Wood anatomy of Korean *Symplocos* Jacq. (Symplocaceae)

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ABSTRACT: Despite poorly documented species delimitation and unresolved taxonomic nomenclature, four species of *Symplocos* (*S. coreana*, *S. purnifolia*, *S. sawafutagi*, and *S. tanakana*) have been described in Korea. In this study, we carried a comparative wood anatomy analysis of all four species of Korean *Symplocos* to understand the wood anatomical variations among them. The results of this study indicated that Korean *Symplocos* are comparatively indistinguishable in terms of their qualitative wood features, except for exclusively uniseriate rays present in *S. purnifolia* instead of uniseriate to multiseriate in other three species. Nevertheless, differences are noticed in quantitative wood variables such as the vessel density, vessel size, and ray density. The vessel density of *S. purnifolia* is more than twice as high as those of *S. sawafutagi* and *S. tanakana*. In contrast, the vessel circumference and diameter on both plants of *S. sawafutagi* and *S. tanakana* is nearly twice as large as those of *S. purnifolia*. *Symplocos coreana* has characteristic intermediacy between these two groups in terms of vessel features and is closer to *S. purnifolia* in terms of its ray density level. A cluster analysis based on a paired group (unweighted pair-group method with the arithmetic mean, UPGMA) algorithm using the Euclidean similarity index clearly differentiates *S. purnifolia* from the remaining species, representing the first branch of the phenogram.

Keywords: wood anatomy, *Symplocos*, taxonomy, UPGMA

Symplocos Jacq. comprising about 350 species is the sole isolated genus of the family Symplocaceae (Fritsch et al., 2008). The species are mostly evergreen or sometimes deciduous, shrubs or trees with widespread distribution in moist tropical to the subtropical region of India through Southeast Asia and Malesia to northeastern Australia, and America (Cronquist, 1981). Although the family is well recognized, its systematic position within the order Ericales is still ambiguous (Caris et al., 2002). In the recent molecular analyses, the family has been positioned as sister to a clade comprising Diapensiaceae and Styracaceae (Schönenberger et al., 2005). The distinguishing features of the family include the combination of leaves without stipules, sympetalous actinomorphic flowers; epipetalous, united, and usually numerous stamens with spheroid thecae; an inferior, incompletely locular ovary, a simple style; unitegmic ovule; and a drupaceous fruit (Nooteboom, 2003).

In the comprehensive taxonomic revision of *Symplocos*, Brand (1901) divided the genus into four subgenera: *Eusymplocos* Brand, *Epigenia* (Vell.) Brand, *Hopea* (L. f.) C. B. Clarke, and *Microsymplocos* Brand. Later, Nooteboom (1975) treated *Epigenia* and *Microsymplocos* within *Hopea*, recognizing only two subgenera, but Nagamasu (1993) again treated *Microsymplocos* as an independent subgenus endemic to South America. Only two subgenera *Symplocos* (with Monadelphous stamens) and *Hopea* (with pentadelphous or free stamens) have been reported in Asia (Nooteboom, 1975; Nagamasu, 1993). Despite poorly documented species delimitation and unresolved taxonomic nomenclature four species of *Symplocos* (*S. coreana* (H. Lev.) Ohwi, *S. sawafutagi* Nagam., *S. tanakana* Nakai, and *S. purnifolia* Siebold & Zucc.) have been described in Korea (Chang et al., 2011; Korea National Arboretum, 2017; Kim and Kim, 2018). These four species belong to two sections, *Palura* G. Don (*S. coreana*, *S.*

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sawafutagi, and *S. tanakana*) and *Lodhra* G. Don. (*S. purnifolia*), of subgenus *Hopea* (Nagamasu, 1993; Soejima and Nagamasu 2004).

Wood anatomical features can provide useful information to resolve the phylogenetic relationships among and within the genera of angiosperms and gymnosperm (Oskolski, 1994, 1995; Baas et al., 2000; Oskolski and Lowry, 2000; Visscher and Jagels, 2003; Lens et al., 2007; Esteban and de Palacios, 2009). However, due to the insufficient knowledge of the microscopic structure of wood among the plant taxonomists, the studies incorporating wood features in phylogenetic analysis are very limited (e.g., Baas et al., 1988; Zhang, 1992; Gasson, 1994, 1996; Noshiro and Baas, 1998; Klaassen, 1999; Olson, 2002; Malécot et al., 2004; Lens et al., 2007). In addition, the wood anatomy of *Symplocos* is scarce in the modern literatures. Yamauchi (1979) reported the wood anatomy of nine species of Japanese *Symplocos* while van den Oever et al. (1981) carried the comparative wood anatomy of 31 *Symplocos* species in relation to latitude and altitudinal variations. More recently, Wang and Ou (2003) described the wood anatomy of 27 *Symplocos* taxa from Taiwan and Lens et al. (2007) included only two species of *Symplocos* in the role of wood anatomy in phylogeny reconstruction of Ericales. In this study, we carried the comparative wood anatomy of all the four species of Korean *Symplocos*. The primary objectives of the study are as follows: (1) to provide an overview of wood anatomical variation within Korean *Symplocos* species, and (2) to identify the systematic significance of wood features in the *Symplocos*.

Materials and Methods

Light microscopy

Mature branches were collected from natural populations. Names of the studied taxa, voucher number, and collection sites are presented in Table 1. Collected wood materials were preserved in 50% ethyl alcohol before section. Preserved wood samples were cut into approximately 2 cm-long circular blocks. For microtome sectioning, the samples were prepared depending on the size of wood; cubic pieces were cut (transverse) or split

(radial and tangential) from circular blocks. Three such pieces—representing three planes: transverse, radial, and tangential—of each sample were prepared. The blocks were preserved in softener solution (glycerin 10 parts/10% aerosol OT 3 parts/distilled water 87 parts) until sectioning and were sectioned according to the standard technique for light microscopy. At least five permanent slides of each species including all three planes of wood in a single slide were prepared for the observation.

After preparing permanent slides, microscopic observations and wood-feature analyses were carried out under an AXIO Imager A1 light microscope (Carl Zeiss, Jena, Germany). We studied several quantitative and qualitative features of the wood structure and pertinent features of them are summarized in Table 2. Observations and measurements of the quantitative features of vessels, fibers, and rays were made with a Hirox 3D microscope and software therein (Hirox, Tokyo, Japan). At least 10–15 cells from each of five slides (at least 50–70 cells for each species) were measured for statistical analysis. Mean values for each feature were calculated from the measurements taken from the same species but different samples and standard deviations were also calculated. Photographs of the best sections with characteristic features were taken using a digital camera system attached to the light microscope.

Statistical analysis

The biometric data were analyzed statistically. For each wood features, one-factor analysis of variance (ANOVA) was used to examine differences in means among the included species. Pearson's correlation coefficients were used to estimate the relationship among the vessel number, vessel diameter, vessel fibers wall thickness, bordered pit, ray number, and ray thickness. All of the statistical analyses were carried out using the SPSS statistical program (IBM SPSS Statistics for Windows version 20.0., IBM Corp., Armonk, NY, USA). The cluster analysis based on the paired group (unweighted pair-group method with arithmetic mean, UPGMA) of seven quantitative characters were also performed to understand the significance of wood features for species delimitation by using the statistical program PAST ver. 4.02 (Hammer et al., 2001).

Table 1. Name of species and collection information.

Taxon	Korean name	Voucher No.	Collection site
<i>Symplocos sawafutagi</i> Nagam.	노린재나무	EKS20180911-001	Pyeongchang-gun, Gangwon-do
<i>Symplocos tanakana</i> Nakai	검노린재나무	EKS20180925-001	Shinan-gun, Jeollanam-do
<i>Symplocos coreana</i> (H. Lev.) Ohwi	섬노린재나무	SN20181024-001	Miaksan, Seogwip-si, Jeju-do
<i>Symplocos purnifolia</i> Siebold & Zucc.	검은재나무	SN20181024-004	Sanghyo-dong, Seogwip-si, Jeju-do

Table 2. Comparative wood features of four *Symplocos* species.

Distinguishing characteristic features	<i>S. sawafutagi</i>	<i>S. tanakana</i>	<i>S. coreana</i>	<i>S. purnifolia</i>
Growth rings	Distinct	Distinct	Distinct	Distinct
Wood	Diffuse-porous	Diffuse-porous	Diffuse-porous	Diffuse-porous
Vessel arrangement	Radial pattern	Radial pattern	Radial pattern	Radial pattern
Vessels	Solitary	Solitary and in a pair	Solitary and a group of 2–3	Solitary and a group of 2–4
Vessel outline	Oval/rounded	Oval/rounded	Oval/rounded	Oval/rounded/angular
Perforation plates	Scalariform	Scalariform	Scalariform	Scalariform
Scalariform perforation plate bars	More than 40	More than 40	More than 40	More than 40
Inter-vessel pits	Scalariform to opposite	Scalariform to opposite	Scalariform to opposite	Scalariform to opposite
Spiral thickenings in vessel elements	Absent	Absent	Absent	Present
Vessel density	69–93	81–100	95–135	160–215
Vessel ray pitting	Reduced borders, pits rounded	Reduced borders, pits rounded	Reduced borders, pits rounded	Reduced borders, pits rounded
Septate fibers	Absent	Absent	Absent	Absent
Fiber pits	Common on radial and tangential walls	Common on radial and tangential walls	Common on radial and tangential walls	Common on radial and tangential walls
Spiral thickenings in fiber cells	Absent	Absent	Absent	Present
Axial parenchyma	Scanty diffuse and scanty paratracheal	Scanty diffuse and scanty paratracheal	Scanty diffuse and scanty paratracheal	Scanty diffuse and scanty paratracheal
Ray width	Uniseriate to triseriate	Uniseriate to triseriate	Uniseriate and biseriate	Exclusively uniseriate
Ray in radial section	Body cells procumbent with mostly 2–4 rows of upright and square marginal	Body cells procumbent with mostly 2–4 rows of upright and square marginal	Body cells procumbent with mostly 2–4 rows of upright and square marginal	Procumbent and square cells mixed throughout the ray
Ray frequency	38–46	38–51	28–39	29–38

Table 3. Wood variables of four *Symplocos* species.

Taxon	VN (/mm ²)	VC (μm)	VD1 (μm)	VD2 (μm)	TW (μm)	RN (/mm ²)	BP (μm)
<i>S. sawafutagi</i>	83.09 ± 7.8 (69–93)	149.31 ± 26.2 (106.5–190.9)	57.95 ± 8.71 (41.4–74.7)	48.85 ± 6.03 (35–62.1)	4.53 ± 0.6 (3.2–5.7)	42.27 ± 2.57 (38–46)	4.88 ± 0.42 (3.9–5.5)
<i>S. tanakana</i>	90.91 ± 5.8 (81–100)	150.44 ± 19.46 (103.5–185.3)	57.42 ± 7.27 (41.8–70.9)	42.52 ± 5.08 (34.8–56)	3.75 ± 0.7 (2.6–5.2)	44.91 ± 3.64 (38–51)	4.78 ± 0.44 (3.8–5.6)
<i>S. coreana</i>	111.64 ± 11.02 (95–135)	124.82 ± 11.78 (102.4–145.6)	56.11 ± 8.62 (32.2–68.9)	42.87 ± 6.2 (30–54.7)	4.18 ± 0.68 (3.1–5.5)	33.27 ± 2.86 (28–39)	5.08 ± 0.43 (4.1–5.7)
<i>S. purnifolia</i>	198.09 ± 16.98 (160–215)	79.47 ± 7.37 (68–92)	28.75 ± 3.06 (23.3–34.1)	24.28 ± 3.2 (19.2–31.5)	3.99 ± 0.58 (2.9–5.2)	34 ± 3.1 (29–38)	5.44 ± 0.56 (4.5–6.6)
ANOVA	$F = 243.7$ $p < 0.001$	$F = 87.58$ $p < 0.001$	$F = 95.46$ $p < 0.001$	$F = 102$ $p < 0.001$	$F = 6.2$ $p < 0.01$	$F = 39.98$ $p < 0.001$	$F = 10.38$ $p < 0.001$

VN, vessel number; VC, vessel circumference; VD1, vessel diameter parallel to ray; VD2, vessel diameter perpendicular to ray; TW, tracheid wall thickness; RN, ray number; BP, bordered pit.

Fig. 1. Cross section of *Symplocos* wood showing growth ring, vessels, fibers, and rays. **A.** *S. tanakana*. **B.** *S. sawafutagi*. **C.** *S. coreana*. **D.** *S. purnifolia*. gr, growth ring; r, rays; v, vessel lumen. Scale bars = 250 μm.

Results

The comparative wood anatomy of four species of Korean *Symplocos* was carried out in this study. The qualitative wood features and quantitative wood variables of all the taxa are presented in Tables 2 and 3. Figs. 1–5 show the detailed wood features in the cross, radial, and tangential sections. All the

taxa included have well-defined growth rings with the gradual transition of late and earlywood (Fig. 1A–D). In all four species, the quantity of late wood is very small with narrow and tangentially elongated fibers whereas early wood is large with thick-walled oval, rounded, and angular fibers. The wood is diffuse-porous. The vessels are radially arranged and exclusively solitary (*S. sawafutagi*), solitary and in a pair (*S.*

Fig. 2. Cross section of *Symplocos* species showing axial parenchyma (magnified). **A.** *S. tanakana*. **B.** *S. sawafutagi*. **C.** *S. coreana*. **D.** *S. purnifolia* (double arrow group of vessels). dp, diffused parenchyma; f, fibers; pp, paratracheal parenchyma cell; r, ray; v, vessel. Scale bars = 50 μ m.

Fig. 3. Radial longitudinal section (RLS) of *Symplocos* wood showing inter vessel pits, scalariform perforation plates, and ray cells. **A.** Scalariform and opposite inter vessel pits in *S. tanakana*. **B.** Scalariform perforation plates in *S. purnifolia*. **C.** Three types (upright, rectangular, and square) of ray cells in *S. coreana*. **D.** Two types (rectangular and square) of ray cells in *S. purnifolia*. bc, body cells of the ray; ivp, inter-vessel pits; ppb, bars on perforation plate; sc, square cells of the ray; uc, upright cells of the ray. Scale bars = 50 μ m.

Fig. 4. Radial longitudinal section (RLS) of *Symplocos* wood showing axial parenchyma and bordered pits. **A.** RLS of *S. sawafutagi* showing diffused and paratracheal parenchyma (double arrowhead indicating bordered pits). **B.** RLS *S. tanakana* showing paratracheal parenchyma (arrow indicating bars of perforation plate). dp, diffused parenchyma; pp, paratracheal parenchyma; ivp, inter-vessel pits; v, vessel. Scale bars = 50 μ m.

Fig. 5. Tangential longitudinal section (TLS) of *Symplocos* wood showing ray and parenchyma. **A.** TLS of *S. tanakana* showing uniseriate and multiseriate rays (single arrow indicating uniseriate ray and double arrow head indicating septate parenchyma). **B.** TLS of *S. sawafutagi* showing uniseriate and multiseriate rays (single arrow indicating uniseriate ray and double arrow head indicating septate parenchyma). **C.** TLS of *S. coreana* showing uniseriate and multiseriate rays (single arrow indicating uniseriate ray). **D.** TLS of *S. purnifolia* with exclusively uniseriate rays. Scale bars = 100 μ m.

tanakana), solitary and a group of 2–3 (*S. coreana*), and solitary and a group of 2–4 (*S. purnifolia*) (Fig. 2A–D). The highest

number of vessels per millimeter is found in *S. purnifolia* ($198.09 \pm 16.98/\text{mm}^2$) followed by *S. coreana* ($111.64 \pm 11.02/$

Table 4. Pearson's correlation coefficients between different wood features in *Symplocos* species.

	VN	VC	VD1	VD2	RN	TW	BP
VN							
VC	-.774**						
VD1	-.750**	.689**					
VD2	-.778**	.592**	.716**				
RN	-.809**	.667**	.730**	.715**			
TW	-.453**	.434**	.392**	.383*	.371*		
BP	.455**	-.412**	-.389*	-.481**	-.196	-.287	

VN, number of vessels (/mm); VC, vessel circumference; VD1, vessel diameter parallel to ray; VD2, vessel diameter perpendicular to ray; RN, number of rays (/mm); TW, tracheid wall thickness; BP, bordered pit.

**Significance = 0.01, *Significance = 0.05.

Fig. 6. UPGMA (unweighted pair-group method with arithmetic mean) phenogram based on wood variables of *Symplocos* species.

mm²) and the fewest number is counted in *S. sawafutagi* (83.09 ± 7.8/mm²). The perforation plates are the scalariform type with more than 40 bars and inter-vessel pits are scalariform or oppositely arranged (Fig. 3A, B). Correspondingly, *S. purnifolia* with the highest number of vessels per area has smaller vessel sizes in terms of circumference and diameter in both planes (Table 2).

The fibers are thick-walled without spiral thickenings (*S. coreana*, *S. tanakana*, and *S. sawafutagi*) or fine spiral thickenings (*S. purnifolia*) in the internal wall. In all species fibers are non-septate and the bordered pits are circular with a slit-like aperture in both on radial and tangential walls. The bordered pits are comparatively larger by diameter (5.44 ± 0.56 μm) in *S. purnifolia* than the other three species. Furthermore, three types of ray cell composition: procumbent body cells, upright cells, and square marginal cells, are found

in *S. tanakana*, *S. sawafutagi*, and *S. coreana* while *S. purnifolia* comprised only procumbent and square cells mixed throughout the ray (Fig. 3C, D). Axial parenchyma is scanty diffuse and scanty paratracheal and septate (Figs. 2A–D, 4A, B). The rays are uni- to- biseriate in *S. tanakana*, uni- to- multiseriate with a maximum of three cells thick (triseriate) in *S. sawafutagi* and *S. tanakana*, and exclusively uniseriate in *S. purnifolia* (Fig. 5A–D).

One factor ANOVA was performed on seven quantitative traits and the differences between species are found to be highly significant (Table 3). Pearson's correlation coefficient also indicated a significant correlation between wood variables (Table 4). The cluster analysis based on the paired group (UPGMA) algorithm using the Euclidean similarity index clearly differentiates *S. purnifolia* from the rest in the taxa representing the first separated branch in the phenogram (Fig.

6). Among the remaining three taxa *S. coreana* alienated first while *S. tanakana* and *S. sawafutagi* remain together in the subcluster.

Discussion

The result of this study indicated that Korean *Symplocos* are comparatively indistinguishable in terms of their qualitative wood features except for exclusively uniseriate rays and narrow vessels present in *S. purnifolia* instead of uni- to- multiseriate rays and wide vessels present in other three species. However, discrepancies are observed in quantitative variables such as vessel number per square millimeter, vessel size, and ray density. The vessel density of *S. purnifolia* (highest among four species) is more than two times higher than the *S. sawafutagi* (lowest among four species) and *S. tanakana*. On the other hand, vessel size is likewise reverse to the vessel number per mm² i.e., vessel circumference and diameter in both planes of *S. sawafutagi* and *S. tanakana* is almost twice a larger than *S. purnifolia*. Similarly, the ray density is comparatively higher in *S. sawafutagi* and *S. tanakana* than *S. purnifolia*. In terms of vessel number per mm² and vessel circumference, *S. coreana* lies in between *S. tanakana* and *S. purnifolia*, but in terms of ray density, it is closer with *S. purnifolia*.

The differences in quantitative wood variables such as vessel number per mm², vessel circumference, and vessel diameter including ray width and ray cells in the radial section between the species of section *Palura* and *S. purnifolia* can be interpreted based on the sectional division. Although we only used *S. purnifolia* of the section *Lodhra*, the wood of this species is well differentiated from section *Palura* by exclusively uniseriate rays with only procumbent and square cells mixed throughout the ray. In addition, fine spiral thickenings are observed in vessel and fiber walls of *S. purnifolia* but these structures are lacking in all species of *Palura* included in this study. Yamauchi (1979) reported the wood anatomy of nine Japanese species and based on the obtained results she concluded that Japanese *Symplocaceae* could be divided into two genera, *Dacalix* Lour. consisting of evergreen species with axillary inflorescence and *Palura* consisting of deciduous species with terminal inflorescence. Although we may not agree with this arbitrary generic discrimination based only on the wood anatomy our results on deciduous and evergreen *Symplocos* is congruent with Yamauchi (1979) in terms of vessel density, size, and vessel and fiber wall thickenings.

Concerning the three species of section *Palura*, *S. coreana* exhibited some differences in wood variables with *S. tanakana* and *S. sawafutagi* in respect of higher vessel density, smaller

vessel size, and lower ray density whereas later two species are almost identical in their wood anatomical features and remain closer in UPGMA phenogram (Fig. 6). Furthermore, these three species showed several morphological similarities including deciduous leaves, paniculate inflorescence, polygamous flower, bilocular ovary, and orbicular fruits (Ohwi, 1965; Soejima and Nagamasu, 2004; Chang et al., 2011; Kim and Kim, 2018). Only a few morphological differences displayed by *S. coreana* with *S. tanakana*, and *S. sawafutagi* include broadly obovate leaf lamina with coarsely serrate margin and bluish black fruit color instead of usually narrower, obovate to oblong leaf lamina with small and incurved toothed margin and bluish or black fruit (Ohwi, 1965; Chang et al., 2011; Kim and Kim, 2018). It has been suggested that some quantitative variations in the wood anatomical structures can be influenced by the growing conditions of the plant species (Baas, 1973; Carlquist, 2001; Campbell et al., 2016). *Symplocos sawafutagi* and *S. tanakana* which were collected from Pyeongchang-gun, Gangwon-do and Shinan-gun, Jeollanam-do, respectively, preferably grow deep in the forest with low sunlight whereas *S. coreana* which was collected from Miaksan, Seogwip-si, Jeju-do (in Korea this species only found in Jeju-do) usually prefer the edge of the forest with high sunlight. Thus, slight variations found in the wood of *S. coreana* can be explained based on the fitness of this species to the growing conditions. Likewise, *S. purnifolia*, sampled from Jeju-do, had the highest vessel density and smallest vessel sizes among the four species also preferably grow on the edge of the forest.

In conclusion, this wood anatomical study evidently offers an additional remark to differentiate *S. purnifolia* with other Korean *Symplocos* species. Some quantitative wood variables, on the other hand, distinguished *S. coreana* from *S. tanakana* and *S. sawafutagi* although an alternative explanation of environmental condition is prevailing. Based on the wood anatomy we are still unable to differentiate *S. tanakana* and *S. sawafutagi* as these two species are very similar in other morphology and also problematic in taxonomic nomenclature (see Ohwi, 1965; Korea National Arboretum, 2017). We believe that these results certainly provide a basis for further studies on the interspecific variation of Korean *Symplocos*. However, the number of species was very low and the wood samples used were juvenile, and thus any interpretation made on this basis could be arbitrary. Further studies considering as many taxa as possible and using mature wood materials certainly be helpful for resolving taxonomic problems in the genus.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

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