# Physical properties *of yellow bamboo* (*Bambusa vulgaris* var. striata Lodd. ex Lindl) Culm in Axial Direction

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**Abstract.** Bamboo is well known for its ecological benefit, such as preventing erosion, regulating water management, and supporting climate change mitigation through high carbon sequestration. As renewable resource bamboo potentially reduce pressure on natural forests, due to its properties that similar to wood. However, the physical properties of bamboo still limited, especially report on yellow bamboo. Samples were taken from one bamboo clump, with three replicates at every 1 m from the base to the tip. The results showed that yellow bamboo has sympodial roots, a height of 11.5 m, a clump diameter of 106 cm, and yellow stems with green stripes, as well as thicker stem walls at the base. The moisture content of fresh bamboo ranged from 96.54-115.85% and air-dried bamboo from 14.17- 15.74%. The fresh specific gravity was 0.54-0.61; air-dry 0.67-0.84; and kiln-dry 0.69-0.84. Tangential shrinkage and total shrinkage ranged from 7.91-14.64%; 9.96-16.35%, radial shrinkage from 10.25-15.03%; 11.82-15.59%, and axial shrinkage from 0.26-0.53%; 0.36- 0.68%. The color change was very clear, from fresh to air-dry and kiln-dry conditions, with $\Delta E^* > 5$. This study aims to assess the suitability of bamboo as a building construction material from Mojosongo, Surakarta.

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# 1 Introduction

Bamboo is a plant from the Poaceae family that grows in clumps and is known for its rapid growth rate, forming dense clumps in a relatively short period of time. In addition to its role in environmental conservation through its root system, which can prevent erosion and regulate water management, bamboo also supports climate change mitigation through its high carbon absorption. In addition, bamboo also has high economic value as a building material, art tools, woven products, food, and even medicine [1].

One type that has potential for use in the construction industry is *Bambusa vulgaris* var. *striata* or yellow bamboo, which has thick bark, long fibers, and an attractive shape. However, the selling value of bamboo handicraft products often fluctuates due to the low quality of raw materials [2], which can be determined through physical parameters such as moisture content, specific gravity, density, dimensional shrinkage, and color change [3].

Color also serves as an important aesthetic aspect, but tends to fade due to the effects of temperature and light during the drying process. Previous studies have shown that yellow bamboo sections experience high shrinkage and weight reduction [4], so further study of its physical characteristics is needed. Therefore, this study aims to examine the morphology and physical properties of yellow bamboo in the axial direction to assess its suitability as a building construction material.

# 2 Method

## 2.1 Time and location

Yellow bamboo was obtained from a home garden in Mojosongo Village, Jebres District, Surakarta. Furthermore, research on physical properties was conducted at the Forest Products Laboratory, Forest Management Study Program, Faculty of Agriculture, Universitas Sebelas Maret. The research was conducted from November to May 2025.

## 2.2 Procedure

### *2.2.1 Sample collection*

A total of three culms of bamboo from one clump, estimated to be 4 years old, were harvested to obtain research samples. Before harvesting, the culm height and diameter at breast height were measured. In addition, leaf morphology, roots between nodes, the number of bamboo culms in a clump, and the morphology of the bamboo were identified. After harvesting, the total length of usable culm, culm wall thickness, and culm diameter of the bamboo nodes were measured. Samples were taken at intervals of 100 cm from the base to the tip. The usable culm can be determined by the criteria of having a minimum diameter of 4 cm at the tip. Specimens for physical properties were taken at intervals of 50-60 cm per meter (Figure 1).

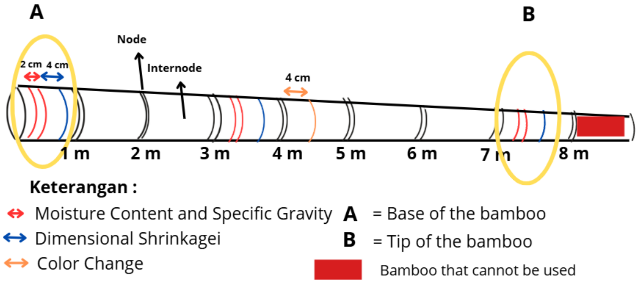



**Figure 1.** Sample positions on a bamboo culm.

Test samples were prepared in accordance to [5] standards, taken from four symmetrical positions on the ring as shown in Figure 2. The thickness of the test samples depended on the wall thickness, and the test samples still had their outer skin and inner layer. For moisture content and specific gravity, the specimen was 2 cm in length and width. The samples measuring 4 cm in length and 2 cm in width were used to measure shrinkage. For color change testing, only one sample per bamboo stem was taken, measuring 4 cm in *length and ring-shaped.* These measurements were observed in fresh, air-dry, and kiln-dry conditions.

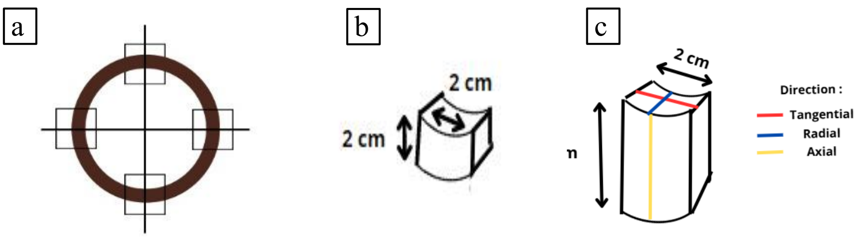



**Figure 2.** Location of test samples according to [5], a) sample position, b) sample for moisture content and specific gravity, b) sample for shrinkage

## 2.3 Data Analysis

Samples of yellow bamboo were divided according to size based on [5]. Then, in fresh, air-dried, and kiln-dried conditions, the moisture content, specific gravity, shrinkage, and color changes of the bamboo were determined using a formula :

$$MC\ (\%) = \frac{m_1 - m_0}{m_0} \text{ x } 100\% \quad (1)$$

$$Specific\ gravity\ = \frac{\frac{m_0\ (g)}{V(cm^3)}}{WD\ (g/cm^3)} \quad (2)$$

$$Shrinkage\ = \frac{Dm - Da}{Dm} x\ 100 \quad (3)$$

$$E^* = \sqrt{(L)^2 + (a)^2 + (b)^2} \quad (4)$$

$$\Delta E^* = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (5)$$

MC, Moisture Content (%); $m_1$, Initial Weight of Test Sample (g); $m_0$, kiln-dry Weight of Test Sample (g), V, is the sample volume in fresh, air-dried, or kiln-dry condition ($cm^3$); WD, water density ($g/cm^3$), Dm, Maksimum dimension; Da, Final dimension, $E^*$, Color value (fresh, air-dried, and kiln-dried bamboo); $L$, Lightness; $a$, Red-greenness; $b$, Yellow-blueness; $\Delta E^*$, *Color changes;* $\Delta L^*$, *Lightness* changes*;* $\Delta a^*$, Red-greenness changes*;* $\Delta b^*$, Yellow-blueness change.

Research samples were observed in fresh bamboo, air-dried, and kiln-dried conditions using *colorimeter* (*ColorReader* CR6, China), then color changes were classified based on Table 1. The formula used is as follows:

**Table 1.** Classification of color difference values ($\Delta\, \boldsymbol{E}$ *)

| Color Difference (ΔE*) | Effect |
|---|---|
| 0 | No visible difference |
| 1-2 | Very small difference seen by trained observers |
| 2-3.5 | Untrained observers can see a slight difference |
| 3.5 | Clear differences |
| >5.0 | Very clear difference |

Source: [6]

# 3 Results and Disscusions

## *3.1 Morphology of Yellow Bamboo (Bambusa vulgaris* var. *striata* Lodd. ex Lindl)

Yellow bamboo has a sympodial root system with culms growing in dense clumps through rhizome branching in the soil. In this study, one clump consisted of 12 culms with a height of 11.5 m and a clump diameter of 106 cm (Figure 3a). The culms were yellow with green stripes (Figure 3b), had a smooth surface, a diameter at breast height of 7-8 cm, and a node length of 27-30 cm. Aerial roots appear on the lower nodes near the ground (Figure 3c). The sheath is easily detachable, black and hairy, with an upright triangular shape and a length of 38 cm (Figure 3d). Unequal polycotome branching appears at the nodes, with 3-5 branches and one dominant branch (Figure 3e). The shoots are slender and triangular in shape, with a brownish-green sheath covered in black hairs (Figure 3f). They are 65 cm tall, 7.96 cm in diameter at the base, and 4.77 cm in diameter at the top. The leaves are bright green on both surfaces, simple, alternate, lanceolate in shape, with pointed tips and rounded bases, and smooth edges. They are 23 cm long and 4 cm wide, with a soft texture and hairless appearance (Figure 3g).

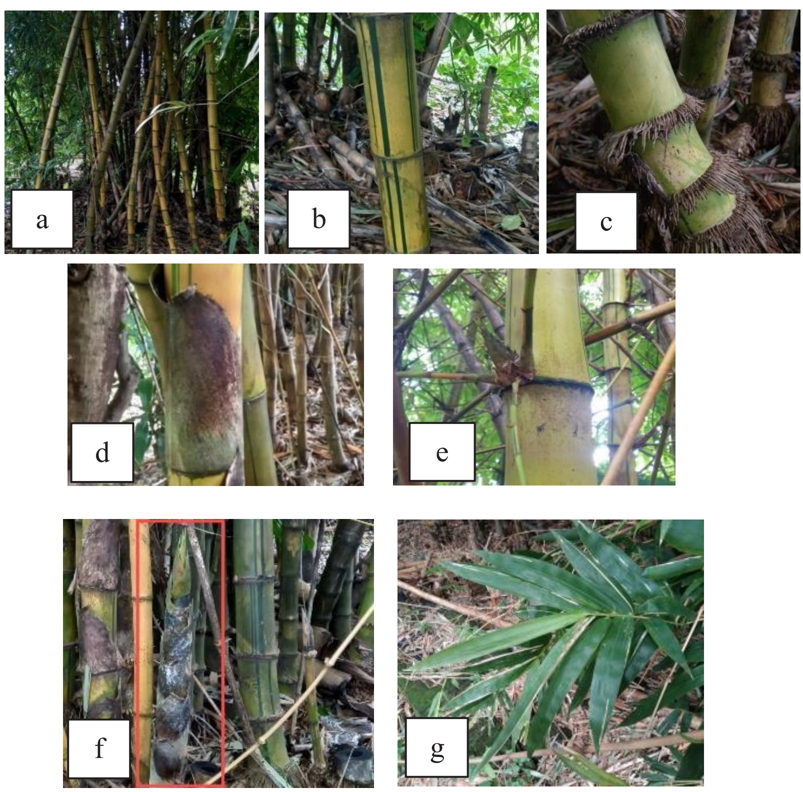



**Figure 3.** *Bambusa vulgaris* var. *striata* (a) bamboo clump, (b) culm, (c) aerial roots, (d) sheath, (e) branching, (f) shoot, (g) leaf

The morphology of the yellow bamboo culm used as research samples is shown in Table 2. The average total length of fallen bamboo culms was 10.19 m. However, not all parts can be utilized because the ends of the culms have a small diameter and lower mechanical properties [7]. Therefore, only parts with a diameter greater than 4 cm were used in the present study, resulting in an average usable length of 7.45 m. In addition, Branching occurs at nodes along the stem, with an average branching height of 1.18 m from the ground surface, in line with the findings of [8], who reported a branching height of 1.46 m.

**Table 2.** The morphology of yellow bamboo culm.

| Culm | TL (m) | UL (m) | T(m) |
|---|---|---|---|
| 1 | 10.54 | 7.65 | 1.52 |
| 2 | 9.74 | 7 | 1.31 |
| 3 | 10.28 | 7.7 | 0.72 |
| Average | 10.19 | 7.45 | 1.18 |

Description: TL: Total length after felling, UL: Usable length, T: Height of first branch from base.

Starting from the base, every 100 cm, the diameter and wall thickness of the bamboo culm were measured (Figure 4). Research on the wall thickness and diameter of bamboo was reported by [8],which found that the wall thickness and diameter of *Dendrocalamus asper* were greater at the base compared to the tip. Figure 4 shows that the wall thickness in the base was thicker than that at the tip. Meanwhile, the diameters of the 3- and 4-m sections were slightly larger than the base. This phenomenon is presumably due to environmental factors such as rainfall, which effects soil moisture and water availability [9].

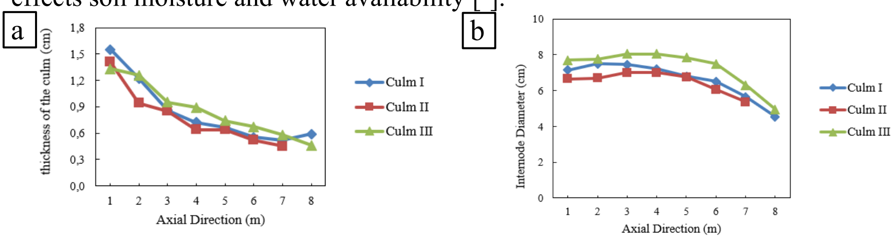



**Figure 4.** The culm morphology of yellow bamboo in axial direction (a) wall thickness, (b) internode diameter

### *3.2 Physical Properties of Yellow Bamboo (Bambusa vulgaris* var. *striata)*

#### *3.2.1. Moisture Content*

Variations in the fresh moisture content of bamboo in each culm was influenced by factors such as age, season, time of harvest, and type of bamboo. The fresh moisture content and air-dry moisture content are presented in Figure 5.

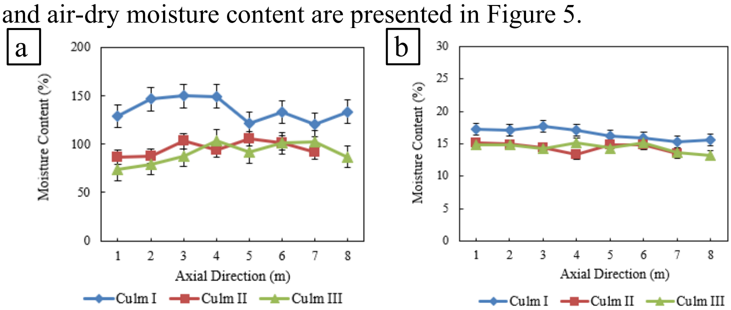



**Figure 5.** Moisture content of yellow bamboo in axial direction
(a) Fresh, (b) Air-dry conditions.

Based on Figure 5a, the fresh moisture content in culm 1 ranged from 120.27-150.02%, culm 2 ranged from 87.04-106.03%, and culm 3 ranged from 73.51-103.89%. The fresh moisture content from the base to the tip did not show a specific pattern. According to [10], the differences in moisture content were due to each part of the bamboo having different functions in plant growth and development.

The air-dry moisture content of yellow bamboo is shown in Figure 5b, indicating that the air-dry moisture content of culm 1 ranged from 15.55-17.30%, culm 2 ranged from 13.36-15.08%, and culm 3 ranged from 13.23-15.17%. This study shows that air-dry moisture content from the base to the tip was slightly decreased. [10] states that the moisture content at the base of bamboo tends to be higher due to a larger proportion of parenchyma and lower fiber density, allowing for greater water absorption.

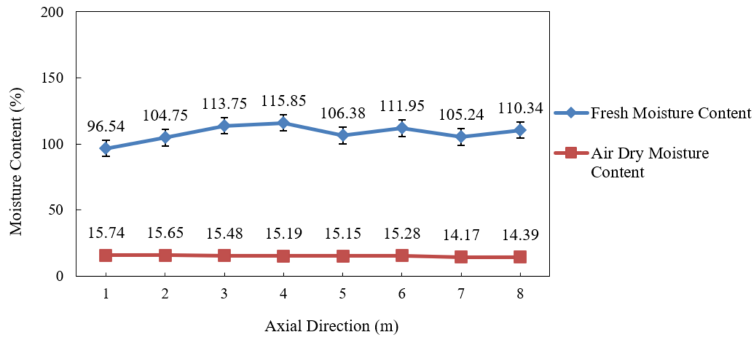
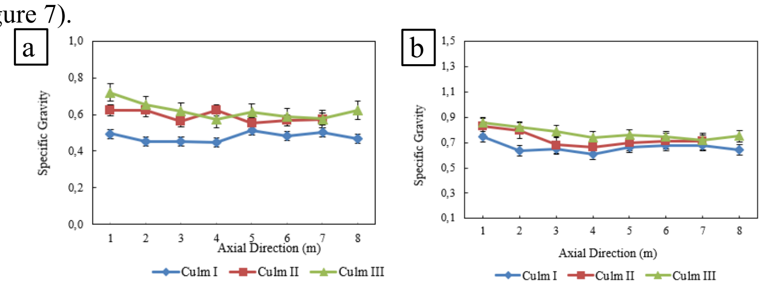



**Figure 6.** Average moisture content of yellow bamboo in axial direction.

The average fresh moisture contents of yellow bamboo were 96.54- 115.85%, while the moisture content in air-dry conditions was 14.17-15.74% (Figure 6). The average fresh moisture content shows a slight increase from base to the tip. Meanwhile, the air-dry moisture content is stable from base to tip. The air-dry moisture content obtained in the present study was slightly higher than that reported in previous studies [10]. The research [10] reported that the air-dry moisture content of bamboo ranged from 8.84% to 10.88%. The difference in results may be due to variations in the timing of implementation and seasonal factors that influence the timing of sampling [11].

### 3.2.2 Specific Gravity

Specific gravity were observed under three conditions: fresh, air-dry, and kiln-dry (Figure 7).



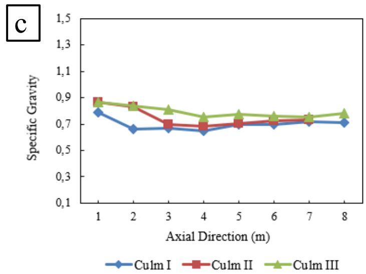



**Figure 7.** Specific gravity of yellow bamboo based on axial direction under conditions (a) fresh, (b) air-dry, (c) kiln-dry.

The fresh specific gravity of yellow bamboo culm 1 ranged from 0.45-0.51, culm 2 ranged from 0.55-0.62, and culm 3 ranged from 0.57-0.72. The specific gratification decreased from base to tip (Figure 7a). The anatomical characteristic influences particular gravity, namely, cell and lumen diameter. The specific gravity of the base was higher than that of the tip, indicating that the cell diameter was wider and the lumen diameter was narrower at the base compared to the tip.

The air-dry specific gravity of culm 1 ranged from 0.61-0.75, culm 2 ranged from 0.66-0.83, and culm 3 ranged from 0.72-0.86. The air-dry density of the base was higher than the tip. The results obtained (Figure 7b) are in accordance with the report by [10], showed specific gravity of yellow bamboo was decreased along with the distance from the base to the tip.

The air-dry specific gravity of culm 1 ranged from 0.65-0.79, culm 2 ranged from 0.69-0.86, and culm 3 ranged from 0.75-0.87 (Figure 7c). The present study shows that the air-dry specific gravity of yellow bamboo was higher than that reported in [10]. [10] reported that the specific gravity of yellow bamboo ranged from 0.61 to 0.70. Variations in air-dry specific gravity within a single bamboo culm are caused by differences in position within the culm, suggesting that one of these was influenced by the higher extractive content at the base than at the tip.

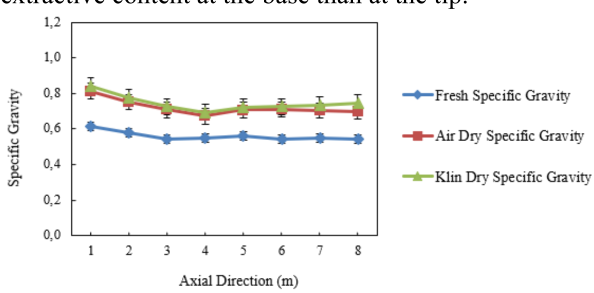



**Figure 8.** Average specific gravity of yellow bamboo in axial direction.

The average specific gravity of yellow bamboo, measured as fresh, air-dry, and kiln-dry, was 0.54-0.61, 0.67-0.84, and 0.69-0.84, respectively, from base to tip (Figure 8). The present study showed that the fresh specific gravity has a lower density than the air-dry and kiln-dry densities. This difference was due to differences in the moisture content. In fresh conditions, high moisture content results in lower density. The drying process plays a role in reducing the water content, thereby increasing the specific gravity of bamboo [10]. Furthermore, the age of bamboo also affects its specific gravity, as younger bamboo has a lower specific gravity.

### *3.2.3 Shrinkage*

The tangential shrinkage of yellow bamboo from fresh to air-dry conditions in the axial direction (Figure 9a) from culms 1 to 3 ranged from 5.61-21.10%, 4.14- 13.12%, and 6.30-10.48%, respectively. The total tangential shrinkage of yellow bamboo from fresh to kiln-dry conditions in the axial direction from culm 1 to 3 ranged from 8.04-23.09%, 6.88-14.93%, and 7.96 to 12.36%, respectively (Figure 9b). The tangential shrinkage of yellow bamboo from fresh to air-dry conditions and from fresh to kiln-dry conditions in the axial direction is shown in Figure 10.

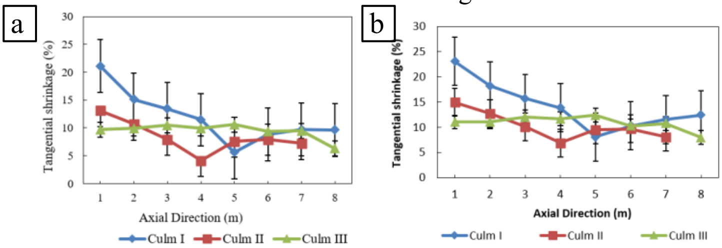



**Figure 9.** Shrinkage of yellow bamboo based on axial direction (a) tangential shrinkage, (b) total tangential shrinkage.

Tangential shrinkage (Figure 9a) from the base to the tip was decreased, except for culm 3, which showed stable tangential shrinkage from 1-7 m, then decreased at 8 m. [[10]] revealed that the high shrinkage was caused by the presence of fiber bundles in the bamboo vascular bundles that lost water. Figure 9b showed that the total tangential shrinkage in culms 1 and 2 was higher in the base than the tip; meanwhile, culm 3 tended to be stable from 1-7 m and then decreased at 8 m. The base of the bamboo has higher density and fiber content, resulting in greater shrinkage.

The radial shrinkage of yellow bamboo from fresh to air-dry and from fresh to kiln-dry conditions in the axial direction is shown in Figure 10. Figure 10a shows radial shrinkage in culms 1, 2, and 3 were 7.90-18.23%, 3.35-14.32%, and 8.67-14.30%, respectively. The shrinkage at the tip is greater than at the base because the tip has a lower fiber content, making it more susceptible to dimensional changes due to water loss during drying. Total radial shrinkage in culms 1, 2, and 3 (Figure 10b) ranged from 15.49-19.15%, 8.79-14.52%, and 9.94-14.74%, respectively. Total radial shrinkage did not show a specific pattern. This condition was suggested due to the increasing silica content and the decreasing size of the vessels at the ends [[11]].

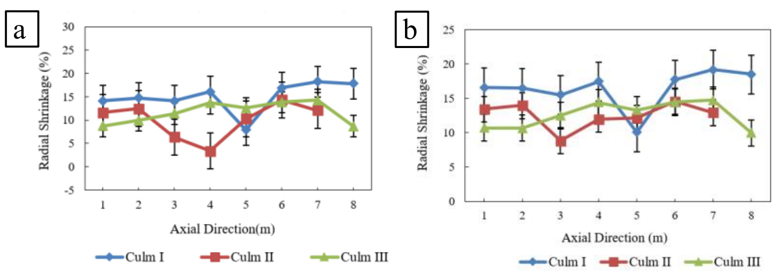



**Figure 10.** Shrinkage of yellow bamboo in axial direction (a) radial shrinkage, (b) total radial shrinkage.

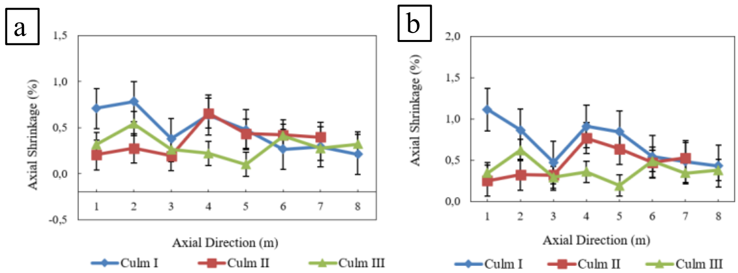



**Figure 11.** Shrinkage of yellow bamboo based on axial direction (a) axial shrinkage, (b) total axial shrinkage.

Axial shrinkage of yellow bamboo from fresh to air-dry and fresh to kiln-dry conditions in the axial direction is shown in Figure 11. Figure 11a shows that the axial shrinkage of yellow bamboo in culms 1 to 3 ranged from 0.21-0.78%, 0.19-0.66%, and 0.10-0.54%, respectively. The results shown in culm 1 (Figure 11a) were in accordance with the research by [12], which indicated variations in the microfibril angle arrangement in layer S2 due to an increase in parenchyma, causing the base to experience higher shrinkage. Conversely, the tip has a higher proportion of fibers and vascular bundles, resulting in less shrinkage at the tip of the bamboo. The total axial shrinkage from fresh to kiln-dry conditions in culms 1 to 3 ranged from 0.43-1.11%, 0.25-0.77%, and 0.19-0.62% (Figure 11b). Figure 11b shows that the shrinkage pattern in culm 1 decreased from the base to the tip; culm 2 increased; and culm 3 was relatively constant from the base to the tip. The high-water content at the base (Figure 6) causes greater shrinkage due to water evaporation during heat treatment [4].

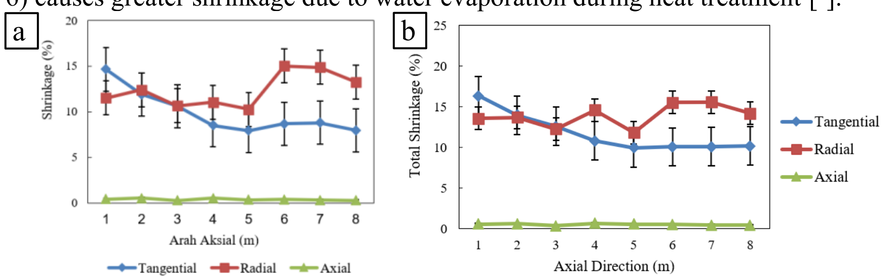



**Figure 12.** Shrinkage of yellow bamboo based on the axial direction (a) average shrinkage, (b) average total shrinkage.

The average tangential, radial, and axial shrinkage of yellow bamboo were 7.91-14.64%, 10.25-15.03%, and 0.26-0.53%, respectively (Figure 12a). Radial and tangential shrinkage showed greater shrinkage than in the axial direction. The average total shrinkage (Figure 12b) of yellow bamboo from fresh to kiln-dry conditions in the axial direction from the base to the tip ranges from 9.96-16.35% for tangential shrinkage, 11.82-15.59% for radial shrinkage, and 0.41-0.68% for axial shrinkage. The results showed that radial shrinkage was greater than tangential and axial shrinkage. The radial shrinkage in bamboo was greater than the tangential because bamboo does not have rays. Bamboo does not have rays, making it easier for water to pass through the pores, resulting in more significant expansion and shrinkage in this direction compared to the tangential and longitudinal directions. Additionally, demonstrated that location and bamboo type have a substantial influence on shrinkage [12].

### *3.3.4 Color Change*

As the water content decreases, bamboo undergoes significant changes in color. The color changes in bamboo from fresh to air-dry and kiln-dry conditions are shown in Figure 13.

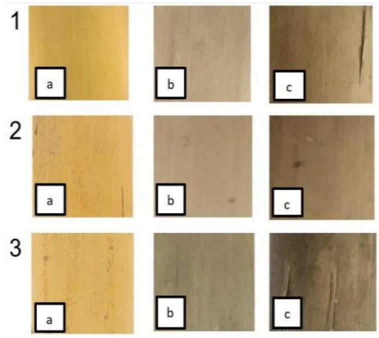



**Figure 13.** Color changes in yellow bamboo from (a) fresh, (b)air-dry, and (c) kiln-dry conditions in culm 1, 2, and 3.

Figure 13 shows that fresh yellow bamboo has a yellow color. When air-dried at room temperature for 1 month, a noticeable color change occurs, with the yellow color fading to a dull one. Then, the yellow bamboo was kiln-dried for 1 week at a temperature of 103 ± 2˚C, indicating that the color of the yellow bamboo tends to become darker. This condition proves that the treatment given to the bamboo culm causes the color of the bamboo to change. The color change is caused by the bamboo losing some of its water content and is thought to be due to the oxidation of phenolic compounds in the presence of air, followed by the formation of dark compounds through the hydrolysis process [4]. The color change of yellow bamboo from fresh to air-dried conditions is presented in Table 3.

**Table 3.** The color change of yellow bamboo from fresh to air-dry condition.

| Culm | Testing using *CIE** Fresh Conditions | | | | Testing using *CIE** Air Dry Condition | | | | Δ*E** |
|---|---|---|---|---|---|---|---|---|---|
| | *L** | *a** | *b** | *E ** | *L** | *a** | *b** | *E ** | |
| 1 | 56.51 | 14.12 | 66.10 | 88.10 | 53.10 | 9.58 | 27.35 | 60.49 | 39.17 |
| 2 | 57.18 | 12.03 | 58.93 | 82.99 | 54.06 | 9.03 | 25.90 | 60.62 | 33.32 |
| 3 | 48.65 | 15.31 | 67.27 | 84.42 | 48.61 | 8.28 | 26.21 | 55.84 | 41.66 |
| | Average | | | 85.17 | Average | | | 58.98 | 38.05 |

Description: *L*: Brightness, *a*: Red-green, *b*: Yellow-blue, *E*: Bamboo color value, Δ*E*: Color change.

Based on Table 3, the color change of yellow bamboo (Δ*E* *) from fresh to air-dry conditions showed clear difference. The color changes in culm1, 2, and 3 were 39.17, 3.32, and 41.66, respectively. Based on the classification by [6], the color change of yellow bamboo in fresh and air-dry conditions (Table 3) showed clear effect of color change with a Δ*E**>5. In addition, the drying process using heat treatment can also cause greater changes in brightness levels compared to drying treatment using the air-drying.

**Table 4 .** The color change of yellow bamboo from fresh to kiln-dry condition.

| Culm | Testing using *CIE** in Fresh Conditions | Testing using *CIE** in Kiln Dry Conditions | Δ*E** |
|---|---|---|---|

| | $L*$ | $a*$ | $b*$ | $E*$ | $L*$ | $a*$ | $b*$ | $E*$ | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 56.51 | 14.12 | 66.10 | 88.10 | 52.86 | 10.05 | 28.13 | 60.72 | 38.36 |
| 2 | 57.18 | 12.03 | 58.93 | 82.99 | 53.50 | 9.56 | 26.81 | 60.60 | 32.43 |
| 3 | 48.65 | 15.31 | 67.27 | 84.42 | 50.53 | 8.25 | 25.22 | 57.07 | 42.68 |
| Average | | | | 85.17 | Average | | | 59.46 | 37.82 |

Description: *L*: Brightness, *a*: Red-green, *b*: Yellow-blue, *E*: Bamboo color value, $\Delta E$ : Color change.

Table 4 shows the difference in color change between the fresh and air-dry conditions of yellow bamboo in culms 1 to 3, which were 38.36%, 32.42%, and 42.68%, respectively. The color change in yellow bamboo was classified as very clearly visible, with an $\Delta E*$ value greater than 5. The drying process causes the color of bamboo to become darker (Figure 13c), which is attributed to oxidation and water evaporation [13]. Water evaporation occurs through chemical reactions, such as oxidation, degradation, and lignin condensation, involving the reduction of hydroxyl groups as a result of heat treatment [4, 14].

The physical properties of bamboo are an essential aspect in determining processing and final product quality. Various factors, including plant age, altitude, moisture content, specific gravity, shrinkage, and color change, influence physical properties. Bamboo exhibits a high moisture content (up to 300%), rendering it less than ideal as a concrete reinforcement material. The optimal moisture content of bamboo for utilization ranges from 10% to 11% [15]. Additionally, preservation is necessary to enhance quality and durability. As a construction material, bamboo must be protected from rain and direct sunlight to prevent biological degradation and heat damage.

## 4 Conclusion

Yellow bamboo has sympodial roots, a height of 11.5 m, a clump diameter of 106 cm, and yellow stems with green stripes, as well as thicker stem walls at the base. The average fresh moisture content of yellow bamboo from base to tip is 96.54-115.85%, while the average air-dry moisture content ranges from 14.17-15.74%. The average fresh specific gravity is 0.54-0.61, the air-dry specific gravity ranges from 0.67-0.84, and the kiln-dry specific gravity ranges from 0.69-0.84. Average tangential shrinkage ranges from 7.91-14.64%, radial shrinkage from 10.25-15.03%, and axial shrinkage from 0.26-0.53%. The color change of yellow bamboo from fresh to air-dried and fresh to kiln-dried showed values of 39.17; 33.32; 41.66 and 38.36; 32.43; 42.68 classified in the very visible category because the $\Delta E* > 5$.

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