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Determination of the Boundary between Juvenile–Mature Wood of *Diospyros kaki* and Their Wood Anatomical Variations

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ABSTRACT

Persimmon wood (*Diospyros kaki*) is a seasonal fruit-producing plant with a beautiful dark pattern in its wood that is suitable for high-quality furniture, sculptures and musical instruments. The utilization of persimmon wood can be improved by determining its anatomical characteristics, such as juvenile and mature wood. This study aimed to determine the boundaries between juvenile and mature wood and observe the anatomical properties of juvenile and mature wood and their variations in the axial direction. Three 30-year-old persimmon (*D. kaki*) trees grown in Karo, North Sumatra, Indonesia, were used in this study. The boundary between juvenile and mature wood was determined by measuring the fiber length and vessel element length from near the pith to near the bark. Anatomical observations were conducted in the juvenile and mature wood areas. The results showed that the average boundaries between juvenile and mature wood were 44.11 mm from the pith and were not significantly different in the axial direction of the trees. Furthermore, the wood anatomy categories of juvenile and mature wood differed significantly in terms of fiber diameter, fiber proportion, vessel proportion, and axial parenchyma proportion. In the axial direction, vessel diameter, ray parenchyma frequency, and ray parenchyma proportion at the base, middle, and top of the tree were significantly different.

Keywords: anatomical structures, axial variations, *Diospyros kaki*, juvenile, mature

1. INTRODUCTION

Persimmon (*Diospyros kaki*, family Ebenaceae) is a seasonal fruit-producing tree native to China, which later spread to Korea, Japan, and other parts of the world as a traditional crop and exotic fruit (Choudhary *et al*., 2022; Nazir *et al*., 2013; Yuniastuti *et al*., 2021). Persimmon tree has 15–17 m height unpruned and should not surpass 5–6 m height for cropping purposes (Baswarsiati *et al*., 2006; Intrigliolo *et al*., 2018). In Indonesia, persimmon trees are commonly found in several regions, including North Sumatra (Berastagi and Toba), West Java (Garut and Ciloto), Magetan, Malang, and East Java (Batu; Baswarsiati *et al*., 2006).

Persimmon wood is suitable for high-quality furniture, sculptures, and musical instruments because of its unique color and physical characteristics (Kiaei and Bakhshi, 2014). The heartwood of *D. kaki* rarely forms black

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streaks called “kurogaki” in Japan, which grows very slowly and has high density, excellent durability, and ornamental value. This blackened portion of *D. kaki* wood is used in tea ceremony goods (e.g., alcove posts in Japanese tea rooms), boxes, and other miscellaneous articles in Japan (Iwami *et al*., 2020; Noda *et al*., 2002; Ogata *et al*., 2008; Tazaki *et al*., 2017). In Indonesia, this species is usually planted for fruit production and is categorized as a slow-growing species (Mayasari *et al*., 2012). It is important to understand the potential wood utilization after the fruit-producing period ends or when the fruit is no longer productive. Because of the decreasing supply of wood as a raw material for the timber industry from natural forests, species diversification, especially from lesser-used species, is required as a raw material substitution (Augustina *et al*., 2020).

Wood utilization requires specific characteristics of the wood depending on its purpose. To develop efficient wood utilization, variations in wood characteristics and properties within trees, among trees, and among species must be understood for proper wood utilization (Fadwati *et al*., 2023; Jang *et al*., 2019; Zobel and van Buitjenen, 1989). Several wood characteristics such as wood cell proportion, wood cell dimensions, and the presence of juvenile wood are important parameters for determining wood quality (Nugroho *et al*., 2012; Savero *et al*., 2020).

Juvenile wood is formed when the cambium is younger, and over time, the cambium forms mature wood (Wang *et al*., 2021). The beginning of mature wood formation differs among species (Shmulsky and Jones, 2011). Palermo *et al*. (2015) reported that mature wood formation in *Eucalyptus grandis* occurs between the age of 8 and 13 year-old, whereas Zanuncio *et al*. (2022) reported that mature wood formed after 20-year-old cambium age in *Pinus caribaea*. In addition, Juvenile and mature woods have different anatomical characteristics. Juvenile wood has smaller and shorter fibers, thinner fiber walls, larger microfibril angles, higher lignin content, lower density, and lower strength than mature wood (Darmawan *et al*., 2013; Lu *et al*., 2021; Nugroho *et al*., 2012; Rahayu *et al*., 2021). Juvenile wood is quite undesirable because of its disadvantageous properties that limit its potential applications in veneer and solid wood products (Darmawan *et al*., 2013; Dirna *et al*., 2020; Hadi *et al*., 2019; Nawrot *et al*., 2014; Nugroho *et al*., 2012). The proportion of juvenile wood in the axial direction also varies; it can be cylindrical (Gatto *et al*., 2013; Zobel and Buijtenen, 1989) or conical in the core of the stem (Yang *et al*., 1986).

There is limited information on the juvenile and mature wood of *D. kaki*, such as their boundaries and anatomical properties in the axial direction. This study aimed to provide complete information about the boundary between the juvenile and mature wood of *D. kaki* along with information on the wood characteristics in the axial and radial directions, so that the utilization of wood can be more efficient.

2. MATERIALS and METHODS

2.1. Study area and plant materials

The *D. kaki* trees in this study were obtained from a smallholder plantation located in Merdeka Village, Berastagi District, Karo Regency, North Sumatra Province, Indonesia (3°11'46.5"N 98°27'19.1"E, 1,375 m asl). Sampling was carried out in September 2019, when the temperature in Berastagi ranged from 19℃ to 26℃, humidity was 79%, and rainfall was 2,100–3,200 mm/year.

Moreover, this study uses three 30-year-old selected *D. kaki* trees, with an average diameter at breast height of 152.8 mm and average height of 6.30 m. Three 30-year-old *D. kaki* were predicted to have formed mature wood. Bhat *et al*. (2001) and Nugroho *et al*. (2012) reported that some species, such as *Acacia mangium* and teak wood, have already formed mature wood at 23 and 20 years, respectively.

Nine disk samples with a thickness of 50 mm were collected from the base, middle, and top of the stems of the trees at an interval distance of 200 cm (divided based on the branch-free height). The disk samples at the base were collected 30 cm above the ground, as shown in Fig. 1. The disk samples were then sprayed with 30% alcohol and wrapped in aluminum foil for preservation. The samples were observed at the Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta, Indonesia.

2.2. Sample preparation, determination, and observation

2.2.1. Maceration samples preparation

Maceration samples were prepared by cutting the disk (at 0–50 mm from the pith at 5 mm intervals; > 50 mm from the pith at 10 mm intervals) into small pieces in the form of sticks (approximately 1 × 1 × 20 mm^3), as illustrated in Fig. 2. The stick samples were macerated with Franklin solution [a mixture of 100% glacial acetic acid (CH_3COOH) and 50% hydrogen peroxide (H_2O_2) in a 1:10 ratio] until they disintegrated into fibers. The macerated fibers and vessel elements were cleaned using distilled water, placed on an object glass, stained with 1% safranin (WAKO Pure Chemical Industries, Richmond, VA, USA), cleared with xylol solution, mounted with resin (Entellan, Merk, Darmstadt, Germany), and covered with a cover glass. Furthermore, the fibers and vessel elements were observed using an Olympus BX51 series light microscope and images were captured using a digital camera (DP70, Olympus, Tokyo, Japan). Fifty cells (fibers and vessel elements) were analyzed using Image-Pro Plus ver. 4.

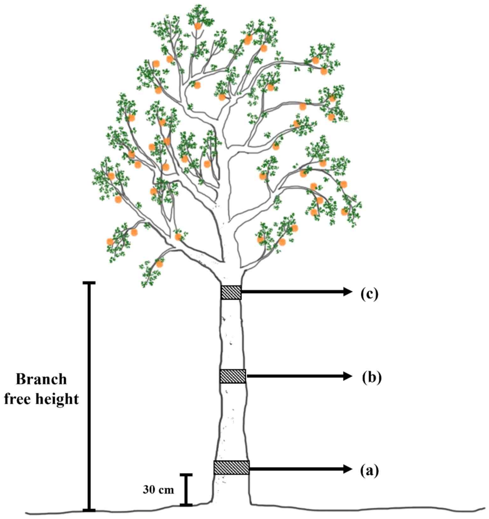

Fig. 1. Illustration of the *Diospyros kaki* tree and the wood disk sampling scheme. The disk samples were taken from the (a) base, (b) middle, and (c) top of the tree.

2.2.2. Determination of juvenile and mature wood boundary

The boundary between juvenile and mature wood was determined by the variation in fiber length (Y) and vessel element length (V) from near the pith to near the bark position (Nugroho *et al.*, 2012), according to the specified interval in this study. Fiber length in the juvenile wood zone rapidly increases and eventually reaches a constant value toward the bark in the mature wood zone (Fujiwara and Yang, 2000; Nugroho *et al.*, 2012). The present study used the vessel element to calculate fiber elongation (Y') because it has a length similar to that of fusiform cambial cells (Kitin *et al.*, 1999). The fiber elongation (Y') was calculated from the difference between fiber and vessel element length. The trend line of the variation in fiber elongation from the pith to the bark position was used to calculate the logarithmic curve of fiber elongation. Furthermore, the increase in wood fiber length (△D) was calculated from the logarithmic curve. The boundary of juvenile and mature wood was measured using a value of 0.3% (Nugroho *et al.*, 2012).

2.2.3. Wood anatomy characteristic observation

After the boundaries of the juvenile and mature wood were determined, small block samples (1 × 1 × 1 cm^3)

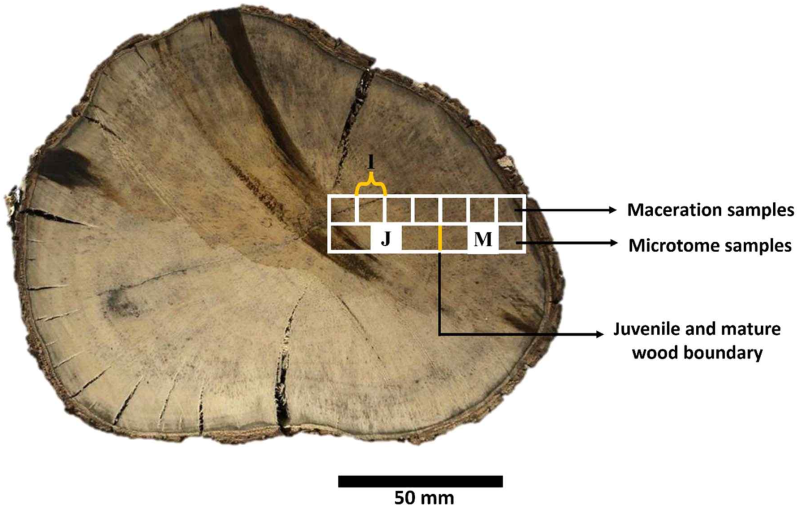

Fig. 2. Illustration of a wood block sampling scheme for maceration and microtome samples (bar = 50 mm). The maceration was taken 0.5 cm from the pith. I: interval distance of maceration sample collection (5 mm), J: juvenile wood sample for anatomical observation, M: mature wood sample for anatomical observation.

were taken from each juvenile and mature part to observe differences in their anatomical characteristics. Samples were taken from the middle area of the juvenile and mature wood, as illustrated in Fig. 2. Samples were sliced using a microtome (Yamatokohki, Saitama, Japan) with 20 μm thickness in the transverse section and 15 μm in the radial and tangential sections. The sliced samples were cleaned with distilled water and placed on object glass. The slices were stained with 1% safranin (WAKO Pure Chemical Industries), cleared with xylol solution, mounted with resin (Entellan, Merk), and covered with a cover glass. Samples were observed using an Olympus BX 51 series microscope and images were captured using an Olympus DP-70 connected to the microscope. The parameters (cell diameter, cell lumen diameter, cell wall thickness, cell height, frequency, and proportion) were measured using Image-Pro Plus ver. 4, based on the IAWA List of Microscopic Features for Hardwood Identification (Wheeler *et al.*, 1989). An analysis of variance (ANOVA) was performed using SPSS Statistics ver. 25 to determine the significant differences in fiber length in persimmon wood, the boundary between juvenile and mature wood and its variation in the axial direction, and the anatomical properties of wood in the radial (juvenile–mature) and axial directions.

3. RESULTS and DISCUSSION

3.1. Fiber and vessel element length

The fiber length of *D. kaki* in the radial direction tended to increase rapidly from near the pith to approximately 40 mm from the pith and then became constant toward the bark, as shown in Fig. 3. This result is in line with those of Marbun *et al.* (2019), Palermo *et al.* (2015), and Shmulsky and Jones (2011), where the length of wood fiber increased from the juvenile area near the pith toward the mature area near the bark. Kiaei and Bakhshi (2014) also stated that the fiber length in *Diospyros lotus* increased from the pith toward the bark. Furthermore, the fiber of *D. kaki* in this study has an average length of 1.33 ± 0.01 mm, categorized as me-

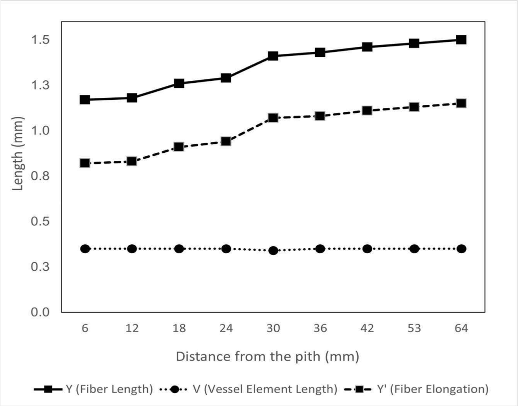

Fig. 3. Fiber length, vessel element length, and fiber elongation graph in *Diospyros kaki*.

dium fiber according to Hosseini and Naghdi (2004). *D. kaki* has a longer fiber compared to other Diospyros species, namely *D. lotus* with 1.13 mm, *D. celebica* with 1.04 mm, *D. blancoi* with 1.19 mm, and *D. mespiliformis* with 0.98 mm (Asdar, 2017; Kiaei and Bakhshi, 2014; Krisdianto and Abdurachman, 2005). The long fibers of *D. kaki* could be beneficial because long cells sometimes affect the strength and stability of boards when combined with steep microfibril angles (Zobel and Buijtenen, 1989). In addition, although hardwood fibers are rarely used in pulp and paper manufacturing, long wood fibers are suitable for pulp processing because they affect the weaving power (Lempang, 2019; Zobel and Buijtenen, 1989). Moreover, the axial variation in *D. kaki* fiber length did not differ significantly among the base, middle, or top of the tree (p = 0.724), as shown in Table 1. The same result was reported by Tavares *et al.* (2011), Taylor (1973), and Zobel and Buijtenen (1989), where the fiber length was essentially the same at all heights and was not influenced by height. Sseremba *et al.* (2016) reported that fiber length decreased from the base to the top of the tree.

The length of the vessel element was relatively constant and formed a linear pattern with an average of 0.35 ± 0.02 mm in the radial direction (Fig. 3). In addition, the axial variation of the vessel element length was slightly increased from the base to the top of the tree (p = 0.173), ranged from 0.33–0.36 mm, as shown in Table 1. Vessel elements are constant (slightly elongated after differentiation) radially and across the stem, similar to the pattern observed in fusiform cambial cells (Kitin *et al.*, 1999).

3.2. Boundary between juvenile and mature wood

The determination of the boundary between juvenile and mature wood was conducted by the calculation of the increase in length of wood fiber, increment rate of fiber length (△D), and logarithmic line of fiber length according to Nugroho *et al.* (2012), as shown in Fig. 4. The average value of the juvenile and mature wood boundaries in *D. kaki* was found at 44.11 mm from the pith, as the fiber length became stable with a 0.3% increase in fiber elongation (△D). This result was slightly different from *Acacia mangium* in Indonesia, where mature wood was formed at 45.8–52.0 mm from the pith (Nugroho *et al.*, 2012). Juvenile and mature wood boundaries vary among species and genotypes and depend on their geographic origin (Boruszewski *et al.*, 2017). These results align with Zobel and Buijtenen's (1989) statement that the transitional age between juvenile and mature wood varies greatly among trees.

Moreover, the boundary between the juvenile and mature wood showed no significant difference in the axial direction (p = 0.996). The proportion of juvenile wood in the axial direction tended to be constant (44–44.33 mm), and its distribution showed a cylindrical shape with mature wood included at the top of the tree, as indicated by the proportion of juvenile wood that showed no significant difference in the axial direction (p = 0.212), as shown in Table 1. Alteyrac *et al.* (2006) reported the same results, in which the estimated proportion of juvenile *Picea mariana* wood along the stem

Table 1. Properties of the wood of *Diospyros kaki* trees

Properties	Axial direction			Average	*p*-value	
	Base	Middle	Top		Wood category	Axial variation
Boundary between juvenile and mature wood (mm)	44 ± 2.65	44 ± 3.21	44.33 ± 3.28	44.11 ± 0.11		0.996^{ns}
Juvenile wood proportion (%)	64.18 ± 3.20	64.79 ± 3.25	71.51 ± 1.90	66.83 ± 2.35		0.212^{ns}
Mature wood proportion (%)	35.82 ± 3.20	35.21 ± 3.25	28.48 ± 1.90	33.17 ± 2.35		0.212^{ns}
Fiber length (mm)	1.34 ± 0.04	1.31 ± 0.04	1.35 ± 0.04	1.33 ± 0.01		0.724^{ns}
Vessel element (mm)	0.33 ± 0.01	0.35 ± 0.01	0.36 ± 0.01	0.35 ± 0.01		0.173^{ns}
Fiber diameter (μm)					0.047*	0.785^{ns}
Juvenile area	17.31 ± 1.47	17.60 ± 1.16	17.71 ± 1.29	17.54 ± 0.21		
Mature area	15.81 ± 1.69	17.51 ± 1.63	15.44 ± 1.25	16.25 ± 1.10		
Fiber lumen diameter (μm)					0.061^{ns}	0.804^{ns}
Juvenile area	10.25 ± 2.09	10.89 ± 1.30	11.08 ± 2.67	10.74 ± 0.43		
Mature area	8.68 ± 1.70	10.60 ± 1.36	8.75 ± 1.30	9.34 ± 1.09		
Fiber wall thickness (μm)					0.151^{ns}	0.329^{ns}
Juvenile area	3.25 ± 0.52	3.09 ± 0.45	3.39 ± 0.32	3.24 ± 0.15		
Mature area	3.49 ± 0.29	3.33 ± 0.22	3.66 ± 0.10	3.49 ± 0.17		
Vessel diameter (μm)					0.575^{ns}	0.014*
Juvenile area	74.18 ± 2.46	83.08 ± 11.02	92.24 ± 10.89	83.17 ± 9.03		
Mature area	76.26 ± 2.03	85.86 ± 9.19	94.64 ± 9.03	85.59 ± 9.19		
Vessel frequency (Σ vessels/mm^2)					0.086^{ns}	0.422^{ns}
Juvenile area	5.67 ± 1.15	5.33 ± 0.58	5.33 ± 1.15	5.44 ± 0.19		
Mature area	5.44 ± 0.19	4.00 ± 1.00	5.33 ± 0.58	4.92 ± 0.80		
Ray parenchyma frequency (Σ ray parenchyma/mm^2)					0.307^{ns}	0.028*
Juvenile area	12.33 ± 0.58	13.00 ± 1.00	11.33 ± 1.53	12.22 ± 0.84		
Mature area	12.67 ± 1.53	14.00 ± 0.00	11.67 ± 1.15	12.78 ± 1.17		
Ray parenchyma height (μm)					0.402^{ns}	0.299^{ns}
Juvenile area	311.33 ± 6.23	311.22 ± 5.73	308.17 ± 5.26	310.24 ± 1.79		
Mature area	312.74 ± 8.42	305.42 ± 2.86	305.68 ± 3.19	307.95 ± 4.16		
Fiber proportion (%)					0.005*	0.729^{ns}
Juvenile area	60.47 ± 5.02	61.43 ± 2.48	60.00 ± 6.54	60.63 ± 0.73		
Mature area	66.19 ± 4.12	69.05 ± 2.98	67.62 ± 2.97	67.62 ± 1.43		
Vessel proportion (%)					0.009*	0.380^{ns}
Juvenile area	9.52 ± 0.83	11.43 ± 1.43	9.52 ± 2.18	10.16 ± 1.10		
Mature area	8.09 ± 1.65	8.09 ± 1.65	7.62 ± 0.83	7.93 ± 0.28		
Ray parenchyma proportion (%)					0.074^{ns}	0.047*
Juvenile area	23.33 ± 5.02	18.09 ± 0.83	22.86 ± 3.78	21.43 ± 2.90		
Mature area	20.48 ± 0.83	17.14 ± 1.43	19.05 ± 1.65	18.89 ± 1.67		
Axial parenchyma proportion (%)					0.016*	0.370^{ns}
Juvenile area	6.66 ± 0.83	9.05 ± 1.65	7.62 ± 2.97	7.78 ± 1.20		
Mature area	5.24 ± 1.65	5.71 ± 0.00	5.71 ± 1.43	5.55 ± 0.27		

* Significantly different at $p < 0.05$.
^{ns}: not significantly different.

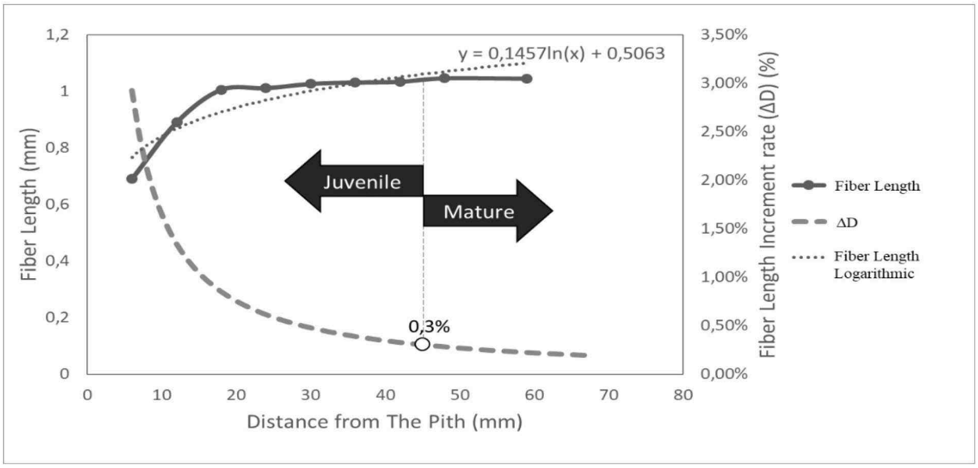

Fig. 4. Determination of the boundary between juvenile and mature wood in *Diospyros kaki*.

remained constant. The results of the present study are in line with those of Gatto *et al*. (2013) and Zobel and Buijtenen (1989), in which juvenile wood had a cylindrical shape with a uniform diameter from the base to the top of the stem.

Based on the boundary between the juvenile and mature wood of *D. kaki* in this study, the proportion of juvenile wood was higher than that of mature wood. The proportion of juvenile wood ranged from 64.18%–71.51%, as shown in Table 1. A high proportion of juvenile wood in trees can be utilized as the central layer of laminated products, such as glulam and cross-laminated timber, without a substantial negative impact on product performance if the drying distortion is not excessive. Furthermore, the impact of juvenile wood on reconstituted panel products, such as medium-density fiberboard and oriented strand board, is smaller than that on solid wood products, where the modulus of elasticity, modulus of rupture, and internal bond are similar to those of mature wood (Moore and Cown, 2017). The quality of wood with poor physical and mechanical properties, such as juvenile wood, must be improved. The properties of low-density wood can be improved through various treatments such as densification and chemical modification (Basri *et al*., 2023; Dirna *et al*., 2020; Hadi *et al*., 2019; Nawawi *et al*., 2023).

3.3. Other anatomical structure

This study showed that juvenile wood of *D. kaki* has a larger fiber diameter (p = 0.047), higher vessel proportion (p = 0.009), and higher axial parenchyma proportion (p = 0.016) than mature wood, as shown in Table 1. The average fiber diameter in juvenile wood was 17.54 ± 0.21 μm and showed significant differences compared to mature wood, that has 16.25 ± 1.10 μm in the diameter of the fiber. A large fiber diameter is related to specific gravity, where both the fiber diameter and cell proportion affect the porosity of wood (Zobel and Buijtenen, 1989). Juvenile wood of *D. kaki* has a large fiber diameter and a high proportion of vessels and axial parenchyma, as illustrated in Fig. 5. A high proportion of vessel elements and axial parenchyma increases wood porosity and lowers specific gravity and strength, as they do not contribute to mechanical stability (Morris *et al*., 2018; Shmulsky and Jones, 2011). In contrast, the proportions of vessels and axial parenchyma decreased from juvenile to mature wood. Palermo *et al*. (2015) reported the same result in

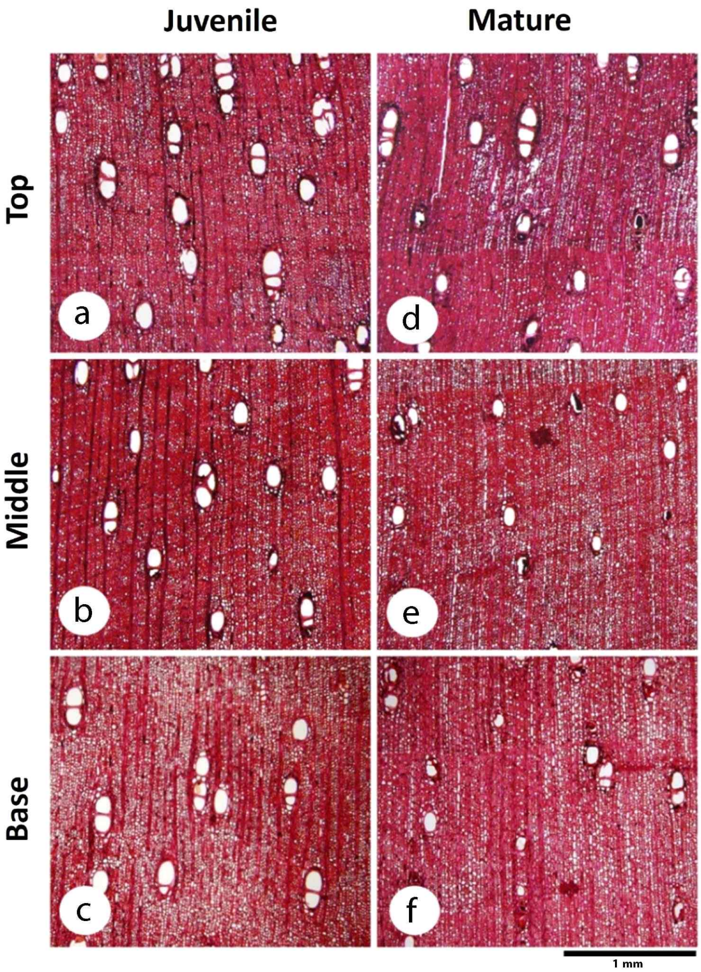

Fig. 5. Transverse sections of juvenile wood (a) and mature wood (d) of *Diospyros kaki* in the top; juvenile wood (b) and mature wood (e) of *D. kaki* in the middle; and juvenile wood (c) and mature wood (d) of *D. kaki* in the base (Safranin O stain, bar = 1 mm).

E. grandis, where the proportion of vessels decreased radially.

Furthermore, juvenile wood of *D. kaki* has no significant differences in fiber lumen diameter (*p* = 0.061), vessel frequency (*p* = 0.086), ray parenchyma height (*p* = 0.402), and ray parenchyma proportion (*p* = 0.074) compared with mature wood. The fiber lumen diameter on juvenile wood of *D. kaki* was 10.74 ± 0.43 μm and mature wood was 9.34 ± 1.09 μm. A previous study conducted by Asdar (2017) reported that *D. celebica* fiber lumen diameter decreased radially to the bark. In *Shorea parvistipulata*, the lumen diameter of the fibers decreases from the pith to the bark (Supartini and Kholik, 2010). In addition, a high vessel frequency and ray parenchyma proportion may increase the porosity of the wood.

The mature wood of *D. kaki* has a significantly higher fiber proportion (%), with average value of 67.62 ± 1.43

compared to juvenile wood ($p = 0.005$). Fiber wall thickness ($p = 0.151$), vessel diameter ($p = 0.575$), and ray parenchyma frequency ($p = 0.307$) in mature wood tended to be higher than in juvenile wood, although the differences were not statistically significant. The fiber wall thickness of *D. kaki* tends to be lower in juvenile wood (3.24 ± 0.15 μm) than mature wood (3.49 ± 0.17 μm), as shown in Table 1 and Fig. 6. The greater fiber wall thickness in the mature wood of *D. kaki* may have been caused by a thicker S2 layer (Borrega *et al*., 2015). Palermo *et al*. (2015) found that the fiber dimensions and tissue composition can predict specific wood properties. Furthermore, thin cell walls formed at the beginning of growth resulted in low-density wood, whereas mature wood with thicker cell walls had a higher density (Rahayu *et al*., 2021; Seta *et al*., 2023). High vessel diameter and ray parenchyma frequency in mature wood increase its porosity and considerably affect the quality of wood products. Wider cells often affect paper quality as they provide bulk to the paper. Abundant ray or parenchyma cells affect the quality of solid wood and pulp products, as thin-walled cells contribute little to the strength properties (Zobel and Buitjenen, 1989).

In terms of wood variation in the axial direction, the vessel diameter ($p = 0.014$), ray parenchyma frequency ($p = 0.028$), and ray parenchyma proportion ($p = 0.047$) were significantly different at the base, middle, and top of the tree. The vessel diameter of *D. kaki* increased from the base to the top in both the juvenile and mature wood. The same result was reported by Noah and Durojaiye (2019), where the vessel diameter increased in the axial direction of *Boscia angustifolia*. Ray parenchyma frequency increased from the base to the top in juvenile wood and decreased at the top of the tree in mature wood, as shown in Table 1, whereas the proportion of ray parenchyma decreased from the base to the middle and then increased to the top of the tree, both in the juvenile and mature wood of *D. kaki*. The same result was found in *S. parvistipulata*, where the proportion of parenchyma of the radius tended to decrease from the base to the middle of the stem and then increase toward the top (Supartini and Kholik, 2010). Wider cells with a high proportion of ray parenchyma cells affect the porosity of wood because they lower wood density. In this study, *D. kaki* tended to have a lower density at the top of the tree in both juvenile and mature wood.

4. CONCLUSIONS

The average value of juvenile and mature wood boundary of thirty-year-old *D. kaki* wood was found at

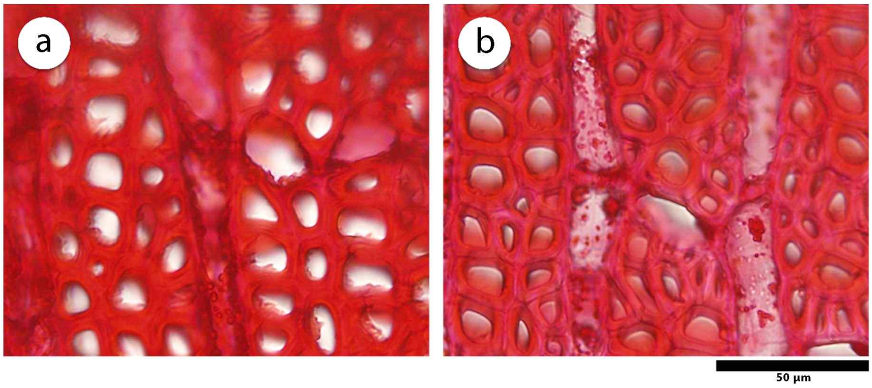

Fig. 6. Fiber wall thickness of *Diospyros kaki* (a) juvenile wood and (b) mature wood in a transverse section (Safranin O stain, bar = 50 μm).

a distance of 44.11 mm from the pith as the fiber length became stable, with 0.3% increase in fiber elongation (△D). In the axial direction, the boundary of juvenile and mature wood tended to have the same distance, and its distribution showed a cylindrical shape, with mature wood included at the top of the tree. Furthermore, the juvenile wood of *D. kaki* had a higher fiber diameter, vessel proportion, and axial parenchyma proportion, with a slightly higher fiber lumen diameter, vessel frequency, ray parenchyma height, and ray parenchyma proportion than mature wood. The mature wood of D. *kaki* had a higher fiber proportion and tended to have a higher fiber wall thickness, vessel diameter, and ray parenchyma frequency. In the axial direction, the vessel diameter, ray parenchyma frequency, and ray parenchyma proportion had different values at the base, middle, and top of the tree.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

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