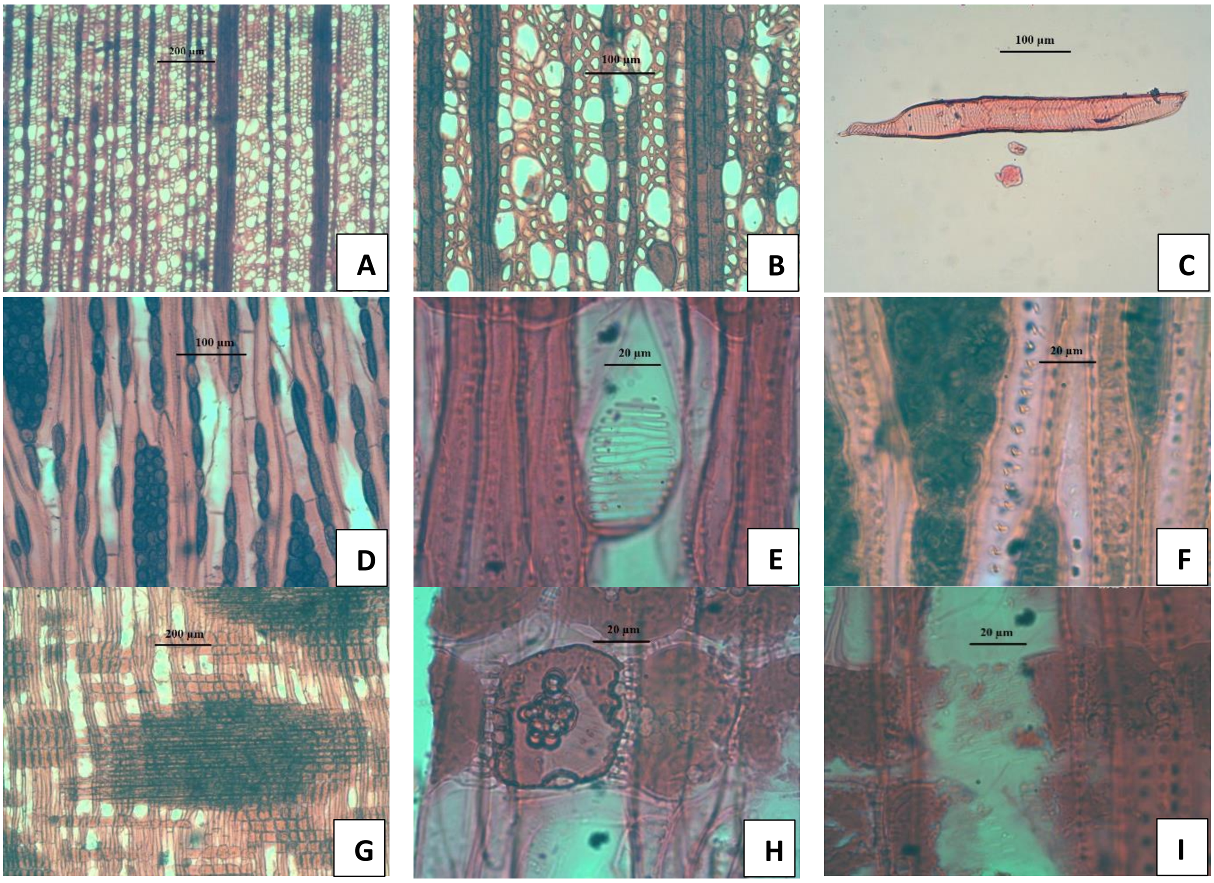


Plate 4. ***Rhododendron arboreum*** **subsp. delavayi: C.S.- diffuse porous wood, solitary vessel, tyloses present, paratracheal scanty axial parenchyma (A & B); barrel-shaped vessel with tail at one end, spiral thickening throughout out body (C); T.L.S. – uniseriate and multiseriate rays, scalariform perforation plate, bordered-pit fibre (D, E & F); R. L. S. - Heterocellular ray of procumbent and upright and/or square marginal cells, homocellular ray of upright cells, disjunctive ray parenchyma cells, vessel-ray pits (G, H, & I)**

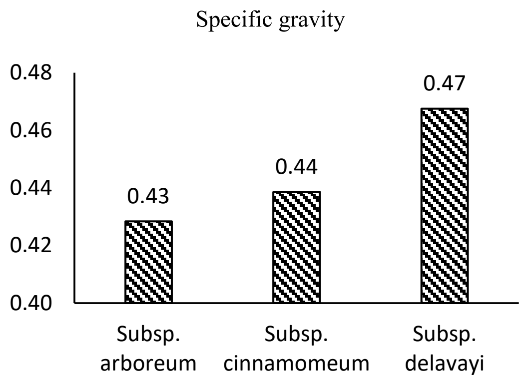


Figure 1. Specific gravity of selected subspecies

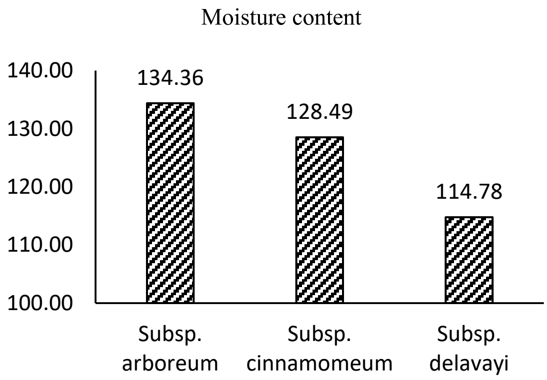


Figure 2. Moisture content of selected subspecies

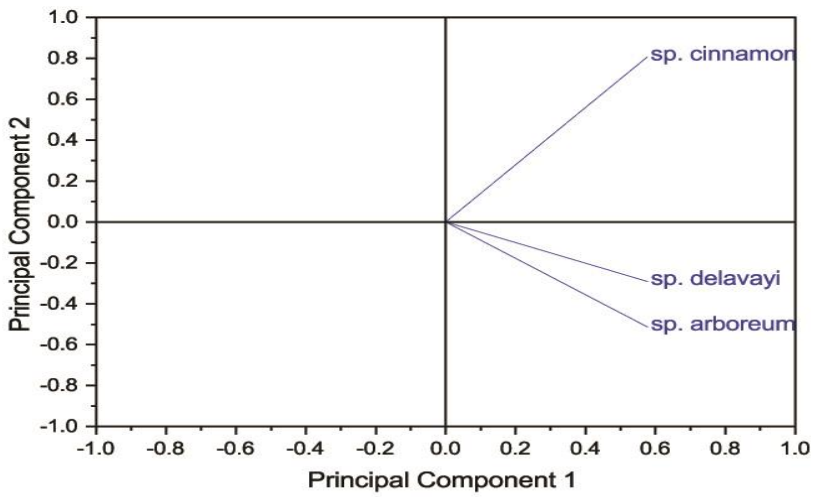


Figure 3. Scattered plot for principal component analysis of selected *R. arboreum* subspecies

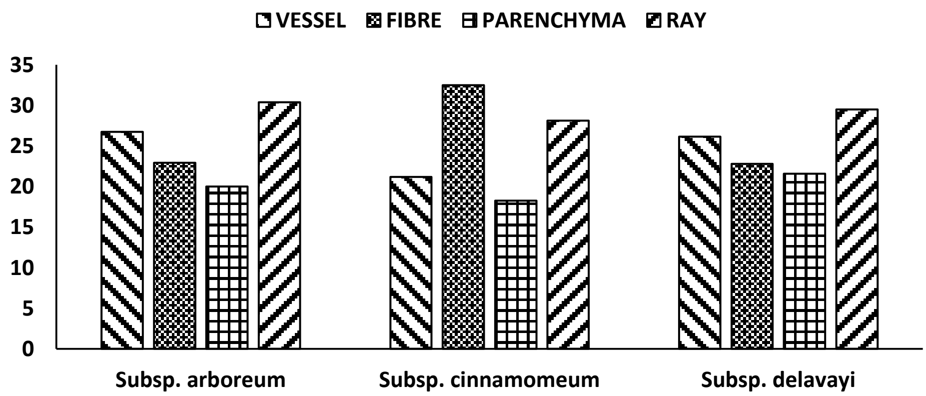


Figure 4. Tissue percentage of the selected *R. arboreum* subspecies