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Anatomical features of four common Mongolian softwoods
モンゴルの主要針葉樹材の組織学的特徴

Murzabyek SARKHAD [1,2,3], Futoshi ISHIGURI[1], Ikumi NEZU[1,2], Haruna AISO[4],
Bayasaa TUMENJARGAL[3], Bayartsetseg BAASAN[5], Ganbaatar CHULTEM[5],
Jyunichi OHSHIMA[1], and Shinso YOKOTA[1]
サルハド・ムルザベク [1,2,3]，石栗　太 [1]，根津郁実 [1,2]，相蘇春菜 [4]，
トゥメンジャルガル・バヤサ [3]，バーサン・バヤルツェツェグ [5]，
チュルテム・ガンバートル [5]，大島潤一 [1]，横田信三 [1]

[1] School of Agriculture, Utsunomiya University, Utsunomiya, Tochigi 321-8505, Japan
宇都宮大学農学部　〒 321-8505 宇都宮市峰町 350
[2] United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Fuchu, Tokyo 183-8509, Japan
東京農工大学大学院連合農学研究科　〒 183-8509 東京都府中市幸町 3-5-8
[3] Training and Research Institute of Forestry and Wood Industry, Mongolian University of Science and Technology, Ulaanbaatar 15172, Mongolia
モンゴル科学技術大学森林・木材産業研究所　モンゴルウランバートル市
[4] Faculty of Agriculture, Yamagata University, Tsuruoka, Yamagata 997-8555, Japan
山形大学農学部　〒 997-8555 山形県鶴岡市若葉町 1-23
[5] School of Industrial Technology, Mongolian University of Science and Technology, Ulaanbaatar 14191, Mongolia
モンゴル科学技術大学生産技術学部　モンゴルウランバートル市

1. Introduction

Although forest area percentage against total land area is low in Mongolia, boreal forests are distributed in the northern part of the country (FRDC 2020). The boreal forest area occupies about 80% of the total forest area of this country (FRDC 2020). The boreal forests have several important coniferous forestry species, such as *Pinus sylvestris* L., *Pinus sibirica* Du Tour., *Picea obovata* Ledeb., and *Larix sibirica* Ledeb. (Tsogtbaatar 2002; Altrell 2019; Sukbaatar et al. 2020). In contrast to the importance of these wood species in forestry, information about basic wood properties, including anatomical characteristics, are still limited. Basic wood information is essential to utilize wood resources from sustainable forestry in boreal forests. In our previous study, we investigated basic wood properties, chemical properties, and dimension lumber quality in four common softwoods in Mongolia (Sarkhad et al. 2020, 2022a,b,c,d). However, available information about anatomical characteristics is still limited for these softwoods.

In the present study, we investigated the anatomical features of four common softwoods in Mongolia according to the "IAWA List of Microscopic Features for Softwood Identification" (IAWA Committee 2004).

2. Materials and methods

Wood samples of the four common Mongolian softwoods (*Pinus sylvestris*, *Pinus sibirica*, *Picea obovata*, and *Larix sibirica*) were collected from naturally growing trees in Mandal, Selenge, Mongolia (Sarkhad et al. 2020, 2022a,b,c,d, Table 1). *Pinus sylvestris* trees were grown in a naturally regenerated forest mixed with *Betula platyphylla* Sukaczev (48°49′N, 106°53′E). The remaining three

Table 1　Growth characteristics and annual ring number of the sample trees (Sarkhad et al. 2020).

Property	*Pinus sylvestris*	*Pinus sibirica*	*Picea obovata*	*Larix sibirica*
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
	Min. – Max.	Min. – Max.	Min. – Max.	Min. – Max.
D (cm)	27.1 (2.2)	26.5 (1.3)	27.9 (2.2)	25.6 (1.6)
	24.3 – 29.9	24.8 – 28.1	24.2 – 29.6	24.0 – 28.2
TH (m)	16.2 (2.2)	11.9 (1.5)	14.3 (2.3)	15.3 (1.3)
	14.3 – 19.2	10.7 – 14.6	10.6 – 16.9	13.9 – 16.8
ARN	72 (3)	62 (4)	60 (5)	50 (9)
	67 – 74	57 – 67	49 – 64	42 – 64

Note: *D*, stem diameter at 1.3 m above the ground; TH, tree height; ARN, annual ring number at 1.3 m above the ground; Min., minimum; Max., maximum. Mean and standard deviation (SD) for each species were calculated from the data of five trees in each species.

species were also collected from other naturally regenerated forest (48° 41 ′ N, 106° 38 ′ E). From the harvested trees, wood samples were obtained at 1.3 m above the ground.

Small wood blocks were collected from each tree. Transverse, radial, and tangential sections (10 to 26 μm in thickness) were prepared using a sliding microtome (REM-710, Yamatokohki, Saitama, Japan). The sections were stained with safranin and then dehydrated with a graded ethanol series. The sections were dipped in xylene, put on glass slides, and then mounted by cover slips with Canada balsam (Kanto Chemical). Anatomical characteristics were checked according to the "IAWA List of Microscopic Features for Softwood Identification" (IAWA Committee 2004).

3. Results and discussion

Figures 1 to 4 show photomicrographs of common four Mongolian softwoods. In all four species, secondary xylem comprised tracheid, ray parenchyma cell, ray tracheid, and epithelial cell. Table 2 also shows a summary of the anatomical characteristics.

In *Pinus sylvestris*, transition from earlywood to latewood was abrupt, and the latewood width was relatively wider (Figure 1a). Axial and radial intercellular canals were present with thin-walled epithelial cells (Figures 1a, b, and f). The axial intercellular canals were distributed in the latewood regions. Ray tracheid presented dentate thickenings (Figures 1d and e). Cross field pitting was window-like pitting with one to two large pittings in a cross field (Figure 1d).

Transition from earlywood to latewood in *Pinus sibirica*

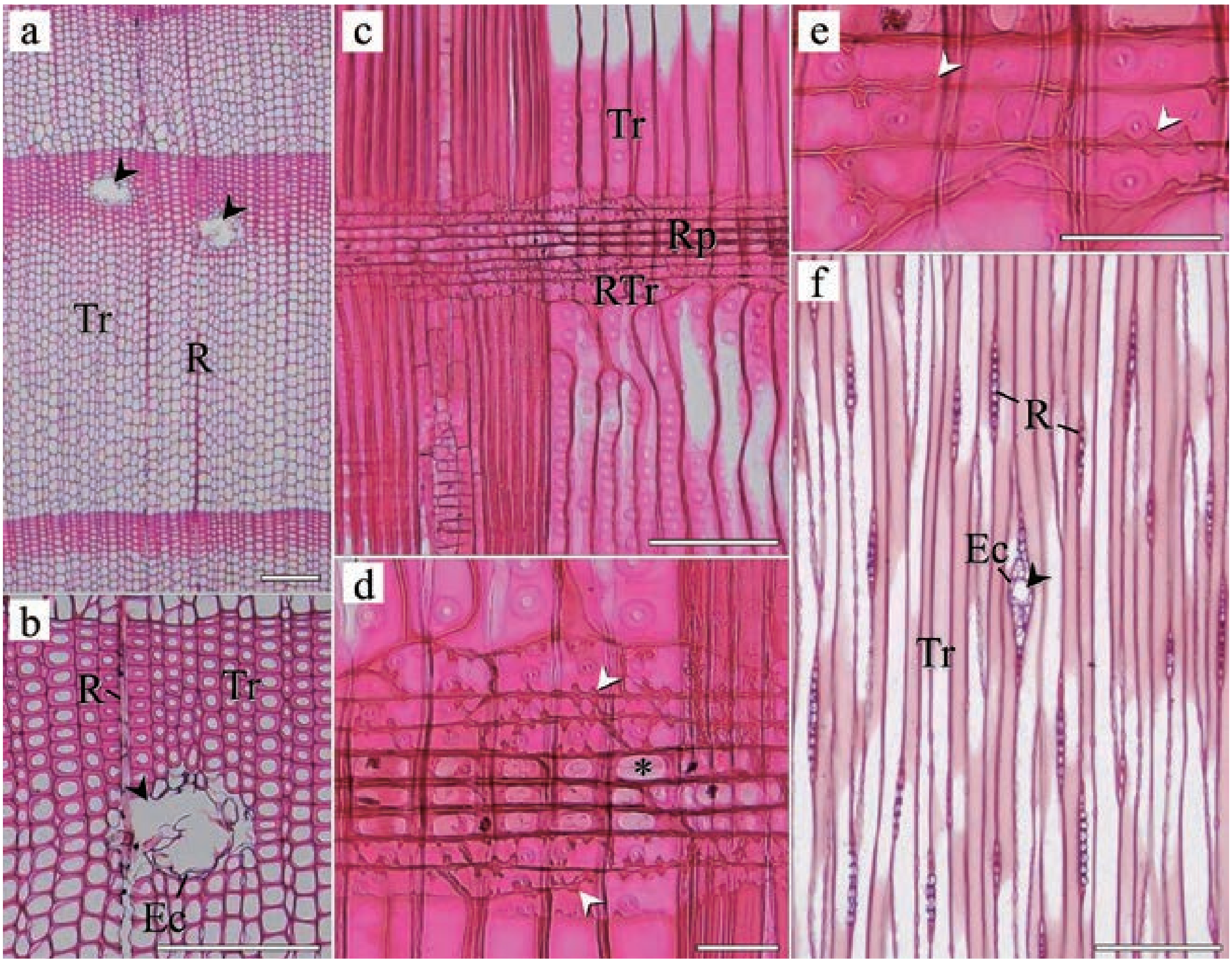

Figure 1 Photomicrographs of transverse, radial, and tangential sections of *Pinus sylvestris*.

Note: Tr, tracheid; R, ray; Ec, epithelial cell; Rp, ray parenchyma; RTr, ray tracheid. Black arrowheads indicate axial and radial intercallular (resin) canal. Asterisk indicates cross field. White arrowheads indicate ray tracheid walls with dentate thickenings. Bars in a to c and f are 200 μm. Bars in d and e are 50 μm.

was gradual with very narrower latewood (Figures 2a and b). Thin-walled epithelial cells surrounded the axial and radial intercellular canals (Figures 2b and c). A smooth cell wall was the characteristic of ray tracheids (Figures 2e and f). Ray parenchyma cells and cross-field pitting (Figure 2e) were similar to those of *Pinus sylvestris* (Figure 1d).

In *Picea obovata*, transition from earlywood to latewood was gradual (Figure 3a), but it was easily identified compared to that of *Pinus sibirica* (Figure 2a). Latewood width was narrow. Ray tracheid had a smooth wall and bordered pit with angular or dentate thickenings (Figures 3d and f). Indentures and nodular end walls were present in the ray parenchyma cells (Figure 3e). Cross field had piceoid type cross-field pitting (with two to four pittings in each cross field, Figure 3e). Axial and radial intercellular canals with thick epithelial cells were present, and axial intercellular canals were distributed in the latewood portion (Figures 3b and g).

Transition from earlywood to latewood in *Larix sibirica* was abrupt, and the latewood width was wider (Figure 4a). Axial and radial intercellular canals were surrounded by thick epithelial cells (Figures 4b and g). Axial intercellular canals were found in the latewood portion (Figures 4a and b). Longitudinal tracheids predominantly had two seriate pittings with opposite arrangements in radial walls (Figures 4c and d). Ray tracheid was present (Figures 4c to e). Ray parenchyma cells had many pits, forming nodular end walls, and distinctly pitted horizontal walls (Figures 4e and f). Types of cross-field pitting were piceoid with two to four pits in each cross field (Figure 4e).

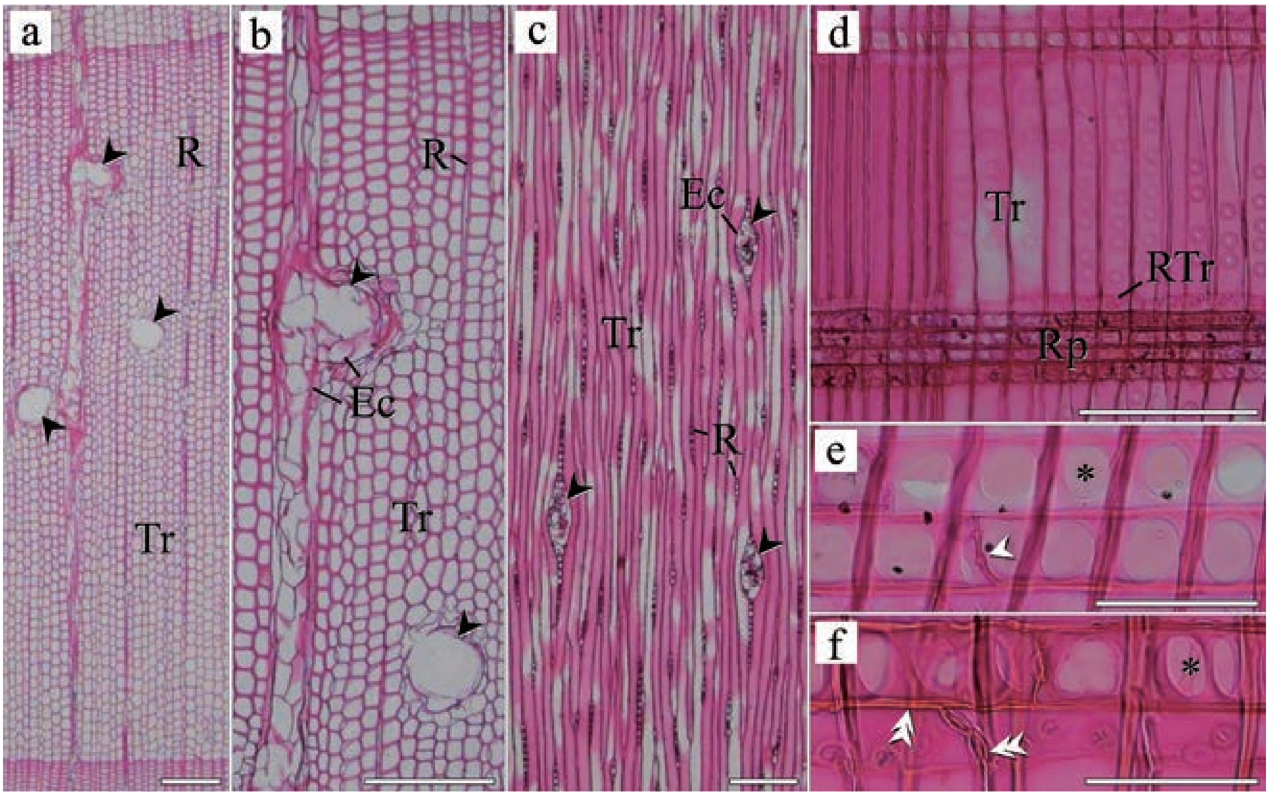

Figure 2 Photomicrographs of transverse, radial, and tangential sections of *Pinus sibirica*.

Note: Tr, tracheid; R, ray; Ec, epithelial cell; Rp, ray parenchyma; RTr, ray tracheid. Black arrowheads indicate axial and radial intercallular (resin) canal. Asterisk indicates cross field. White arrowhead indicates nodular end walls of ray parenchyma cell. White double arrowheads indicate smooth walls of ray tracheid. Bars in a to d are 200 μm. Bar in e and f are 50 μm.

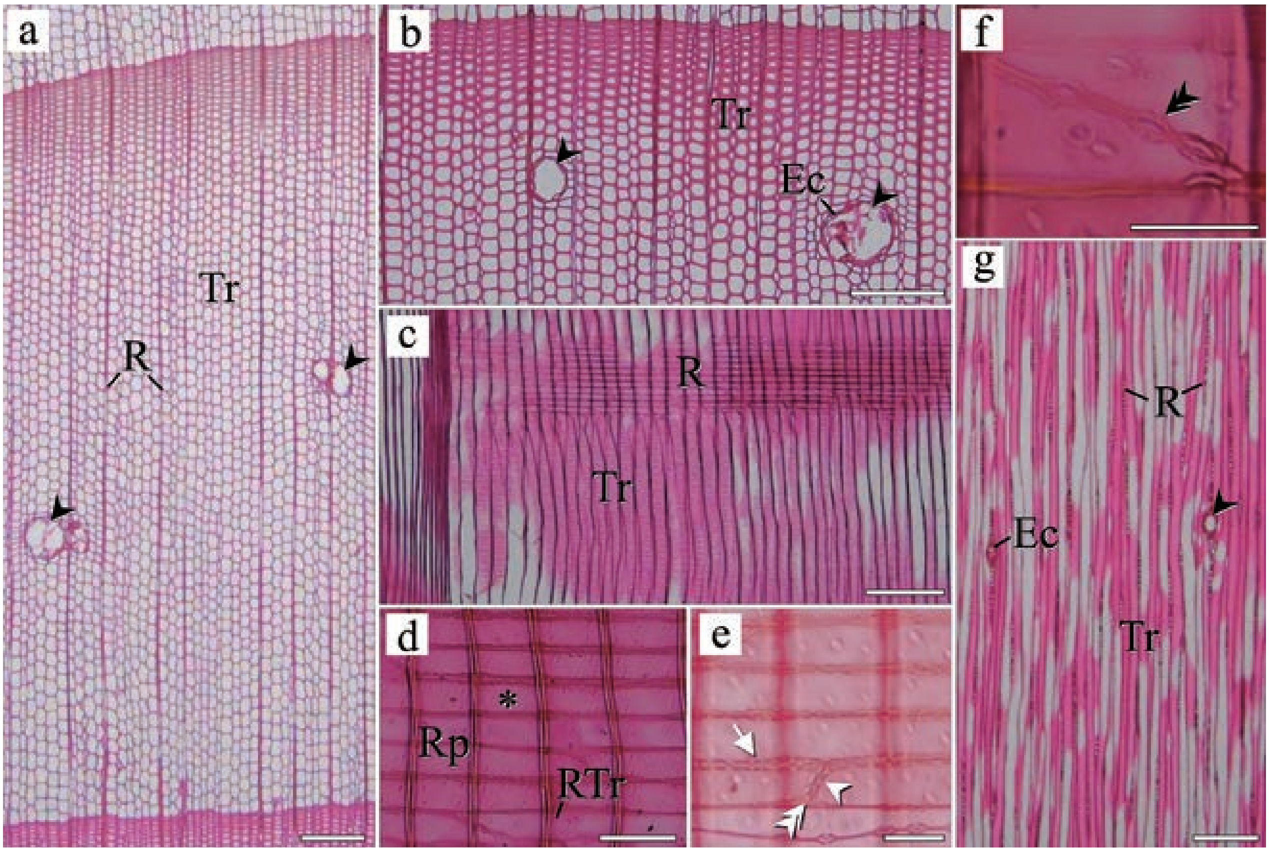

Figure 3 Photomicrographs of transverse, radial, and tangential sections of *Picea obovata*.
Note: Tr, tracheid; R, ray; Ec, epithelial cell; Rp, ray parenchyma; RTr, ray tracheid. Black arrowheads indicate axial and radial intercallular (resin) canal. Asterisk indicates cross field. White arrowhead indicates nodular end walls of ray parenchyma cell. White arrow indicates distinctly pitted in horizontal walls of ray parenchyma cells. White double arrowhead indicates indentures of ray parenchyma cell. Black double arrowhead indicates ray tracheid pit borders angular thickenings. Bars in a to c and g are 200 μm. Bars in d is 50 μm. Bars in e and f are 20 μm.

Table 2 Summary of anatomical characteristics of four common Mongolian softwoods.

Character	Code in IAWA List	*Pinus sylvestris*	*Pinus sibirica*	*Picea obovata*	*Larix sibirica*
Transition from EW to LW	42 – 43	A	G	G	A
Tracheid	44 – 47, 61 – 68				2, O
Resin cell	72 – 78				
Ray tracheid	69 – 70, 79 – 84	P, D	P, S	P, S,*	P, S
Ray parenchyma cell	85 – 89		N	N, I	N, DP
Cross field pitting	90 – 100	W	W	Pic	Pic
Intercellular canals	109 – 110	A, R	A, R	A, R	A, R
Epithelial cell	116 – 117	Thin	Thin	Thick	Thick

Note: Transition from earlywood (EW) to latewood (LW): A, abrupt; G, gradual

Tracheid: 2, predominantly two seriate for tracheid pitting in radial walls in EW; O, opposite for arrangement of tracheid pitting in radial wall in EW

Ray tracheid: P, present; S or D, smooth or dentate in cell walls of ray tracheids; *, ray tracheids pit borders angular or with dentate thickenings (radial section)

Ray parenchyma cell: N, nodular end walls of ray parenchyma cell; I, indentures; DP, distinctly pitted in horizontal walls of ray parenchyma cells

Cross-field pitting; W, window-like; Pic, piceoid

Intercellular canals: A, presence of axial intercellular (resin) canals; R, presence of radial intercellular (resin) canals

Epithelial cell: Thick, thick-walled epithelial cells; Thin, thin-walled epithelial cells.

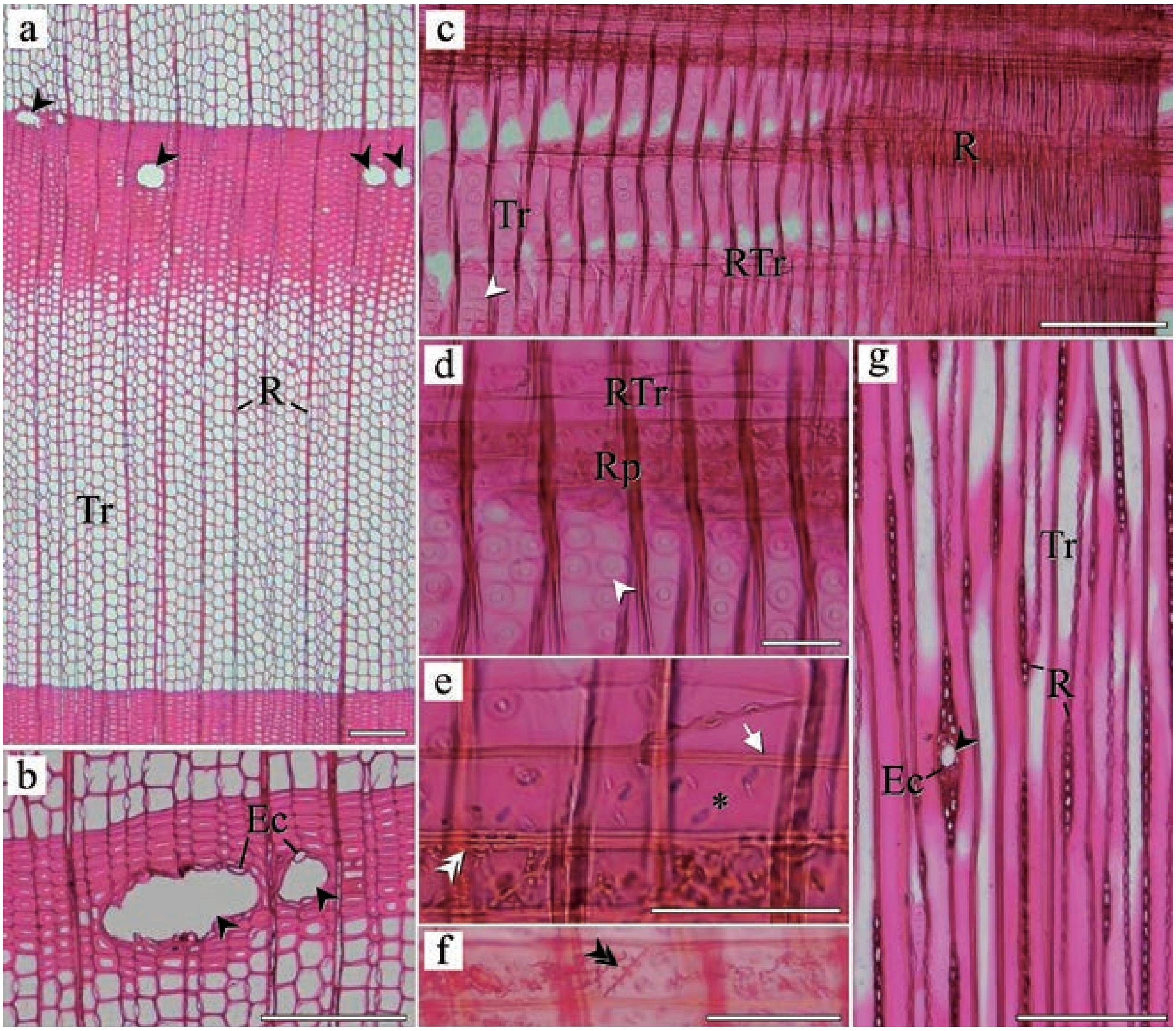

Figure 4 Photomicrographs of transverse, radial, and tangential sections of *Larix sibirica*.

Note: Tr, tracheid; R, ray; Ec, epithelial cell; Rp, ray parenchyma; RTr, ray tracheid. Black arrowheads indicate axial and radial intercallular (resin) canal. Asterisk indicates cross field. White arrowheads indicate tracheid pitting in radial wall with two seriate. White arrow indicates smooth cell wall of ray tracheids. White double arrowhead indicates distinctly pitted in horizontal walls of ray parenchyma cells. Black double arrowheads indicate nodular end walls of ray parenchyma wall. Bars in a to c and g are 200 μm. Bars in d to f are 50 μm.

4. Concluding remarks

Anatomical characteristics were examined in four common softwoods in Mongolia, *Pinus sylvestris*, *Pinus sibirica*, *Picea obovata*, and *Larix sibirica*. The results were similar to those reported in the same species or similar species found in other countries (Wood Technological Association of Japan. 1984; Schweingruber 1990; Benkova and Schweingruber 2004). Based on the results obtained in the present study and previous study, we concluded that wood resources of four common species naturally growing in Mongolia can be utilized for similar purposes with the same or similar species growing in other countries.

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