

# Microscopic Structure of Yellow Bamboo (*Bambusa vulgaris* var. *striata* Lodd. Ex Lindl) at Various Axial Position in the Culm

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**Abstract.** A faster harvest period compared to wood, along with bamboo's crucial ecological role as a rapidly growing plant that efficiently absorbs carbon and accumulates biomass in a short time and contributes significantly to global climate change mitigation. This study aims to determine the anatomical properties of yellow bamboo at the base, middle, and tip. The anatomical properties were observed using 2 cm ring samples from each position. Samples were macerated using the FPL method. Cell proportions and fiber dimension were observed with a microscope. Cell proportions were calculated using the dot grid method, and fiber dimensions were measured using ImageJ. Data were analyzed using ANOVA. The average proportion of vascular bundles at the base, middle, and tip were 57.52%, 57.46%, and 56.65%. Average fiber length, diameter, lumen, and wall thickness were 2.8 mm, 13.68  $\mu\text{m}$ , 5.45  $\mu\text{m}$ , and 4.12  $\mu\text{m}$ . The ANOVA test results showed no significant effect of axial position on anatomical properties and derivative values. The derived value is 300 (Class II) indicates yellow bamboo fibers are suitable for pulp and paper with good folding strength and not easily torn. This research provides essential baseline data to support sustainable bamboo industry development, community utilization, and future scientific studies.

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## 1 Introduction

Indonesia is one of the countries with a vast forest area. The potential that can be utilized by the community from forests extends beyond wood to include non-timber forest products. Based on [1], Non-Timber Forest Products (NTFPs) are biological, both plant and animal, along with their derivative products and cultivation, except for wood originating from forests. Bamboo is one of the NTFPs that the community has widely utilized. According to [2], bamboo has several advantages, including being inexpensive, its stems being strong, resilient, straight, smooth, and rugged, making them easy to split, shape, and work with, which in turn makes the material lightweight and easy to transport. Additionally, it is worth that bamboo has various beneficial properties and is affordable, making it widely utilized by the community. Bamboo can generally be used for multiple purposes, including animal feed, construction materials, charcoal, and other products. One of the main concerns today is its use as a raw material for the pulp and paper industry, as bamboo is a fast-growing species with a high fiber content.

A faster harvest period compared to wood is one reason for the increased use of bamboo. Additionally, bamboo plays a crucial ecological role. According to [3], bamboo is a rapidly growing plant that efficiently absorbs carbon and accumulates biomass in a relatively short period, also that bamboo forests play a crucial role in mitigating global climate change, particularly in carbon sequestration. Based on this, bamboo forests have significant ecological and economic potential for the community, so their management needs to be considered in accordance with the principles of sustainability. However, to maximize the use of bamboo in sustainable development, a better understanding on microscopic structure of bamboo is required. The microscopic structure of bamboo such as fiber distribution are crucial factors on determining the quality.

According to [4], Indonesia is home to approximately 11.5% of the world's 1,439 bamboo species, comprising 161 species across 12 native genera and 10 introduced genera. Yellow bamboo (*Bambusa vulgaris* var. *striata* Lodd. ex Lindl) is one of the bamboo species found in Indonesia, as it is native to the Tropical Asia region. This bamboo species can be cultivated as an ornamental plant or grows wild in various places. *Bambusa vulgaris* species in Indonesia has two varieties, namely the green variety (*Bambusa vulgaris* var. *vulgaris*), commonly known as ampel bamboo, and the yellow variety (*Bambusa vulgaris* var. *striata*). Yellow bamboo exhibits morphological characteristics, including a yellow stem with green stripes, green leaves with yellow stripes, and black hairs. Yellow bamboo has thick bark, a beautiful shape, and long fibers, making it widely used as a raw material for industry and household needs. Currently, the use of yellow bamboo in Indonesia is growing, particularly in the healthcare sector. The community in Cicurug village, Cianjur Regency, believes that yellow bamboo can cure liver disease and prevent intestinal worms, as it is said to have antibacterial properties that can inhibit the growth of microbes that interfere with health [5]. According to [6], yellow bamboo contains bioactive compounds, including flavonoids, saponins, tannins, alkaloids, terpenoids, and steroids, which are beneficial for protecting the body against free radicals. The use of yellow bamboo as a raw material for pulp and paper is currently still limited. This may be due to the lack of research on the microscopic properties of yellow bamboo cells. The anatomical properties of bamboo need to be understood to optimize the utilization and processing of bamboo in accordance with the condition of its constituent cells, that because the anatomical structures shape its mechanical properties and ultimately determine its species-specific characteristics and uses. The present study aims to determine the anatomical properties of yellow bamboo to assess fiber quality based on fiber derivative value at the base, middle, and tip sections.

## 2 Research Method

The research samples were obtained from home garden in Mojosongo Village, Jebres District, Surakarta. The bamboo used in the present study were estimated on the harvesting period, 4-year-old. Totally, three culms bamboo were harvested to obtain research samples. The anatomical properties were observed using 2 cm ring samples [7], taken from the base, middle, and tip (Figure 1).

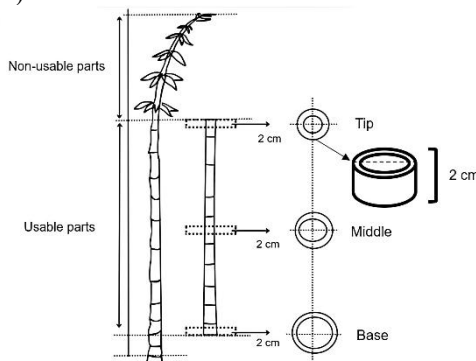


Fig. 1. Sample method

The air-dried ring samples were divided into two parts: one part was used to determine the percentage of vascular bundles, and the other part was used to measure fiber dimensions. The fiber quality was then assessed based on the fiber derivative values to determine the fiber characteristics of pulp and paper materials.

### 2.1 Cell Proportion

Bamboo sections on the transverse cross-section were photographed at  $25\times$  magnification using a Dinolite microscope based on the radial direction (outside, middle, and inside). To calculate the proportion of yellow bamboo cells, the dot grid method with a grid accuracy of 0.5 mm was applied in each section. This method involved counting the dots visible in the measured cells. The cell proportion of yellow bamboo was calculated by using the following formula (1):

$$\text{Cell Proportion (\%)} = \frac{\text{the number of grid in the cell}}{\text{total number of point}} \times 100\% \quad (1)$$

### 2.2 Fiber dimension

The maceration process was conducted according to the Forest Products Laboratory (FPL) method. The bamboo samples were cut longitudinally into small pieces, then placed in test tube and treated with a mixture of 30% hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) and 60% acetic acid ( $\text{CH}_3\text{COOH}$ ) in a ratio of 1:10. The samples were heated in a water bath at a temperature of  $80\pm 1^\circ\text{C}$  for 1-2 hours or until they swell. The samples were washed using distilled water ( $\text{H}_2\text{O}$ ) until free of acid. Once the sample was acid-free, the bamboo fibers were stained with 2% safranin and left for  $\pm 24$  hours. A permanent slide was created by using xylene to remove water content from the specimen (dehydration) and glued using entellan. Furthermore, the fibers were photographed using a microscope connected to a camera. Fiber length was measured using Dinolite microscope with  $40\times$  magnification. Meanwhile, the fiber diameter were observed by Olympus microscope with  $10\times$  magnification.

The number of fibers measured in each repetition is 100 for the fiber length and 50 for the fiber diameter. The measured fibers were those in good condition, including intact, undamaged fibers, as well as unfolded or otherwise damaged fibers. Based on [8], the fiber dimension data obtained were fiber length, fiber wall thickness, fiber diameter, and lumen diameter. Then the fiber dimension derivative values were calculated using the formulas (2-6) as follows:

$$\text{Runkle Ratio (RR)} = \frac{2w}{l} \tag{2}$$

$$\text{Felting Power (FP)} = \frac{l}{d} \tag{3}$$

$$\text{Muhlsteph Ratio (MR)} = \frac{d^2 - l^2}{d^2} \tag{4}$$

$$\text{Coefficient of Rigidity (CR)} = \frac{w}{d} \tag{5}$$

$$\text{Flexibility Ratio (FR)} = \frac{l}{d} \tag{6}$$

L, fiber length; w, fiber wall thickness; d, fiber diameter; l, lumen diameter.

The derived fiber dimension values then score according to the fiber quality criteria (Table 1).

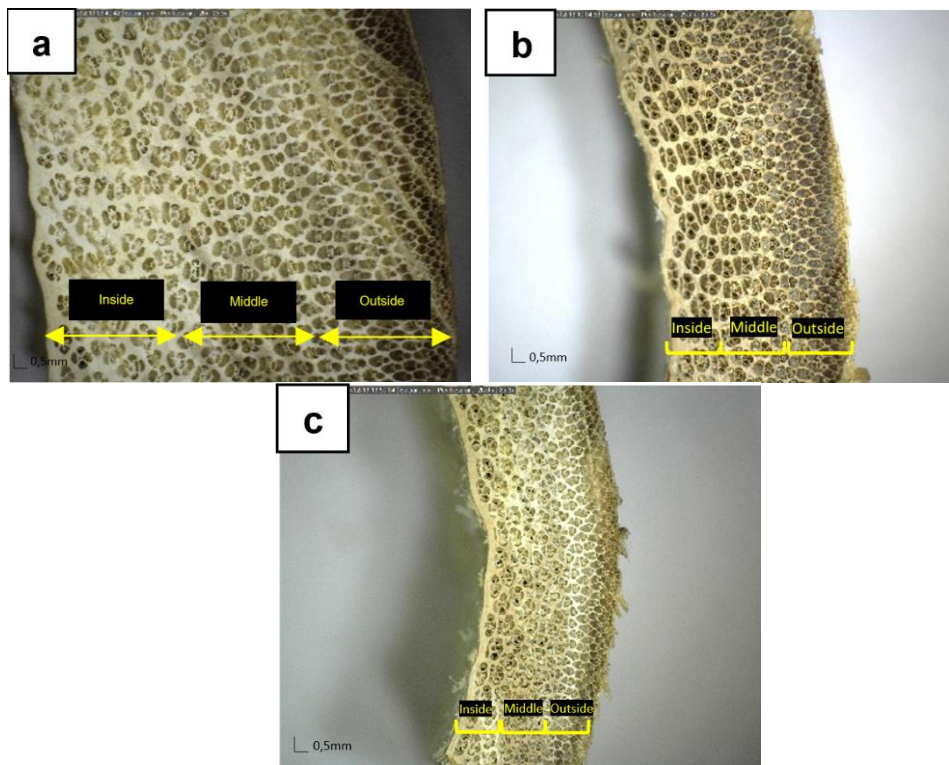
**Table 1.** Fiber quality criteria

Criteria	Class I		Class II		Class III	
	Requirements	Score	Requirements	Score	Requirements	Score
L (μm)	> 2.000	100	1.000–2.000	50	< 1.000	25
RR	< 0.25	100	0.25–0.50	50	0.50-1.0	25
FP	> 90	100	50-90	50	< 50	25
MR	< 30	100	30-60	50	60-80	25
CR	< 0.10	100	0.10-0.15	50	> 0.15	25
FR	> 0.80	100	0.50-0.80	50	< 0.50	25
Interval	450-600		225-449		< 225	

Source: [8]; L= Fiber Length; RR= Runkle Ratio; FP= Felting Power; MR= Muhlsteph Ratio; CR= Coefficient of Rigidity; FR= Flexibility Ratio

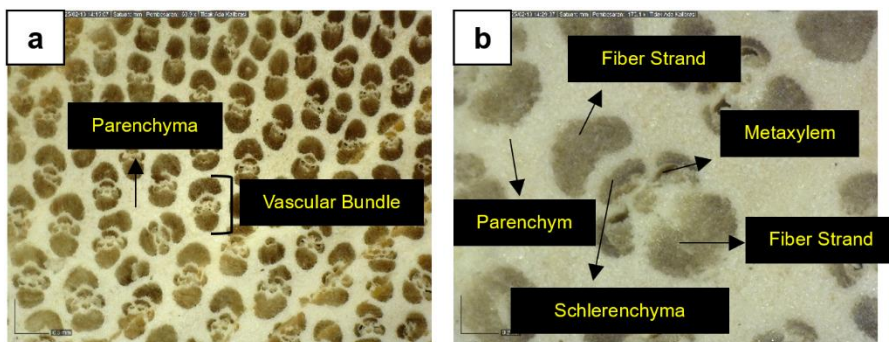
### 3 Result and Discussion

Microscopic properties include the arrangement, shape, and size of cells or tissues that make up wood. The anatomical structure in the form of the percentage of cells composing yellow bamboo (*Bambusa vulgaris* var. *striata* Lodd. ex Lindl) was observed in the axial direction, namely the base, middle, and tip, by observing the distribution of cells in the radial direction. The cross-section of yellow bamboo is shown in Figure 2.



**Fig. 2.** Transverse sections of yellow bamboo at various positions; (a) base, (b) middle, and (c) tip with 25× magnification using a Dinolite microscope.

Bamboo belongs to the angiosperm and has different constituent cells than wood. In general, bamboo is composed of basic tissue in the form of parenchyma cells and vascular bundles. According to Grosser dan Liese cited as [9], the primary cells that make up bamboo are parenchyma cells and vascular bundles, which contain metaxylem, phloem, and fiber bundles. In general, the distribution of vascular bundles, based on the radial direction from the inner edge to the skin, becomes increasingly dense. The density of vascular bundle in the transverse section of bamboo is increasingly dense closer to the skin, with small and numerous vascular bundles. Based on this condition, the outer edge of the bamboo has better mechanical properties than the inner part.

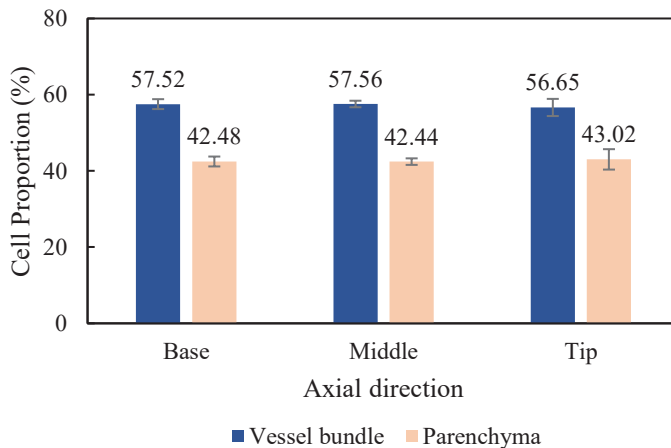


**Fig. 3.** Vascular bundle pattern of yellow bamboo; (a) 63× magnification, and (b) 175× magnification using a Dinolite microscope

One of the anatomical differences between the various types of bamboo is the shape or pattern of the vascular bundles. The pattern of vascular bundles in bamboo was observed in a transverse section using a Dinolite microscope with 63× and 175× magnification. Based on the cross-sectional image above (Figure 3), the yellow bamboo exhibits a vascular bundle type 4, characterized by three parts, namely vascular strand and two fiber bundles (outside and inside the central strand). According to Grosser & Liese as cited [9], pattern 4 is a vascular bundle pattern consisting of metaxylem, phloem, intercellular spaces, and two fiber strands.

### 3.1 Cells Proportion of Yellow Bamboo

The composition of bamboo cells varies depending on the species, but in general, bamboo consists of 50% parenchyma cells, 40% fiber bundles, and 10% vascular tissue (metaxylem and phloem). The proportion of yellow bamboo cells in the axial direction is shown in Figure 4.



**Fig. 4.** Cell proportion of yellow bamboo at various axial positions

Figure 4 showed that the cell proportion of yellow bamboo at the base, middle, and tip. The lowest vascular bundles proportion was found at the tip, namely 56.65%. In the middle and base position, the percentage of vascular bundles were almost the same, namely 57.56 and 57.52%. Furthermore, the lowest parenchyma cells proportion of yellow bamboo was in the middle section, namely 42.44%. Meanwhile, parenchyma cells proportion in the base and tip sections were 42.48 and 43.02%. Based on the statistical analysis, the vascular bundle and parenchyma cell proportion were not significant among axial positions (Table 3).

### 3.2 Fiber Dimensions of Yellow Bamboo

The fiber dimensions consist of fiber length, fiber diameter, lumen diameter, and cell wall thickness.

**Table 2.** Fiber Dimension of Yellow Bamboo in various axial positions

Axial Direction	Fiber Dimension	Min	Max	Average	SD
<b>Base</b>	Fiber Length (mm)	2.1	3.4	2.8	0.364
	Fiber Diameter (µm)	10.89	17.00	13.68	1.677
	Lumen Diameter (µm)	2.29	8.36	5.45	1.301
	Fiber Wall Thickness (µm)	3.04	5.90	4.12	0.715
<b>Middle</b>	Fiber Length (mm)	1.7	3.0	2.3	0.353
	Fiber Diameter (µm)	8.77	15.13	11.85	1.671
	Lumen Diameter (µm)	2.08	7.07	3.98	1.241
	Fiber Wall Thickness (µm)	2.92	5.18	3.94	0.502
<b>Tip</b>	Fiber Length (mm)	1.8	3.3	2.4	0.358
	Fiber Diameter (µm)	8.63	15.06	11.39	1.732
	Lumen Diameter (µm)	2.19	7.90	4.23	1.221
	Fiber Wall Thickness (µm)	2.59	4.69	3.58	0.498

The longest fibers were found at the base, measuring 2.8 mm. At the middle and tip, the lengths were 2.3 and 2.4 mm, respectively (Table 2). According to the classification based on fiber quality criteria in the [8], the length of yellow bamboo fibers falls within the criteria for class I quality, which is a fiber length of >2,000 µm. The average diameter of yellow bamboo fibers in the axial direction is presented in Table 2. The largest average diameter was found at the base, which was 13.68 µm. The average fiber diameter at the middle was 11.85 µm, while the smallest average diameter was at the tip, which was 11.39 µm. The average lumen diameter of yellow bamboo in the axial direction is shown in Table 2. The largest average lumen diameter is at the base, which is 5.45 µm. The smallest lumen diameter is in the middle, which is 3.98 µm. Meanwhile, the lumen diameter at the tip is 4.23 µm. The average thickness of the yellow bamboo fiber wall in the axial position is shown in Table 2. The lowest average fiber wall thickness is at the tip, which is 3.58 µm, and the highest is at the base, which is 4.12 µm. The middle part of the bamboo has an average fiber wall thickness of 3.94 µm. Based on the statistical analysis, the fiber length, fiber diameter, lumen diameter, and cell wall thickness were not significant among axial positions (Table 3).

**Table 3.** Statistical analysis among axial positions of Yellow Bamboo

Criteria	Sign	Description
Parenchyma cell proportion	0.905	ns
Vascular Bundle proportion	0.736	ns
Fiber Length	2.656	ns
Fiber Diameter	2.914	ns
Lumen Diameter	2.576	ns
Cell Wall Thickness	3.742	ns

ns: no significant

### 3.3 Derived Values of Yellow Bamboo Fiber Dimensions

Derived values of yellow bamboo fiber dimensions serve as the basis for determining the potential quality of the fibers as raw materials for pulp and paper. The results of calculating the fiber dimension derivative values at various axial positions of yellow bamboo are presented in Table 4.

**Table 4.** Derived Values of Yellow Bamboo Fiber Dimensions at Various Axial Positions in The Culm

Derived Values	Axial Position							
	Base	Score	Middle	Score	Tip	Score	Average	Score
<b>L (mm)</b>	2.8	100	2.3	100	2.4	100	2.5	100
<b>RR</b>	1.51	25	1.98	25	1.70	25	1.73	25
<b>FP</b>	202.52	100	195.39	100	213.49	100	203.80	100
<b>MR</b>	84.14	25	88.74	25	86.24	25	86.37	25
<b>CR</b>	0.30	25	0.33	25	0.31	25	0.31	25
<b>FR</b>	0.40	25	0.34	25	0.37	25	0.37	25
<b>Total Score</b>	300		300		300		300	
<b>Class</b>	II		II		II		II	

Description: L = Fiber Length; RR = Runkle Ratio; FP = Felting Power; MR = Muhlsteph Ratio; CR = Coefficient of Rigidity; FR = Flexibility Ratio

Based on the table above, the Runkle ratio (RR) of yellow bamboo at the base, middle, and tip was 1.51, 1.98, and 1.70, respectively. The average RR was 1.73, indicating that the score for yellow bamboo was 25. Fibers in this criterion are of poor quality when processed into pulp because they have a wide lumen diameter and thin cell walls [10]. The FP of the yellow bamboo at the base, middle, and tip was 202.52, 195.39, and 213.49, respectively. The average FP score for yellow bamboo was 100. Felting power significantly affects the tear strength of paper, so the higher the value, the better, as it indicates that the fibers are more flexible and can form better inter-fiber bonds [11]. The MR of the yellow bamboo at the base, middle, and tip were 84.14, 88.74, and 86.24%, respectively. The average MR was 86.37%. The lower the MR, the higher the density of the resulting pulp sheet, producing paper that is smoother, stronger, and more pliable. A pliable sheet indicates that the paper does not tear easily when crumpled. Fibers with a large lumen diameter will have a smaller MR value, so that the fibers are easier to compress, have high folding strength, and are not stiff [11]. The CR of the yellow bamboo at the base was 0.30; in the middle 0.33; and at the tip 0.31; with an average value of 0.31. The average CR score of yellow bamboo in this study was 25. The higher the CR value, the lower the tensile strength and other paper strengths such as bursting strength, tear strength, and folding strength [10]. The FR of the yellow bamboo at the base, middle, and tip are 0.40, 0.34, and 0.37, respectively, resulting in a score of 25. A high FR indicates that the greater the density, burst factor, breaking length, and folding endurance of the resulting pulp and paper sheets.

The total score of the derived values of yellow bamboo fiber dimensions was 300, which is classified as class II. The results obtained show that yellow bamboo fibers are suitable for raw material for pulp and paper. According to [12], Fibers classified as Quality Class II tend to collapse easily during refining and form strong inter-fiber bonds, resulting in pulp sheets with good tear strength, burst resistance, and tensile strength. Therefore, they are considered suitable for use as raw material for pulp and paper production. Based on the results obtained in the present study, the axial position of yellow bamboo does not affect the fiber dimension. The yellow bamboo showed long fibers and high FP, which will produce pulp sheets that are not easily torn and have good folding strength. Furthermore, the assessment criteria from the Ministry of Agriculture as cited [13] state that fiber with quality class II is suitable for use as raw material for art paper, packaging like wrapping paper, bag paper, or other types of paper that undergo stretching in the printing process. Those, all parts of culm; namely base, middle, and tip have uniform properties and can be utilized in their entirety.

**Table 5.** Derived Values of Yellow Bamboo Fiber Dimensions with other types of plants

Derived Values	Yellow Bamboo		Ampel Bamboo*		<i>Acacia mangium</i> **		Sengon***	
	Value	Score	Value	Score	Value	Score	Value	Score
<b>L (mm)</b>	2.5	100	3.22	100	1.2	50	1.3	50
<b>RR</b>	1.73	25	2.77	25	0.40	50	0.14	100
<b>FP</b>	203.80	100	316.62	100	47.74	25	37.43	25
<b>MR</b>	86.37	25	93	25	51.24	50	21.92	100
<b>CR</b>	0.31	25	0.37	25	0.14	50	0.06	100
<b>FR</b>	0.37	25	0.27	25	0.69	50	0.88	100
<b>Total Score</b>	300		300		275		475	
<b>Class</b>	II		II		II		I	

L = Fiber Length; RR = *Runkle Ratio*; FP = *Felting Power*; MR = *Muhlsteph Ratio*; CR = *Coefficient of Rigidity*; FR = *Flexibility Ratio*; \*= Derived values of ampel bamboo (*Bambusa vulgaris* var. *vulgaris*) fiber dimensions based on a research report by [10]; \*\*= Derived values of *Acacia mangium* fiber dimensions based on a research report by [14]; \*\*\*= Derived values of sengon (*Falcataria falcata*) wood fiber dimensions based on a research report by [15]

Table 5 shows the comparison of the derived values of yellow bamboo to those of other plant fibers. The total score of yellow bamboo fiber in the present study was similar to that of ampel bamboo. According to the research report by [10], the derivative value of ampel bamboo fiber was classified as quality class II, with a score of 300. The derived value of yellow bamboo fiber dimensions in the present study was greater than that reported by [14] for *A. mangium* wood fiber. However, it was smaller compared to sengon fiber reported by [15], indicating that sengon fiber shows excellent quality as a raw material for pulp and paper.

## 4 Conclusion and Recommendation

### 4.1 Conclusion

Based on the results in the present study, it can be concluded that the average proportion of vascular bundles at the base, middle, and tip were 57.52; 57.46; and 56.65%, respectively. The average fiber length, diameter, lumen, and cell wall thickness were 2.8 mm, 13.68 μm, 5.45 μm, and 4.12 μm, respectively. The derived value of yellow bamboo fiber dimensions was 300 (Class II), indicating that yellow bamboo fiber is suitable as a raw material for pulp and paper, with sheet characteristics that show good folding strength and are not easily torn.

### 4.2 Recommendation

Recommendations that can be given based on the research conducted that the axial position of the culm, yellow bamboo, as a whole (including the base, middle, and tip), can be used as a raw material for pulp and paper, yielding fairly good pulp quality. Further research is needed on the chemical composition of yellow bamboo, particularly in its application as a raw material for pulp and paper production.

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