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by Tri Mulyaningsih

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Volume 1

December 2022

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Comparison of stem anatomy of *Bambusa vulgaris* Schrad and *Schizostachyum brachycladum* (Kurz) Kurz (Poaceae) in Lombok

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Highlights

- Trichome Type of bamboo culm is a combination of stingous, puberulous, scabrous, and machete types.
- The shape of the bamboo stem fiber is elongated, narrowed and widened or shortened, slimmed and broadly.
- Bamboo pith parenchymal tissues are composed of short cells and long cells.

Abstract

Bambusa vulgaris and *Schizostachyum brachycladum* are similar but differ in stem shape, branching type, and the presence of aerial roots. *B. vulgaris* bamboo has various uses, such as a support in concrete construction, and because it is resistant to river abrasion, while its shoots are used as a vegetable. *S. brachycladum*, which has a very thin stem pith, is used for cooking grilled sticky rice (*lemang*), so it is often called bamboo *lemang*. The aim of this study was to compare the anatomical structure of the culms of *B. vulgaris* and *S. brachycladum* in Lombok. Two methods were used in the preparation of the samples: the permanent slide

method with glycerin jelly closure and the maceration method. Transverse and tangential stem slides were used with double staining, using 0.5% safranin O (50% alcohol) and 1% (1 part Aniline Blue + 4 parts picric acid) in 95% alcohol. Fibre slides were prepared using 50% acetic acid maceration solution and staining 50% peroxide and 0.5% Safranin O (50% alcohol). The results showed that the stems of *S. brachycladum* cv. Green are characterized by short and long cells, a number of vascular bundles in the pith, and a different periderm structure from *B. vulgaris*. The greatest anatomical differences in the culms of *B. vulgaris* var. *vulgaris* and var. *striata* lie in the arrangement of the periderm tissue and the number of vascular bundles.

Keywords

stem anatomy; *Bambusa vulgaris*; *S. brachycladum*; Lombok

1. Introduction

Bamboo is an important non-timber forest product, often found growing in rural community gardens (Murtodo & Setyati, 2015). Bamboo can help maintain an environmental balance as its dense root system can prevent erosion and regulate water management (Mentari et al., 2018). Bamboo is widely used by communities as a raw material for construction, in the handicraft industry, and as a source of nutrients that are beneficial to health (Sukawi, 2010).

Lombok Island has a diversity of bamboo species, with 12 documented species from six genera: *Bambusa*, *Dendrocalamus*, *Gigantochloa*, *Guadua*, *Shcyzostachyum* and *Thyrsostachys* [(Damayanto et al., 2020; Fatmalasari et al., 2019; Huzaemah et al., 2016; Mentari et al., 2018; Munawarah et al., 2019; Peneng et al., 2005; Putri et al., 2016; Santi et al., 2019)]. In addition, there are two varieties of *B. vulgaris*: var. *vulgaris* and var. *striata* and two cultivars of *S. brachycladum*: "Green" and "Yellow" (Huzaemah and Aryanti, 2016, Mentari et al., 2018, Munawarah et al., 2019, Peneng et al., 2005).

Bamboo culms have a number of properties that make them useful, including being strong, ductile, flat, hard, straight, easy to split, shape and work with, and light to carry. The benefits of bamboo for the community include light construction materials, furniture, handicrafts, composite boards (lamina board, particleboard, and fibre), paper-making raw materials, and others (Puspitasari & Wulandari, 2017).

Lestari (2014) has stated that the stems of *B. vulgaris* are rich in lignin, with a 20–30% lignin content. The lignification process is the last stage of cell development in woody plants. Lignin is a natural adhesive for cellulose fibre cells. Therefore, it can be assumed that the higher the lignin content, the higher the strength of bamboo, and its value as a construction raw material (Dransfield & Widjaja, 1995).

S. brachycladum cv. Green in Sulawesi, Sumatra, West Java and Lombok is usually used as a medium to cook sticky rice called Nasi Lemang. It is also used to hold new sap (*nira*), being carved into special containers such as those used for the sacred wine served during the Gawai festival. Another use is for household crafts such as *gedek* (woven bamboo for walls), *sokasi* (woven bamboo for containers with lids), *semat* (small ropes), photo frames and decorative materials. This bamboo is used in Bali for sacred water, *penjor*, *bale ivory*, and *sunari* (a type of sacred flute) (Arinasa & Peneng, 2013; Bambu batu. The House of Bamboo., 2022; Dransfiel, 2016; S. Schröder., 2022).

B. vulgaris var. *striata* is used to make furniture, cupboards, and shelves, while *B. vulgaris* var. *vulgaris* is often used as a support for forming concrete and for the manufacture of brooms and banana plant supports (S. Schröder., 2022; Tropical Plants Database, 2022). Both varieties of bamboo are used to make simple houses, stilts, huts, kitchens, warehouses, fences, and cattle pens (Arinasa & Peneng, 2013).

In this study, we investigated the anatomical properties of the culms of *S. brachycladum* cv. Green, *B. vulgaris* var. *striata* and *B. vulgaris* var. *vulgaris* to determine why each is favoured for the different types of uses described above.

The anatomical structure of bamboo culms is determined by the shape, size, arrangement, and number of vascular bundles. The number of vascular bundles is greater on the outside than the inside of the pith. The shape of the outer vascular bundle is oval and small, while the inner part is rounded and large. The amount decreases towards the end of the stem, and the arrangement becomes closer (Liese, 1998). Loiwatu & Manuhuwa (2008) suggested that the length and diameter of the stem fibres differ significantly among species and can be used to distinguish between species.

2. Materials and methods

2.1. Sampling

Bamboo stem samples were obtained from *B. vulgaris* var. *vulgaris* and var. *striata* growing in Mataram City and *S. brachycladum* cv. Green growing in Sidemen Village, Batu Layar District, West Lombok. Samples were taken from the shoots of young branches for permanent slides. Specimens were selected at the 3–8th segment from the tip, where the internode diameter was 0.4–0.7 cm. Maceration slides were prepared from mature branches, where the internodes were 1–1.5 cm in diameter, and cut 5 cm long.

2.2. Preparation Procedure

2.2.1. Preparation of transverse and tangential slices

Permanent slides were closed using glycerin-Jelly (Sass, 1958). Specimens were cut into pieces and fixed in 70% alcohol. Tangential cross sections of bamboo branches were obtained using standard freehand slices (Berden, 2020, Lux et al., 2005). The sample was sliced transversely and tangentially using a sharp (new) razor blade, resulting in a very thin incision. The incision sample was taken and placed on an object glass that has been washed by dripping water on it and then dried using tissue paper. The sample was then stained with 0.5% Safranin O (50% alcohol) and allowed to stand for 20 minutes. The incision sample was washed with 50% alcohol until clean. The incisions were dehydrated using 75% and 95% alcohol and stained with Aniline Blue, 1% of one part Aniline Blue and three parts Picric Acid in 95% alcohol, allowed to stand for 20 minutes, and washed with 95% alcohol. Rehydration was undertaken using 75% and 50% alcohol. Purification using 50% glycerin was carried out three times and the last closure used Glycerin-Jelly, with the edges of the cover glass being glued using Entellan.

2.2.2. Preparation of stem fibre slides

Bamboo stem fibre slides were made using the maceration method. The stem specimens were shaved using a razor blade, and the shavings were collected in a penicillin vial. Fine shavings were immersed in a

maceration solution of 30% Hydrogen Peroxide and 60% Glacial Acetic Acid, with a ratio of 1:1 (Han et al., 1999, Rizqiani et al., 2016). They were then heated in a water bath at a temperature of 60° C, for 1 hour. The fibre was then washed with running water until it was free of acid. Fibres were stained using 0.5% Safranin O (50% alcohol) (Mahesh et al., 2015), allowed to stand for 10 minutes, and then washed using 50% alcohol until the object glass was clear. Slides were cleared three times using 50% glycerin and the last closure used Glycerin-Jelly, with the edges of the cover glass again being glued using Entellan.

2.3. Observation of Anatomical Structure

Observations were mainly on the length and diameter of the fibre cells and the diameter of the fibre lumen; metaxylem diameter, and long and short cell length and diameter, as well as of the number of vascular bundles, periderm structure and trichome shape. Observations were based on three replicate slides using a Zeiss Binocular Microscope Primo Star type. Cell measurements using Image J software (Baviskar, 2011).

3. Results

3.1. Description of *B. vulgaris* var. *vulgaris* stem anatomy

The composition of the anatomical structure of the culm of *B. vulgaris* var. *vulgaris* starts from the outermost layer, namely the periderm tissue. The periderm consists of sclerenchyma fibre cells, and the outermost periderm tissue is the epidermal cells. These are tightly packed, rounded in shape, periderm surface is grooved (uneven) so that when seen with the naked eye the surface of the stem is like grooved and has stingous-type trichomes.

Periderm tissue is composed of a strand of sclerenchyma fibre tissue that stands alone and a network of sclerenchyma sheaths or vascular bundle sheets. The two networks are arranged alternately. Inside the periderm tissue is the pith tissue, which is composed of pith parenchyma (consisting of long cells and short cells). According to Nishida & Christophel (1999) there are eight patterns of thickening, namely: smooth and angular, irregularly thickened, and beaded, buttressed, branched, rounded, undulated, sinuous. Within the pith tissue, there are scattered, closed collateral-type vascular bundles. In the vascular bundle of *B. vulgaris* var. *vulgaris*, the vascular bundle tissue is of the closed collateral type and does not have a cambium. The vascular bundle network is composed of phloem and protoxylem flanked by two metaxylem, the tissue is surrounded by a sclerenchyma fibre sheath (vascular bundle sheet). The pith tissue is composed of vascular bundles and the pith parenchyma are scattered in the vascular bundle. The fibre cells are composed of long and short cells. Neither the long cells not the short cells contained starch (Fig. 1, Fig. 2, Fig. 3).

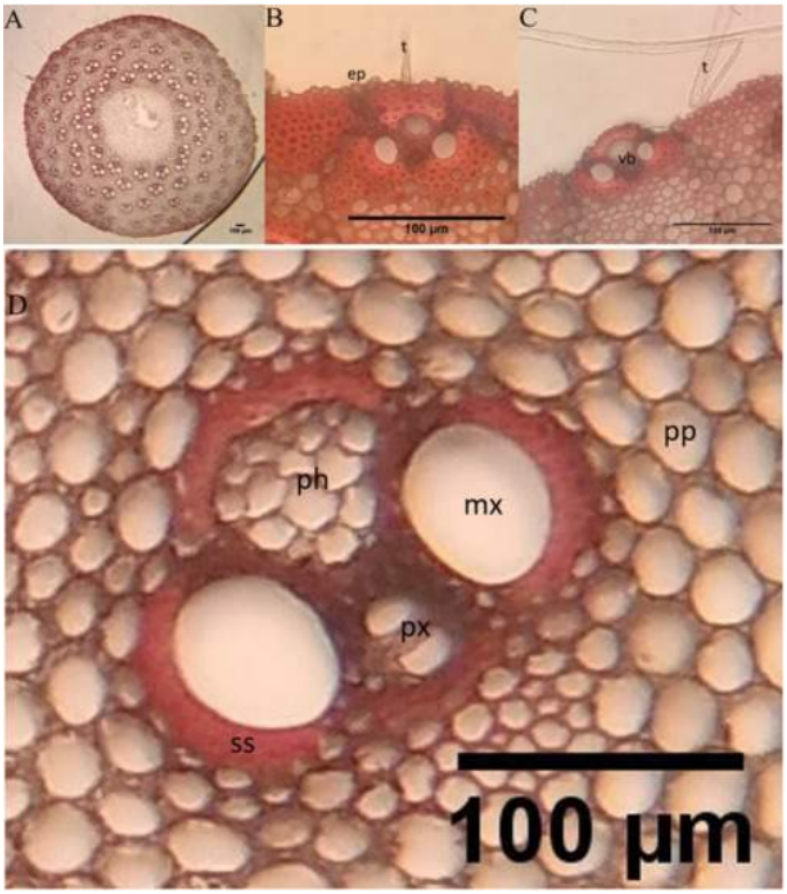

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Fig. 1. Cross-section of the culm of *B. vulgaris* var. *vulgaris*. Notes: A. outline of the cross-section of the stem; B and C. Periderm of the stem; D. Pith network and vascular bundle; ep. Epidermis; ph. Phloem; mx. Metaxylem; pp. Pith parenchyma; px. Protoxylem; ss. Sclerenchyma sheath; t. Trichome; vb. Vascular bundles.

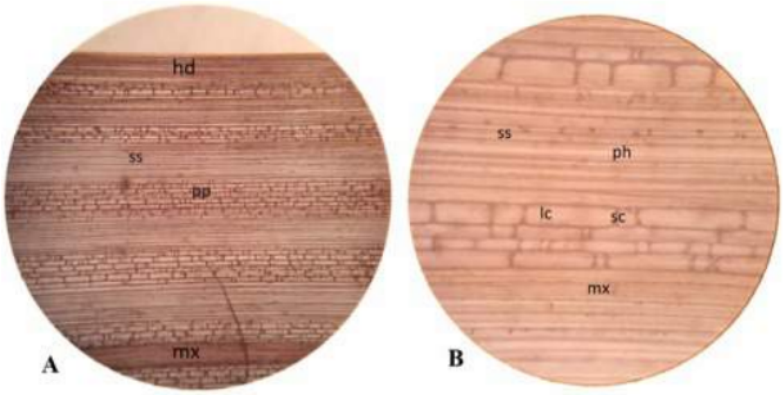

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Fig. 2. Tangential longitudinal section of the stem of *Bambusa vulgaris* var. *vulgaris*. Notes: A Tangential longitudinal section of the periderm, magnification 100x; B. The pith tangential longitudinal section, magnification 400x; hd. Hypodermis; lc. Long cell; mx. Metaxylem; ph. Phloem; pp. Pith parenchyma; sc. Short cell; ss. Sclerenchyma sheath.

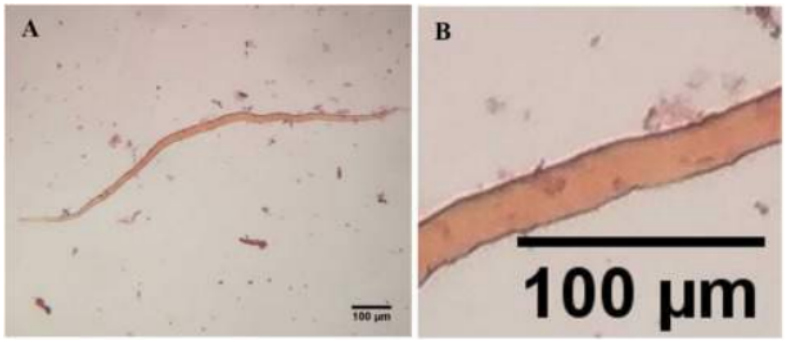

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Fig. 3. Tracheid fibre cells in the stem pith of *Bambusa vulgaris* var. *vulgaris*.

Long cells had an average thickness of 343 µm, and short cells 134 µm. These parenchymal pith cells have cell walls with beaded anticlinal thickening. *B. vulgaris* var. *vulgaris* fibre has characteristic short, thick and wide cells: 1461 µm length, 149 µm in diameter, and lumen diameter 127 µm. The vascular bundle is composed of phloem and protoxylem flanked by two metaxylem cells, with the diameter of the metaxylem cells being 105 µm (Fig. 1, Fig. 2; Table 1). The culm has a 2 cm thick pith, 7 cm in diameter, and a hole diameter of 3 cm. The segment is not very long, the lower internode 27 cm length, the middle 34 cm length, the top 37 cm length, the number of segments 32, and the stem 9 m in height (Fig. 2, Fig. 3; Table 2).

Table 1. Character size, number and type of cells and tissues that make up stems of *B. vulgaris* var. *vulgaris* and var. *striata* and *Schizostachyum brachycladum* cv. Green.

No	Variable	*B. vulgaris* var. *vulgaris*	*B. vulgaris* var. *striata*	*S. brachycladum* cv. Green
1	Fibre length (µm)	1452	1674	836
2	Fibre Diameter (µm)	149	85	148
3	Lumen Diameter (µm)	127	74	120
4	Long cell length (µm)	544	488	605
5	Long cell diameter (µm)	132	191	134
6	Short cell length (µm)	189	127	260
7	Diameter short cell (µm)	120	126	122
8	Diameter metaxylem (µm)	305	255	189
9	Number of vascular bundles	124	58	38
10	Trichome Type	Stingous, puberulous	Scabrous, puberulous	*Stingous, machete*
11	Vascular bundle type	Closed Collateral	Closed Collateral	Closed Collateral

Table 2. Stem characteristics of *B. vulgaris* var. *vulgaris* and var. *striata* and *Schizostachyum brachycladum* cv. Green.

No.	Variable	*B. vulgaris* var. *vulgaris*	*B. vulgaris* var. *striata*	*S. brachycladum* cv. Green
1	Stem pith thickness (cm)	2	2	0,8
2	Pit hole diameter (cm)	3	3	5,4
3	Stem Diameter (cm)	7	7	7
5	Stem length (m)	9	10	12
4	Number of internodes	32	38	23
6	Basal internode length (cm)	27	24	49
7	Middle internode length (cm)	34	33	62

No.	Variable	*B. vulgaris* var. *vulgaris*	*B. vulgaris* var. *striata*	*S. brachycladum* cv. Green
8	Above internode length (cm)	37	29	77

3.2. Description of *B. vulgaris* var. *striata* stem anatomy

The outer surface of the stem is lined with flat and dense epidermal cells, and there are two types of trichomes: scabrous and puberulous. The periderm is composed of strands of sclerenchyma tissue, pith tissue, and sclerenchyma sheath as a protective covering for the vascular bundle tissue (Fig. 4). Inside the periderm tissue is the pith parenchyma tissue (composed of long cells and short cells), as well as vascular bundles of closed collateral type, scattered within the pith tissue. The pith parenchyma cells are hexagonal (polygonal), the cells have cell walls with rounded-type thickenings and do not contain starch (Fig. 4, Fig. 5). The vascular bundle tissue is composed of phloem and two protoxylems flanked by two metaxylem, this tissue is surrounded by sclerenchyma tissue.

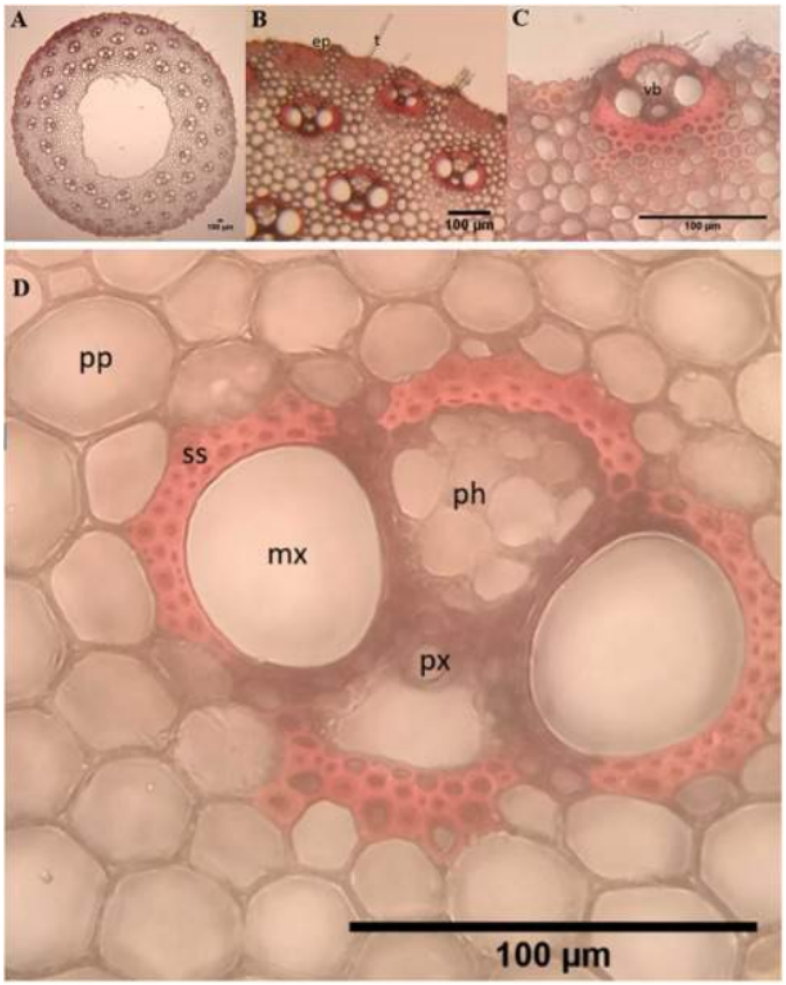

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Fig. 4. Cross-section of the culm of *Bambusa vulgaris* var. *striata*. Notes: A. Outline cross-section of the stem; B. and C. Periderm tissue of the stem; D. Pith tissue and vascular bundle; ep. Epidermis; t. Trichome., vb; Vascular bundles; pp. Pith parenchyma; mx. Metaxylem; ph. Phloem; ss. Sclerenchyma sheath; px. Protoxylem.

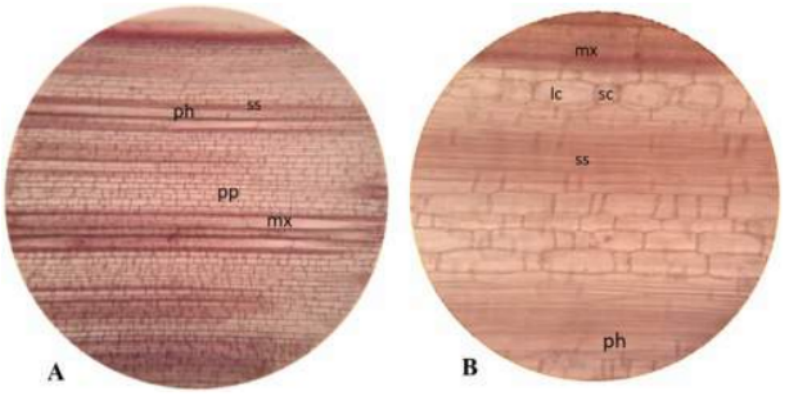

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Fig. 5. Tangential longitudinal section of the culm of *Bambusa vulgaris* var. *striata*. Notes: A. Tangential longitudinal section of the periderm, magnification 10×10; B. Tangential longitudinal section of the pith, magnification 10×40; lc. Long cell; mx. Metaxylem; ph. Phloem; pp. Pith parenchyma; sc. Short cell; ss. Sclerenchyma sheath.

The pith parenchyma has long cells with a mean length of 542 μm, and mean diameter of 191 μm. The short cells average 127 μm length and 126 μm diameter. Fibrer cells have cell walls that have an anticlinal thickening of the rounded type. Fibre in var. *striata* is leaner than var. *vulgaris*, (length 1461 μm, diameter 85 μm, and lumen diameter 74 μm) (Fig. 5, Fig. 6, Table 1). The vascular bundle structure is the same as in var. *vulgaris*, while the metaxylem diameter is narrower (255 μm) (Fig. 4, Table 1). Stem height of *B. vulgaris* var. *striata* is higher than var. vulgaris: 10 m, with a total of 38 segments, and the length of the lower segment is 24 cm, the middle segment is 33 cm, and the upper segment is 29 cm. However, the size of the stem diameter, stem hole and pith thickness were the same as var. *vulgaris* (Table 2).

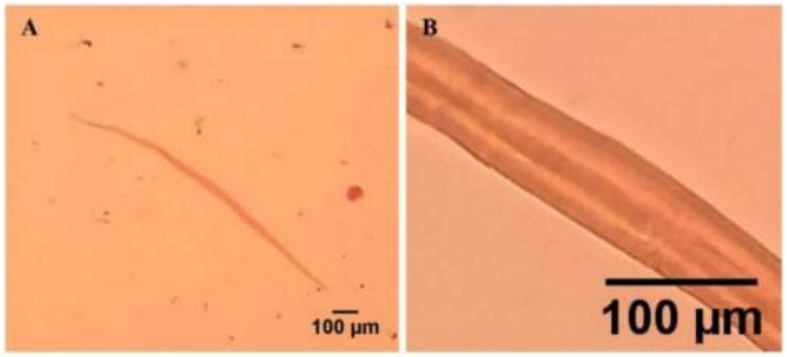

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Fig. 6. Tracheid fibre cells in the stem pith of *Bambusa vulgaris* var. *striata*.

3.3. Description of *Schizostachyum brachycladum* cv. Green stem anatomy

The outer surface of the stem is covered by epidermal cells which are round, dense, and flat, and only have protrusions on the peripheral vascular bundle. The epidermis has two types of trichomes: *stingous* and *machete* specific. The structure of the periderm is different to that of *B. vulgaris* var. *vulgaris* and var. *striata*. *S. brachycladum* cv. Green is composed of stacks of sclerenchyma tissue and a sclerenchyma sheath that protects the peripheral vascular bundle (Fig. 7). The pith consists of pith parenchyma and vascular bundles, and pith parenchyma tissue (composed of long cells and short cells) (Fig. 8). Its cells are round (circular) to diagonal (Fig. 7).

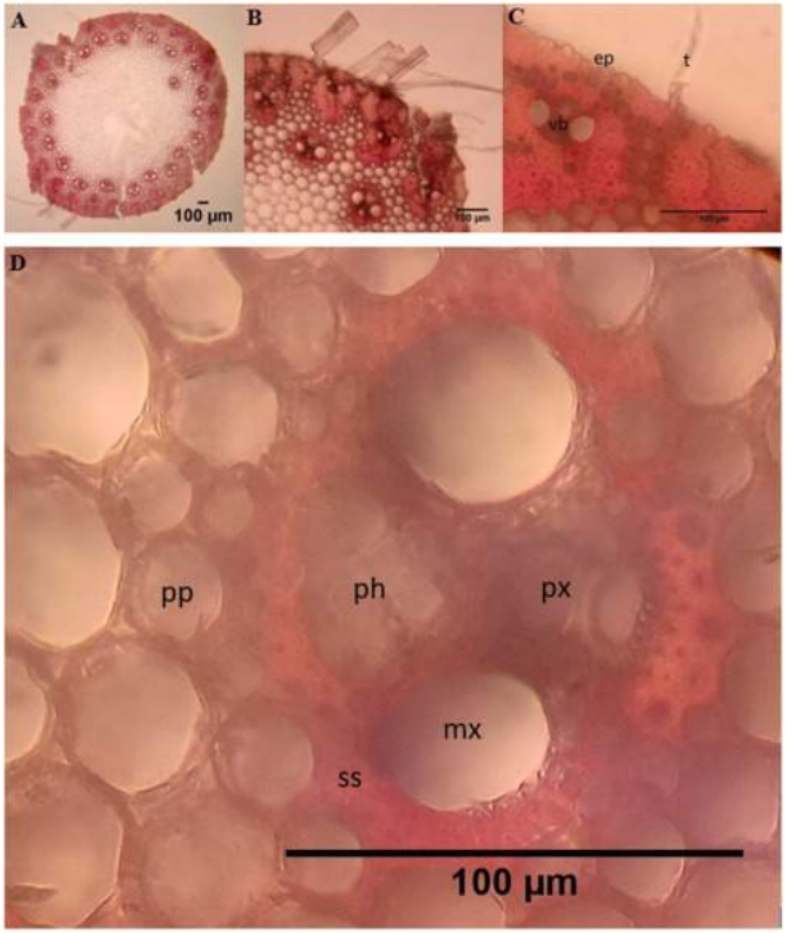

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Fig. 7. Cross-section of the culm of *Schizostachyum brachycladum* cv. Greens. Notes: A. Outline of the cross-section of the stem; B. Transverse slices of the periderms of the stem; c. Vascular bundle in the periderm; D. Pith; ep. Epidermis; t. Trichome., vb; Vascular bundles; pe. Pith parenchyma; mt. Metaxylem; ph. Phloem; ss. Sclerenchyma sheath; px. Protoxylem.

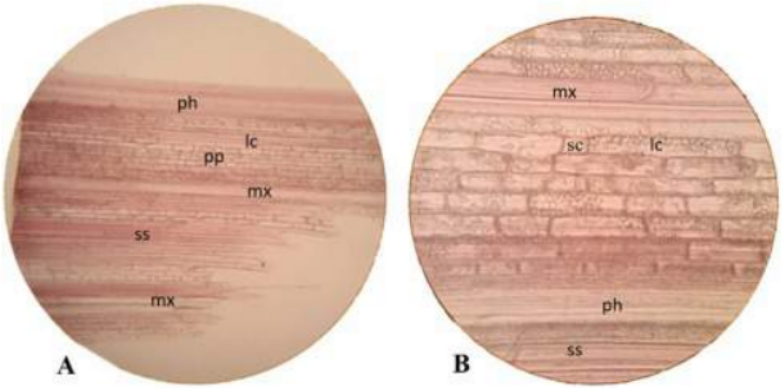

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Fig. 8. Tangential longitudinal section of the culm of *Schizostachyum brachycladum* cv. Green. Notes: A. Tangential longitudinal section of the periderm, magnification 10×10; B. The pith tangential longitudinal section, magnification 10×40; lc. Long cell; mx. Metaxylem; ph. Phloem; pp. Pith parenchyma; sc. Short cell; ss. Sclerenchyma sheath.

These parenchymal pith cells are characterized by irregular anticlinal thickening, and consist of long cells and short cells. The length of the pith parenchyma cells is greater than in *B. vulgaris* var. *vulgaris* and var. *striata*. Long cells have a length of 605 μm and diameter of 134 μm, and short cells are 260 μm long and 112 μm in diameter (Fig. 8, Fig. 9; Table 1). Vascular bundles are of the closed collateral type. Fibre cells had a length of 836 μm, diameter of 148 μm, lumen diameter of 120 μm and metaxylem diameter of 189 μm. The vascular bundle is surrounded by unbroken sclerenchyma tissue (the sclerenchyma sheath) (Fig. 7). A prominent character of this bamboo is the number of bundles, with at least 38 pieces (Table 1).

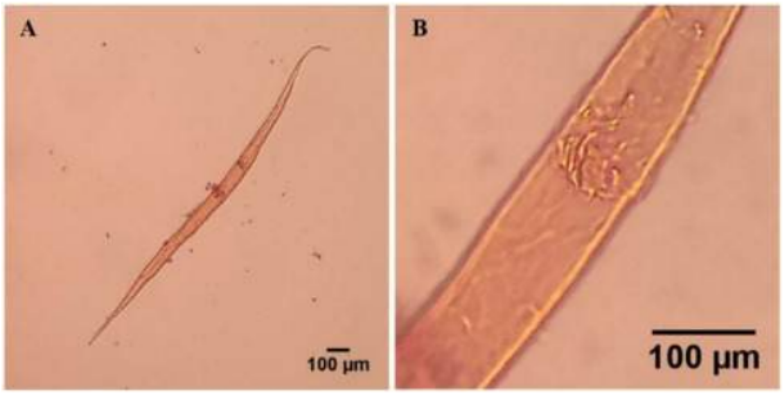

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Fig. 9. Tracheid fibre cells in the stem pith of *Schizostachyum brachycladum* cv. Green.

The stems of *S. brachycladum* cv. Green were taller than *B. vulgaris* var. *vulgaris*, with a stem height 12 m. However, they had the fewest internodes (23). Internode lengths reached 77 cm at the top of the stem, 62 cm in the middle and 49 cm at the base. The stem diameter was 7 cm, and the stem hole had the largest diameter, 5.4 cm, and the thinnest stem pith thickness (0.8 cm).

4. Discussion

B. vulgaris var. *vulgaris* from Mataram City, Lombok, has a fibre length of 1452 μm, whereas the value for the *striata* variety is 674 μm. This is much shorter than recorded elsewhere. For example, fibre length of *B. vulgaris* from Nigeria has been reported t be 2800–3700 μm (Aderounmu & Adelusi, 2019), while the fibre length of *B. vulgaris* from Sleman Yogyakarta, has been reported as being even longer: 3.28–3.98 mm ((Praptoyo & Yogasara, 2012). Differences in variety, species, organ (culms or branches), plant age, geography, and ecology can cause differences in fibre size. Fibre diameter and lumen of *B. vulgaris* var. *vulgaris* were 149 μm and 127 μm respectively, with the values for var. *striata* being 85 μm and 74 μm, respectively. The fibre diameter and lumen of *B. vulgaris* from Sabah, Malaysia were narrower, 7.1 μm (two year old) to 7.6 μm (four year old) and 2.4 μm (four year old) to 2.5 μm (two year old), respectively, but the fibre length was longer, namely 3.6–4.1 mm. This resulted in the fibres being long and slender (Wahab et al., 2010). The fibre length from this species grown on the Malay Peninsula was shorter than that from Sabah, Malaysia, but longer than Lombok, where it was 1.9–2.4 μm (Mohmod, 1996).

S. brachycladum cv. Green has the shortest fibre size: 836 μm, and a fairly wide diameter: 148 μm. The lumen diameter was 120 μm. In contrast to the fibre length of *S. brachycladum* from Malaysia which is three times longer at 2840 μm, but much slimmer, the fibre diameter was 23.73 μm, and the lumen diameter was 6.43 μm (Nordahlia et al., 2011). *S. brachycladum* fibres from the island of Seram, Moluccas, were the longest and very slender compared to the previous two locations. Fibre length was 3.55 mm, fibre diameter was 4.6 μm and the fiber lumen was 3 μm (Loiwatu & Manuhuwa, 2008). *B. vulgaris* var. *vulgaris* had the greatest number of bundles (124 pieces), while the others had less than half, with var. *striata* having 58 pieces and *S. brachycladum* cv. Green 38 pieces. However, the lowest number of vascular bundles was recorded in *B. vulgaris* var. *vulgaris* from Sabah, with only 36 pieces (Wahab et al., 2010).

A high vascular bundle count can be used as an indicator of high lignin content (which implies stronger material) and vice versa. *B. vulgaris* var. *vulgaris* is widely used for concrete supports, whereas var. *striata*, and *S. brachycladum* cv. Green contain small amounts of lignin and are good as a basic material for making paper. *S. brachycladum* cv Green has a thin pith layer (< 1 cm), so it is often used for making grilled sticky rice (*lemang*) in Lombok and Java.

The pith parenchyma of *B. vulgaris* var. *vulgaris* and var. *striata*, especially the long and short cells, did not contain starch, whereas *S. brachycladum* cv. Green contains starch. Solomon et al. (2020), have argued that the pith parenchyma of *B. vulgaris* in young stems contains starch. The base of the bamboo stem contains less starch than the middle and top. The maximum starch content in four-year-old bamboo stems differed between species, being 10.1% for *B. vulgaris* and 7.4% for *Gigantochloa atter* (Mohmod, 1996). The starch content in the stems of *B. vulgaris* from Java varied over the course of the year, being 0.48% in January and 7.97% in November (Liese, 1998).

The two varieties of *B. vulgaris* and *S. brachycladum* cv. Green had similar mature stem diameters (7 cm), and the thickness of the pith in var. *vulgaris* and striata were the same (2 cm). In contrast, *B. vulgaris* var. *vulgaris* originating from West Java had a thinner pith (13.34 mm) although the stem diameter was the same. *B. vulgaris* var. *striata* had a wood tissue thickness of 17.37 mm but a slightly wider culm diameter (7.9 cm) (Park et al., 2018). *S. brachycladum* cv. Green has a thinner pith than *B. vulgaris*, being less than 1 cm (0.8 cm). The greatest culm length occurred in *S. brachycladum* cv. Green (14 m), followed by *B. vulgaris* var. striata (12 m) and var. *vulgaris* (10 m). In contrast, *B. vulgaris* originating from Sabah was almost the same size as *S. brachycladum* cv. Green (14.52–14.69 m) (Wahab et al., 2010).

4.1. Identification key

Key to identification of stem anatomy of *B. vulgaris* and *S. brachycladum* varieties.

1. a. Periderm tissue is composed of stacked sclerenchyma tissue bundles. Long cells and short cells contain starch……*S. brachycladum* cv. Greens.

b. Periderm tissue is composed of a layer of a strand sclerenchyma tissues. Long cells and short cells do not contain starch ……2

2. a. Periderm tissue is only composed of 2 types of tissue, namely a layer of a strand of sclerenchyma tissues and vascular bundles. The pith fiber cell wall has beaded anticlinal wall thickening ……*B. vulgaris* var. *vulgaris*.

b. Periderm tissue is only composed of three types of tissue, namely a layer of sclerenchyma tissue bundles, pith parenchyma, and transport bundles. The pith fiber cell wall has an anticlinal wall thickening of the rounded type …… *B. vulgaris* var. *striata*.

5. Conclusion

The culms of *S. brachycladum* cv. Green have different characteristics to those of *B. vulgaris* especially in the structure of periderm, starch in the short and long cells, and the smallest number of vascular bundles in the pith tissues. *B. vulgaris* var. *vulgaris* can be distinguished from var. *striata* due to the arrangement of periderm and the number of vascular bundles.

Uncited references

(Bambu batu (2022)

Data availability

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23