Jurnal Ilmu Pertanian Indonesia (JIPI), April 2025
(Indonesian Journal of Agricultural Sciences)
ISSN 0853-4217 EISSN 2443-3462

Vol. 30 (2): 359–367
http://journal.ipb.ac.id/index.php/JIPI
DOI: 10.18343/jipi.30.2.359

Cell Dimension and Proportion of *Acacia aulacocarpa* Wood in Axial and Radial Directions from Gunung Kidul, Yogyakarta

Viola Elizabeth, Fanny Hidayati*

(Received March 2024/Accepted January 2025)

ABSTRACT

This research aimed to analyze variation of the anatomical characteristics (cell dimension and proportion) in axial and radial direction of *Acacia aulacocarpa* planted in Indonesia. Three trees of 27-year-old *A. aulacocarpa* planted in Gunung Kidul Yogyakarta were used. This research covered a completely randomized design with two factors, the axial direction (base, middle, and top of the stem) and the radial direction (near pith, middle, and near bark) in triplicate. A two-way analysis of variants was used. The measured parameters were fiber dimensions (length, diameter, lumen diameter, and wall thickness) and cell proportions (fiber, vessel, ray parenchyma, and axial parenchyma). The results showed that average value of fiber dimensions was as follow: fiber length 0.94 mm; fiber diameter 17.43 μm; fiber lumen diameter 11.75 μm; and cell wall thickness 2.84 μm. The average value of cell proportions was 52.48% of fibers cell proportion; 17.5% of vessel cell proportion; 15.69% of axial parenchyma cell proportion; and 16.68% of ray cell proportion. The axial direction factor does not affect the proportion and dimensions of the fiber. However, the radial direction factor affects the proportion of fiber cells, the proportion of vessel cells, the proportion of axial parenchyma cell, fiber length, fiber lumen diameter, and cell wall thickness. Fiber length, fiber lumen diameter, cell wall thickness increased from near the pith to the middle and then remained relatively constant toward the bark. Based on these results, it is suggesting that the middle and near the bark are mature wood.

Keywords: ***Acacia aulacocarpa*, axial direction, cell dimension, cell proportion, radial direction**

INTRODUCTION

The timber industry is rapidly developing; according to the 2019 forestry production report, total log production in Indonesia was 57.93 million m^3 (Badan Pusat Statistik 2020a), while log availability in 2019 was only 41.46 million m^3 (Badan Pusat Statistik 2020b). Timber demand grows year after year as population and prosperity rise (Depari *et al*. 2015), both for structural and industrial purposes (Lempang and Asdar 2006). This demonstrates an imbalance between Indonesia's total timber industry capacity and the production forests' ability to deliver raw materials in a sustainable manner. According to the Ministry of Industry (2018), one of the most pressing issues facing the timber industry is the availability and continuity of raw materials due to scarcity. As a result, alternative species must be developed to satisfy the needs of wood while also using knowledge about wood types, qualities, and processing processes to ensure that wood is used effectively and efficiently.

Acacia aulacocarpa is an endemic acacia tree that grows naturally in Australia, extending from the north of New South Wales, east of Queensland, and the northern part of the Northern Territory to the south of Papua New Guinea and the areas adjacent to the southeastern part of Irian Jaya (Pinyopusarerk 1997). *A. aulacocarpa* is a tree that can reach a height of 15 m, has a cylindrical, monopodial stem, many branches, and a spreading crown. This species is a powerful nitrogen-fixing tree that grows quickly and is tolerant of a wide range of less fertile growing conditions. It has shown tremendous potential for timber production in tropical and subtropical locations. Wood is appealing for use in furniture, can be used as fuel, and appears to be appropriate for chemical pulping (Doran *et al*. 1997). Acacia is another species of wood that is being prioritized for development on Industrial Plantation Forest (HTI) land with the expectation of producing high-quality and homogeneous products (Sugesty *et al*. 2015).

According to Zobel and Buijtenen (1989), wood exhibits significant variation at the species level, between species and genera within a plant division, and/or within a single tree trunk. Furthermore, Panshin and de Zeeuw (1980) said that information on changes in wood structure, such as cell size and cell wall thickness, is required to evaluate wood's physical qualities. Shmulsky and Jones (2019) also discovered that anatomical qualities, such as the proportion of fibers in the volume of wood and the thickness of fiber walls, are related to the density and strength of hardwood when used for building or furniture. Variations in anatomical properties tend to follow the

Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia
* Corresponding Author: Email: fanny_hidayati@ugm.ac.id

position of wood in the trunk, either radially, where the variation in wood properties is influenced by environmental conditions, seasonal differences over time, and the influence of juvenile wood in the early period of wood formation, or axially, where the wood properties at the base differ from the top due to different timber formation times (Panshin and de Zeeuw 1980).

Sundari *et al*. (2005) discovered in a 15-year-old *A. auriculiformis* wood from Gunungkidul that radial direction influences the length of the fibers, the diameter of the fibers, the diameter of the lumen, the cell wall thickness, and the proportion of parenchyma cells. According to Rao *et al*. (2011), there were significant changes in the proportion of fibers, vessels, axial parenchyma, and ray cells of the 4.5-year-old of *A. aulacocarpa* species planted in Kerala, India, to the radial and axial directions. However, little is known about the basic features of *A. aulacocarpa* wood, including its anatomical properties (cell dimensions and proportions), which grow in Indonesia, particularly in the Special Region of Yogyakarta. To determine the variations in the characteristics of *A*. *aulacocarpa* wood grown in Indonesia, anatomical characteristics must be observed in both the axial and radial directions.

METHODS

This study employed three 27-year-old *A. aulacocarpa* trees planted in the Wanagama Special Purpose Forest Area (KHDTK) in Playen District, Gunungkidul Regency, Yogyakarta Special Region Province (100°30'–100°33' E; 7°53–'7°54' SL; 214 m asl). Environmental conditions were as follows: rainfall 1900 mm/yr; average temperature 27.7°C; air humidity 80–90%; Entisol soil type with karst rock (Gaol *et al*. 2023). The geography of the site is flat. The three trees were chosen from the same area, the same age, and the same growth range. The diameter of the determined trees was measured up to the chest, after which the three trees were cut down and the overall height was calculated (Table 1). For the fallen trees, the trunk was separated every 3 m in length from the base to the top (axial direction) into three parts: base, middle, and top. Furthermore, sampling in the radial direction was accomplished by separating the wood surface (transverse section) near the pith, middle, and bark on each side of the stem in one direction. To examine the anatomical characteritics of this wood, a disk with a thickness of 5 cm was used, namely the dimensions and proportions of the cells.

To prepare for observation, a 1×1×1 cm wood sample was taken from the base, center, and top (axial direction), followed by near the pith, middle, and near the bark (radial direction). The wood samples were sliced using a microtome (NS-31 Yamamoto) on a transverse cross-section of 20 µm. The sample slices were then dyed with 1% safranin solution and mounted using entellan. The following step involved using a microscope (Olympus BX 51) with a digital camera (Olympus Dp 70). Next, photos were utilized to measure cell dimensions using Image Pro Plus, an image analysis software. For each preparation, 30 fiber cells were utilized to measure cell dimensions.

In addition to determining cell size, the transverse cross-section was used to measure the fraction of wood cells. Cell proportions were determined using dot grid method, which finds the ratio of cell type area using a standard and consistently arranged point network system at the same distance in a certain area (Praptoyo 2010). This method involves labeling representative cells at a specified place in a cross-sectional photograph of the wood. Fibers, vessels, axial parenchyma, and ray parenchyma were all proportionally measured cells. The proportion of cells was calculated by comparing the number of representation points in a specific cell to the total number of points, and the result was expressed as a percentage. Measurements were taken with Image Pro Plus.

The preparation of maceration began with obtaining a wood sample from each portion taken. Each portion was formed into a stick of 1×1×20 mm and macerated with a solution of glacial acetic acid (CH_3COOH) and hydrogen peroxide (H_2O_2). Maceration preparations were used to measure fiber length. The fiber length was determined by measuring the outcomes of the maceration preparation picture. There were 30 fibers measured in each sample unit.

This study used two research factors: axial direction (base, middle, top) and radial direction (near the pith, middle, near the bark). Two-way ANOVA was used to evaluate the data, followed by Tukey HSD (honestly significant difference) tests.

RESULTS AND DISCUSSION

Cell Dimensions

The average fiber length, diameter, lumen diameter, and cell wall thickness of *A. aulacocarpa* were 936.72 µm (0.94 mm), 17.43 µm, 11.75 µm, and 2.84 µm,

Table 1 Data of sample trees

Characteristic	Tree 1	Tree 2	Tree 3
Height (m)	22.4	25.7	26.0
BFSH (m)	8.0	11.5	9.0
Dbh (cm)	33.5	30.8	31.0

Source: Gaol *et al*. (2023)
Remarks: BFSH = Branch-free stem height and Dbh = Diameter at breast height.

respectively (Tables 2 and 3). Malinen *et al*. (2006) found that 7-year-old *A. aulacocarpa* cultivated in Thailand had fiber lengths of 0.6 mm, fiber diameters of 16.1 µm, lumen diameters of 11.86 µm, and cell wall thickness of 2.15 µm. Sundari *et al*. (2005) reported that 15-year-old wood cells of *A. auriculiformis* grown in Gunung Kidul Yogyakarta had average fiber length, diameter, lumen diameter, and wall thickness of 0.92 mm, 13.46 µm, 9.42 µm, and 2.05 µm, respectively. According to Yahya *et al*. (2010), the 7-year-old wood cell wall of *A. mangium* planted in Palembang, South Sumatra was 0.98 mm in fiber length, 19.39 µm in fiber diameter, 14.19 µm in lumen diameter, and 2.55 µm in thickness. The fiber length obtained in this study was longer than in earlier studies (Malinen *et al*. 2006), but about the same as in other species of acacia (Yahya *et al*. 2010, Sundari *et al*. 2005). This study's results for measuring fiber diameter are higher than those of Malinen *et al*. (2006) and Sundari *et al*. (2005), but lower than those of Yahya *et al*. (2010). The average lumen diameter in this study is nearly identical to the results of the Malinen *et al*. (2006) study, which is narrower than the results of Yahya *et al.* (2010) but wider than Sundari *et al*. (2005). The average cell wall thickness in this study was thicker than that of earlier studies (Malinen *et al*. 2006; Yahya *et al*. 2010; Sundari *et al.* 2005).

The variation in fiber dimensional value is thought to be caused by age as well as tree species. Sundari *et al*. (2005) found that in *A. auriculiformis* aged 5, 10, and 15 years, the fiber length and diameter tended to increase at age 10 and decrease at age 15. The age of older trees is one of the factors that affect the length of fibers and the thickness of the cell wall, according to a study by Samariha (2011) on *Eucalyptus camadulensis* aged 14 and 20 years in Iran, which found that the age of the tree had a significant effect on the fiber length, with the age of 20 years having a longer fiber and thicker cell wall. The fiber length found in this investigation is consistent with the fiber length in hardwood reported by Shmulsky and Jones (2019), which is less than 1 mm. According to IAWA (2008), the length of this fiber falls within the medium fiber range of 900–1600 µm.

Cell Proportion

Tables 2 and 3 show the average proportion of wood cells in *A. aulacocarpa*. The average percentages of fiber cells, vessel cells, axial

Table 2 Average values of the anatomical characteritics of *A. aulacocarpa* wood in the axial and radial directions

Factor		Anatomical characteritics							
Axial direction	Radial direction	FL (µm)	FD (µm)	FLD (µm)	CWT (µm)	FCP (%)	VCP (%)	PACP (%)	RCP (%)
Base	Near pith	807.68	17.97	13.47	2.25	58.77	10.56	11.98	18.68
	Middle	1,057.12	16.72	11.55	2.59	52.00	16.77	12.83	18.40
	Near bark	991.92	17.44	10.54	3.45	45.60	22.65	19.20	12.54
	Average	952.24	17.38	11.85	2.76	52.12	16.66	14.67	16.54
Middle	Near pith	786.41	18.63	14.91	1.86	62.90	10.96	10.00	16.15
	Middle	1,037.49	18.56	12.41	3.08	53.81	16.35	18.97	10.88
	Near bark	999.39	15.37	8.92	3.22	48.27	23.02	17.97	10.74
	Average	941.10	17.52	12.08	2.72	54.99	16.78	15.64	12.59
Top	Near pith	758.53	19.04	14.93	2.06	62.36	9.37	11.54	16.38
	Middle	1,006.72	16.97	9.96	3.51	52.46	17.03	15.20	15.31
	Near bark	985.17	16.20	9.08	3.56	36.17	27.32	23.50	13.01
	Average	916.81	17.40	11.32	3.04	50.33	18.02	16.75	14.90

Remaks: FL = Fiber length; FD = Fiber diameter; FLD = Fiber lumen diameter; CWT = Cell wall thickness; FCP = Fiber cell proportion; VCP = Vessel cell proportion; PACP = Parenchymal axial cell proportion; and RCP = Ray cell proportion.

Table 3 Average value of the anatomical characteristics of *A. aulacocarpa* wood and the results of its statistical analysis (Anova)

Parameter	Average	Standard deviation	Anova results		
			Axial direction	Radial direction	Interaction of Radial direction *Axial direction
Cell dimensions					
Fiber length (µm)	936.72	117.19	0.240ns	0.000**	0.906ns
Fiber diameter (µm)	17.43	1.23	0.987ns	0.093ns	0.498ns
Fiber lumen diameter (µm)	11.75	2.33	0.814ns	0.003**	0.675ns
Cell wall thickness (µm)	2.84	0.66	0.583ns	0.002**	0.691ns
Cell proportion					
Fiber cell proportion (%)	52.48	8.51	0.631ns	0.006**	0.789ns
Vessel cell proportion (%)	17.15	6.18	0.880ns	0.001**	0.931ns
Parenchymal axial cell proportion (%)	15.69	4.49	0.500ns	0.000**	0.178ns
Ray cell proportion (%)	14.68	3.01	0.142ns	0.054ns	0.707ns

Remarks: **= significant difference at the test level of 1% and ns = not significant difference.

parenchymal cells, and ray cells were 52.48%, 17.15%, 15.69%, and 16.68%, respectively. Another species of acacia, *A. auriculiformis,* aged 15 years planted in Gunung Kidul, Yogyakarta, has an average proportion of fiber cells, vessel cells, axial parenchymal cells, and ray cells, were 57,42%, 9,42%, 18,78%, dan13,56%, respectively (Sundari *et al*. 2005). Furthermore, Yahya *et al.* (2006) found that the average percentages of fiber cells, vessel cells, axial parenchymal cells, and ray cells were 62.46%, 12.11%, 15.66%, and 9.77%, respectively. Shmulsky and Jones (2019) reported that the proportions of fiber cells, vessel cells, axial parenchymal cells, and ray cells were 15–60%, 20–60%, 10–23.50%, and 5–30%, respectively. This study found that the fiber proportion was lower, the proportion of vessels was higher, the axial parenchyma was lower and equal, and the ray proportion was larger than in earlier studies on other species of acacia. In general, the findings of this study are consistent with Shmulsky and Jones (2019) assertions regarding the proportion of broadleaf wood cells.

Differences in the type and age of the tree can contribute to this phenomenon. Sundari *et al*. (2005) studied *A. auriculiformis* aged 5, 10, and 15 years and found that the proportion of fiber cells was ±3% in each age group, whereas the number of vessel cells and ray cells increased with age. Furthermore, changes in the type of axial parenchyma influence cell proportions. The types of parenchyma found in *A. aulacocarpa* and *A. auriculiformis* differ. *A. aulacocarpa* possesses vasicentric and aliform-type parenchyma, whereas *A. auriculiformis* has vasicentric and confluent parenchyma types (Inside Wood 2004), implying that *A. aulacocarpa* has a smaller axial parenchyma cell area than *A. auriculiformis*.

A high concentration of parenchyma cells can reduce mechanical strength (Shmulsky and Jones 2019). However, the overall proportion of axial parenchyma in *A. aulacocarpa* studied is low compared to the proportion of axial parenchyma cells according to Smulsky and Jones (2019), raising the possibility that the low proportion of axial parenchyma in this species can increase its mechanical strength. According to Shmulsky and Jones (2019), axial and radial parenchyma have shorter dimensions and thinner walls than fibers, and their presence in high amounts in wood can reduce mechanical strength. As a result, the reduced amount of parenchyma, both axial and radial, is expected to create comparatively high mechanical strength in *A. aulacocarpa* wood.

Axial and Radial Variation of Cell Dimensions and Proportions

Tables 2 and 3 indicate the average values of anatomical parameters (cell dimensions and proportions) as well as statistical analysis of *A. aulacocarpa* wood in axial and radial directions. According to the diversity test, the axial direction has no significant effect on cell dimension or proportions (Table 3). The fiber length decreased from the base (952.24 μm) to the middle (941.10 μm) and top (916.81 μm). The base has the longest fiber, while the top has the shortest. The fiber cell diameter increased from the base (17.38 μm) to the middle (17.52 μm) and then decreased to the top (17.40 μm). The widest fiber diameter was in the middle, while the narrowest was at the base. The fiber lumen diameter increased from 11.85 μm at the base to 12.08 μm in the middle and decreased to 11.32 μm at the top. The maximum fiber lumen diameter was found in the middle, while the narrowest was at the top. The cell wall thickness decreased from the base (2.76 μm) to the middle (2.72 μm) and increased to the top (3.04 μm) along its axial length. The fiber wall was thickest at the top and thinnest in the middle. Sharma *et al*. (2015) found longitudinal variation in fiber length, fiber diameter, fiber lumen diameter, cell wall thickness, and vessel diameter in the *Eucalypt urograndis* hybrid (*Eucalyptus grandis* × *E. urophylla*) growing in India. Another type of broadleaf wood, teak wood, developed in East Timor showed the diameter of the fibers decreased from base to top, while the proportions of axial parenchyma and ray cells increases significantly. The proportion of vessels increased from the base to the middle, then decreased towards the top, but the difference is not significant. Furthermore, the proportion of fibers, length, and diameter of fibers decrease significantly from base to top. The cell wall thickness is often consistent from base to top (Cardose *et al*. 2015). Although the results of the axial direction study were not significant in all parameters, they followed a similar trend to prior investigations (Cardose *et al.* 2015), in which some parameters, such as fiber length, decreased from the base. This axial variation is affected by auxins, which stimulate rapid cell development and shorter maturation time, resulting in smaller cells toward the tree's tops (Cardose *et al*. 2015). Furthermore, recent research on the physical and mechanical properties of the same wood found that axial direction variables had no significant effect on all physical and mechanical test parameters of wood (Gaol *et al*. 2023). This is consistent with existing research on these anatomical characteristics.

In the radial direction, analysis of variance demonstrates that this component has a considerable influence on cell dimensions, specifically fiber length, fiber lumen diameter, and cell wall thickness, except for fiber diameter (Table 3). The HSD follow-up test results revealed a significant difference between the part near the pith, the middle section, and the part near the bark, although there was no significant difference between the middle and near the bark (Figure 1). The fiber length increases from near the pith (784.21 μm) to the middle (1033.78 μm), then reduced significantly near the bark (992.16 μm). This is consistent with Panshin and Zeeuw's (1980) observation that one of the patterns of variation in fiber length is increased and then constant from the pith to bark. The radial direction on the tree is one of the factors that affect the length of the fibers, as evidenced by the findings of a study conducted by Samariha (2011) on *Eucalyptus camadulensis* in Iran, which found that the radial direction has a significant effect on the value of fiber length, with fiber length values being low near the pith and increasing towards the bark. This is closely related to the state of the wood near the pith, which is often made up of juvenile wood with shorter fibers and lesser quality than mature wood (Praptoyo 2005). This study suggests that mature wood is in the middle and near the bark. Figure 2 shows a decrease in fiber lumen diameter from near the pith (14.44 μm) to the center (11.31 μm) and towards the bark (9.51 μm). This trend is like the findings of Sundari *et al*. (2005) on 15-year-old *A. auriculiformis* from Gunungkidul. The HSD follow-up test results revealed a significant difference between the section near the pith, the middle part, and the part near the bark, whereas there was no significant difference between the middle and the part near the bark (Figure 2). Figure 3 shows that the fiber wall thickness increases from near the pith (2.05 μm) to the middle (3.06 μm) and near the bark (3.41 μm). This trend is similar to the findings of Sundari *et al.* (2005) on 15-year-old *A. auriculiformis* from Gunungkidul. The HSD follow-up test results revealed a significant difference in the area near the pith compared to the middle and near the bark, but there was no significant difference in the area near the bark. According to Gaol *et al*. (2023), the radial direction has a significant effect on the specific gravity of green and air dry, as well as the static bending strength, compressive strength parallel to grain, and compressive strength perpendicular to grain, with variations increase from the pith to the bark and a consistent tendency from the middle to near the bark. This is connected to the findings of this study, which show that the length of fibers and the cell wall thickness increase from the pith to the bark, with a consistent tendency from the middle to near the bark. This is connected to the findings of this study, which show that the length of fibers and the cell wall thickness increase from the pith to the bark,

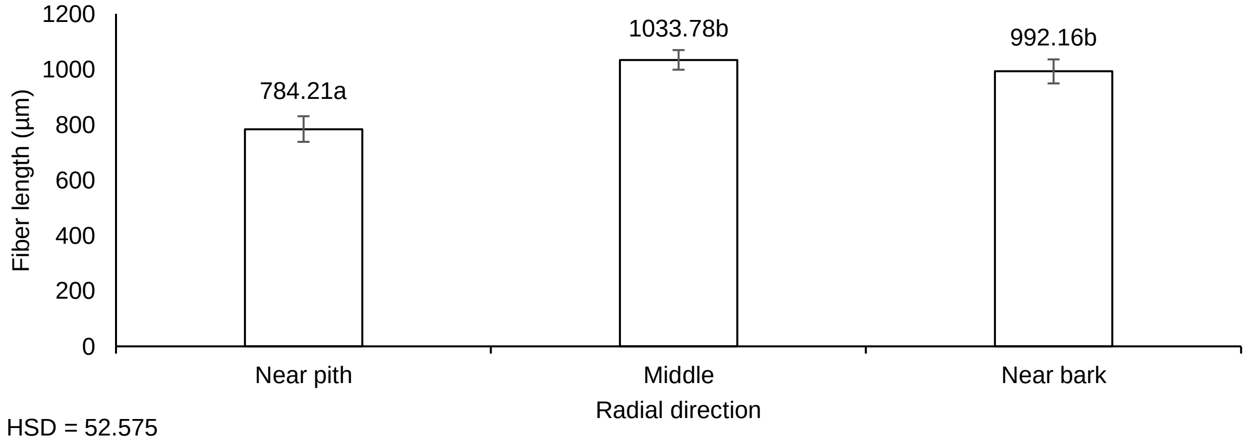

Figure 1 Pattern of fiber length diversity in the radial direction. The same letter after the number indicates not significantly different.

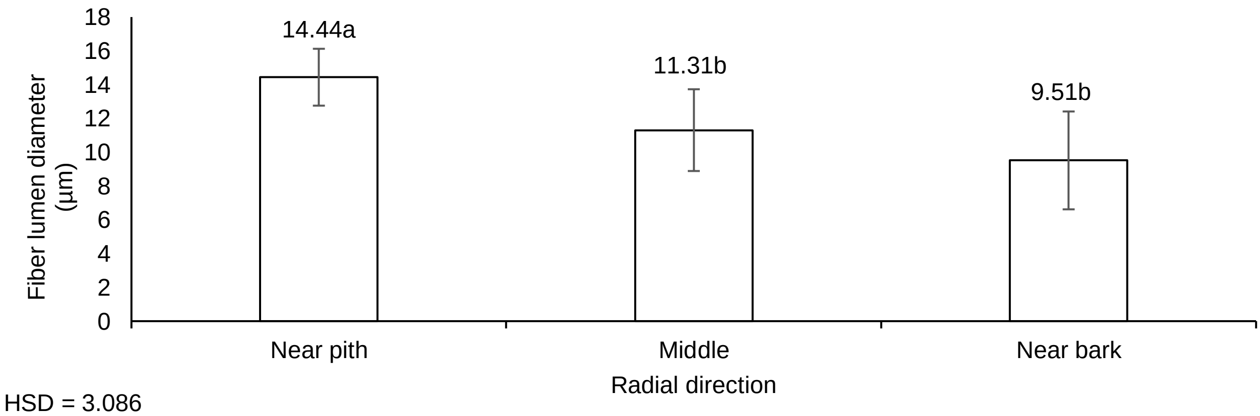

Figure 2 Pattern of diversity in fiber lumen diameters in the radial direction. The same letter after the number indicates not significantly different.

with a consistent tendency from the middle to near the bark.

Except for the ray proportion, the radial direction has a considerable influence on cell proportions, namely the proportions of fibers, vessels, and axial parenchyma. The proportion of fiber cells decreased from near the pith (61.34%), to the middle (52.76%), and finally to the bark (43.35%) (Figure 4). The decrease in the proportion of fiber cells in the radial direction is assumed to be linked to an increase in the proportion of vessel cells from the pith to the bark. The HSD follow-up test findings revealed a substantial difference between the parts near the pith and the parts near the bark, with no significant difference in the middle. The proportion of vessel cells increased from near the pith (10.42%) to the middle (16.71%) and finally to the bark (24.33%) (Figure 5). Based on the findings of this study, there may be an increase in the proportion of vessel cells in the radial direction from near the pith to near the bark The HSD follow-up test results revealed a substantial difference between the parts near the pith and the parts near the bark, with no significant difference in the center. This finding is consistent with that of Rao *et al*. (2011), who studied a 4.5-year-old A. *aulacocarpa* planted in Kerala, India, and discovered that the radial direction had a significant effect on the proportion of vessel cells. Furthermore, the proportion of axial parenchymal cells increases radially, from near the pith (11.17%) to the middle (15.66%), and finally to the bark (20.22%) (Figure 6). This is presumably due to the higher concentration of parenchyma cells in sapwood (Bajpai 2018). The HSD follow-up test revealed a significant difference between the part near the pith, the middle part, and the part near the bark, as well as the middle part with the two sections.

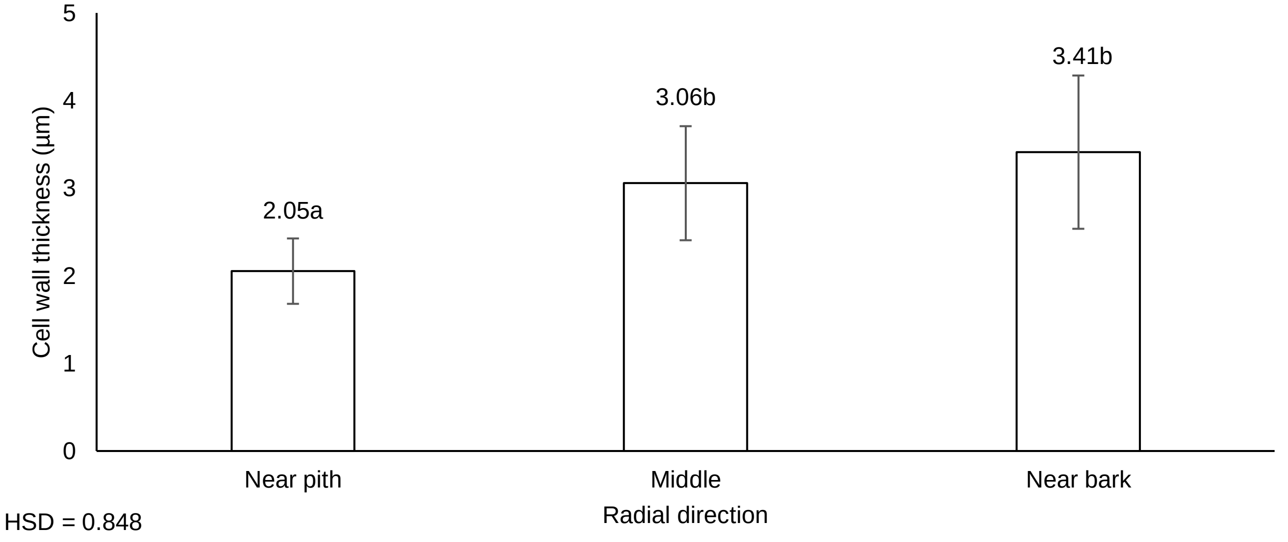

Figure 3 Pattern of cell wall thickness diversity in the radial direction. The same letter after the number indicates a not significantly different.

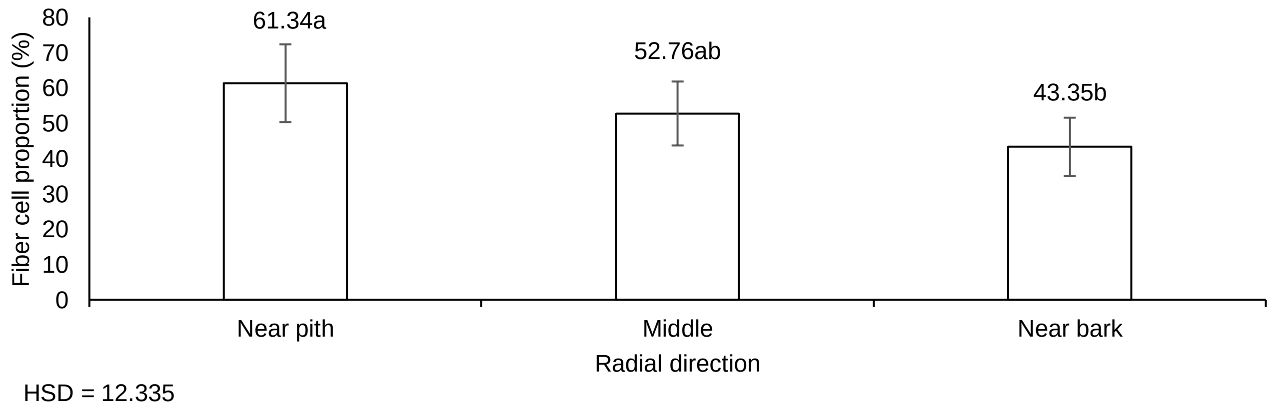

Figure 4 The pattern of diversity of the proportion of fiber cells in the radial direction. The same letter after the number indicates not significantly different.

Furthermore, the Anova test findings (Table 3) revealed no interaction between axial and radial direction components in the dimension and proportion of *A. aulacocarpa* wood cells. In a prior investigation on the same wood, Gaol *et al*. (2023) discovered that there was no interaction between axial and radial direction factors in all physical and mechanical properties investigated.

CONCLUSION

A total of three 27-year-old *A. aulacocarpa* trees planted at the Wanagama KHDTK were used in this study to determine the wood's anatomical characteristics, namely the dimensions and proportions of cells in the axial and radial directions. The findings revealed that the axial direction in the tree had no effect on the research parameters, leading to the hypothesis that the base, middle, and top of the trunk had relatively uniform anatomical characteristics. The radial direction factor determines the fiber length, lumen diameter, and wall thickness, as well as the proportions of fiber cells, vessel cells, and axial parenchymal cells. Fiber length, lumen diameter, and cell wall thickness increase from near the pith to the middle, where they remain relatively constant and do not differ considerably from near the bark. Based on these findings, it is suggesting that the middle and near the bark are mature wood.

ACKNOWLEDGEMENT

The author wishes to thank KHDTK Wanagama for granting permission for tree sampling in this study.

REFERENCES

Badan Pusat Statistik. 2020a. *Statistik Produksi Kehutanan*. Jakarta (ID): Badan Pusat Statistik (in Indonesian)

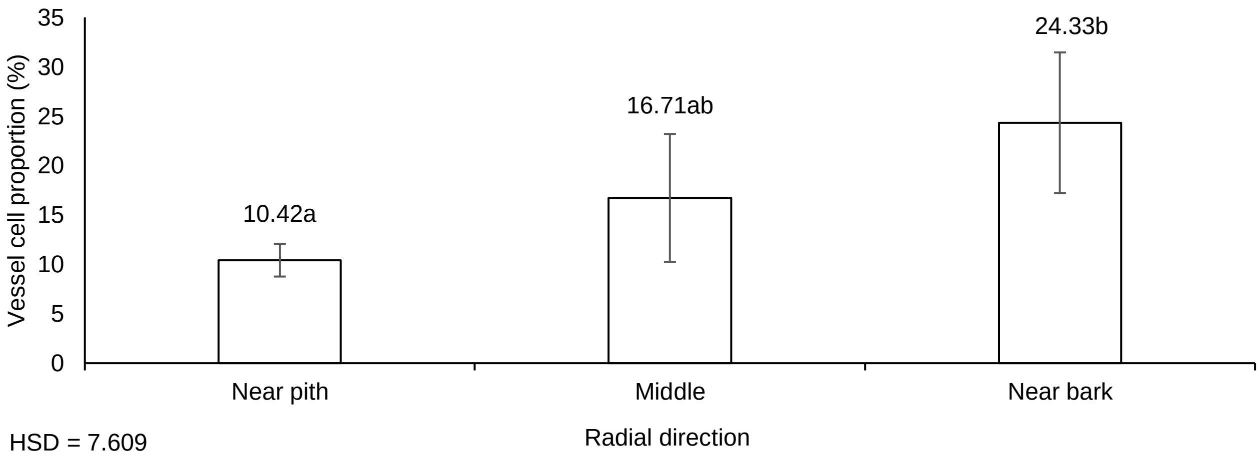

Figure 5 The pattern of diversity of the proportion of vessel cells in the radial direction. The same letter after the number indicates not significantly different.

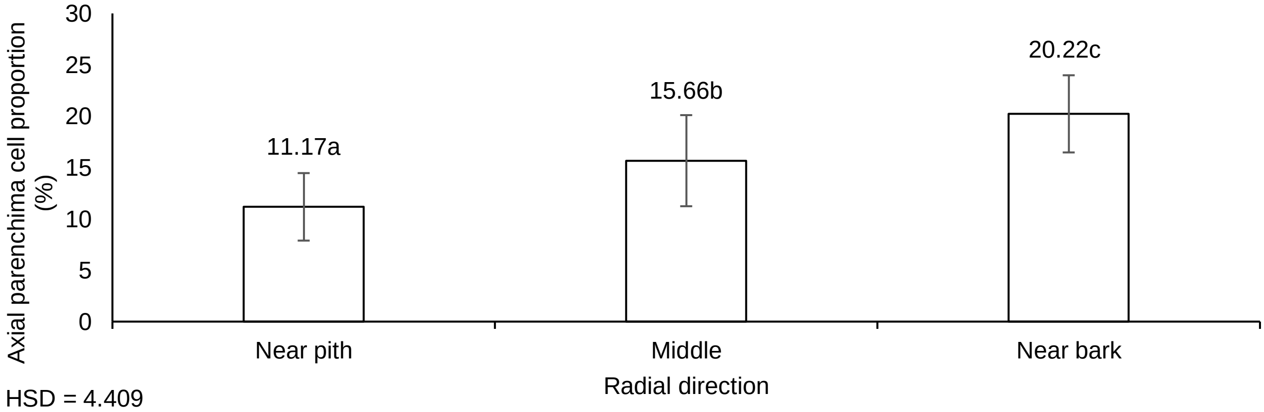

Figure 6 Pattern of diversity of the proportions of axial parenchyma cells in the radial direction. The same letter after the number indicates not significantly different.

Badan Pusat Statistik. 2020b. *Statistik Perusahaan Pembudidaya Tanaman Kehutanan* 2019. Jakarta (ID): Badan Pusat Statistik. (in Indonesian)

Bajpai P. 2018. *Biermann's Handbook of Pulp and Paper: Raw Material and Pulp Making*. Third Edition., Cambridge (US): Elsevier.

Cordoso S, Sousa VB, Quilho T, Pereira H. 2015. Anatomical variation of teakwood from unmanaged mature plantation in East Timor. *Journal of Wood Science*. 61: 326–333. https://doi.org/10.1007/s10086-015-1474-y

Depari EK, Wiryono, Susatya A. 2015. Potensi Tegakan kayu bawang (*Dysoxylum mollissimum* Blume) pada sistem agroforestri sederhana di Kabupaten Bengkulu Utara. *Jurnal Hutan Tropis.* 3(2): 166–172. (in Indonesian)

Doran JC, Turnbull JW, Martensz PN, Thomson LAJ, Hall N. 1997. *Introduction to the Species' Digests. In: John C Doran, JW Turnbull, editor. Australian Trees and Shrubs: Species for Land Rehabilitation and Farm Planting in The Tropics*. Canberra (AU): Australian Centre for International Agricultural Research.

Gaol NIL, Hidayati F, Nugroho WD, Praptoyo H, Karyanto O, Marsoem SN. 2023. Sifat fisika dan mekanika kayu *A. aulacocarpa* dari KHDTK Wanagam. *Jurnal Ilmu Pertanian Indonesia*. 28(4): 630–640. https://doi.org/10.18343/jipi.28.4.630 (in Indonesia)

InsideWood. 2004. *Acacia auriculiformis*. [internet]. Tersedia pada: https://insidewood.lib.ncsu.edu/description?5. [Diakses pada: 20 August 2021].

InsideWood. 2004. *Acacia mangium*. [internet]. Tersedia pada: https://insidewood.lib.ncsu.edu/description?4. [Diakses pada: 8 November 2021.

Keanekaragaman Hayati Daerah Istimewa Yogyakarta. 2020. *Acacia aulalocarpa*. [internet]. Tersedia pada: http://kehati.jogjaprov.go.id/detailpost/acacia-aulalocarpa. [Diakses pada: 6 February 2021. (in Indonesian)

Kemenperin. 2018. *Perkembangan Regulasi Terbaru Mengenai Industri Pulp dan Kertas termasuk Sertifikasi dan Pemasaran Hasil Hutan Serta Potensi Bisnis Hasil Hutan Lestari*. Jakarta (ID) Kementerian Perindustrian Republik Indonesia. (in Indonesian)

Lempang M, Asdar M. 2006. Struktur anatomi, sifat fisik dan mekanik kayu palado (*Aglaia* sp.). *Jurnal Penelitian Hasil Hutan*. 24(2): 171–181. https://doi.org/10.20886/jphh.2006.24.2.171-181 (in Indonesian)

Malinen RO, Pisuttopiched S, Kolehmainen H, Kusuma FN. 2006. Potential of acacia species as pulpwood in Thailand. *Appita Journal*. 59(3): 190–196.

Panshin AJ, de Zeeuw C. 1980. *Textbook of Wood Technology: Structure, Identification, Properties, and Uses of the Commercial Woods of the United States and Canada*. Fourth Edition. New York (US): McGraw-Hill.

Pinyopusarerk K. 1997. *Acacia aulacocarpa* A. Cunn. ex Benth. In IF Hanum, LJG van der Maesen, editors. *Plant Resources of South-East Asia* 11: *Auxiliary plants*. Bogor (ID): PROSEA Foundation. Database record: prota4u.org/prosea.

Praptoyo, H. 2005. Studi perbandingan metode sampling bor riap dengan disk untuk pengukuran proporsi dan dimensi serat kayu sengon Salomon (*Paraserianthes falcataria*, (L.) Nielsen). *Jurnal Ilmu dan Teknologi Kayu Tropis*. 3(2): 16–19. https://doi.org/10.22146/jik.1558 (in Indonesian)

Praptoyo H. 2010. Sifat anatomi dan sifat fisika kayu mindi (*Melia azedarach* Linn) dari hutan rakyat di Yogyakarta. *Jurnal Ilmu Kehutanan*. 4(1): 21–27. (in Indonesian)

Rao RV, Anoop EV, Sheena VV, Aruna P, Ajayghosh V. 2011. Anatomical variation in the juvenile wood of acacias grown in the South Indian State of Kerala. *Journal of the Indian Academy of Wood Science.* 8(2): 130–135. https://doi.org/10.1007/s13196-012-0055-6

Samariha A. 2011. The Influence of trees's age on the physical properties and fiber length of *Eucalyptus camaldulensis* in the Zabol Region at Iran. *Middle-East Journal of Scientific Research.* 8(5): 851–854.

Sharma SK, Shukla SR, Shashikala S, Poornima VS. 2015. Axial variations in anatomical properties and basic density of *Eucalypt urograndis* hybrid (*Eucalyptus grandis* × *E. urophylla*) clones. *Journal of Forestry Research*. 26(3): 739–744. https://doi.org/10.1007/s11676-015-0080-6

Shmulsky R, Jones PD. 2019. *Forest Products and Wood Science: An Introduction*. Seventh edition. Hoboken, New Jersey (US): Wiley Blackwell. https://doi.org/10.1002/9781119426400

Sugesty S, Kardiansyah T, Pratiwi W. 2015. Potensi *Acacia crassicarpa* sebagai bahan baku pulp kertas untuk hutan tanaman industri. *Jurnal Selulosa.* 5(1): 21–32. https://doi.org/10.25269/jsel.v5i01.75 (in Indonesian)

Sudari T, Siagian B, Widyanto DN. 2005. Dimensi serat dan proporsi sel pada beberapa variasi umur pohon dan letak radial batang Acacia auriculiformis A.

Cunn. Ex Benth. Dari Desa Kedungpoh, Gunungkidul. Proceeding: Seminar Nasional Pengembangan, Pengelolaan, dan Pemanfaatan Hasil Hutan Rakyat di Indonesia. 195-201. (In Indonesian).

Yahya R, Sugiyama J, Silsia D, Gril J. 2010. Some anatomical features of an Acacia hybrid, *A. mangium* and *A. auriculiformis* Grown in Indonesia with Regard to Pulp Yield and Paper Strength. *Journal of Tropical Forest Science*. 22(3): 343–351.

Zobel BJ, van Buijtenen JP. 1989. *Wood Variation: Its Causes and Control*. Berlin (DE): Springer Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-642-74069-5