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HEARTWOOD AND SAPWOOD FEATURES OF *SORBUS TORMINALIS* GROWN IN IRANIAN FORESTS

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ABSTRACT

In the present study anatomical, histometrical, chemical and physical properties of the wood of 45-year old trees were determined. For this purpose, three trees were randomly cut at Sangdeh-Mazndaran located in the northern part of Iran. Disks and logs were removed at breast height to study the respective wood properties. Fiber length, fiber diameter, fiber lumen diameter, cell wall thickness as well as lignin and cellulose content of sapwood are superior to those of heartwood. Growth rings boundaries are fairly distinct and can be distinguished by only two to three compact fiber layers. The wood is diffuse-porous and vessels are small and predominately solitary, hardly visible to the naked eye on transverse sections. Most rays are 2-seriate interspersed with only few 3-seriate and uniseriate rays, and composed of procumbent body cells with occasional marginal rows of upright and/or square cells.

KEYWORDS: *Sorbus torminalis*, wood structure, heartwood-sapwood relationship, chemical and physical properties.

INTRODUCTION

Sorbus torminalis (L.) Crantz is an important commercial species growing in the northern forests of Iran from Astara to Golidaghi. In Iran the tree is known as 'Barank', other names are 'Wild service tree' or 'Mountain ash' (GB), alisier des bois (FR) and 'Elsbeere' (DE). According to Espahbodi et al. (2008) and Tabandeh et al. (2007), it grows in mixed stands with beech (*Fagus orientalis*), hornbeam (*Carpinus betulus*) and chestnut-leaved oaks (*Quercus castaneifolia*). The distribution of *Sorbus torminalis* in Eurasia covers a wide range, from the north of the Maghreb to the south of Sweden and from eastern Great Britain to northern Iran (Demersure et al. 2000). Trees grow to a height of 15 to 25 m with a diameter at breast height (DBH) from 60 to 90 cm (Welk et al. 2016). The wood has a fine texture and is often used for manufacturing highly valued artistic objects and musical instruments. Medicinal uses of the Sorbus species are also known (Termentzi et al. 2006). In Iran, studies on this species are mainly related to tree-physiology and ecology (Espahbodi et al. 2008). Golbabaei et al. (2015) determined some strength properties (static bending, compression parallel to grain, impact bending and shear) of *S. torminalis* from different regions in the north of Iran. Studies of the anatomical, biometrical, chemical and physical properties are very rare in Iran (Aghajani et al. 2019). Kol et al. (2009) reported that physical and mechanical properties of *S. aucuparia* are sufficient to produce an acceptable product and that this species constitutes a suitable alternative for alder (*Alnus* spp.) and beech. However, it is quite different from *S. torminalis* and its wood properties should not be taken as equivalent.

S. torminalis and S. domestica are naturally distributed and available in Europe. Although both species belong to the same genus, from the point of view of dendrology and wood quality they are quite different. Schoch et al. (2014) reported that the wood of *S. torminalis* is diffuse to semi-ring-porous, rays almost homocellular and generally 2-seriate, vessels with simple perforation plates and intervessel pits opposite. Ďurkovič et al. (2011) studied some anatomical and chemical properties of the genus *Sorbus* except *S. torminalis*. They reported that most are semi-ring-porous with simple perforation plates, with the exception of *S. aria*. Richter and Dallwitz (2018) described the wood of *S. torminalis* as diffuse porous, vessels arranged in no specific pattern, exclusively solitary or with few multiples, medium fiber cell wall thickness, axial parenchyma in narrow marginal bands, apotracheal diffuse and paratracheal scanty; rays multiseriate, generally 2-3 cells wide.

S. torminalis is tolerant to direct sunlight and short-time water deficit in the soil, therefore it is considered suitable for afforestation on arid and warm sites and constitutes a valid option for wider utilization in forestry and landscape management. As *S. torminalis* in Iranian forests has considerable potential, the aim of the current study is to investigate wood structural features, fiber morphology, physical and chemical properties of this species.

MATERIAL AND METHODS

The raw material was obtained from 45-year-old *S. torminalis* trees grown on an experimental site of the Paradukale forestry project located at the Shirin-e-Rud river basin No. 66 watershed, and cut down in June 2018. The 2347 ha plot is about 60 kilometres from the city of Sari.

The altitude of this site is 350 m, the climate is mild, generally warm and temperate, with an annual precipitation of 690 mm and a mean temperature 16.7°C. October and November are the rainy season in this area. The temperature reaches its maximum in June, July and August.

Physical properties

5-cm thick discs were cut from three 3-m logs with base diameter 60 cm for determination of physical properties (dry density, basic density and volumetric shrinkage and swelling, n = 60). In order to determine the physical properties, test specimens with dimensions of 3 × 2 × 2 cm were prepared from heartwood and sapwood according to ISO 13061-2. Specimen dimensions were measured in green (saturated) and oven-dry condition with a slide calliper; oven-dry mass was determined with an electric balance to an accuracy of 0.01 g. Shrinkage was calculated using the dimensional change from the green to oven-dry condition. The physical properties were calculated by the following Eqs. 1-4.

$$D_0 = P_0 / V_0 \tag{1}$$
$$D_b = P_0 / V_s \tag{2}$$
$$\beta_v = (V_s - V_0) / V_s \tag{3}$$
$$\alpha_v = (V_s - V_0) / V_0 \tag{4}$$

where:
D_0 - oven dry density ($g \cdot cm^{-3}$),
D_b - basic density ($g \cdot cm^{-3}$),
β_v - volumetric shrinkage (%),
α_v - volumetric swelling (%),
V_s - volume in state of saturate (cm),
V_0 - volume in state of oven-dry (cm),
P_0 - weight in state of oven dry (g),
P_s - weight in state of saturate (g).

Biometric properties

Thirty specimens were prepared for fiber dimension (15 × 10 × 2 mm) like fiber length, fiber diameter, lumen diameter and cell wall thickness (n = 50). Franklin (1945) method was applied for separation of wood fibers. Samples for measuring fiber dimensions were macerated in a mixture (1:1) of 30% hydrogen peroxide and glacial acid in an oven at 64°C oven for 24 hours. After that, the samples were washed with distilled water. The fiber dimensions were determined by using Leica Image Analysis System. For this test, it was necessary to measure 20 fiber dimensions per sub-samples.

Chemical compounds

The chemical analysis was performed according to TAPPI test methods, cellulose (T 257 cm-85), lignin (T 222 om-98), ash (T 211 om-93), solubility in alcohol-acetone (T 204 cm-88). All measurements were repeated three times and the mean values calculated.

Wood anatomical parameters

Small blocks of approximately 1 (L) ×1 (R) ×1 (T) cm were cut from each disk. The wood was softened by boiling to remove excess air, followed by immersion in distilled water. 20-30 μm thin transverse, radial and tangential sections were cut with a sliding microtome, bleached, stained with safranin red and rinsed in an ethanol series (50, 95 and 100%) until all traces of excess stain and water were removed. After bleaching, staining and dehydrating, sections were mounted in Canada balsam for subsequent microscopic examination using Olympus BH-2 microscope in different magnification (4x, 10x, 20x and 40x). The description of the anatomical characters followed the IAWA "List of Microscopic Features for Hardwood Identification" (IAWA 1989).

RESULTS AND DISCUSSION

Physical properties

Fig. 1 shows the results for oven-dry density, basic density, volumetric shrinkage and volumetric swelling for heartwood and sapwood. The results reveal that there are significant differences between sapwood and heartwood, all determined properties being higher in heartwood than in sapwood. The corresponding numerical values of mean oven-dry density, basic density, volumetric shrinkage, and volumetric swelling values are as follows:

Heartwood: 887 ± 49.2 kg·cm^{-3}, 634 ± 37.2 kg·cm^{-3}, 16.60 ± 2.5% and 20.4 ± 3.6%, respectively. Sapwood: 721 ± 20.4 kg·cm^{-3}, 567 ± 12.7 kg·cm^{-3}, 15.1 ± 1.44% and 17.7 ± 1.9%, respectively.

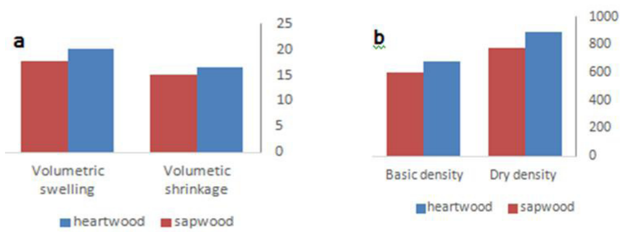

Fig. 1: (a) Volumetric shrinkage and volumetric swelling (%), (b) average of wood density (kg·m^{-3}) of Sorbus torminalis in heartwood and sapwood.

Generally, the wood can be classified as heavy with oven-dry and basic density of 831 kg·m^{-3} and 643 kg·m^{-3}, respectively. The oven-dry density measured in the present study is much higher than reported by Gholbabei et al. (2014). It is comparable with the values reported by Richter and Dallwitz (2018) (750 kg·m^{-3}). Moreover, the density is higher than that reported for Persian ironwood (820 kg·m^{-3}, Enayati 2010) and hornbeam (800 kg·m^{-3}, Khalkhali 2013) but lower than that of Persian oak (0.99 kg.cm3, Saedi et al. 2017). For comparison, oven-dry and basic density of *S. aucuparia* are 737 kg·m^{-3} and 635 kg·m^{-3}, respectively (Korkut et al. 2009).

Chemical composition

Tab. 1 shows the mean values of the chemical constituents of *S. torminalis*. On average, hardwood is composed of 40-45% cellulose, 17-25% lignin and less than 10% of extractives (Efhamisisi et al. 2009). In other Sorbus species such as *S. aria, S. zuzanae, S. montisalpae*, *S. haljamovae*, *S. chamaemmespilus* and *S. aucuparia*, the lignin content is 16-19%, that of cellulose 28-30%, and that of extractives 3-5% (Ďurkovič et al. 2011). By comparison, for *S. torminalis* from the northern forests of Iran, cellulose content is somewhat lower, extractives content somewhat higher and lignin content about equal. Such differences could be related to site, growth conditions and forest management practices (Zobel and Buijtenen 1989, Bahmani et al. 2018). Overall, the lignin content of *S. torminalis* is less than the average of most hardwoods, whereas the cellulose content does not differ significantly.

Tab. 1: The average chemical composition of heartwood and sapwood of S. torminalis (according to TAPPI test methods).

Area	Cellulose (%)	Lignin (%)	Extractives (%)	Ash (%)
Sapwood	49.8	17.8	1.6	0.6
Heartwood	47.9	19.2	2.7	0.8
Combined	48.9 ± 3.5	18.5 ±1.2	2.2 ± 0.6	0.7 ± 0.2

Histometrical parameters

Sapwood has longer fibers than heartwood (Tab. 2). Similar results were previously reported by several researchers (Mariana et al. 2005, Rayirath and Avramidis 2008, Saraeian et al. 2011). On the other hand, sapwood has fibers with larger lumens and thicker walls. Longer fibers in sapwood were reported by Ay and Şahin (1998) and Mariani et al. (2005). Thicker fibers in sapwood were reported by Mariana et al. (2005) and Liukkonen et al. (2007).

Tab. 2: The average biometric features of heartwood and sapwood of S. torminalis.

Area	Fiber length (µm)	Fiber diameter (µm)	Lumen diameter (µm)	Cell wall thickness (µm)
Sapwood	1725	25.2	6.6	10.3
Heartwood	1414	22.9	4.1	8.7
Combined	1570 ± 182.1	24.1 ± 2.4	5.4 ± 1.9	9.5 ± 1.6

Fibers are classified into three groups (IAWA 1989):

- short fibers with a length less 900 microns;
- fibers of medium length between 900-1900 microns including *S. torminalis* with an average fiber length of 1570 microns;
- fibers longer than 1900 microns.

The average fiber length of *S. torminalis* is higher than that reported for most hardwoods (Khalkhali 2013). Among Iranian wood species cell wall thickness is high compared to *Populus* species (5 µm) and about equal to that of Persian oak with 9 µm (Efhamisisi 2009, Saedi et al. 2017).

Wood anatomy

According to the standardized description of the "List of microscopic features for hardwood identification" (IAWA 1989) following microscopic characters were determined for the individual cell types (tissue):

Vessels: wood diffuse porous, vessels commonly in short (2-3) radial rows. Average tangential vessel diameter 50 µm, average number of vessels/mm^2 40–100. Perforations mainly simple; in very narrow vessels occasionally with scalariform to reticulate perforations. Vessel-ray pits with distinct borders, similar to intervessel pits. Helical thickenings present, in narrow and wide vessel elements, throughout the body of vessel elements.

Tracheids and fibres: Fibres of medium wall thickness. Average fibre length 900–1600 µm. Fibre pits common in both radial and tangential walls, distinctly bordered.

Axial parenchyma: Axial parenchyma banded or diffuse-in aggregates, bands are marginal or seemingly marginal.

Rays: Rays 8–12 per tangential mm, multiseriate, even if only few, 1–3 cells wide, narrow (2–4 seriate). Height of large rays more than 1 mm. Rays composed of a single cell type (homocellular), or two or more cell types (heterocellular); heterocellular rays with square and upright cells restricted to marginal rows, mostly 1 marginal row of upright or square cells.

The following microscopic images show representative transverse sections of *S. torminalis* (Fig. 2). The wood is diffuse-porous with no specific pattern in vessel arrangement. The vessels are predominantly solitary with a mostly rounded, rarely angular outline. The ground tissue fibers are relatively thick-walled and can be clearly distinguished from the thinner-walled apotracheal parenchyma which is banded or diffuse-in aggregates (Fig. 2 left and center).

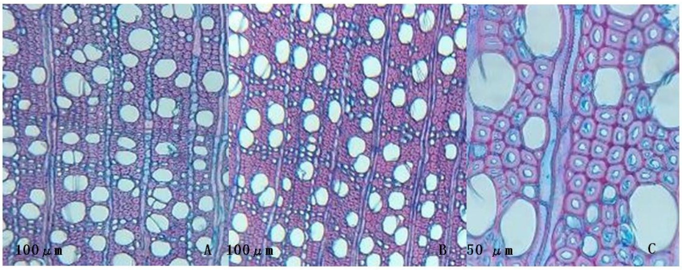

Fig 2: Transverse section of Sorbus torminalis L.

The tangential sections (Fig. 3) show the characteristic arrangement of the predominantly 2-seriate rays. Rays either homocellular and composed of procumbent cells or, more frequently, heterocellular with one or more marginal rows of square to upright cells. Ray cells round to slightly oval-elongated; large rays up to 500 µm high; sheath and tile cells absent.

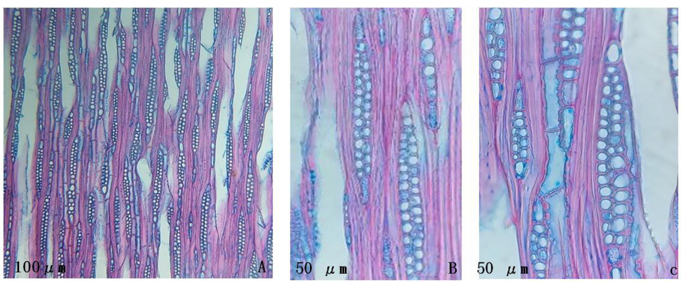

Fig 3: Tangential section of Sorbus torminalis L.

The radial sections (Fig. 4) show a heterocellular ray with one marginal row of upright cells (left) or up to 3 square cells (right). The intervessel pits are opposite or alternate with an average diameter (vertical) of 5-7 µm. The vessel-ray pits have distinct borders, similar to intervessel pits (Fig. 4 right). Scalariform to sometimes reticulate perforations are occasionally present in narrow vessel elements (Fig. 4 center); narrow and wide vessel elements with helical thickenings.

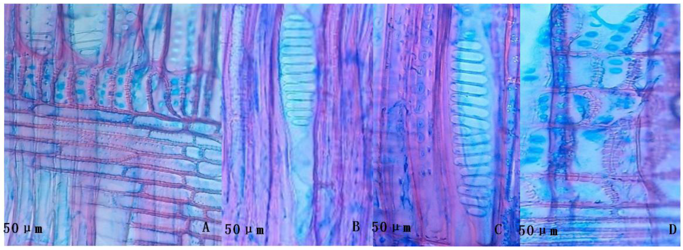

Fig 4: Radial section of Sorbus torminalis L.

There is agreement between these results and the wood description of *S. torminalis* by Richter and Dallwitz (2000). Noteworthy anatomical similarities include: growth ring boundaries distinct; wood diffuse porous, vessels solitary or in multiples, the latter few and commonly in short (2–3 vessels) radial rows; perforation plates simple, occasionally with scalariform to reticulate perforations, axial parenchyma present, helical thickenings in vessels present, tyloses absent, sheath and tile cells absent.

CONCLUSIONS

Sorbus torminalis grown in Iran is a diffuse porous wood with a very high density. It can be utilized in various industrial applications. Its anatomical features do not differ significantly from congeneric. Cellulose content is in the range of other hardwoods but the lignin content is lower. It is suggested that in further studies additional properties such as the natural durability of Iranian *S. torminalis* wood against fungi, molds, insects, and termites be investigated.

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