Anatomical and Physical Characteristics of Three Species *of Schizostachyum* from Nagaland, India

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Abstract: The present study was carried out on three *Schizostachyum* species namely *S. dulloa*, *S. fuschianum* and *S. polymorphum* to evaluate the anatomical and physical characteristics and their variation across and along the culms. The vascular bundles were well developed and larger in size in middle zone at all height positions except top position of *S. polymorphum*. All the selected species had Type I vascular bundles in inner zone. Type II and Type III vascular bundles in *S. dulloa* and *S. polymorphum* and Type I and Type II vascular bundles in *S. fuschianum* were present in middle zone at bottom position. The number of vascular bundles increased but vascular bundle size (R/T ratio) decreased both along and across the culms in all the species. There was increase in fibre and parenchyma percentage along the culm height. Whereas, the vessel percentage did not show much variation. The dimensions of fibre, vessel and parenchyma characteristics (except fibre length and fibre diameter) decreased and most of them exhibited non-significant variation along and across the culms in all the species. Among physical characteristics, moisture content and shrinkage in culm wall thickness decreased along the culm height. While, there was increase in specific gravity and shrinkage in culm diameter. The results obtained from present study reveals that middle zone at bottom and middle positions is best for identification of *Schizostachyum* species. It will also be helpful to increase the utilization of these species for various end products.

Keywords: Culm height, Middle zone, Physical characteristics, *Schizostachyum species*, Tissue proportion

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Introduction

Bamboo is one of the important plant groups of family Poaceae. It is widely distributed in all parts of India except Kashmir. It helps in restoration of degraded land as it is able to thrive under any type of soil conditions (FSI, 2017). Due to its fast growth, high biomass production and annual growth, bamboo helps in carbon sequestration as that of fast growing tree species (Lobovikov *et al*., 2009). It has high strength to weight ratio and is considered as a suitable ecofriendly substitute to wood for future. Therefore, it is widely used in furniture, construction, pulp and paper, handicrafts and composite wood industries.

India is second largest producer of bamboos after China in the world. About 125 indigenous and 11 exotic bamboo species are reported to occur in India. More than 50% of bamboo species are found in north eastern states namely Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. Among these states, Arunachal Pradesh has the maximum bamboo bearing area

in recorded forests followed by Manipur, Assam, Nagaland, Meghalaya, Tripura, Mizoram and Sikkim (FSI, 2017). Nagaland lies in the extremes of North East India and is rich in bio resources. The people of Nagaland are dependent on the forest resources for their survival. Bamboos constitute one of the most important non-wood resources for people. The cutting of umbilical cord with bamboo during child birth and wrapping of dead body in a bamboo mat reflects its importance in their life from birth to death. In addition, they use bamboo for making agricultural and musical implements, shelter, food and livelihood.

There are about 10 genera and 39 species of bamboos which are widely distributed all over the state of Nagaland. *Schizostachyum* is one of the most important genera and is represented by six species in Nagaland (Bendangtemjen, 2016). Utilization of any bamboo species for various end uses are associated with anatomical, physical and mechanical properties. Most of the workers (Razak *et al*., 2006; Kelemwork, 2009) reported that strength, toughness, durability and preservative absorption of bamboos are related with anatomical properties, whereas the suitability of bamboos for different applications and their liability to chemical treatments are related to physical properties like density, moisture content and shrinkage (Razak *et al*., 2010). An examination of literature reveals a limited information on anatomical and physical properties of genus *Schizostachyum* (Nordahlia *et al*., 2011, 2015; Sharma *et al*., 2017). The present investigation was undertaken to study anatomical and physical properties and their variation across and along the culms of three *Schizostachyum* species.

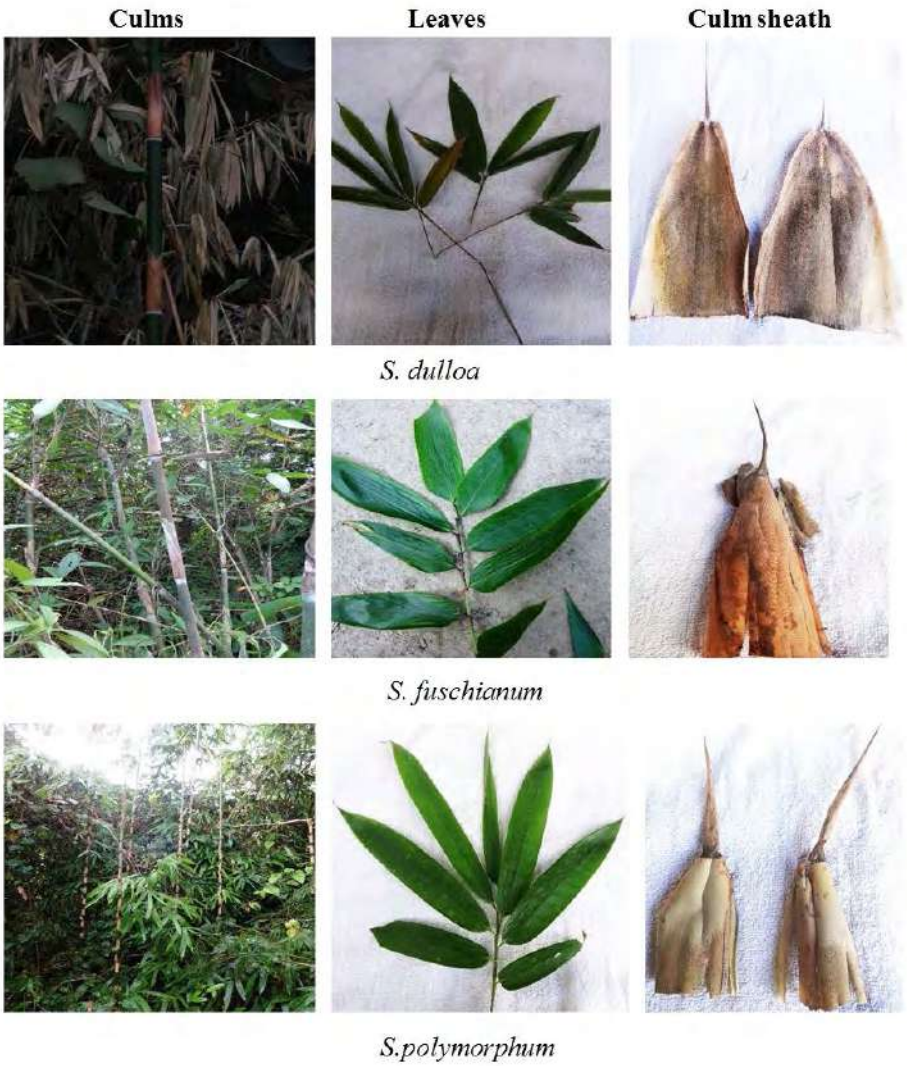

Fig 1. Morphological characteristics of selected *Schizostachyum* Species

Table 1. Morphological characteristics of selected species of *Schizostachyum*

Characteristics	*S. dullooa* Range (Mean±SD)	*S. fuchsianum* Range (Mean±SD)	*S. polymorphum* Range (Mean±SD)
Culm height(cm)	710-804 (757.8±42.65)	503-697 (580.2±83.39)	597-851 (710.2±96.21)
No. of internodes per culm	12-17 (14.2±1.92)	10-14 (12.00±1.58)	40-47 (43.60±2.70)
Internode length (cm)			
Bottom	42-75 (61.75±16.13)	33-52 (41.64±5.46)	13-21 (16.19±1.80)
Middle	52-80 (60.73±9.87)	40-59 (48.54±4.63)	11-24 (18.82±4.33)
Top	47-62 (51.67±5.09)	38-60 (46.91±5.56)	14-19 (15.52±1.62)
Internode diameter (cm)			
Bottom	2.9-3.6 (3.36±0.21)	2.2-2.9 (2.73±.25)	2.9-3.6 (2.85±0.19)
Middle	2.9-3.5 (3.26±0.18)	2.1-2.8 (2.66±0.23)	2.6-3 (2.78±0.16)
Top	2.2-2.9 (2.75±0.26)	2-2.7 (2.46±0.22)	2-2.5 (2.28±0.20)
Culm wall thickness(cm)			
Bottom	0.24-0.32 (0.29±0.03)	0.59-0.69 (0.65±.04)	0.22-0.26 (0.24±0.02)
Middle	0.21-0.24 (0.22±0.01)	0.41-0.51 (0.44±0.03)	0.14-0.20 (0.18±0.02)
Top	0.16-0.18 (0.17±0.005)	0.33-0.39 (0.35±0.02)	0.13-0.16 (0.15±0.009)

Materials and Methods

Study Site and Sample Collection

Three species of *Schizostachyum* namely *S. dul looa* (Gamble) Majumdar, *S. fuchsianum* (Gamble) Majumdar, *S. polymorphum* (Munro) Majumdar were collected from Old Chalkot and Asangki of Peren District, Nagaland (fig. 1). The geographical co-ordinates of the selected sites recorded with GPS were 25.30′54"N to 25.32′N and 93.38'E to 93.40′E.

Five mature culms of each species were harvested randomly from naturally grown clumps and cut at 30 cm above the ground. The age of culms was estimated on the basis of color of culm sheath, culm surface and by existing literature (Naithani, 2011). The clumps, culms, culm sheath and leaves were photographed in the field. All the physical characteristics like culm height, culm diameter, internode length, culm wall thickness at various heights were measured in green condition at the time of felling (Table 1). The top most portion of culms with lofty branches were discarded due to their small diameter and minimum wall thickness the number of internodes were counted from bottom to top in all culms. Accordingly, each culm was sub divided into three equal portions with approximate equal number of internodes and were labelled as bottom, middle and top positions. The cut ends were painted black to minimize sap evaporation and were brought to laboratory for further studies. The samples in the form of rings were taken from the middle portion of selected internodes from bottom to top and were divided into inner,

Table 2. Anatomical characteristics variation across and along the culms in *S. dulloa*

Position	Zone	FL (µm) (Mean± SD)	FD (µm) (Mean ± SD)	FLD (µm) (Mean ± SD)	FWT (µm) (Mean ± SD)	VL (µm) (Mean ± SD)	VD (µm) (Mean ± SD)	PL (µm) (Mean ± SD)	PD (µm) (Mean ± SD)
Bottom	Inner	3585.03±233.65a	16.76±2.80a	3.49±0.697a	6.64±0.77b	329.96±167.60a	66.99±40.01a	78.39±4.62a	44.71±4.02a
	Middle	3746.16±209.45a	17.41±1.02b	4.09±0.93ab	6.66±0.46b	332.70±99.11a	56.12±13.71a	81.12±5.93a	41.86±2.82a
	Outer	3713.00±235.66a	18.92±3.25b	4.29±0.85ab	7.32±0.49b	301.07±53.15a	45.98±8.75a	78.69±5.74b	38.46±2.89b
Middle	Inner	3570.50±194.06ab	15.41±0.43a	3.05±0.58a	6.18±0.29a	323.02±142.23a	60.53±29.66a	79.07±6.72ab	43.85±1.65a
	Middle	3610.61±269.08a	17.85±1.00b	3.74±1.16a	7.05±0.48a	360.01±84.38a	46.46±21.57a	81.14±7.40b	37.91±5.23a
	Outer	3508.01±326.36ab	18.45±1.14b	3.56±1.10a	7.44±0.73b	278.94±128.04a	61.66±28.17a	77.01±4.80b	38.78±4.53a
Top	Inner	3493.62±274.96a	14.73±0.59a	2.91±0.52a	5.91±0.30a	310.45±134.54ab	64.35±40.51a	73.80±6.45a	38.61±2.33a
	Middle	3490.12±207.60a	17.10±1.05b	3.38±0.85a	6.86±0.56b	380.66±84.54a	56.64±22.75a	76.68±3.88b	36.37±2.22a
	Outer	3193.05±170.70a	18.11±0.99c	3.38±0.92a	7.36±0.51b	280.51±129.01b	60.24±25.76a	74.77±4.39a	35.06±3.72a

FL-Fibre Length, FD-Fibre Diameter, FLD-Fibre Lumen Diameter, FWT-Fibre Wall Thickness, VL-Vessel Length, VD-Vessel Diameter, PL-Parenchyma Length, PD-Parenchyma Diameter
Values with same letter in the same column are not significantly different at 0.05 probability level

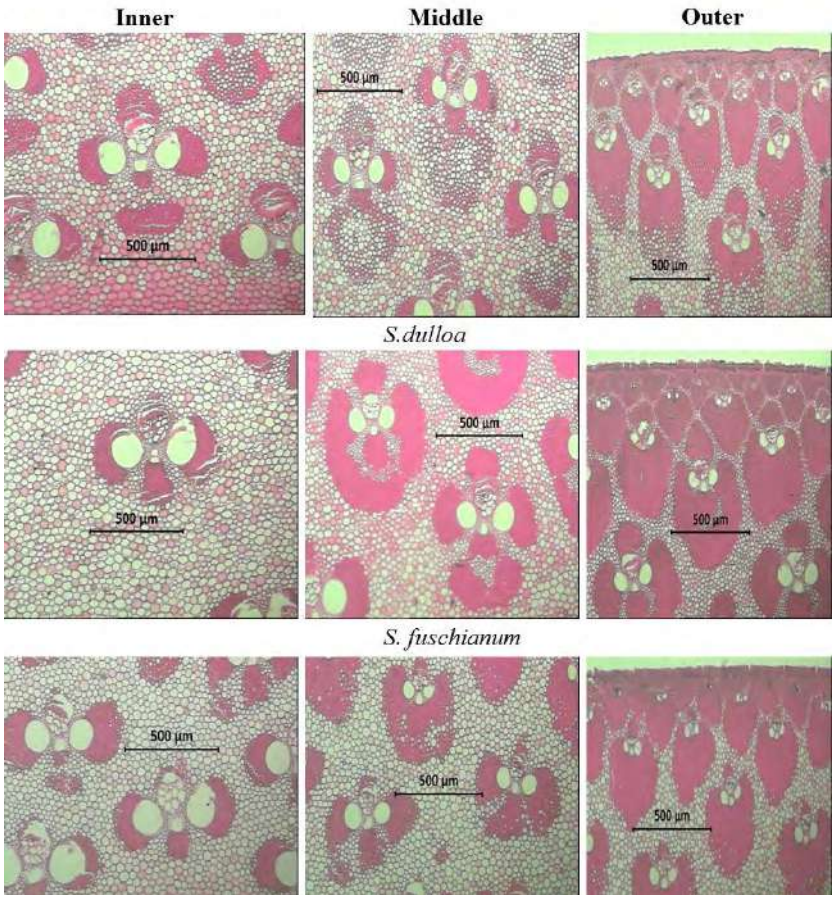

Fig 2. Cross-sections of culms of selected *Schizostachyum* species showing vascular bundles in different zones at bottom position

middle and outer zones across the culms radially for bottom, middle and top positions.

Determination of Anatomical Characteristics

The middle portion of the internodes about 2.5 cm long was cut from bottom, middle and top positions along the culms and preserved in FAA solution for 24 hours and then shifted to 70% alcohol for further preservation. Blocks of 2.5 cm x 1 cm of culm were taken from the preserved samples at each height positions. Cross-sections were cut with the help of a sliding microtome. Permanent slides were prepared by following standard method for further studies (Johansen, 1940).

For determination of number of vascular bundles per mm^2, 10 fields from each zone (outer, middle and inner) were selected. Radial and tangential

Fig 3. Variation in number of vascular bundles across the culms at different height positions

Table 3. Anatomical characteristics variation across and along the culms *S. fushianum*

Position	Zone	FL (µm) (Mean± SD)	FD (µm) (Mean±SD)	FLD (µm) (Mean± SD)	FWT (µm) (Mean± SD)	VL (µm) (Mean±SD)	VD (µm) (Mean± SD)	PL (µm) (Mean± SD)	PD (µm) (Mean± SD)
Bottom	Inner	3517.81±221.47a	14.82±2.04b	3.48±0.969a	5.68±0.32a	478.05±301.15a	118.34±62.20a	78.50±4.25a	43.10±4.09a
	Middle	3765.67±146.17a	15.15±0.96a	3.57±1.36a	5.79±0.79a	336.65±76.61a	97.10±74.30a	82.57±12.64a	46.84±2.74b
	Outer	3735.00±271.84a	15.29±2.29a	3.07±1.05a	6.11±0.61a	308.94±118.90a	69.14±31.79b	69.64±6.50a	33.08±5.61a
Middle	Inner	3768.01±178.82b	15.15±1.05a	3.55±0.79ab	5.80±0.35a	223.36±15.57a	59.45±8.58a	82.29±8.89b	47.69±3.55b
	Middle	4186.60±266.37b	16.04±1.01a	3.65±0.90a	6.20±0.35a	282.12±76.41 a	67.60±20.62ab	77.50±6.76ab	40.73±3.68a
	Outer	3858.90±419.29b	15.62±0.67a	2.99±0.87a	6.31±0.36a	266.72±146.01a	45.92±15.67a	66.30±9.33a	33.37±5.05a
Top	Inner	3470.44±412.51a	14.48±0.69a	3.96±0.76ab	5.27±0.25a	391.52±213.45a	111.74±83.35a	77.13±7.21a	37.01±3.64a
	Middle	3415.23±371.15a	15.22±1.04a	3.79±0.97a	5.72±0.36a	208.91±20.25a	49.04±10.02a	76.12±6.67b	38.13±2.82a
	Outer	3216.07±228.78a	14.67±1.01a	3.42±0.86a	5.62±0.54a	273.96±82.18a	46.09±17.16ab	67.95±10,06a	33.11±6.22a

FL-Fibre Length, FD-Fibre Diameter, FLD-Fibre Lumen Diameter, FWT-Fibre Wall Thickness, VL-Vessel Length, VD-Vessel Diameter, PL-Parenchyma Length, PD-Parenchyma Diameter

Values with same letter in the same column are not significantly different at 0.05 probability level

Table 4. Anatomical characteristics variation across and along the culms *S. polymorphum*

Position	Zone	FL (µm) (Mean± SD)	FD (µm) (Mean±SD)	FLD (µm) (Mean± SD)	FWT (µm) (Mean± SD)	VL (µm) (Mean±SD)	VD (µm) (Mean± SD)	PL (µm) (Mean± SD)	PD (µm) (Mean± SD)
Bottom	Inner	3510.74±726.92a	17.22±3.08a	5.60±1.74b	5.81±1.13ab	420.05±223.08a	77.82±37.72a	78.18±13.23a	43.83±4.72a
	Middle	3519.65±301.65a	16.74±0.81b	5.18±1.89b	5.78±0.84a	386.65±66.50a	85.01±70.81a	81.12±9.41a	38.96±3.62a
	Outer	3074.60±568.99b	16.21±3.12a	4.91±2.47b	5.85±0.67a	240.68±156.70a	38.27±11.64a	74.49±9.41ab	28.55±3.44a
Middle	Inner	3458.80±232.29a	16.76±1.52b	4.09±1.25b	6.04±0.57 a	472.53±169.90b	74.13±39.55a	65.59±18.56a	35.74±2.63a
	Middle	3543.38±150.79a	15.93±1.89a	3.95±1.01a	6.33±1.03a	450.47±250.61a	114.96±78.37b	67.80±11.51a	40.03±4.80a
	Outer	3406.70±308.55a	16.16±0.92a	4.09±1.18a	7.23±2.95a	396.24±218.20a	61.50±39.24a	66.26±8.36a	34.48±5.55a
Top	Inner	3585.58±269.46a	15.31±1.06b	4.54±1.70b	5.72±0.45a	613.76±215.56b	105.48±34.73a	75.23±11.55a	47.47±4.13b
	Middle	3538.66±315.83a	15.81±1.46ab	5.36±1.47b	5.41±0.18a	618.98±177.38b	159.83±82.80b	65.73±7.98a	34.65±2.88a
	Outer	3110.99±314.50a	16.38±1.36b	4.94±1.92b	7.26±3.29b	267.96±99.05a	37.99±11.11a	102.57±73.9a	42.94±2.87a

FL-Fibre Length, FD-Fibre Diameter, FLD-Fibre Lumen Diameter, FWT-Fibre Wall Thickness, VL-Vessel Length, VD-Vessel Diameter, PL-Parenchyma Length, PD-Parenchyma Diameter
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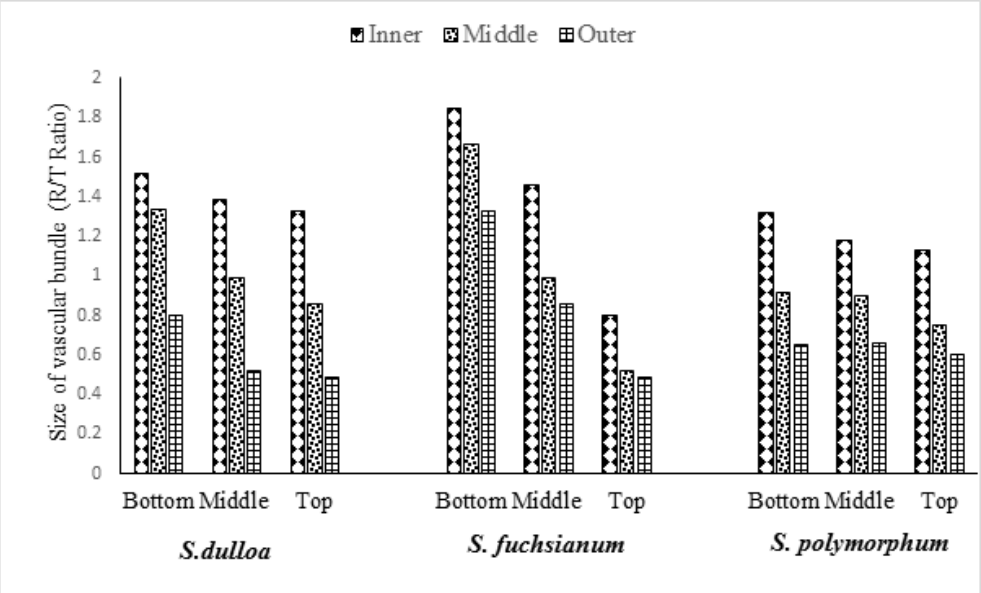

Fig 4. Variation in size of vascular bundles across the culms at different height positions

diameters of 50 vascular bundles of each zone at each height position (bottom, middle and top) were taken at 100x magnification. Types of vascular bundles present in each species were classified according to Grosser and Liese (1971). The tissue percentage of xylem elements (fibres, vessels and parenchyma) was determined by selecting 10 fields at each height (bottom, middle and top) position.

For biometric analyses, the bamboo slivers were cut radially and macerated with Franklin's solution at 60°C for 24 hours in an oven till the materials become soft and white in color. Temporary slides for measurement of xylem elements were prepared in 50% glycerol. A total of 50 fibres, 30 vessels and 30 parenchyma were selected randomly from each zone (inner, middle and outer) to measure their dimensions. Fibre length and vessel length were taken at 40X magnification while other dimensions like fibre diameter, fibre wall thickness, vessel diameter, parenchyma length and parenchyma diameter were taken at 400X magnification.

Determination of Physical Properties

Blocks of 2.5 × 1 cm culm were taken from the middle of the internodes at different heights (bottom, middle, top). Moisture content was determined by using IS 6874 (2008). Specific gravity was determined by water displacement method. At each height position (bottom, middle and top), a total of 45 replicates (15×3) were taken for determination of moisture content and specific gravity. For determination of shrinkage in wall thickness and culm diameter, samples were taken in the form of rings from middle portion of internodes at each height position and were determined by following the method of Kamruzzaman *et al*., (2008). The percentage shrinkage in culm diameter and wall thickness were determined as given by Panshin and deZeeuw (1980).

Statistical analyses were performed by using SPSS 16.0 software.

Results

The culms of *S. dulloa* were maximum in height and had longest internodes with maximum diameter. The maximum number of internodes in *S. polymorphum* and maximum culm wall thickness in *S. fuschianum* were observed (Table1).

The selected *Schizostachyum* species were covered by epidermis with elongated cells and stomata. The cortex was present below epidermis and number of vascular bundles were scattered in the ground tissue consisting of round shaped parenchyma cells. The innermost 4-5 layers of ground tissue lining the culm wall consisted of radially flattened hexagonal parenchyma cells. The anatomical characters were studied in inner, middle and outer zones across the culm wall at all height positions. The vascular bundles were small and incomplete with

Table 5. Physical properties of selected Schizostachyum species at different height position

Species	Position	Moisture content	Specific gravity	Shrinkage	
				Culm diameter	Culm wall thickness
S. dulloa	Bottom	37.50±7.87	0.62±0.12	3.10±1.45	4.70±2.34
	Middle	25.86±8.19	0.63±0.03	6.99±5.50	4.72±1.54
	Top	22.16±5.88	0.63±0.02	13.20±8.58	5.21±2.56
S. fuschianum	Bottom	89.64±7.52	0.55±0.04	7.49±2.91	18.74±3.96
	Middle	68.85±5.76	0.56±0.02	10.21±4.84	11.38±3.86
	Top	51.24±4.55	0.58±0.02	14.46±4.97	5.61±1.87
S. polymorphum	Bottom	68.09±17.18	0.53±0.31	5.91±2.23	14.57±4.14
	Middle	44.21±8.63	0.57±0.03	11.30±3.35	10.72±3.28
	Top	31.36±7.91	0.59±0.03	15.07±9.55	7.33±3.38

or without metaxylem vessels in peripheral layers of outer zone. Below it, most of the vascular bundles had sclerenchymatous sheath fused with fibrous strands as in other bamboo species. The anatomical characters studied in inner, middle and outer zones across the culm wall at all height positions were given in fig. 2 which showed that vascular bundles were small and incomplete with or without metaxylem vessels in peripheral layers of outer zone. Type II and III vascular bundles were present at bottom and middle positions of *S. dulloa*. Type I and II vascular bundles at bottom position and Type II vascular bundles in middle position of *S. fuschianum* were seen. Type II and III vascular bundles at bottom position and Type II vascular bundles in middle position of *S. polymorphum* were observed. In top position, the middle zone consisted of Type II vascular bundles in *S. dulloa* and *S. fuschianum* but in *S. polymorphum*, number of undifferentiated vascular bundles with fused sclerenchymatous and fibrous sheath were observed. All the species had Type I vascular bundles in inner zone at all height positions.

The number of vascular bundles per mm^2 increased from inner to outer zone and bottom to top in all species. The number of vascular bundles was maximum in *S. polymorphum* and the average number was 3.63, 3.66 and 3.56 at bottom, middle and top positions (fig. 3). The vascular bundles of *S. fuschianum* were biggest in size with average R/T ratio of 1.61, 1.10 and 0.60 at bottom, middle and top positions. There was decrease in size of vascular bundles (R/T ratio) across and along the culms in all species (fig. 4).

The results given in fig. 5 showed that the fibre percentage was maximum in *S. dulloa*. On contrary to it, parenchyma percentage was maximum in *S. fuschianum* than *S. polymorphum* and *S. dulloa*. However, the vessel percentage did not show much variation among species. An increase in fibre and parenchyma percentage and decrease in vessel percentage from bottom to top was observed in all species. The variation in anatomical characteristics across and along the culms of different *Schizostachyum* species presented in Tables 2-4 showed that fibre characteristics namely fibre length, fibre diameter and fibre wall thickness varied from 3074.60±568.99µm (*S. polymorphum*) to 4186.60±266.37µm (*S. fuschianum*), 14.82±2.04µm (*S. fuschianum*) to 18.92±3.25µm (*S. dulloa*) and 5.68± 0.32µm (*S. fuschianum*) to 7.32± 0.49µm (*S. dulloa*), 38.27± 11.64µm (*S. polymorphum*) to 97.10±74.30µm (*S. fuschianum*). Vessels had length and diameter from 223.36±15.57µm (*S. fuschianum*) to 613.76±215.56µm (*S. polymorphum*) and 37.99±11.11µm (*S. polymorphum*) to 118.34±62.20µm (*S. fuschianum*). The length and diameter of parenchyma ranged from 65.73±7.98µm

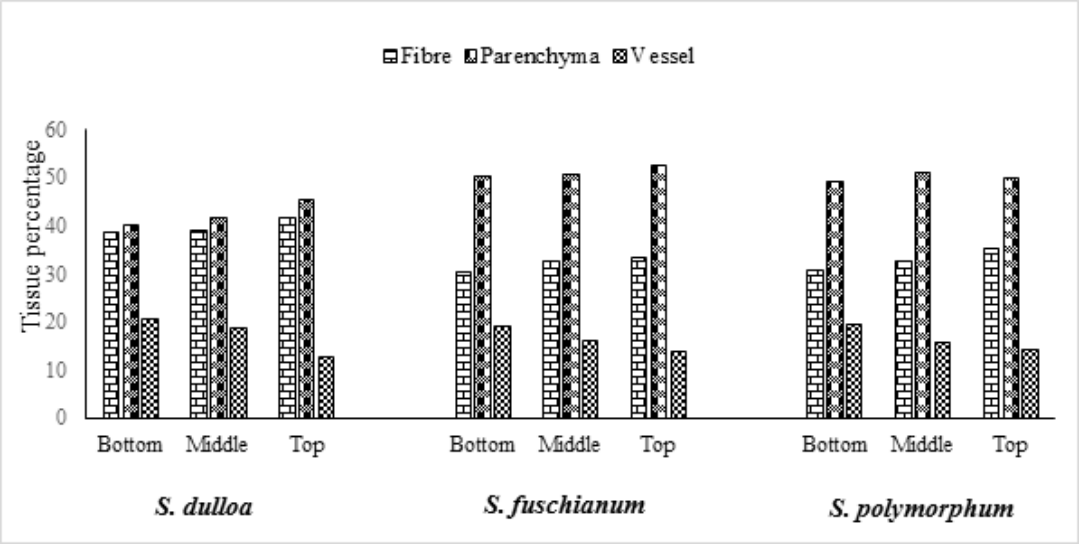

Fig 5. Tissue proportion of selected species at different height positions

(*S. polymorphum*) to 82.57±12.64µm (*S. fuschianum*) and 28.55±3.44 µm (*S. polymorphum*) to 43.83±4.72µm (*S. dulloa*). The dimensions of fibre, vessel and parenchyma characteristics (except fibre length and fibre diameter) decreased across and along the culms and most of them exhibited non-significant variation along and across the culms in selected species.

The moisture content was highest in *S. fuschianum* and minimum in *S. dulloa* whereas, specific gravity was highest in *S. dulloa* than other two species. The shrinkage in culm diameter and culm wall thickness was minimum in *S. dulloa* than *S. fuschianum* and *S. polymorphum*. In all selected species, moisture content and shrinkage in wall thickness decreased from bottom to top. On the other hand, specific gravity and shrinkage in culm diameter increased from bottom to top in all species (Table 5).

Discussion

The present study revealed variation in types of vascular bundles in middle zone of both bottom and middle positions along the culm height. Type II and III vascular bundles at bottom and middle positions of *S. dulloa*, Type I and II vascular bundles at bottom position, Type II vascular bundles in middle position in *S. fuschianum*, Type II and III vascular bundles at bottom positions and Type II vascular bundles in middle position of *S. polymorphum* were observed. In top position, the middle zone consisted of Type II vascular bundles in *S. dulloa* and *S. fuschianum* but in *S. polymorphum*, number of undifferentiated vascular bundles with fused sclerenchymatous and fibrous sheath were observed. All the species had Type I vascular bundles in inner zone at all height positions. The present study reveals variation in types of vascular bundles in *Schizostachyum* species along and across the culms. The types of vascular bundles were studied in inner, middle and outer zones whereas most of the workers have studied types of vascular bundles in middle zone only (Nordahlia *et al*., 2015; Grosser and Liese, 1971).

The number of vascular bundles per mm^2 increased from inner to outer zone across the culm wall and bottom to top in all species. The more number of vascular bundles in *S. polymorphum* may be due to presence of only one type of vascular bundles (Type II). Along the culm height, maximum number of vascular bundles were present in the outer zone of top position of *S. polymorphum* because the vascular bundles were smaller and arranged more compactly than other two species. The present findings corroborates with the result of Maya *et al*., (2013) and Razak *et al*., (2006, 2010).

The vascular bundle size is determined by taking ratio of its radial and tangential diameter (R/T) in bamboos. Most of the workers have observed increase in R/T ratio from inner to outer zone (Wang *et al*., 2011; Razak *et al*., 2012; Kumar *et al*., 2015

and Xing *et al*., 2015). On contrary to it, decrease in R/T ratio of vascular bundles from inner to outer zone across the culm wall and from bottom to top positions along the culm height was observed in present study. The decrease in R/T ratio across the culm wall and along the culm height may be due to less tangential diameter of vascular bundles in the middle and outer zones. Similar observations were made in other *Schizostachyum* species by Sharma *et al.*, (2017).

The fibres are long, slender, thick walled with pointed ends. They are present in the form of sheath around the vessel and also in the form of isolated strands in bamboos (Grosser and Liese, 1971). Vessels were long drum or barrel shaped with or without tails. The parenchyma cells were thin walled and rectangular in shape. Bamboo stem tissue constitute 44-45% fibres, 47-48% parenchyma and 8% vessels. The present study reveals that tissue proportion varies from species to species and even within same species along culm height. The fibre percentage was maximum in *S. dulloa*. On contrary to it, parenchyma percentage was maximum in *S. fuschianum* than *S. polymorphum* and *S. dulloa*. However, the vessel percentage did not show much variation among species. Overall, the selected species had 30.36 – 41.64% fibres, 40.45-52.45% parenchyma and 12.46-20.73% vessels.. The condensation of vascular bundles and small sized parenchyma cells may attribute to increase in fibre and parenchyma percentage at the top position and along the culms. The vessel percentage was higher at base and middle positions in selected species due to presence of well-developed vascular bundles in inner and middle zones. The variation in quantitative anatomical characteristics of selected species are comparable with other bamboo species (Nordahlia *et al*., 2012, 2015; Sharma *et al*., 2017; Wang *et al*., 2016; Xing *et al*., 2015).

Moisture content, specific gravity and shrinkage are important physical properties for bamboo utilization. These properties are related to anatomical characteristics and affect the dimensional stability and strength of bamboos (Anokye *et al*., 2014). The present study revealed maximum moisture content in *S. fuschianum* due to more parenchyma percentage as compared to *S. polymorphum* and *S. dulloa*. The maximum percentage of fibres in *S. dulloa* may be the reason for highest specific gravity among all species. In all species, moisture content and shrinkage in culm wall thickness decreased from bottom to top which may be due to decrease in diameter of parenchyma cells and vessels. The increase in fibre percentage and number of vascular bundles in outer zone may contribute to increase in specific gravity along the culm height in all species. Shrinkage in culm diameter increased from bottom to top in all selected species which may be due to increase in parenchyma percentage along the culm height. The present study corroborates the previous report in other *Schizostachyum* species (Sharma *et al*., 2017).

Conclusions

The present study on anatomical and physical characteristics of *Schizostachyum* species revealed that all species had similar type of vascular bundles (Type I) in inner zone and these were small and incomplete with or without *metaxylem* vessels in peripheral layers of outer zone. A variation in types of vascular bundles in bottom and middle positions of selected species were observed. The number of vascular bundles increased across and along the culms in all species. R/T ratio of vascular bundles decreased along and across the culm wall. The fibre, vessel and parenchyma characteristics (except fibre length and fibre diameter) decreased across and along the culms in all species and most of them exhibited non-significant variation along and across the culms in selected species. In all selected species, moisture content and shrinkage in wall thickness decreased from bottom to top. While, specific gravity and shrinkage in culm diameter increased from bottom to top. Based on the present study, middle zone at bottom and middle positions is best for identification of *Schizostachyum* species. Since all species have desirable anatomical and physical characteristics, they may have good potential for basketry, handicrafts and other general utility products.

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