Macroscopic and Microscopic Diagnosis of Three *Entandrophragma* Species Traded in Türkiye

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The anatomical characteristics are highlighted for *Entandrophragma cylindricum, Entandrophragma utile*, and *Entandrophragma angolense*. Wood samples, which were previously obtained from commercial timber industries in the Marmara region of Türkiye and used as course materials, were used. Qualitative and quantitative anatomical characteristics were determined. Qualitatively, characters such as distinct growth rings, diffuse-porous wood, deposits in vessel elements, simple perforation plates, alternate intervessel pits, heterogeneous ray type, and septate fibres, were common to all species. The quantitative evaluation showed that there were differences between species. *Entandrophragma* species differ in some wood characteristics such as the tangential diameter of the vessel, ray height, ray width, and fibre lumen diameter. *E. utile* had higher values of the mean tangential vessel diameter (180 µm) and fiber lumen diameter (18.4 µm) than the other two species. It is possible to say that the anatomical features of *E. cylindricum* differ from that of other species and that it will be easier to diagnose among other species. *E. cylindricum* had the lowest values of the mean tangential vessel diameter (147 µm) and ray height (361 µm). Distinctive characters for *E. utile* and *E. angolense* are tangential vessel diameter, vessel length, ray height, ray width, and all fibre dimensions.

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INTRODUCTION

The annual wood consumption in Türkiye is 32 million m^3. Of this, approximately 26.3 million m^3 is produced by the General Directorate of Forestry; the remaining 5 million m^3 is covered by the private sector and 1.5 to 2 million m^3 by imports (GDF 2021). As a country, it is impossible to fully meet the forest products sector's raw material needs entirely from domestic production, both in terms of demand and quantity. To close this gap, raw materials are procured from other countries. The import of wood materials belonging to exotic species in Türkiye, as well as all over the world, has an important place in the trade of forest products. The Turkish Forest industry operates in the production of timber, veneer, parquet, plywood, particleboard, joinery and carpentry products, furniture, paper and cardboard, pallets, and packaging. The rational use of wood raw materials in these fields of activity depends on precise knowledge of their structural properties. Thus, new areas of use can be found by ensuring that the woods of tree species are optimally evaluated. An accurate diagnosis is required for the correct selection of the place of use for a species. The identification of a wood sample in terms of genus or species is not only important for plant taxonomy, but also for the trade in wood material, art, archeology, anthropology, conservation, restoration, and criminology (Doğu 2001).

One of the problems encountered in the trade of wood-based materials is the existence of tree species with similar macromorphological features. The macroscopic characteristics of the wood are those that can be seen when examined with the eye or with the help of special magnifying glasses called loops (Ruffinatto *et al*. 2015). When the cells extending longitudinally and transversely in the tree are cut at different angles to the tree axis, different images appear on their surfaces. These appearance features are used in the macroscopic examination. Characteristics such as the natural color, brightness, odour, texture, fibre structure, weight, and hardness of the wood material are also considered (Erdin and Bozkurt 2013). However, the macroscopic diagnosis of a wood material may not be sufficient to identify similar species. Thus, macromorphological and micromorphological features are needed for identification. As mentioned earlier, individuals or organisations purchasing wood materials need to be sure of the type of material they are buying. Otherwise, material-related problems at the point of use are largely unavoidable. From a legal perspective, such incorrect purchases can even lead to criminal prosecution.

One of the wood types imported into Türkiye is *Entandrophragma* species belonging to the Meliaceae (Mahogany) family, which is described as African Mahogany. The Meliaceae are a widely distributed subtropical and tropical angiosperm family occurring in various habitats, from rainforests and mangrove swamps to semi-deserts. *Entandrophragma* species are distributed in West, Central, and East Africa (Newton *et al.* 1994; Hall 2008). The family Meliaceae is composed of 702 species in 53 genera of trees and shrubs native to tropical and subtropical regions (Koenen *et al.* 2015), many of which are highly valuable timbers such as *Swietenia* (Mahogany) and *Cedrela* in the Neotropics and *Entandrophragma* and *Khaya* in Africa. Mahogany accounts for a relatively high proportion of the international trade in tropical hardwoods (Tchoundieu and Leakey 1996; Newton *et al.* 1994; Hall 2008). In general, they have a fine grain, reddish-brown heartwood, and are resistant to drought and pest infestation (Edlin 1969; Knees and Gardner 1983; Dunisch and Ruhmanm 2006).

Entandrophragma species are used in the furniture industry, in the production of veneer, plywood, paneling, and parquet, and the interior and exterior of buildings. These species, which have such a wide usage area in Türkiye, are very similar to each other visually, and they can even be confused in many places. In the face of the situation encountered in this way, serious problems, such as economic and raw material losses that threaten the sustainability of species and production, are observed at the place of use.

Numerous publications in the world have comparatively examined the anatomy of similar tropical woods (Gasson 2010; Sint *et al*. 2013; Hidayat *et al*. 2017; Uetimane *et al*. 2018; Nobre *et al*. 2019; Jayusman and Hakim 2021; Siam *et al*. 2022; Sandratriniaina *et al*. 2022; Kim *et al*. 2023). The basic quantitative and qualitative wood description of *Entandrophragma* has been described by several researchers (Panshin 1933; Ayensu and Bentum 1974; Wiemann 1994; Rufinatto and Crivellaro 2019; Richter and Dallwitz 2000; Inside Wood 2022). However, these descriptions are still not specific, leading to confusion in distinguishing between *E. cylindricum*, *E. utile*, and *E. angolense*. Therefore, this study aimed to determine the delimiting features of the three *Entandrophragma* species (*E. cylindricum*, *E. utile*, and *E. angolense*) and thus overcome the identification problem.

EXPERIMENTAL

Materials

Three wood samples *E. cylindricum* (Sapele, Sapelli, Lifaki, Penkwa), *E. utile* (Sipo, Utile, Kosi-kosi), and *E. angolense* (Edinam, Tiama), which were previously obtained from commercial timber industries in the Marmara region of Türkiye and used as course materials in Istanbul-Cerrahpaşa University, Forestry Faculty, Department of Forest Industry Engineering in Istanbul, were the subject of this investigation. Wood samples were obtained by cutting small cubes with dimensions of x10 mm (radial) x10 mm (tangential) x20 mm (longitudinal) from the course materials used in the exotic woods lesson, in which the identification of wood is explained to the students (Fig. 1).

Fig. 1. Radial planes of *Entadrophragma* species: (A) *E. cylindricum*, (B) *E. utile*, (C) *E. angolense*

Methods

For the macroscopic analysis, the transverse surfaces of the wood were smoothed with sandpaper (80 and 150 grit). The macroscopic images were captured using a digital camera (Nikon DS-Fil), a mobile phone (Huawei P20 lite, 16 MP), and a stereo photomicroscope (Nikon SMZ 745T) from longitudinal and transverse sections of wood species.

For microscopic analysis, from the small cubes of approximately 2 cm^3, thin sections were cut with the help of a sliding microtome (Leica SM2010 R, Wetzlar, Germany), in three sections (transverse, radial, and tangential) with a thickness of approximately 15 µm to 25 µm. All sections were stained with 1% safranin O solution and washed with distilled water. They were then dehydrated with the ethanol series (50%, 75%, and 99%) for 5 minutes per stage, cleaned with xylene, and mounted on a sliding glass using Entellan. To measure the vessel and fibre lengths, the wood samples were cut into approximately matchstick-sized chips. Wood macerations were carried out according to Schultze's method, as adopted by Merev (1998). These chips were placed in test tubes with added potassium chlorate ($KClO_3$) and nitric acid (HNO_3) (1:1) and heated to 60 °C. The set-up was allowed to react in a fume cupboard until the chips were softened and bleached. Distilled water was then poured into each tube, and the bleached and softened chips were washed several times with distilled water until they became clear. The washed fibres were filtered and rinsed with alcohol. Then glycerin was added to each bottle and stained with safranine O. All the chemicals and dyes used in the present work were from Sigma-Aldrich®. The photomicrographs were taken using a light microscope (DP71 digital camera installed on an Olympus BX51 light microscope, Tokyo, Japan), and measurements were made with BAB Bs200Pro image processing and analysis software.

Tangential and radial vessel diameter (μm), ray width (μm), ray height (μm and number), ray frequency (number of rays per millimeter), from the macerated samples, fiber length (mm), fiber diameter (μm), fiber lumen diameter (μm), and fiber cell wall thickness (μm) were measured. Twenty-five measurements for all anatomical features except fibre dimensions (fifty measurements) were taken and the mean, maximum, and minimum values were shown in tables. Terminology, definitions, cell counts, and measurements were performed according to the recommendations of the IAWA list of microscopic features (Wheeler *et al*. 1989). Significant differences in quantitative anatomical characteristics between three species were analysed by one-way analysis of variance (ANOVA) with a 5% significance level using SPSS ver. 23 (IBM Corp., Armonk, NY, USA).

RESULTS AND DISCUSSION

Qualitative Anatomical Characteristics

Macroscopic Features

Macroscopic photographs taken with a mobile phone adapted to a handlens were shown in Fig. 2. Wood color was copper red-brown in *E. cylindricum*, reddish brown with a distinct golden lustre in *E. utile*, and reddish brown with gold shades in *E. angolense*. The distinct boundaries of the growth rings were marked by marginal parenchyma bands and a narrow zone of denser fibrous tissue in *E. cylindricum* and *E. angolense* (Fig. 2A, C). In *E. utile*, growth ring boundaries were distinct and marked by a fine, straightish line of marginal parenchyma bands and a narrow zone of denser fibrous tissue (Fig. 2B).

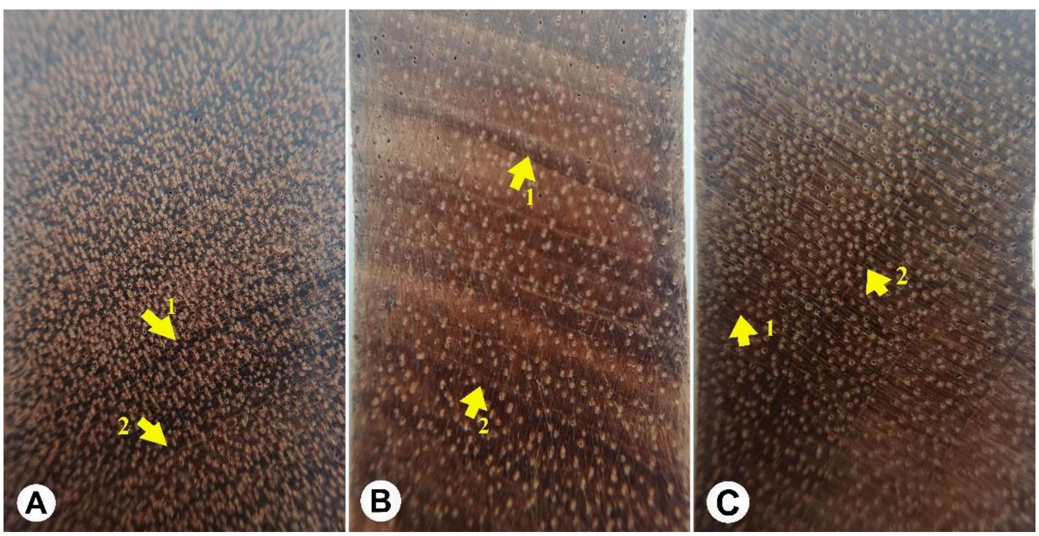

Fig. 2. Macroscopic views of *Entandrophragma* species. (A) *E. cylindricum,* a narrow zone of denser fibrous tissue (arrow 1), marginal parenchyma bands (arrow 2); (B) *E. utile*, a narrow zone of denser fibrous tissue (arrow 1), marginal parenchyma bands (arrow 2); (C) *E. angolense*, a narrow zone of denser fibrous tissue (arrow 1), marginal parenchyma bands (arrow 2) (Hand lens adapted to mobile phone, 10x)

The texture was medium in *E. utile* and *E. angolense*, whereas it was medium fine in *E. cylindricum*. The grain of the wood was interlocked and slightly wavy in *E. cylindricum*, slightly interlocked in *E. utile*, and markedly interlocked in *E. angolense*. Pores were fairly numerous, uniformly distributed, in short, and long radial groups, occasionally solitary, and barely visible with the naked eye in *E. cylindricum*, scarce, evenly distributed, solitary, and in short radial groups, and visible with the naked eye in *E. utile*, and fairly numerous, uniformly distributed, and barely visible with the naked eye in *E. angolense*. As Ruwanpathirana (2014) mentioned, the size of vessels may help to identify the timber by hand lens. *E. cylindricum* was distinguished from other species by its smaller vessels.

Marginal parenchyma bands were distinctly visible with the naked eye, appearing as white lines (Fig. 3A, arrow 1), and paratracheal and apotracheal parenchyma as wavy, interrupted, or continuous bands (Fig. 3A, arrow 2). These were less distinguishable with the naked eye in *E. cylindricum*, marginal parenchyma bands were fine (Fig. 3B, arrow 1), paratracheal and apotracheal parenchyma were scarce, in broken and wavy tangential lines (Fig 3B, arrows 2,3). These were inconspicuous to the naked eye in *E. utile*, and marginal parenchyma bands (Fig. 3C, arrow 1) were narrow and invisible with the naked eye; paratracheal parenchyma surrounding the pores (Fig. 3C, arrow 2), distinguishable with a 10x hand lens in *E. angolense*. *E. cylindricum* can be separated from the other two species because of its marginal parenchyma bands and uniform wavy and narrow parenchyma bands. Rays are fairly numerous and uniform in width for *E. cylindricum* and *E. utile*, and indistinguishable to the naked eye for all species. Rays of *E. angolense* were nearly uniform in width and distinguishable with the hand lens (Fig. 3C).

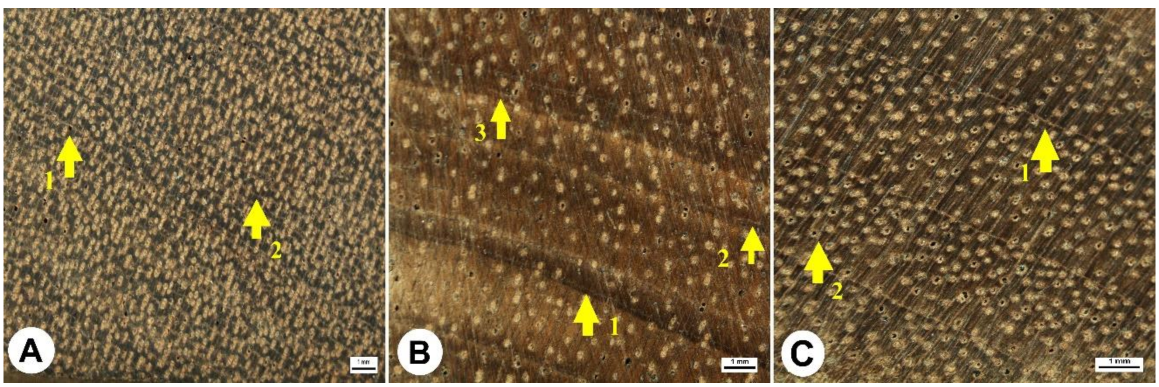

Fig. 3. Macroscopic views of *Entandrophragma* species. (A) *E. cylindricum*, marginal parenchyma bands (arrow 1), paratracheal and apotracheal parenchyma as wavy, interrupted, or continuous bands (arrow 2); (B) *E. utile*, marginal parenchyma bands (arrow 1), paratracheal and apotracheal parenchyma were scarce, in broken and wavy tangential lines (arrows 2,3), (C) *E. angolense*, marginal parenchyma bands (arrow 1), paratracheal parenchyma surrounded the pores (arrow 2). Scale bars: 1 mm

In the diagnosis of macroscopic wood type, the arrangement and quantity of parenchyma cells and the size and arrangement of the vessels are diagnostically very valuable (Koch *et al*. 2007; Pj *et al*. 2021). These cells were found to be effective in the macroscopic differentiation of the three species used in this study.

Microscopic features

Figure 1 shows optical micrographs of the cross-surfaces of the sample species. All species were identified as diffuse-porous wood. Vessels were generally in radial rows of 2 to 4 elements, occasionally solitary, and in longer rows (up to 6) in *E. cylindricum* (Fig. 4A). In *E. utile* (Fig. 4B), vessels were arranged in no specific pattern, in multiples, commonly solitary and in short rows (1 to 3 elements), whereas *E. angolense* (Fig. 4C) was mostly composed of solitary pores and rarely in radial groups of 2 to 3 elements. Dark gum deposits were observed in the vessels of all sample species. In *E. cylindricum*, vessels were slightly oval and round, but mostly oval and round in *E. utile* and *E. angolense*.

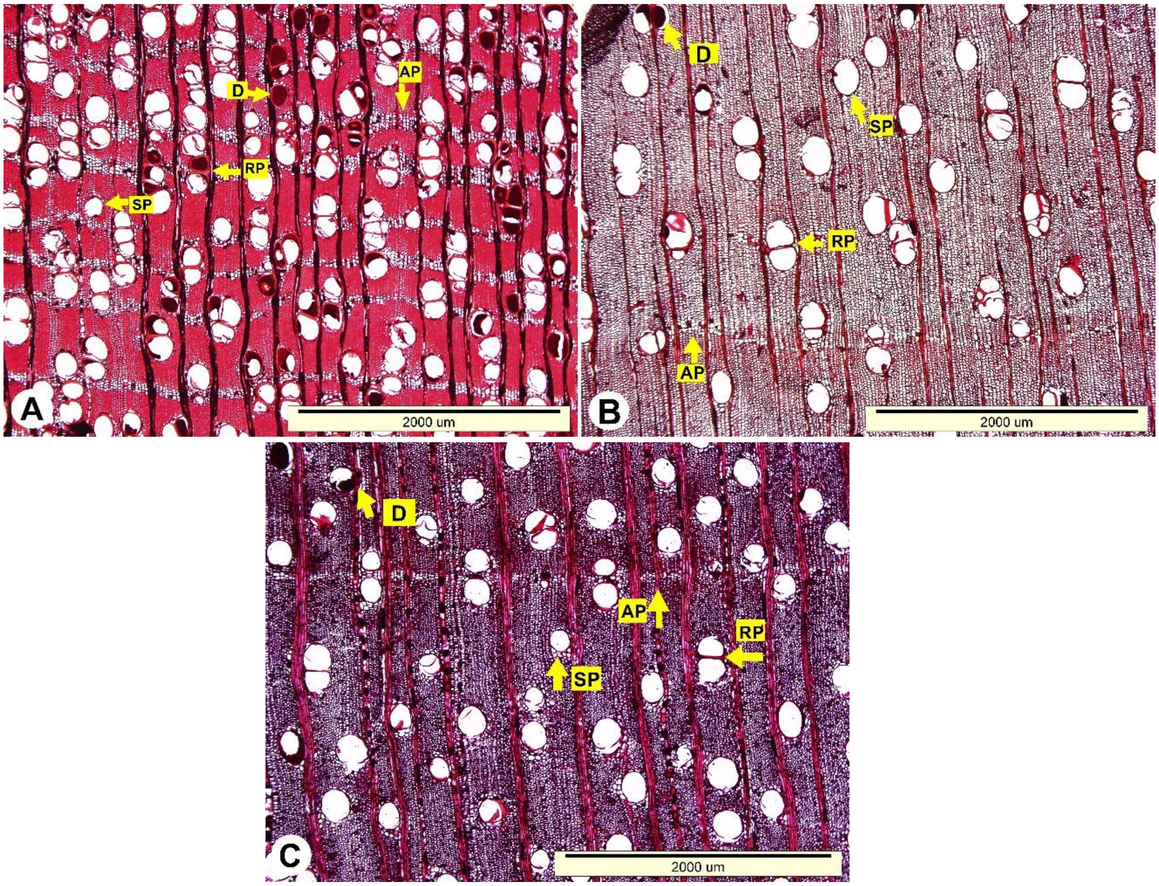

Fig. 4. Cross sections of *Entandrophragma* species. (A) *E. cylindricum*; (B) *E. utile*; (C) *E. angolense*. (SP) solitary pore; (RP) radial pore multiple; (AP) axial parenchyma; and (D) deposits. Scale bars: A, B, C =2000 μm

The arrangement of the axial parenchyma was paratracheal narrow bands composed of 6 to 8 cells (Fig. 4A), apotracheal diffuse-in-aggregate (1 to 4 cells wide) (Fig. 5A2), vasicentric unilateral, confluent, and scanty, in *E. cylindricum*, paratracheal narrow bands composed of 2 to 4 cells (Fig. 4B), scanty, confluent, aliform, and apotracheal diffuse and diffuse-in-aggregate (1 to 2 cells wide) (Fig. 5B2), in *E. utile*, and paratracheal narrow bands composed of 2 to 3 cells (Fig. 4C), scanty and vasicentric (Fig. 5C1), apotracheal diffuse (Fig. 5C2) in *E. angolense*.

According to Richter and Dallwitz (2000), *E. cylindricum*, *E. utile*, and *E. angolense* showed diffuse-porous vessels with radial multiples of 2 to 3 cells. The axial parenchyma appeared to be seemingly marginal bands, apotracheal diffuse-in-aggregates, paratracheal vasicentric, confluent, and unilateral in *E. cylindricum*, marginal bands, apotracheal diffuse, or diffuse-in-aggregates, paratracheal scanty, vasicentric, and confluent in *E. utile*, and marginal bands, paratracheal vasicentric in *E. angolense*. It was reported that axial parenchyma was predominantly confluent paratracheal and seemingly marginal bands in *E. cylindricum*, predominantly vasicentric in *E. angolense* (Dadzie *et al*. 2018).

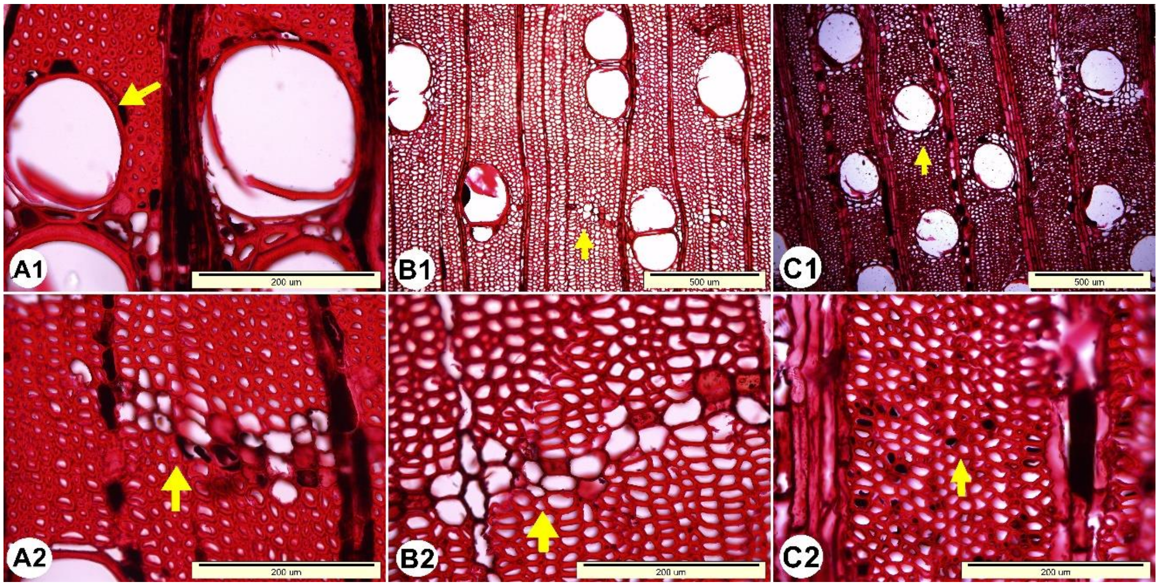

Fig. 5. Cross sections of *Entandrophragma* species. *Entandrophragma cylindricum*: (A1) paratracheal axial parenchyma in scanty (arrow); (A2) apotracheal axial parenchyma in diffuse-in-aggregates (arrow); *Entandrophragma utile*: (B1-B2) apotracheal axial parenchyma in diffuse-in-aggregates (arrow); *Entandrophragma angolense:* (C1) paractracheal axial parenchyma in scanty, confluent, and vassisentric; (C2) apotracheal axial parenchyma in diffuse. Scale bars: A1, A2, B2, C2= 200 μm; B1, C1=500 μm

Ruffinatto and Crivellaro (2019) showed that the anatomical characteristics of *E. cylindricum* included solitary vessels and radial multiples of 2 to 3 elements. The axial parenchyma was vasicentric, lozenge-aliform, winged-aliform, confluent, and in marginal bands. In this study, it was found that the vessel arrangement of the two *Entandrophragma* species in cross-section showed similar patterns (*E. utile* and *E. angolense*). *E. utile* and *E. angolense* had mostly solitary and radial multiple vessels (2 to 3), while *E. cylindricum* had solitary and radial multiple vessels (3 to 4). All three species had marginal parenchyma bands, but *E. cylindricum* had wider marginal bands than the other species.

Photomicrographs of the radial surface of the sample species are presented in Fig. 6. The ray type of the three species was procumbent with one row of upright and/or square marginal cells. For all species, perforation plates were simple, round or oval, intervessel pits were alternate, numerous, crowded, minute, and polygonal shaped, and vessel-ray pits had distinct borders similar to intervessel pits (Fig. 6 A2, B2, and C2).

E. cylindricum, and *E. angolense* could be classified into heterocellular ray types as mixed structures with procumbent cells and a marginal row of upright or square cells, while *E. utile* was classified into homogenous ray types or heterogeneous ray types. The rays of the three *Entandrophragma* species were generally composed of heterocellular rays with square or/and upright restricted to the marginal rows (Fig. 6A1, B1, C1).

Prismatic crystals were present and located in axial parenchyma cells (Fig. 7A1, B1) and ray cells (Fig. 7A2, B2) in *E. cylindricum* and *E. angolense*. In *E. utile*, prismatic crystals were located in axial parenchyma cells (Richter and Dallwitz 2000). Inside Wood (2022) stated that the rays were homocellular cell types (all ray cells were procumbent) in *E. cylindricum* and *E. utile*. The rays were heterocellular and composed of procumbent ray cells with one row of upright and/or square marginal cells for all three species. Additionally, it was reported that the presence of prismatic crystals in the three species.

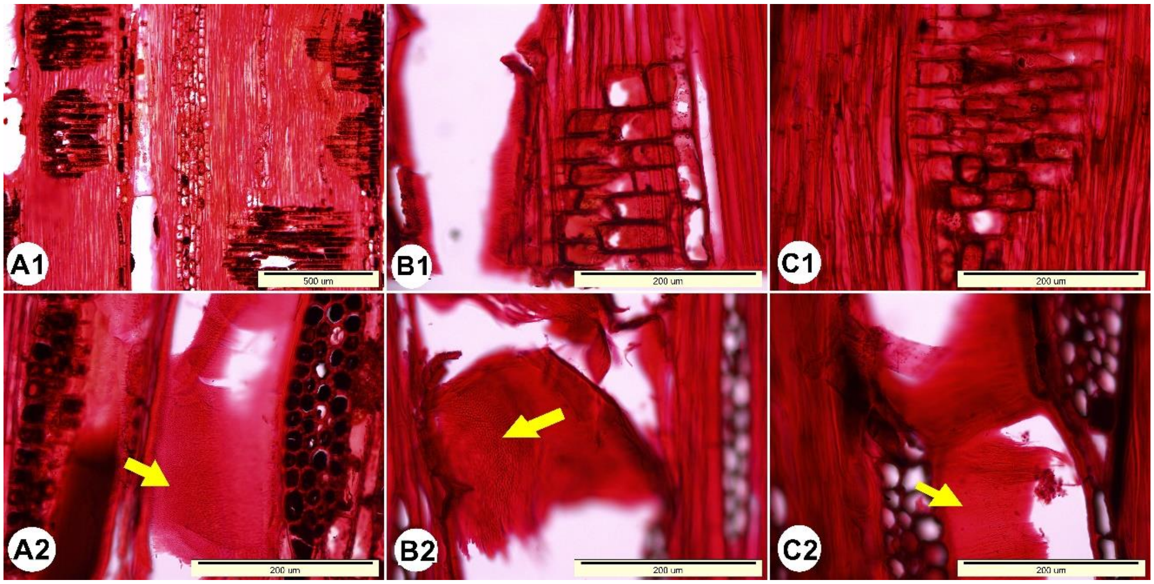

Fig. 6. Radial sections of *Entandrophragma* species. *Entandrophragma cylindricum;* (A1) rays in radial section; (A2) numerously, small inter-vessel pits (arrow); *Entandrophragma utile;* (B1) heterogenous rays; (B2) numerously, small inter-vessel pits (arrow); *Entandrophragma angolense;* (C1) heterogenous rays; (C2) numerously, small inter-vessel pits (arrow). Scale bars: A1= 500 µm; A2, B1, B2, C1, C2=200 µm

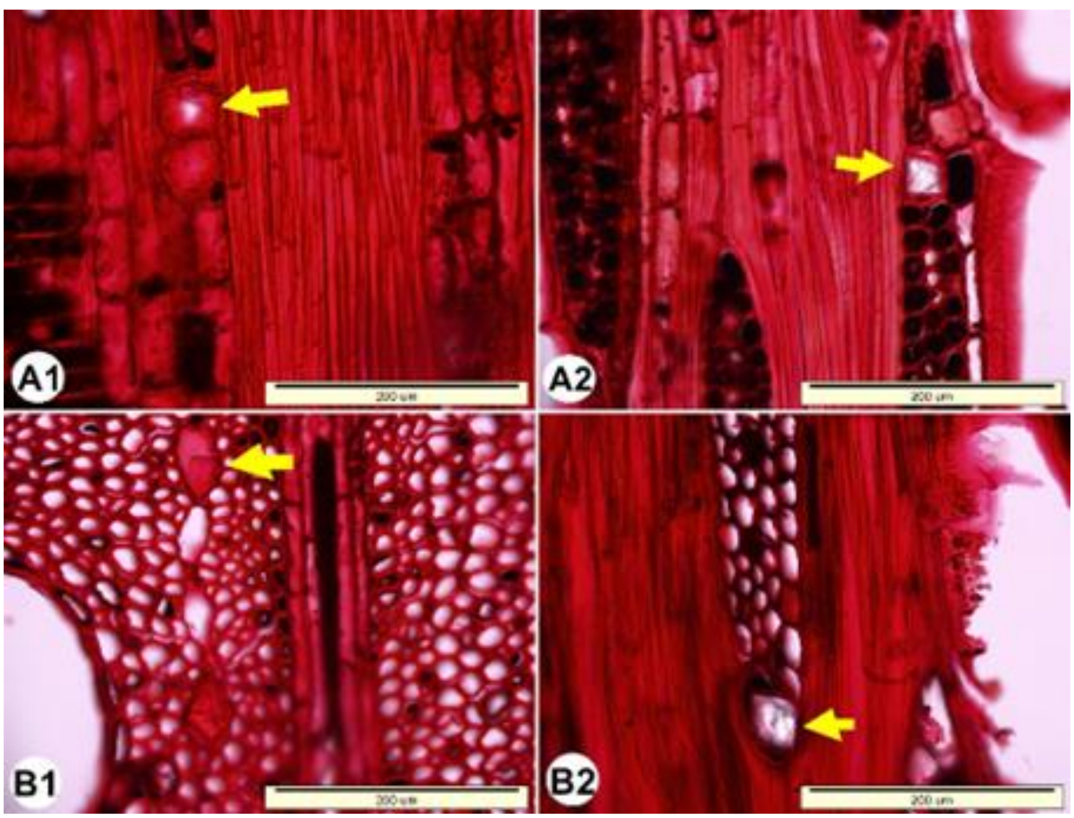

Fig. 7. *Entandrophragma cylindricum;* (A1) prismatic crystal in axial parenchyma cell (arrow); (A2) prismatic crystal in ray cell (arrow); *Entandrophragma angolense*; (B1) prismatic crystal in axial parenchyma cell (arrow); (B2) prismatic crystal in ray cell (arrow). Scale bars: A1, A2, B1, B2= 200 µm

It was observed that the rays of the three species were heterocellular with procumbent cells with one row of square marginal cells in this study. In *E. cylindricum* and *E. angolense*, prismatic crystals in the ray and axial parenchyma cells were frequently observed. However, in *E. utile*, prismatic crystals were not found in ray cells and axial parenchyma cells. According to Richter and Dallwitz (2000), prismatic crystals occurred very rarely in marginal ray cells.

Photomicrographs of the tangential surface of the sample species are shown in Fig. 8. The ray was multiseriate for *E. cylindricum* whereas the ray was uniseriate and multiseriate in *E. utile* and *E. angolense*. Multiseriate rays were 2 to 5 cells wide in *E. cylindricum*, 2 to 4 cells wide in *E. utile,* and 3 to 7 cells wide in *E. angolense*.

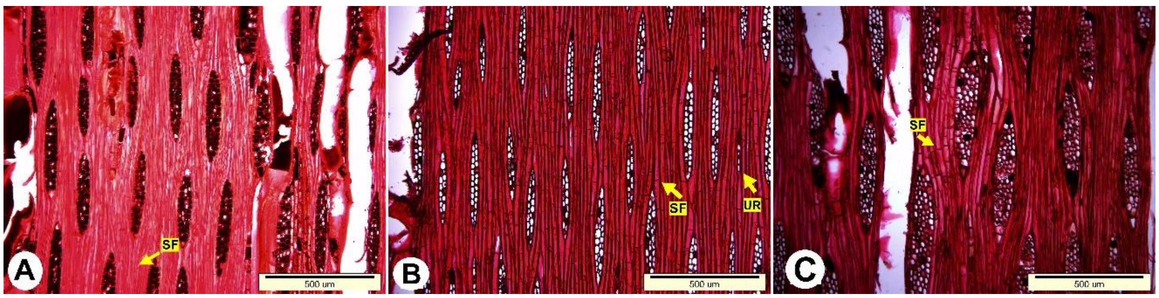

Fig. 8. Tangential section of *Entandrophragma* species. (A) *E. cylindricum*; (B) *E. utile*; (C) *E. angolense*. (SF) septate fibre; (UR) uniseriate ray. Scale bars: 500 μm

The ray properties of ray height, ray width, and ray number per millimeter are the main anatomical indicators of the tangential section (Wheeler *et al* 1989). The rays were 5 to 7 per millimeter in *E. cylindricum* and *E. utile*, and 3 to 5 per millimeter in *E. angolense*. Ray width was different between *Entandrophragma* species, 2 to 5 cells in *E. cylindricum*, 2 to 4 cells in *E. utile*, and 3to 7 cells in *E. angolense* (Richter and Dallwitz 2000). Based on the information from *Inside Wood* (2022), the ray widths were 4 to 12 per millimeter in all three species. The present study found that the ray widths were a range of multiseriate in all three species. In *E. utile*, uniseriate rays were observed. The fibres were exclusively septate, septate and non-septate in *E. cylindricum* and *E. utile*, and rarely septate and non-septate in *E. angolense*. The fibres were libriform fibres and thin-to thick walled (Fig. 9).

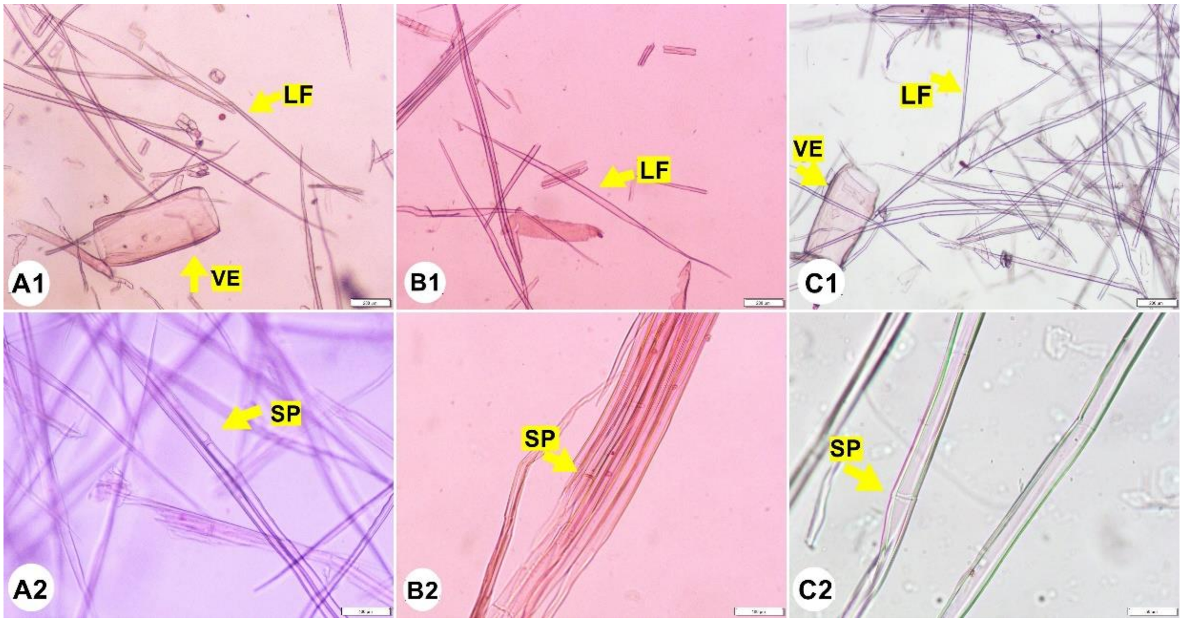

Fig. 9. Macerated woods of *Entandrophragma* species. (A1-A2) *E. cylindricum*; (B1-B2) *E. utile*; (C1-C2) *E. angolense*. (LF) libriform fibre; (VE) vessel element; (SP) septate. Scale bars: A1, B1, C1= 200 µm; A2, B2=100 µm; C2= 50 µm

Quantitative Anatomical Characteristics

The quantitative anatomical characteristics of *E. cylindricum*, *E. utile*, and *E. angolense* are presented in Table 1. *E. cylindricum*, *E. utile*, and *E. angolense* each had the mean tangential vessel diameter of 147, 181, and 168 µm, and the mean radial vessel diameter of 165, 204, and 191 µm, respectively. The one-way ANOVA results showed that the mean tangential vessel diameter was significantly different at the 5% significance level between *Entandrophragma* species. *E. angolense* had a significantly higher tangential vessel diameter than *E. utile* and *E. angolense*. According to Ayensu and Bentum (1974), *E. angolense* showed a range of 45 to 110 µm, *E. cylindricum* showed a range of 98 to 182 µm and *E. utile* showed a range of 80 to 250 µm. The tangential vessel diameters of 180 to 220 µm (Panshin 1933) and 166 µm (Dadzie *et al*. 2018) in *E. angolense*, and 150 to 250 µm (Panshin 1933) and 136 µm (Dadzie *et al*. 2018) in *E. cylindricum* were also found. Richter and Dallwitz (2000) found the tangential diameter of vessels as 90 to 200 µm in *E. cylindricum*, 140 to 295 µm in *E. utile*, and 140 to 220 µm in *E. angolense*. The tangential diameter of the species sampled in this study was similar to Panshin (1933), Ayensu and Bentum (1974), and Dadzie *et al*. (2018) except for *E. angolense* by Ayensu and Bentum (1974) and *E. cylindricum* by Dadzie *et al*. (2018). *E. utile* (204.08 µm) and *E. angolense* (190.82 µm) had significantly higher radial vessel diameters than *E. cylindricum* (165 µm). *E. cylindricum* showed a range of 11 to 22 in the number of vessels per square millimeter, *E. utile* showed a range of 2 to 7 in the number of vessels per square millimeter, and *E. angolense* showed a range of 2 to 8 in the number of vessels per square millimeter. The number of vessels per square millimeter was found to be 9 to 17 vessels/mm^2 in *E. cylindricum*, 3 to 6 vessels/mm^2 in *E. utile*, and 2 to 8 vessels/mm^2 in *E. angolense* (Richter and Dallwitz 2000).

Comparing the vessel properties of the *Entandrophragma* species, *E. cylindricum* wood showed a significantly narrower diameter and denser spacing of the vessels than that of the other two species.

E. cylindricum, *E. utile*, and *E. angolense* each had vessel element lengths of 503, 545, and 433 µm, respectively. The one-way ANOVA results showed that the vessel element length was not significantly different at the 5% level between *E. cylindricum* and *E. utile*. The lowest vessel element length belongs to *E. angolense*. The previously reported vessel element length of *E. cylindricum* was 150 to 500 µm (Panshin 1933), 420 µm (Ayensu and Bentum 1974), and 450 to 500 µm (Richter and Dallwitz 2000), while that of *E. utile* was 636 µm (Ayensu and Bentum 1974) and 500 to 600 µm (Richter and Dallwitz 2000), and that of *E. angolense* was 150 to 500 µm (Panshin 1933), 556 µm (Ayensu and Bentum 1974), and 430 to 600 µm (Richter and Dallwitz 2000). The vessel element length of *E. angolense* in Ayensu and Bentum (1974) and Richter and Dallwitz (2000) had a considerably higher value than that in the study.

There were no significant differences between the *E. cylindricum* and *E. utile* woods in the number of rays per millimeter, with these being 5.16 (3 to 7) and 4.68 (3 to 6), respectively. However, the number of rays per millimeter of *E. angolense* (3.40 (2 to 5)) was significantly different from that of the other two species. The number of rays per millimeter of *E. cylindricum*, *E. utile*, and *E. angolense* was reported by Panshin (1933) as 4 to 6, 5 to 7, and 3 to 6, and by Richter and Dallwitz (2000) as 3 to 7, 2 to 7, and 2 to 5 respectively. The ray heights of the three species were 361 µm, and 19.2 cells in the *E. cylindricum* wood, 428 µm and 13.7 cells in the *E. utile* wood, and 574 µm and 23.5 cells in the *E. angolense* wood. There were significant differences in ray height. The highest ray height belonged to the *E. angolense* wood. According to Richter and Dallwitz (2000), the ray height of the three species is up to 500 µm. This value was seen to be similar only in *E. angolense* in this study. The mean multiseriate ray widths of *E. cylindricum*, *E. utile*, and *E. angolense* were 56.4 µm (2 to 5 cells), 40.9 µm (2 to 4 cells), and 82.7 µm (3 to 7 cells), respectively. The one-way ANOVA results showed that the vessel element length was significantly different at the 5% level between the species. The highest ray width belonged to *E. angolense*.

Table 1. Anatomical Features of the Three *Entandrophragma* Species

Species	Anatomical features	N	Mean	Min.	Max.	Std. Dev.	Cv.
E.cylindricum	Tangential diameter of vessel, µm	25	147.30^{a}	107.34	184.28	19.89	13.51
	Radial diameter of vessel, µm	25	165.40^{a}	115.70	217.79	24.12	14.58
	Vessels per mm^2 (number)	25	15.68^{b}	11	22	2.82	18.01
	Vessel length, µm	25	503.37^{b}	396.17	595.75	49.93	9.92
	Ray frequency per mm	25	5.16^{b}	3	7	0.90	17.41
	Ray height (number)	25	19.20^{b}	10	26	4.42	23.00
	Ray height, µm	25	360.54^{a}	219.62	454.00	54.97	15.25
	Ray width, µm	25	56.36^{b}	35.22	76.05	10.27	18.22
	Fibre length, µm	50	1403.93^{a}	1018.63	1927.81	198.71	14.15
	Fibre diameter, µm	50	21.26^{a}	13.82	27.21	2.90	13.64
	Fibre lumen diameter, µm	50	12.19^{a}	7.37	18.04	2.40	19.69
	Fibre cell wall thickness, µm	50	4.54^{b}	1.93	7.94	1.35	29.74
E. utile	Tangential diameter of vessel, µm	25	180.94^{c}	121.56	239.77	25.52	14.11
	Radial diameter of vessel, µm	25	204.08^{b}	137.95	245.21	27.68	13.57
	Vessels per mm^2 (number)	25	4.16^{a}	2	7	1.21	29.18
	Vessel length, µm	25	544.89^{b}	306.56	764.25	99.94	18.34

	Ray frequency per mm	25	4.68[b]	3	6	1.03	22.00
	Ray height (number)	25	13.68[a]	8	19	2.58	18.84
	Ray height, µm	25	427.29[b]	279.95	532.95	63.24	14.80
	Ray width, µm	25	40.92[a]	28.48	55.28	8.42	20.57
	Fibre length, µm	50	1398.41[a]	891.18	1824.49	244.57	17.49
	Fibre diameter, µm	50	27.93[b]	17.70	38.90	5.20	18.62
	Fibre lumen diameter, µm	50	18.58[c]	10.81	27.14	3.70	19.91
	Fibre cell wall thickness, µm	50	4.68[b]	1.80	7.82	1.51	32.26
E. angolense	Tangential diameter of vessel, µm	25	167.75[b]	124.69	208.87	21.44	12.78
	Radial diameter of vessel, µm	25	190.82[b]	109.66	239.39	29.47	15.44
	Vessels per mm² (number)	25	4.52[a]	2	8	1.42	31.37
	Vessel length, µm	25	432.69[a]	215.11	558.28	90.79	20.98
	Ray frequency per mm	25	3.40[a]	2	5	0.65	18.99
	Ray height (number)	25	23.48[c]	14	32	4.58	19.48
	Ray height, µm	25	573.50[c]	372.09	749.16	93.33	16.27
	Ray width, µm	25	82.68[c]	65.42	114.70	11.84	14.32
	Fibre length, µm	50	1735.25[b]	879.55	2332.28	300.95	17.34
	Fibre diameter, µm	50	22.57[a]	16.14	30.80	3.53	15.64
	Fibre lumen diameter, µm	50	14.99[b]	8.04	25.12	3.19	21.28
	Fibre cell wall thickness, µm	50	3.79[a]	1.70	6.44	0.95	25.07

Note: Different letters on the same line indicate statistically significant differences between *Entandrophragma* species.

The mean fibre length of *E. cylindricum*, *E. utile*, and *E. angolense* were 1400, 1400, and 1740 µm, respectively. The ANOVA results revealed that there was a significant difference in fibre length between *E. angolense* and the other two species. *E. angolense* had a longer fibre length than that of the other two species. There was no significant difference between *E. cylindricum* and *E. utile* in fibre length. The fibre length of *E. cylindricum* was reported by Panshin (1933), Dadzie *et al*. (2018), and Richter and Dallwitz (2000) as 700 to 1700, 1480, and 690 to 2005 µm, respectively. The fibre length of *E. angolense* was reported by Ayensu and Bentum (1974), Panshin (1933), Dadzie *et al*. (2018), and Richter and Dallwitz (2000) as 1800, 900 to 2000 µm, 1550 µm, and 960 to 2080 µm, respectively. The mean fibre diameters of *E. cylindricum*, *E. utile*, and *E. angolense* were evaluated as 21.3, 27.9, and 22.6 µm respectively, and there were no significant differences between *E. cylindricum* and *E. angolense*. *E. utile* had a significantly larger diameter than the other two species. *E. angolense* had the longest fibre, while *E. utile* had the widest fibre among the studied species. The mean fibre lumen diameters of *E. cylindricum*, *E. utile*, and *E. angolense* were 12.2, 18.6, and 15.0 µm, respectively. There were significant differences between the three species in the fibre lumen diameters. The mean fibre cell wall thickness was 4.54 µm for *E. cylindricum*, 4.68 µm for *E. utile*, and 3.79 µm for *E. angolense*. *Entandrophragma* species studied in this study had medium wall thickness. There was no significant difference between *E. cylindricum* and *E. utile*. *E. angolense* had the lowest thickness.

Although many studies have shown that there may be anatomical differences in the wood of the same species growing in different ecological conditions (Hacke and Sperry 2001; Sperry 2003; Carrillo-Parra *et al*. 2013; Gratani 2014; Marques *et al.* 2015; Maitili *et al.* 2016; Koçer 2018; Odiye *et al.* 2019; Hızal Tırak 2020; Koçer *et al*. 2022; Yıldız and Keleş Özden 2022; Tripathi *et al.* 2023; Hızal Tırak and Birtürk 2024), it is impossible to prioritize ecological differences when identifying species traded from different countries. Anatomical identification of species traded from different countries is important to prevent the trade of illegal species, to prevent the use of wrong species for different purposes, and to reduce the economic losses of companies and countries engaged in trade. With the current type of studies, better recognition of the traded species will be achieved, which will guide especially those interested in identification.

CONCLUSIONS

The three *Entandrophragma* woods from sawmills in Türkiye showed some qualitative and quantitative differences in anatomical features.

1. Macroscopically, common features for all species were distinct growth rings, growth rings with marginal parenchyma bands and denser fibrous tissue, and diffuse-porous wood. While lower pore density and large pores were seen in *E. utile*, higher pore density, and small pores were seen in *E. cylindricum*. Pores were commonly solitary *in E. utile* and *E. angolense*.
2. Microscopic features common to all species were distinct growth rings, diffuse-porous wood, heterogeneous ray type, simple perforation plate, alternate intervessel pits, deposits in vessel elements, and septate fibres.
3. Quantitative anatomical features including tangential vessel diameter, ray height, ray width, and fibre lumen diameter showed statistically significant variation within species. *E. cylindricum* was the one that differed the most among the species with respect to tangential and radial vessel diameter, vessel grouping, number of vessels per mm^2, ray height, and fibre diameter. Tangential vessel diameter, vessel length, ray height, ray width, fibre length, fibre lumen diameter, and fibre cell wall thickness may be distinguishing characteristics for *E. utile* and *E. angolense*. *E. angolense* possessed relatively wider rays than *E. utile*.

In conclusion, the tree species identification by the macroscopic and microscopic anatomy allows an efficient tool for inspection and illegal wood logging and transport, and time. We believe that these results provide a basis for further studies on the interspecific variations.

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