CHAPTER - 5
RESULTS AND DISCUSSION

5.1. Dimensional study of external culm structures

In bamboo the external dimensional characters of different species is different. The strength of a bamboo can determined with the help of its external dimensional characters. In bamboo the numbers of vascular bundle are higher towards the apex. In the apex region, the culm wall is much thinner than the base with longer fiber length which result the less registance to external forces and also the less strength than the base portion of the culm. The result of the present study shows that the bamboo species with thicker and shorter internodes have higher concentration of vascular bundle and shorter fiber length which are the important properties for strength in bamboo. The external morphological structure of bamboo performs both analytical and interpretative values of bamboo (Stapleton, 1997).

The length and shape of culm sheath distinctly varies from species to species (Chatterji and Raizada, 1963). The dimensional study of bamboo culm of *Dendrocalamus strictus* was studied by Bhonde *et al*. (2014). The culm diameter and culm wall thickness of 3 years old *Bambusa blumeana*, *B. vulgaris* and *Gigantochloa scortechinii* were studied by Abd. Latif *et al*. (1990). The finding of these studies revealed the culm diameter of *B. blumeana* as 8.71 cm followed by *B. vulgaris* as 8.62 cm and *G. scortechinii* as 7.52 cm. The record of culm wall thickness of *B. blumeana*, *B. vulgaris* and *G. scortechinii* was 0.98 cm, 0.91 cm and 0.58 cm respectively. The present dimensional study of 6 numbers of bamboo species was confined to total culm height, culm diameter, culm wall thickness, internodes, leaves and culm sheath. The result of dimentional values of the external culm structure were presented in **Table 5.1**. The result showed the *B. polymorpha* with the highest culm length of 1890.53±66.37 cm followed by *M. baccifera* with 1850.72±34.75 cm and the *B. assamica* showed the lowest culm length with 1209.34±114.55 cm. The result of culm diameter and culm wall thickness of studied bamboo species followed the same pattern *i.e.* larger the culm diameter larger the culm wall thickness as described by Abd. Latif *et al*. (1990). The result showed *B. bambos* with culm diameter and culm wall thickness of 9.50±1.80 cm and 20.80±2.07 mm respectively and *B. assamica* with smallest culm diameter and culm wall thickness of 3.08±1.22 cm and 3.50±3.31 mm respectively.

Table 5.1: Average dimensional values of external structure of studied bamboo species

Sample no.	Number of individual sample studied	Average total numbers of internodes (nos.)	Average length of internodes (cm)	Average culm height (cm)	Average culm diameter (cm)	Average culm wall thickness (mm)	Average length of leaves (cm)	Average width of leaves (cm)	Average length of culm sheath (cm)	Average width of culm sheath (cm)
1	5	33.44 ±1.95	40.37 ±0.96	1550.12 ±26.15	8.25 ±1.58	12.10 ±3.03	24.48 ±1.50	2.39 ±0.75	11.63 ±1.33	22.59 ±3.97
2	5	30.92 ±2.11	38.40 ±1.16	1209.34 ±14.55	3.08 ±1.22	3.50 ±3.31	24.62 ±2.55	3.34 ±0.87	15.58 ±1.49	11.53 ±1.99
3	5	36.80 ±1.48	44.52 ±2.63	1758.09 ±44.16	7.13 ±2.00	10.80 ±2.29	22.62 ±1.79	2.46 ±0.86	18.48 ±2.34	20.51 ±2.88
4	5	38.25 ±1.48	45.66 ±3.07	1850.72 ±34.75	6.22 ±1.87	04.70 ±0.60	27.86 ±1.66	4.82 ±0.69	15.24 ±1.58	24.36 ±2.98
5	5	42.41 ±3.05	41.61 ±1.52	1890.53 ±66.37	8.15 ±1.30	09.80 ±0.79	29.74 ±1.59	2.66 ±0.55	23.86 ±2.96	30.48 ±2.56
6	5	32.73 ±2.13	39.13 ±2.76	1278.17 ±42.04	9.50 ±1.80	20.80 ±2.07	18.36 ±2.06	2.14 ±0.55	20.24 ±2.57	16.12 ±3.36

Note:1. *Bambusa garuchokua* Barooah *et* Borthakur., 2. *B. assamica* Barooah *et* Borthakur., 3. *B. pallida* Munro., 4. *Melocanna baccifera* (Roxb.) Kurz., 5. *B. polymorpha* Munro., 6. *B. bambos* (L.) Voss.

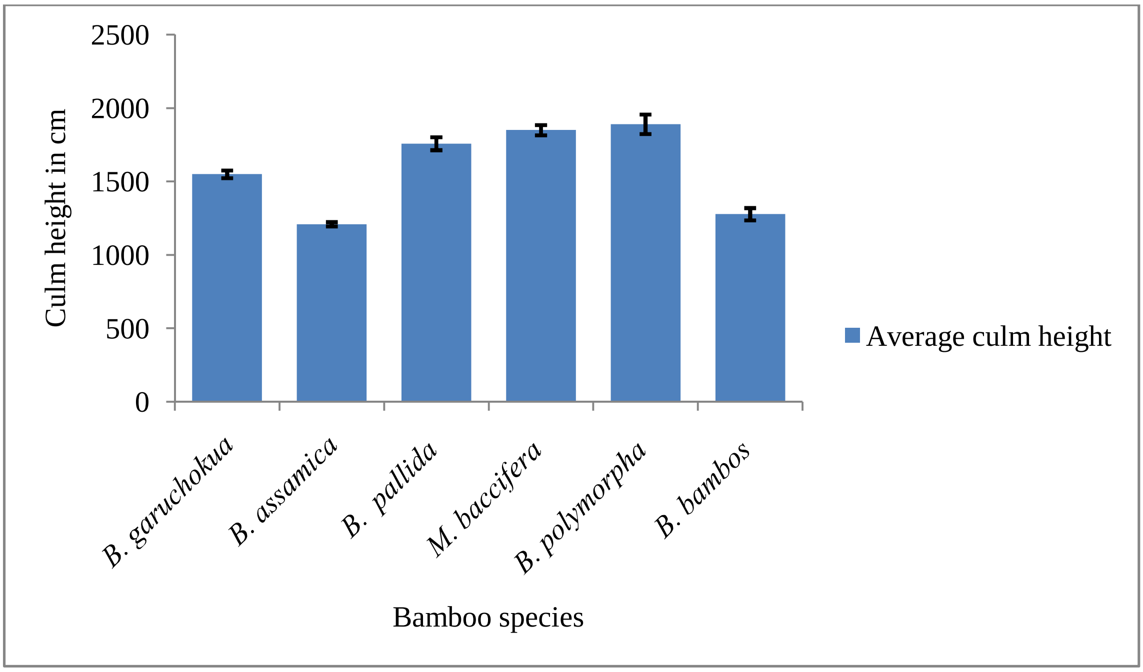


Figure 5.1: Average of culm height of studied bamboo species

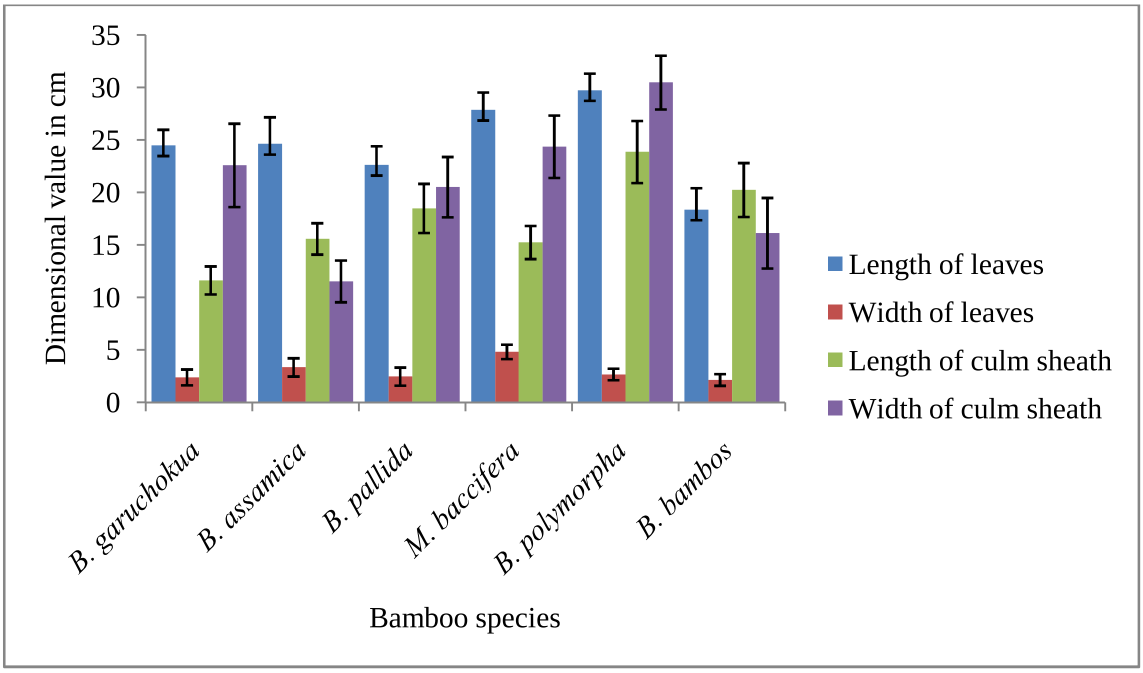
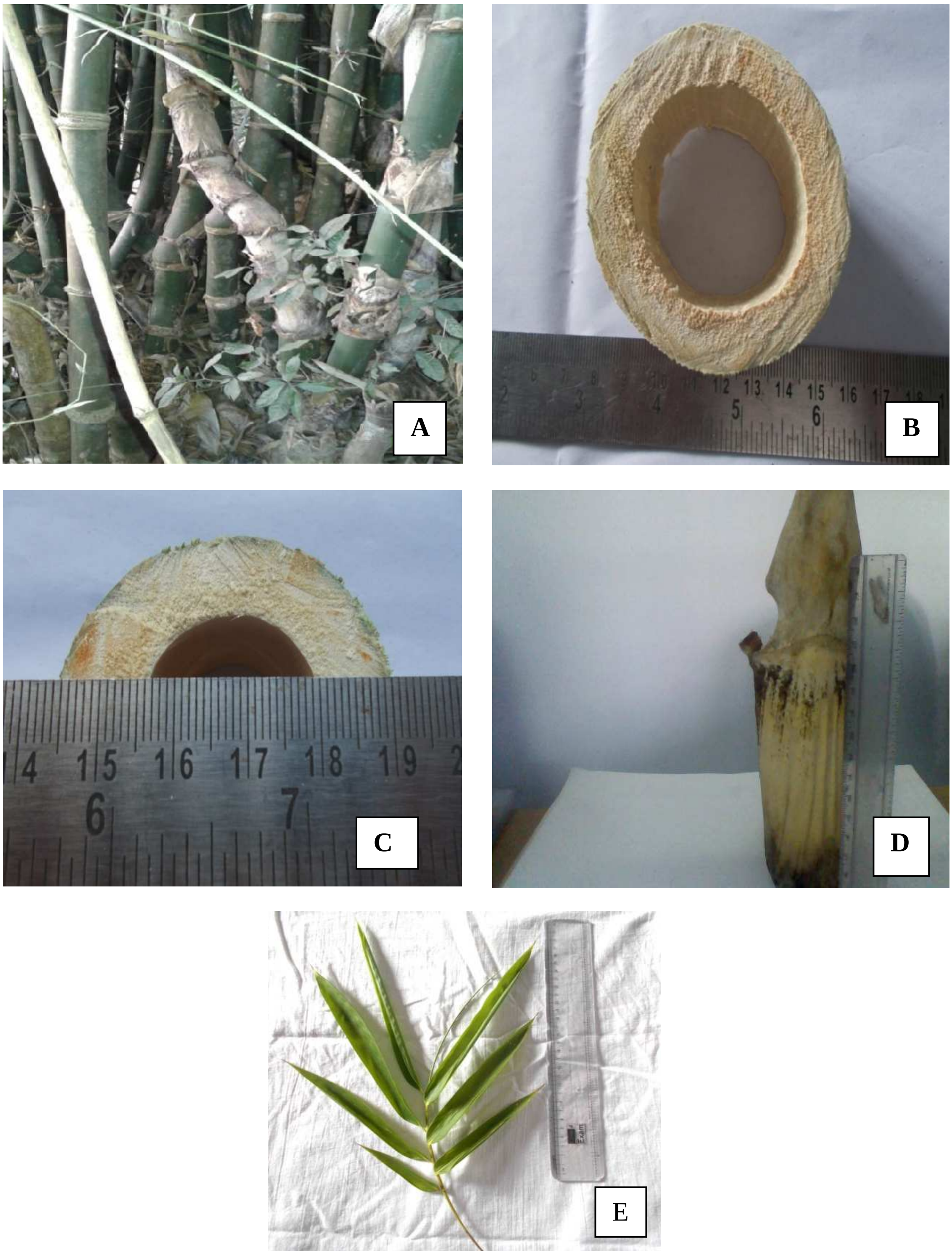


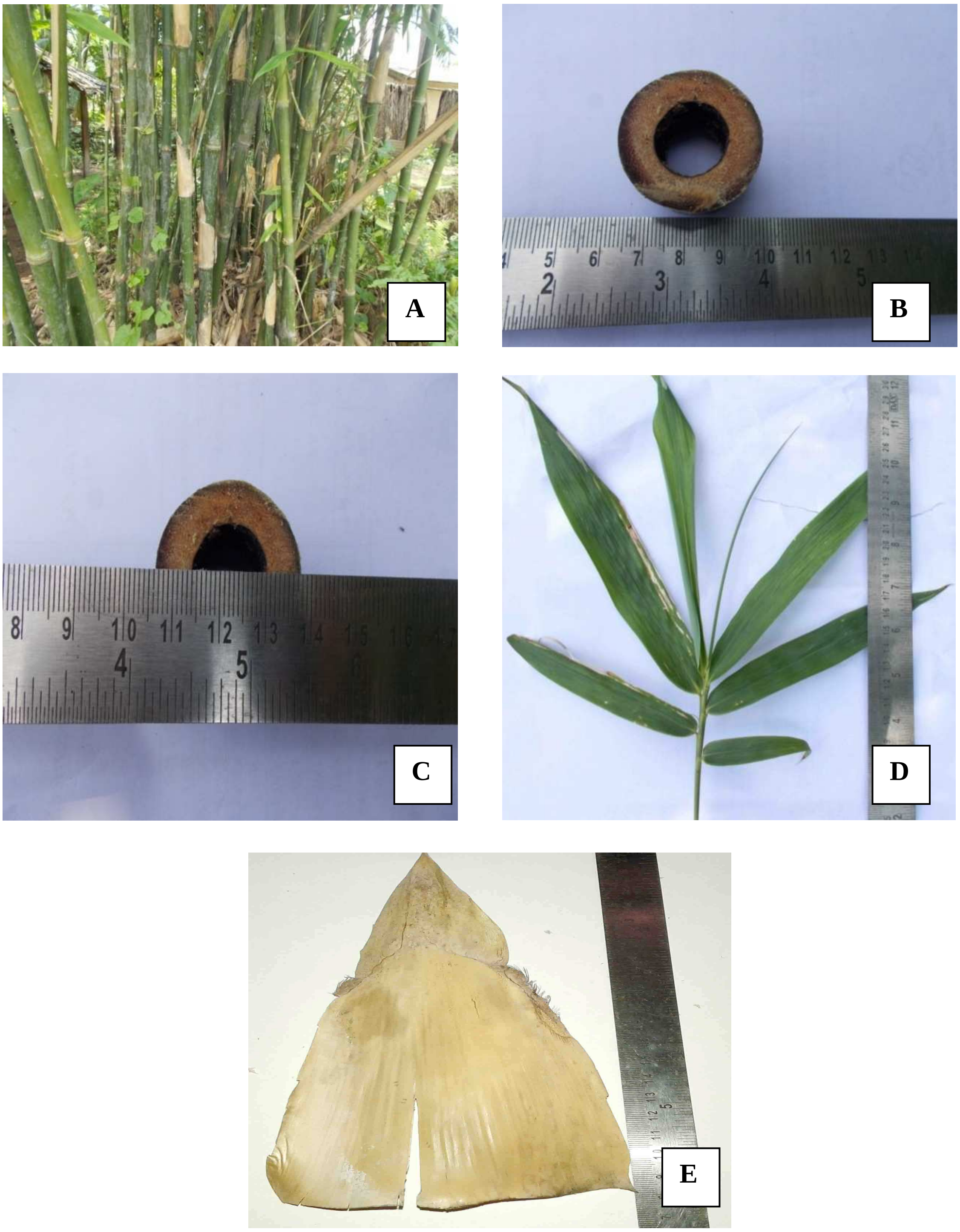
Figure 5.2: Average dimensional value of leaves and culm sheath of studied bamboo species

PLATE 5.1: Study of culm characters, *Bambusa garuchokua* Barooah *et* Borthakur.



[A] - Portion of culm; [B] - Portion of culm showing culm diameter; [C] - Portion of culm showing culm wall thickness; [D] - Culm sheath [E] - Leaves.

PLATE 5.2: Study of culm characters, *Bambusa assamica* Barooah *et* Borthakur.

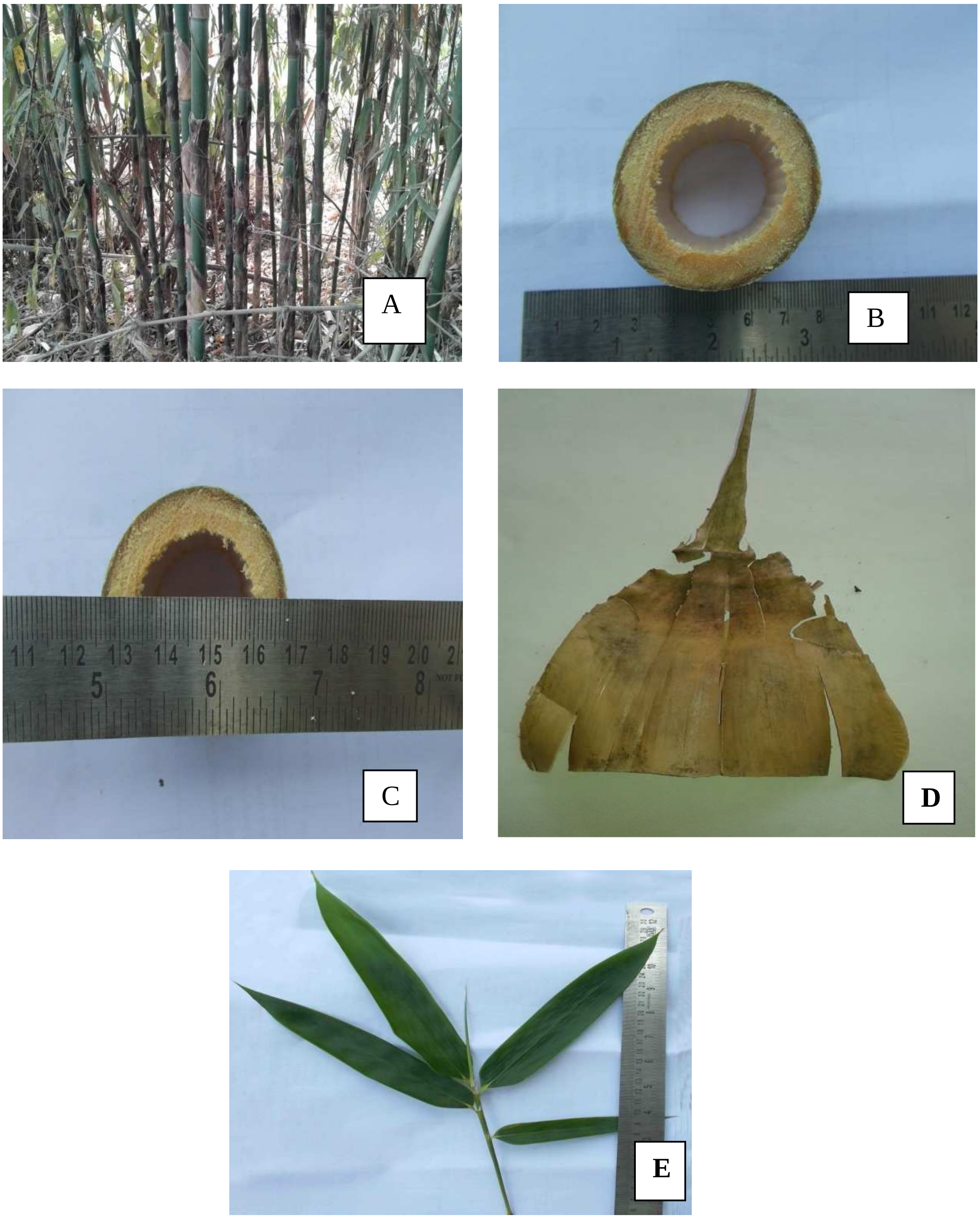


[A] - Portion of culm; [B] - Portion of culm showing culm diameter; [C] - Portion of culm showing culm wall thickness; [D] - Leaves; [E] - Culm sheath.

PLATE 5.3: Study of culm characters, *Bambusa pallida* Munro.

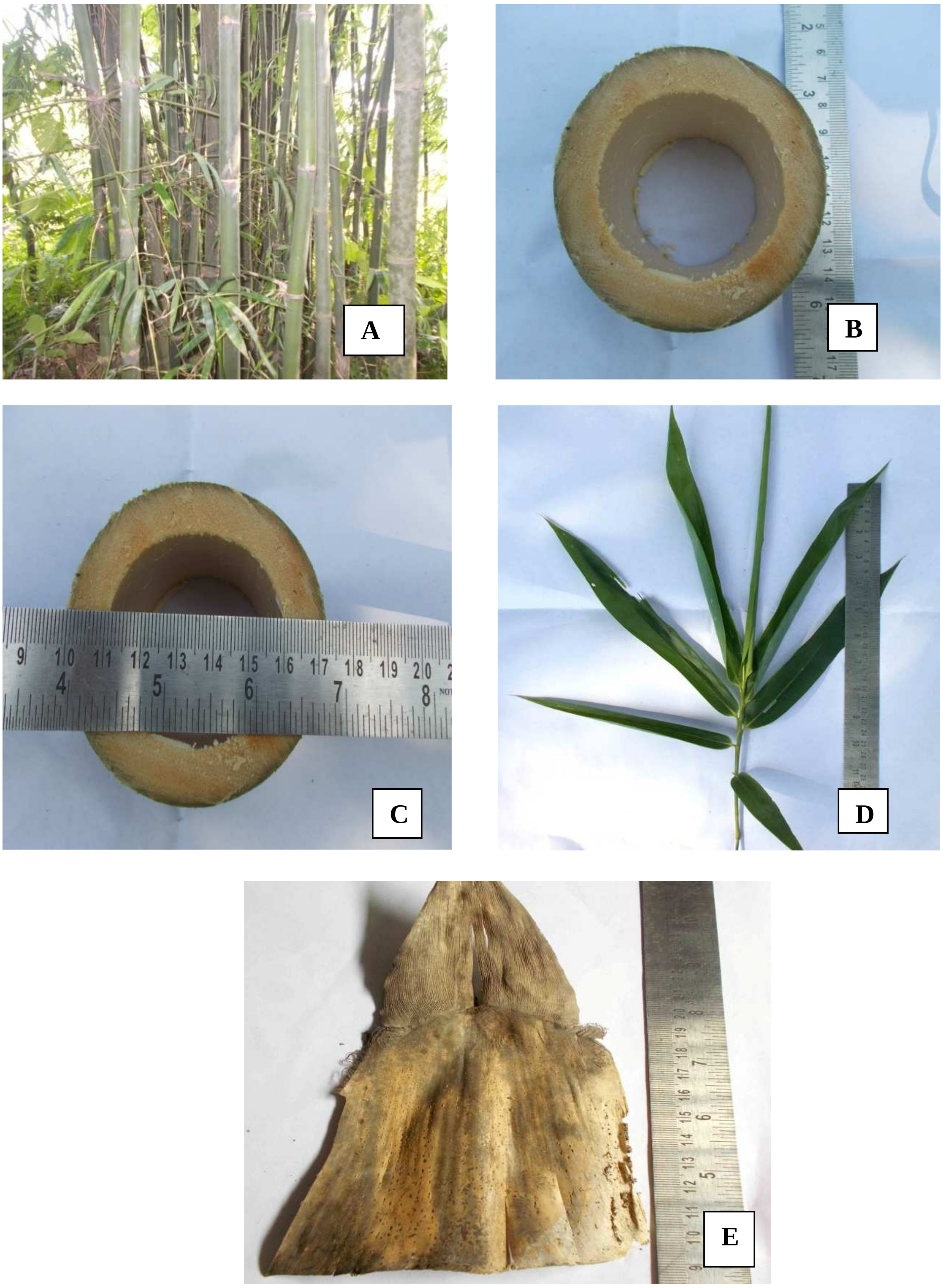
[A] - Portion of culm; [B] - Portion of culm showing culm diameter; [C] - Portion of culm showing culm wall thickness; [D] - Culm sheath. [E] - Leaves.

PLATE 5.4: Study of culm characters, *Melocanna baccifera* (Roxb.) Kurz.



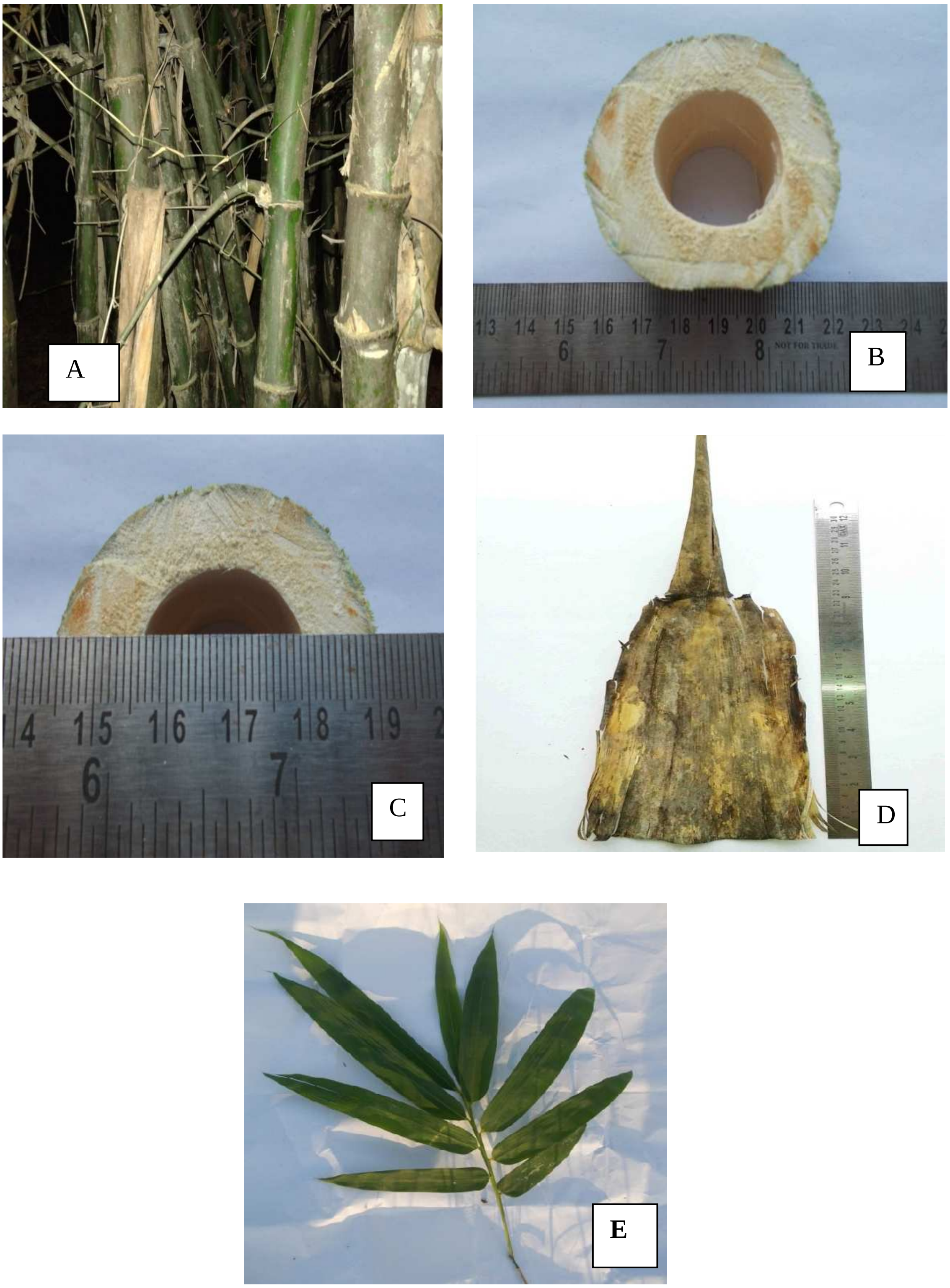
[A] - Portion of culm; [B] - Portion of culm showing culm diameter; [C] - Portion of culm showing culm wall thickness; [D] - culm sheath; [E] - Leaves.

PLATE 5.5: Study of culm characters, *Bambusa polymorpha* Munro.



[A] - Portion of culm; [B] - Portion of culm showing culm diameter; [C] - Portion of culm showing culm wall thickness; [D] - Leaves; [E] - Culm sheath.

PLATE 5.6: Study of culm characters, *Bambusa bambos* (L.) Voss.



[A] - Portion of culm; [B] - Portion of culm showing culm diameter; [C] - Portion of culm showing culm wall thickness;[D] - Culm sheath; [E] - Leaves.

5.2 Chemical properties

5.2.1 Alcohol-toluene solubility

The alcohol-toluene extract of bamboo are primarily wax, resin, gums and fats along with certain water soluble substances. Wang *et al*. (2016) studied the alcohol-tolune solubility of *Dendrocalamus brandisii* and reported that the average of alcohol-toluene solubility content of 3 years old *D. brandisii* was 2.06±0.15% and recorded the increase of alcohol-toluene extract with the increase of age. The present study shows the alcohol-toluene solubility content of 6 numbers of bamboo species. The result shows alcohol-toluene solubility content ranges from 4.29±0.06 to 5.72±0.20% in these studied species. The result also shows the alcohol-toluene solubility content in cross sectional position (outer, middle and inner) within a culm. The inner position shows the higher alcohol-toluene solubility content than middle and outer which followed the same pattern of alcohol-toluene solubility content described by Li (2004).

Out of 6 studied bamboo species the *B. assamica* shows the lowest average alcohol-toluene solubility content with 4.29±0.06% where, *B. bambos* shows the highest alcohol-toluene solubility content with 5.72±0.20%. The result of alcohol-toluene solubility content of present study of 6 number of bamboo species are comparable with the alcohol-toluene solubility content of 3 years old *P. pubescens* with 4.38% (Li, 2004).

Table 5.2: Alcohol-toluene solubility content (%), showing three cross sectional position outer, middle and inner

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	3.76 ±0.10	3.07 ±0.20	3.85 ±0.06	4.02 ±0.16	3.51 ±0.07	3.92 ±0.14
Middle	4.39 ±0.09	3.56 ±0.18	4.70 ±0.15	4.88 ±0.12	4.23 ±0.14	4.70 ±0.15
Inner	4.82 ±0.07	4.29 ±0.06	5.15 ±0.13	5.41 ±0.15	4.95 ±0.10	5.72 ±0.20

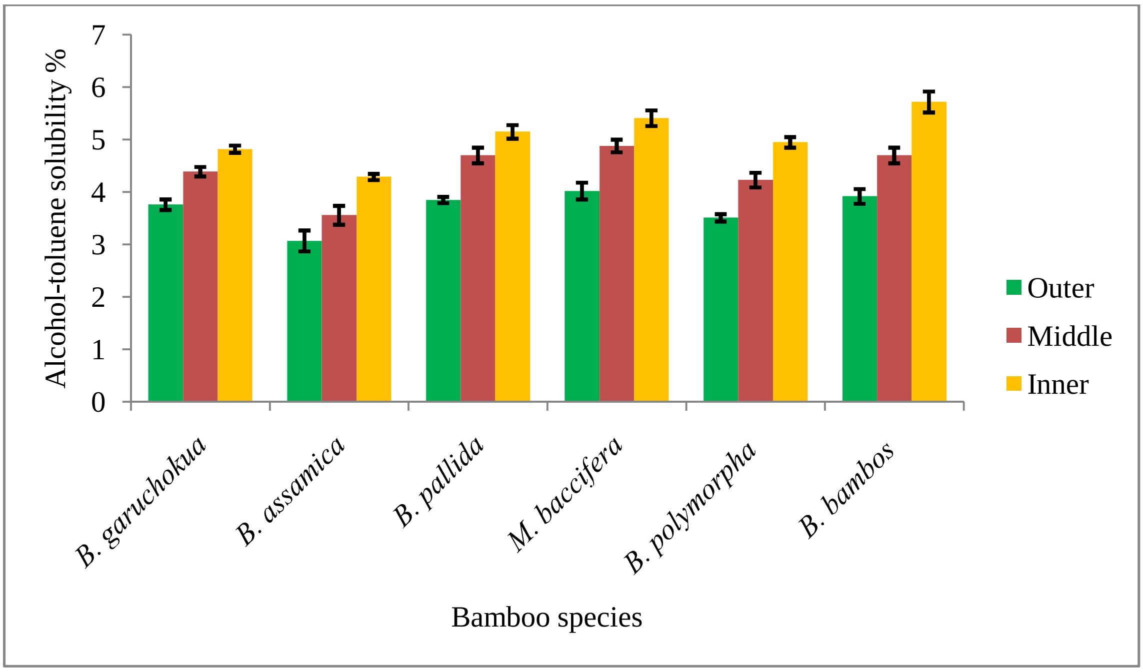


Figure 5.3: Alcohol-toluene solubility content (%), showing three cross sectional position outer, middle and inner

5.2.2 Hot water solubility content

The hot water solubility content of bamboo culm primarily consists of tannin, gum, sugars, starch and some colouring substances. The effect of age and height of bamboo on hot water solubility content was studied by several workers. Li (2004) in his study on *Phyllostachys pubescens* found that 3 years old bamboo has highest hot water solubility content, whereas, 1 and 5 years old bamboo do not show any significance by having less hot water solubility content. He mentioned about the highest hot water solubility content in top portion of the culm as compared to middle and bottom portion. He also mentioned about the similar pattern of hot water solubility content in cross sectional layer of inner, middle and outer by having highest content in inner layer.

The result of this study shows that the hot water solubility content of different species is different. The hot water solubility content ranges from 5.54±0.03 to 7.01±0.12%. The result shows the *B. assamica* with lowest content of 5.54±0.03% and *B. bambos* with highest content of 7.01±0.12%. The result of present study of 6 numbers of bamboo species satisfied the findings of both Wang *et al.* (2016) and Li (2004) by having highest hot water solubility content in inner position of cross sectional layer as compared to middle and outer position. Sharma *et al*. (2011) studied hot water solubility content of *B. tulda, D. hamiltonii, B. balcooa, M. baccifera, B. arundinacea* with 6.8, 6.7, 7.0 5.8 and 6.0% respectively. The result of present study is very much close and comparable with his study by having 6.31±0.08, 5.54±0.03, 6.38±0.26, 5.98±0.16, and 6.17±0.18 and 7.01±0.12% of hot water solubility content in *B. garuchokua, B. assamica, B. pallida, M. baccifera, B. polymorpha* and *B. bambos* respectively.

Table 5.3: Hot water solubility content (%), showing three cross sectional position outer, middle and inner

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	5.87 ±0.05	3.03 ±0.16	5.00 ±0.15	3.97 ±0.07	4.50 ±0.15	5.62 ±0.07
Middle	6.12 ±0.12	4.76 ±0.19	5.69 ±0.04	4.59 ±0.10	5.89 ±0.11	6.85 ±0.12
Inner	6.31 ±0.08	5.54 ±0.03	6.38 ±0.26	5.98 ±0.16	6.17 ±0.18	7.01 ±0.12

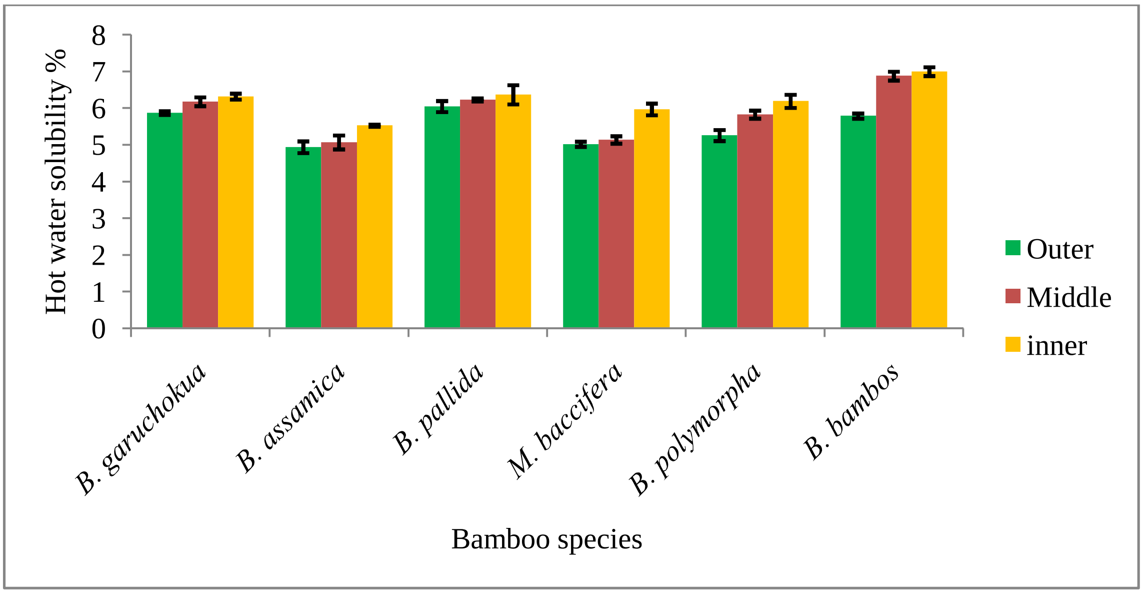


Figure 5.4: Hot water solubility content (%), showing three cross sectional position outer, middle and inner

5.2.3 Ash content

The ash content of 6 numbers of studied bamboo species was determined. Bamboo ash is primarily composed of calcium, potassium and silica. Contents of ash have shown disadvantage in certain species as it hampers the processing machineries (Chaowana, 2013). The majority of inorganic content of ash are carbonates, silicates, sulphates or ions of metal (Rydholm, 1965). As compared to node, the internodes of bamboo contain higher ash content percentage (Mabilangan *et al*., 2002). Ash content of several regular used bamboos has been studied by many authors. Hisham *et al*. (2006) reported range of ash contant percentage of 1.90 to 3.50% in *G. scortechinii*. *B. blumeana* contain ash percentage of 1.67% (Ireana, 2010). The result of ash content in present study of 6 number of studied bamboo species can be compared with such findings by different authors. According to Ashori (2006) several bamboo species from genus Gigantochloa contain high ash content even higher than common wood species, however Kenaf have similar ash content with *Gigantochloa* by having 1.6 to 2.2% (Ashori, 2006).

The present study of 6 numbers of bamboo species shows ash content percentage ranges from 1.16±0.07 to 1.03±0.03% in inner position, 1.00±0.05 to 0.88±0.16% in middle position and 0.95±0.03 to 0.76±0.08% in outer position. These results show that in a cross sectional positions of a bamboo culm wall the inner layers has higher ash content than the middle and the outer. This pattern of ash content in 6 numbers of studied bamboo species satisfied the findings of ash content pattern of inner, middle and outer of bamboo culm which shows similarity with findings of Li *et al*. (2007). This result also shows the similar pattern of ash content in both sympodial and monopodial bamboo.

The result of the present study shows the highest ash content in *B. assamica* with 1.16±0.07% followed by *M. baccifera* with 1.11±0.01% and lowest ash content in *B. garuchokua* with 1.04±0.03%.

Table 5.4: Ash content (%), showing three cross sectional position outer, middle and inner

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	0.76 ±0.08	0.89 ±0.08	0.90 ±0.10	0.84 ±0.06	0.95 ±0.03	0.95 ±0.02
Middle	0.88 ±0.16	1.00 ±0.05	0.95 ±0.09	0.92 ±0.03	0.99 ±0.07	1.00 ±0.05
Inner	1.04 ±0.03	1.16 ±0.07	1.10 ±0.01	1.11 ±0.01	1.09 ±0.01	1.06 ±0.02

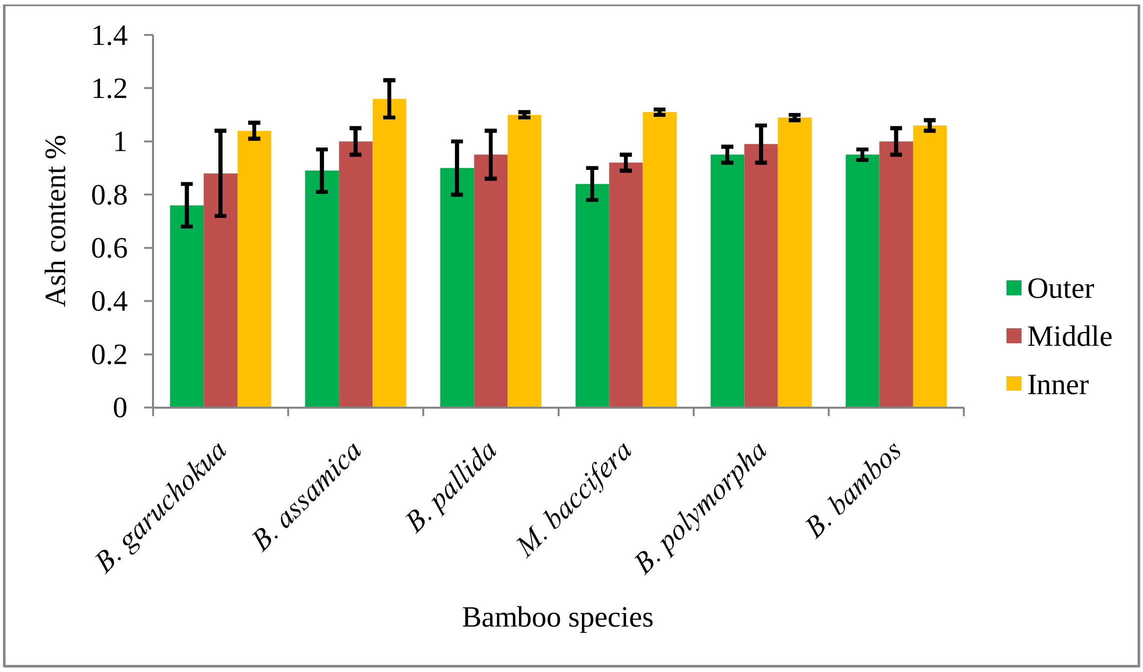


Figure 5.5: Ash content (%), showing three cross sectional position outer, middle and inner

5.2.4 Klason-lignin content

A resin free wood extract is hydrolyzed with 72% H_2SO_4 for removing of polysaccharides to obtain lignin (Sjostrom, 1981). The high end normal range of lignin in bamboo lies 20 to 26% and 11 to 27% for biomass of non woody substances (Bagby *et al*., 1971). The high heating value and structural rigidity is due to lignin content which make bamboo as valuable building material (Scurlock *et al*., 2000). Azooz and

Ahmad (2016) stated that bamboo pulp contain good amount of natural lignin are used in the production of newsprint paper. The lignin content of various bamboo species under genus *Gigantochloa* was studied by Razak *et al*. (2013). His result shows that the lignin content of 4 *Gigantochloa* species (*G. brang*, *G. levis*, *G. scortechinii and G. wrayi*) ranged from 24.84 to 32.65%. The result of the present study shows the variation of lignin content in different bamboo species. Among the 6 numbers of studied bamboo species, *B. garuchokua* has the highest lignin content with 26.86±0.81%, followed by *B. bambos* with 26.20±0.82% and the *B. assamica* contains the lowest percentage with 20.44±0.94%.

This study determine the lignin content of 6 numbers of bamboo species in its cross sectional layer outer, middle and inner, which follow the same pattern of lignin content by having the highest percentage in outer layer then inner and middle of culm cross section as reported by Li (2004). The result also satisfies the relationship between fiber length and lignin content mentioned by Razak *et al*. (2013). Higher the lignin content, shorter is the fiber length.The middle layer has longer fiber than outer and inner by having less lignin content.

Table 5.5: Klason lignin content (%), showing three cross sectional position outer, middle and inner

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	26.86 ±0.81	20.44 ±0.94	25.25 ±1.50	24.65 ±1.46	25.66 ±1.57	26.20 ±0.82
Middle	20.11 ±1.37	15.38 ±0.43	18.35 ±0.97	16.82 ±0.21	18.02 ±0.05	18.53 ±0.15
Inner	22.73 ±1.98	19.66 ±0.54	24.27 ±1.09	19.63 ±1.20	21.69 ±0.67	20.12 ±0.65

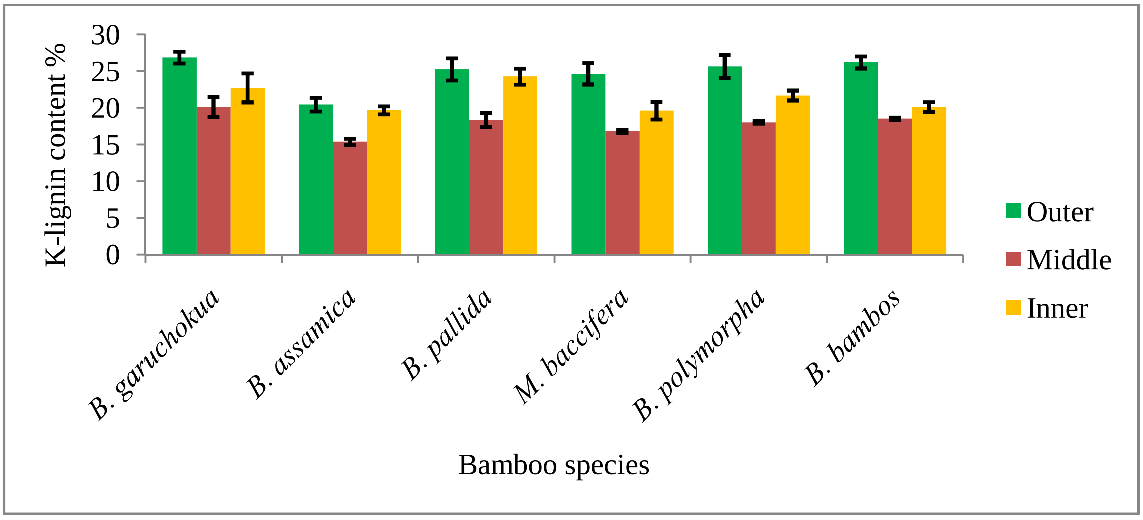


Figure 5.6: Klason lignin content (%), showing three cross sectional position outer, middle and inner

5.2.5 Holocellulose content

Holocellulose is the combination of both α-cellulose and hemicelluloses. In bamboo the holocellulose content percentage normally ranges from 50 to 70% (Tamalong *et al.*, 1980; Chen *et al.*, 1985). Holocellulose content of some species of genus *Gigantochloa* was studied and found little difference in holocellulose content among the species. The average holocellulose content in genus *Gigantochloa* ranges 74 to 85% (Razak *et al.*, 2013) and 78.60 to 82.30% of holocellulose content in *G. scortechinii* was reported (Hisham *et al*., 2006).

Sharma *et al*. (2011) studied holocellulose content of *B. tulda, D. hamiltoni, B. balcooa, M. baccifera, B. arundinacea* with 73.0, 73.8, 74.9, 74.1 and 74.1% respectively. The result of present study is very much close and comparable by having 76.15±0.39, 64.31±0.45, 69.84±0.51, 70.43±0.59, and 71.40±0.59 and 79.13±0.72% of holocellulose content in *B. garuchokua, B. assamica, B. pallida, M. baccifera, B. polymorpha* and *B. bambos* respectively.

This study shows the result of highest holocellulose content in the outer side of the cross section of culm wall with 79.13±0.72% in *B. bambos* and lowest content with 64.31±0.45% in *B. assamica.*

The present study of some bamboo species shows the significant difference in holocellulose content between species and position and followed the same pattern of having of highest holocellulose in the outer side than middle and inner side of the cross section of culm wall that studied by various workers including, Razak *et al*. (2013). The holocellulose contain in outer, middle and inner position in the present study followed the same pattern that was explained by Li *et al*. (2007).

Table 5.6: Holocellulose content (%), showing three cross sectional position outer, middle and inner

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	76.15 ±0.39	64.31 ±0.45	69.84 ±0.51	70.43 ±0.59	71.40 ±0.59	79.13 ±0.72
Middle	66.08 ±0.31	58.43 ±1.16	64.53 ±0.78	68.88 ±3.35	66.21 ±0.28	70.29 ±0.21
Inner	65.76 ±0.54	58.40 ±0.51	63.98 ±0.36	64.71 ±0.50	65.36 ±0.73	64.95 ±0.64

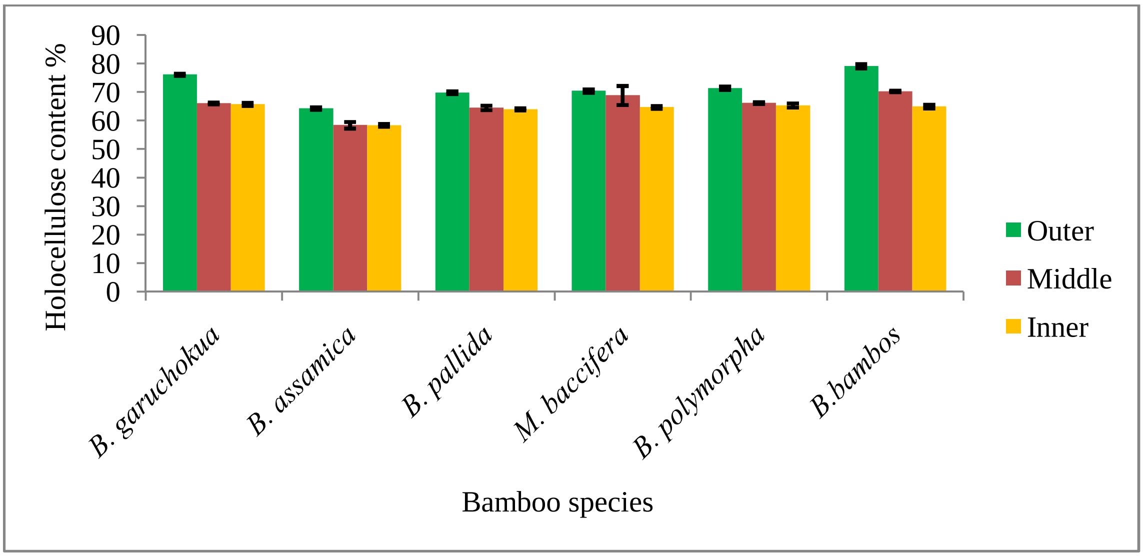


Figure 5.7: Holocellulose content (%), showing three cross sectional position outer, middle and inner

5.2.6 α-cellulose content

The α-cellulose content of four cultivated tropical bamboo *G. brang*, *G. levis*, *G. scortechinii* and *G. wrayi* under genus *Gigantochloa* was studied by Razak *et al*. (2013). In his study it is observed that highest α-cellulose content in *G. brang* was 51.58% and lowest in *G. levis* with 33.80%. Many authors have conducted studies on α-cellulose content of several bamboo species. Ireana (2010) reported 58.72% α-cellulose content in *B. blumeana*. Norul *et al*. (2006) reported 63.30 to 64.60% α-cellulose content in *G. scortechinii*. Li *et al*. (2007) reported 41.71 to 49.02% α-cellulose content in *P. pubescens*. The comparison of α-cellulose content of bamboo (33.79 to 51.76%) with softwood (42%) and hardwood (45%) was done by Thomas (1977). His result showed the higher α-cellulose content in bamboo as compared to softwood and hardwood. Nieschlag *et al*. (1960) made recommendation on pulp and paper making bamboo from chemical point of view. According to him the content of 34% and above α-cellulose in pulp and paper is a promising quality, as α-cellulose is non degraded high molecular weight cellulose.

The result of the present study shows the significant difference of α-cellulose content among the 6 numbers of studied bamboo species. The result shows that *B. assamica* contains highest α-cellulose content of 46.03±2.83% and *B. bambos* contains lowest content of 37.51±0.35%. This result established a negative relation of holocellulose content and α-cellulose content, as higher the α-cellulose content lower the holocellulose content.

The range of α-cellulose content (37.51±0.35 to 46.04±2.83%) in 6 numbers of studied bamboo species satisfies the results of α-cellulose content studied by different authors mentioned above and also followed the same pattern of content by having the higher content in outer side than middle and inner as shown in **Table 5.7**.

Table 5.7: Average α-cellulose content (%), showing three cross sectional position outer, middle and inner

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	39.72 ±0.57	46.04 ±2.83	44.43 ±0.61	41.71 ±1.31	40.89 ±1.31	37.51 ±0.35
Middle	35.92 ±0.96	40.08 ±0.39	36.54 ±1.78	38.78 ±1.32	34.93 ±0.95	32.91 ±0.73
Inner	35.22 ±0.48	38.58 ±0.59	34.51 ±0.89	36.65 ±2.15	31.76 ±0.77	30.25 ±0.54

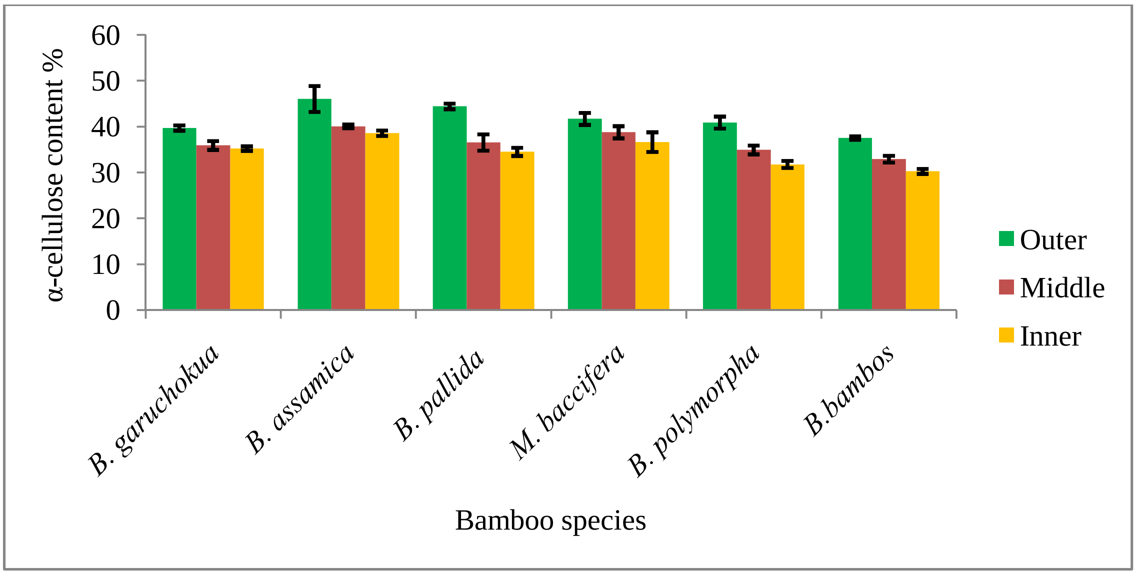


Figure 5.8: α-cellulose content (%), showing three cross sectional position outer, middle and inner

5.2.7 Elements content

Takeshi *et al*. (2001) studied on the determination of trace element in the ash of wood and bamboo. They found higher Ca and lower Mn and Zn contain in wood charcoal while bamboo charcoals contain higher K and Mg.

The present study determine the Ca, Mn, K, Mg and Zn content of 6 number of bamboo species. The result satisfies the statement given by previous worker by containing higher K and Mg contant as compared to Ca, Mn and Zn as shown in **Table 5.8**. Among the studied species *B. garuchokua* contain highest K with 0.916±2.08 mg/g followed by *B. bambos* with 0.854±0.92 mg/g. The result shows that almost all the 6 studied species contained negligible amount of Zn (0.005±1.51 mg/g).

Table 5.8: Elements content of studied bamboo species

Sample	**E L E M E N T S (mg/g)**				
	Ca	**Mn**	**K**	**Mg**	**Zn**
B. garuchokua	0.142 ±0.61	0.010 ±0.03	0.916 ±2.08	0.285 ±0.04	0.005 ±0.01
B. assamica	0.122 ±0.58	0.008 ±0.08	0.758 ±2.01	0.278 ±0.01	0.005 ±0.03
B. pallida	0.129 ±0.65	0.009 ±0.18	0.811 ±3.02	0.301 ±0.12	0.008 ±0.14
M. baccifera	0.115 ±0.25	0.008 ±0.39	0.794 ±0.63	0.279 ±1.78	0.008 ±0.39
B. polymorpha	0.126 ±0.36	0.010 ±1.53	0.819 ±0.82	0.282 ±1.03	0.005 ±1.51
B. bambos	0.127 ±1.03	0.008 ±0.16	0.854 ±0.92	0.284 ±1.23	0.006 ±0.30

Table 5.9: Summary of ANOVA for chemical content between species and position

SPECIES	Alcohol-toluene solubility	Hot water solubility	K-lignin content	Holocellulolose content	α-cellulose content
B. garuchokua	3.84	6.10	23.23 ^{c1}	69.33 ^{d1}	37.83 ^{e1}
B. assamica	3.24	4.45 ^{b1}	18.50	60.39	41.57 ^{e2}
B. pallida	4.57^{a1}	5.69 ^{b2}	22.63 ^{c2}	66.12 ^{d2}	40.77 ^{e3}
M. baccifera	4.77 ^{a2}	4.85	20.37 ^{c3}	68.34 ^{d3}	39.05 ^{e4}
B. polymorpha	4.23	5.52	21.79 ^{c4}	67.66	39.20
B. bambos	4.78	6.49	21.62	71.46	36.95
POSITION					
OUTER					
B. garuchokua	3.46 ^{a1}	5.87	26.86 ^{c1}	76.15	42.43 ^{e1}
B. assamica	2.69	3.04	20.44	64.31	46.04 ^{e2}
B. pallida	3.85 ^{a2}	5.01	25.25 ^{c2}	69.84 ^{d1}	45.19
M. baccifera	4.02	3.97	24.66 ^{c3}	70.43	41.71 ^{e3}
B. polymorpha	3.51	4.50	25.67 ^{c4}	71.40	40.90
B. bambos	3.92	5.62	26.20	79.13	39.72
MIDDLE					
B. garuchokua	3.99	6.12	20.11	66.08 ^{d1}	36.54 ^{e1}
B. assamica	3.06	4.76 ^{b1}	15.38	58.44	40.08 ^{e2}
B. pallida	4.70 ^{a1}	5.69	18.36 ^{c1}	64.53	39.44 ^{e3}
M. baccifera	4.87	4.59	16.83	68.88	38.80 ^{e4}
B. polymorpha	4.23	5.89	18.02	66.21	38.94
B. bambos	4.69	6.85	18.53	70.29	35.92
INNER					
B. garuchokua	4.25	6.31 ^{b1}	22.73 ^{c1}	65.76 ^{d1}	34.51 ^{e1}
B. assamica	3.98	5.54	19.67 ^{c2}	58.41	38.58
B. pallida	5.15	6.36 ^{b2}	24.27	63.98	37.67 ^{e2}
M. baccifera	5.41	5.98	19.63 ^{c3}	64.71 ^{d2}	36.65 ^{e3}
B. polymorpha	4.95	6.17	21.69	65.36 ^{d3}	37.76
B. bambos	5.72	7.01	20.12	64.95	35.22

NOTE: All the mean value in the table is significant at 0.05 and non-significant are shown with superscript for each parateter.

5.3 Physical properties

5.3.1 Moisture content

Along with the other physical factors, the moisture content can be regarded as one of the important factor that influences the mechanical properties of bamboo. Wakchaure *et al*. (2012) mentioned about the influence of moisture content on durability of bamboo. There is a significant difference of the important mechanical properties including bending and compression strength in green and air dried bamboo (Chung and Yu, 2002). The moisture content of a bamboo along the culm is higher in bottom portion and decreases towards to middle and the top with having of average moisture content in its green condition around 60% (Li, 2004). On dry weight basis of measurement of moisture content a green bamboo shows 100% and it may be high even 150% in inner layer and up to 70% in outer layer. *B. blumeana* and *D. strictus* showed moisture content from 57 to 97% and 55 to 95% respectively (Abd. Latif *et al*., 1993).

The present study shows that the moisture content percentage of 6 number of studied bamboo species ranges from 56 to 60% which is comparable to the result of the previous studies. Among the studied bamboo species the *B. bambos* shows the lowest percentage of moisture content with 56.2934±3.02% and *B. assamica* shows the highest moisture content percentage with 60.3911±1.34%.

Table 5.10: Moisture content (%) of studied bamboo species

Bambusa garuchokua	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
59.34 ±1.69	60.39 ±1.34	60.19 ±1.92	60.25 ±0.67	59.58 ±1.41	56.30 ±2.02

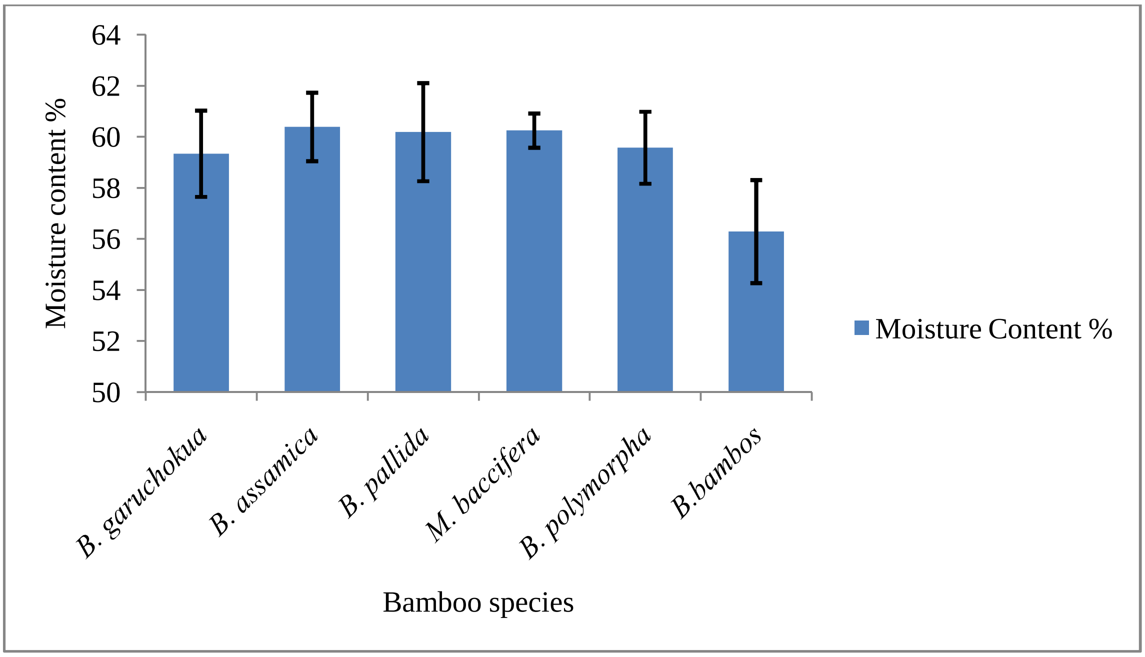


Figure 5.9: Moisture content (%) of studied bamboos

5.3.2 Specific gravity

The influence of SG on total strength of bamboo was studied by several workers including Razak *et al*. (1995), Anwar *et al*. (2005) and Yu *et al*. (2008). The result of specific gravity from present study shows the differences of specific gravity in different bamboo species. This study shows a reverse relation of specific gravity with moisture content. The result shows that as the moisture content decrease the specific gravity increases which satisfies the pattern of relation of moisture content and specific gravity described by Abd. Latif and Zin (1992).

Among the studied bamboo species, *B. assamica* shows lower specific gravity with 0.5735±0.01 g/cm^3 and *B. bambos* shows higher specific gravity with 0.6457±0.02 g/cm^3.

Table 5.11: Specific gravity (SG) of studied bamboo species in g/cm^3

Bambusa garuchokua	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
0.63 ±0.96	0.57 ±1.01	0.61 ±1.02	0.59 ±1.05	0.63 ±1.32	0.65 ±0.92

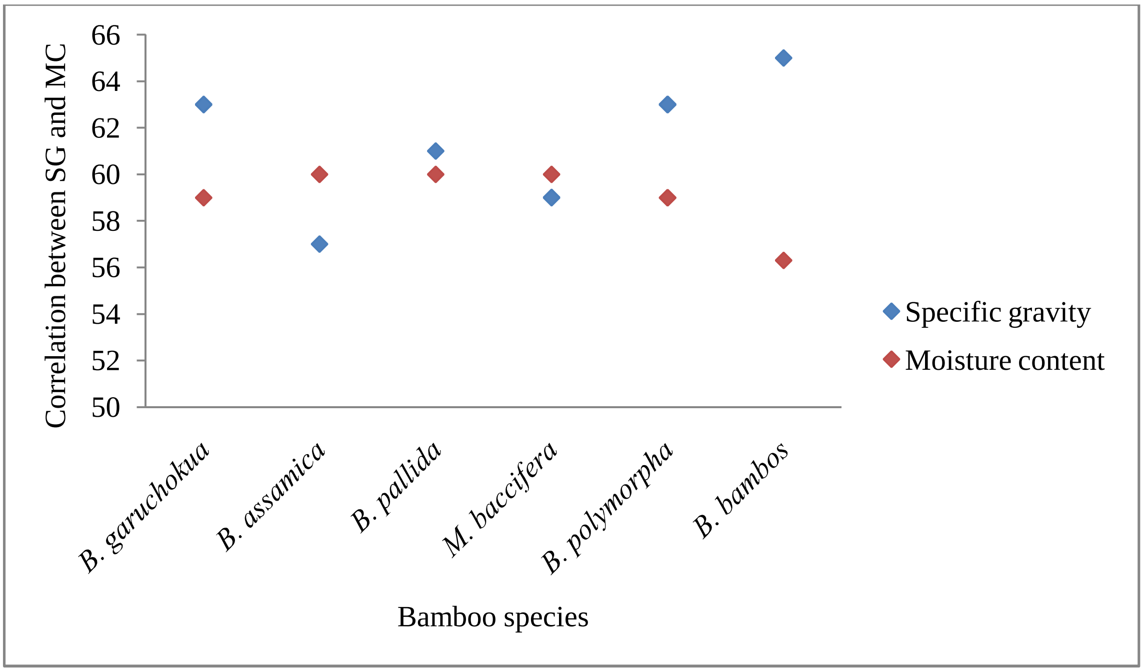


Figure 5.10: Relationship between Specific gravity (SG) and moisture content (MC) of studied bamboo species

5.3.3 Shrinkage

Kamruzzaman (2008) studied the shrinkage in culm diameter and wall thickness of four numbers of bamboo species, *B. balcooa, B. tulda, B. salarkhanii and M. baccifera*. He mentioned about highest wall thickness shrinkage ratio in *B. balcooa* and lowest in *M. baccifera*. His result also showed almost similar proportion of wall thickness shrinkage in *M. baccifera* and *B. tulda.*

Nordahlia *et al*. (2011) studied the shrinkage percentage of *Shizostachyum brachycladum* and reported 8.17%, 5.78% and 0.52% radial, tangential and longitudinal shrinkage respectively. The findings of his study are close and comparable with the result of shrinkage percentage of present study.

The result of present study on the shrinkage percentage shows differences in different species and dimension (Tangential, Radial, and Longitudinal). Among the present studied species, *B. assamica* shows highest shrinkage percentage in all direction with 7.62±0.97% (Radial), 5.54±0.42% (Tangential), 0.27±0.06% (Longitudinal) followed by *M. baccifera* with 7.41±0.12% (Radial), 5.39±0.27% (Tangential), 0.25±0.07% (Longitudinal) and *B. garuchokua* shows the lowest shrinkage percentage with 5.89±0.56% (Radial), 3.11±0.40% (Tangential), 0.13±0.04% (Longitudinal).

The results of the present study almost satisfy the statement made by Lee *et al*. (1994) as shrinkage in radial direction is almost double than tangential direction with negligible longitudinal shrinkage. The result of the present study also satisfy the statement higher the initial moisture content (MC) higher the shrinkage percentage (Rehman and Ishaq, 1947; Liese, 1998).

Table 5.12: Shrinkage (%) of studied bamboo species

Sample	Radial Shrinkage	Tangential Shrinkage	Longitudinal Shrinkage
B. garuchokua	5.89±0.56	3.11±0.40	0.13±0.04
B. assamica	7.62±0.97	5.54±0.42	0.27±0.06
B. pallida	7.15±0.45	4.05±0.17	0.23±0.05
M. baccifera	7.41±0.12	5.39±0.27	0.25±0.07
B. polymorpha	7.24±0.19	4.96±0.27	0.19±0.05
B. bambos	6.75±0.23	3.80±0.22	0.17±0.07

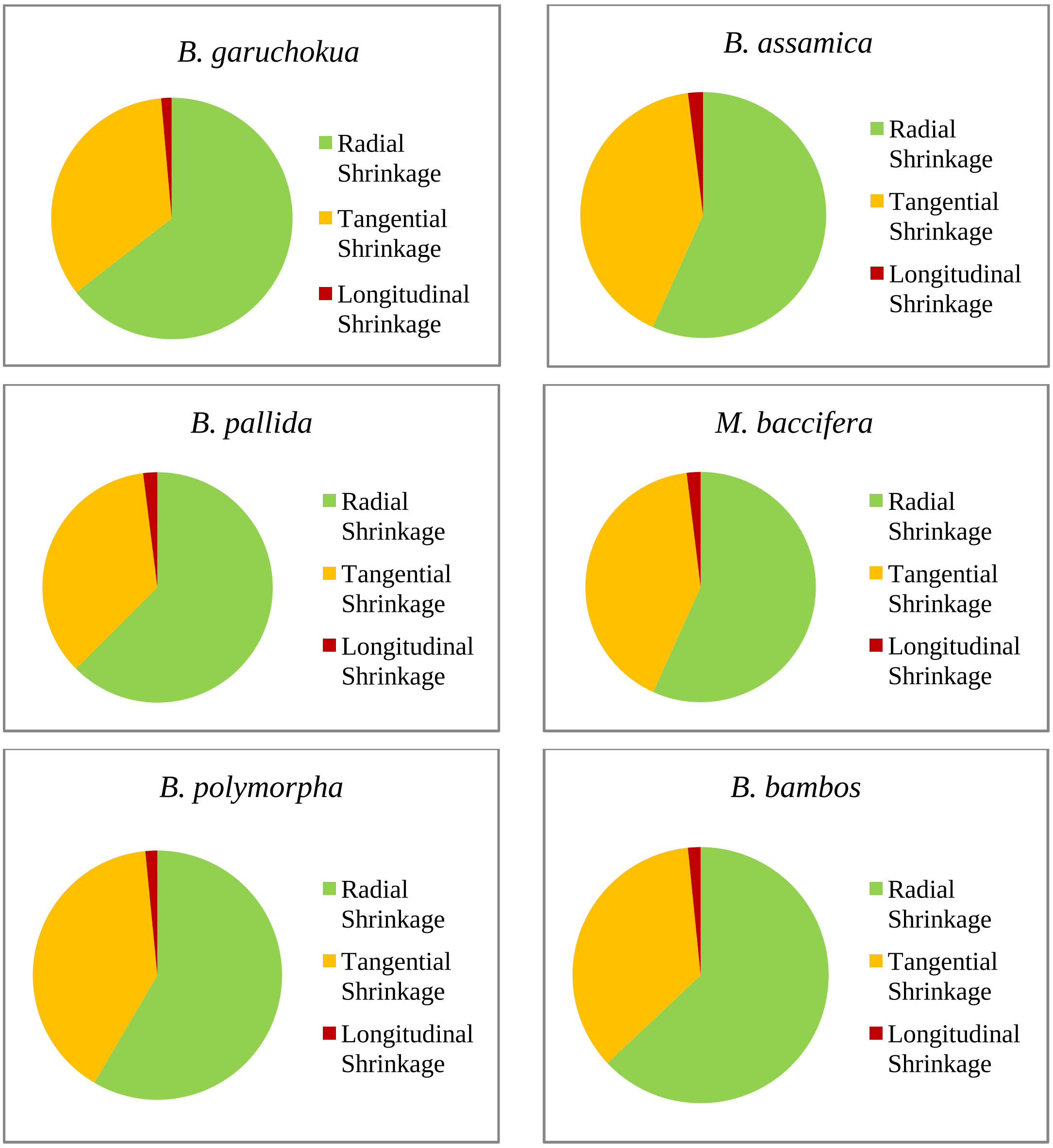


Figure 5.11: Shrinkage (%) of studied bamboo species

5.3.4 Bending properties

5.3.4.1 Modulus of elasticity (MOE) and modulus of rupture (MOR) in MPa

Francisco *et al*. (2010) described about the variations of MOR of *Guadua angustifolia*, *Bambusa balcooa*, *Gigantochloa scortechinii*, *B. vulgaris* and *B. blumeana*. He reported 20 to 39% higher MOR in *G. angustifolia* as compared to *B. balcooa*, *G. scortechinii*, *B. vulgaris* and *B. blumeana*. Chaowana *et al*. (2012) studied *D. asper* and found specific gravity (SG) range 0.58 to 0.71 g/cm^3, modulus of rupture

(MOR) with range 132 to 181 MPa and modulus of elasticity (MOE) with 9,465 to 15,115 MPa. This result is very close and comparable with the result of the present study.

Soenardi (1988) studied the bending strength of *Bambusa arundinacea*, *B. vulgaris*, *Dendrocalamus asper*, *G. apus*, *G. atter*, *G. verticillata* and concluded that moisture content and species difference have significant effect on modulus of rupture (MOR). The result of the present study followed the same pattern *i.e.* higher the moisture content higher the value of modulus of rupture (MOR) in corresponding to modulus of elasticity (MOE). The result shows exceptional with little differences in the value of *B. polymorpha.*

The result of the present study shows that *B. bambos* and *B. garuchokua* have very close MOE (MPa) with 10361.59±410.98 and 10153.91±373.54 respectively and MOR (MPa) with 179.06±2.93 and 158.05±1.60 respectively. Among the studied species, *B. assamica* shows the lowest MOE (MPa) and MOR (MPa) by having 6861.94±114.92 and 120.04±2.71 respectively.

Table 5.13: Modulus of elasticity (MOE) and modulus of rupture (MOR) of studied bamboo species in MPa

Parameters	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
MOE(MPa)	10153.91 ±373.54	6861.94 ±114.92	7416.47 ±95.11	7380.22 ±185.87	9745.87 ±101.81	10361.59 ±410.98
MOR(MPa)	158.05 ±1.60	120.04 ±2.71	128.46 ±1.41	124.91 ±4.38	153.39 ±3.63	179.06 ±2.93

5.3.4.2 Compression strength (f_c)

The result of the present study of selected bamboo species showed that different species have different compression strength. This result is supported by the description given by Francisco *et al*. (2010). Compression strength parallel to the longitudinal and perpendicular to the longitudinal was determined. This result shows that the compression strength perpendicular to the longitudinal direction is lower than the compression strength parallel to the longitudinal. Same pattern was also described by Li (2004).

Among the studied bamboo species *B. garuchokua* shows highest compressive value in both the directions by having 73.85±3.24 MPa (longitudinal), 30.16±1.11 MPa (tangential) followed by *B. polymorpha* with 71.89±3.05 MPa (longitudinal), 29.84±0.94 MPa (tangential) and *B. assamica* shows the lowest compressive value in both the directions with 58.71±3.36 MPa (longitudinal), 18.83±2.01 MPa (tangential) which satisfy the above statement.

Table 5.14: Compression strength (f_c) in MPa

Directions	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Longitudinal	73.85 ±3.24	58.71 ±3.36	69.32 ±2.88	66.86 ±1.93	71.89 ±3.05	70.43 ±2.01
Tangential	30.16 ±1.11	18.83 ±2.01	25.67 ±0.79	20.91 ±1.06	29.84 ±0.94	25.88 ±1.13

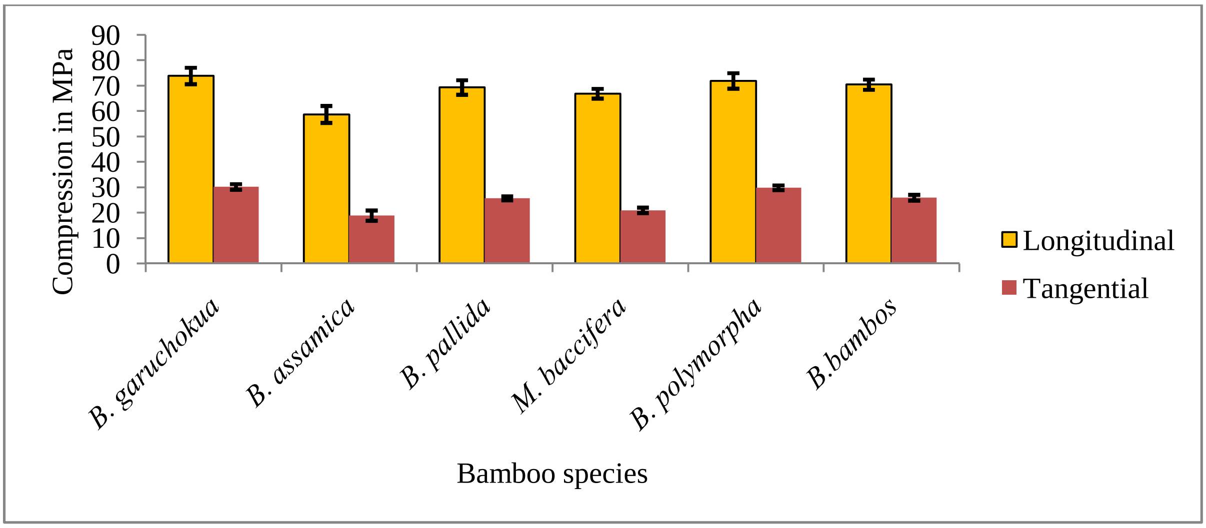


Figure 5.12: Compression strength (f_c) in MPa

5.4 Anatomical properties

5.4.1 Determination of vascular bundle concentration and size

Distribution of vascular bundle along the culm height and across the culm diameter was studied by Li (2004) in *Phyllostachys edulis*. He described about the decreasing vascular bundle with increasing culm height of bamboo. His result shows the highest vascular bundle concentration at the top portion of the 3 year old bamboo culm by having 467 bundles per cm^2. Razak *et al*. (2013) studied the vascular bundle characters of *G. levis* and *G. scortechinii*. The result of his study shows the vascular bundle concentration across the culm wall outer, middle and inner was 8.5, 4.88 and 3.4 bundle per 4 mm^2 respectively. This result of his study is very close and comparable with the result of present study of 6 number of bamboo species. *B. bambos* shows highest bundle concentration of 361.35±8.52 bundles per cm^2 followed by *B. garuchokua* with 358.11±11.10 bundles per cm^2 and *B. assamica* shows lowest bundle concentration of 302.63±13.10 bundles per cm^2. Razak *et al*. (2012) studied vascular bundle concentration on *G. scortechinii* and mentioned the highest number of vascular bundle with more closed to each other in the outer layer as compared to the middle and the inner layer. The result of the present study satisfies his statement by having highest vascular bundle concentration in the outer layer than the middle and the inner. Wang *et al*. (2011) mentioned the longer and smaller vascular bundle at the outer layer of culm wall section and shorter and larger towards the middle and inner layer in *Fargesia yunnanensis*. The result of the vascular bundle dimensions of studied bamboo species followed the same pattern.

Razak *et al*. (2013) studied corelation between vascular bundle concentration and extractive content of 4 numbers of bamboos from genus *Gigantochloa*. His result shows that the larger the size of vascular bundle higher the extractive content. The results of the present study satisfy this statement and follow the same pattern of relationship with solubility content and vascular bundle size. Out of 6 studied bamboo species the *B. bambos* shows the largest bundle size of 861.30±1.82 µm length and 529.98±1.17 µm diameter and *B. assamica* shows smallest bundle size of 782.47±2.26 µm in length and 516.40±1.51 µm in diameter.

Table 5.15: Vascular bundle concentration showing three cross sectional position outer, middle and inner in /cm^2

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	358.11 ±11.10	302.63 ±13.10	341.02 ±8.51	342.63 ±9.48	357.76 ±9.62	361.35 ±8.52
Middle	193.69 ±17.82	190.56 ±23.27	228.87 ±18.67	229.39 ±18.20	233.01 ±5.57	245.68 ±14.46
Inner	174.96 ±3.93	150.37 ±17.58	162.43 ±23.35	163.45 ±2.75	196.78 ±15.45	207.28 ±14.29

Table 5.16: Vascular bundle length showing three cross sectional position outer, middle and inner in µm

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	854.43 ±12.08	786.85 ±25.37	850.89 ±20.53	834.52 ±20.06	849.63 ±8.82	857.99 ±7.72
Middle	807.87 ±9.42	700.74 ±11.71	787.51 ±13.90	685.55 ±12.56	779.73 ±20.73	809.95 ±20.68
Inner	638.41 ±25.24	663.73 ±6.27	751.84 ±2.29	608.19 ±17.91	651.65 ±13.38	683.73 ±15.69

Table 5.17: Vascular bundle diameter showing three cross sectional position outer, middle and inner in µm

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	370.94 ±3.28	405.78 ±1.07	319.73 ±0.91	297.64 ±2.50	301.66 ±0.47	352.41 ±2.07.
Middle	418.14 ±2.04	449.51 ±3.02	476.67 ±2.43	446.59 ±1.62	397.48 ±0.83	457.48 ±0.75
Inner	533.11 ±2.12	516.40 ±1.51	537.92 ±1.58	527.84 ±1.79	536.97 ±3.31	529.98 ±1.17

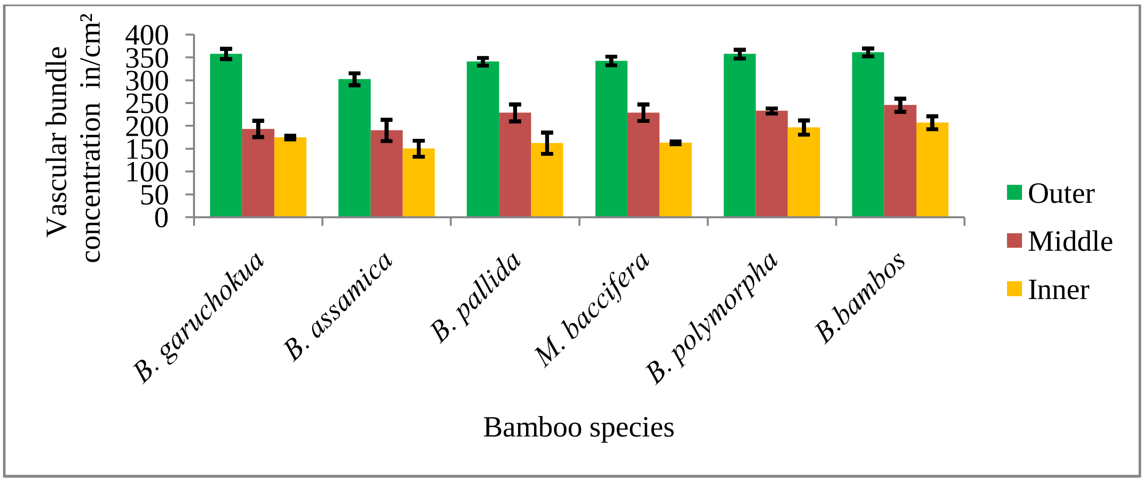


Figure 5.13: Vascular bundle concentration showing three cross sectional position outer, middle and inner in /cm^2

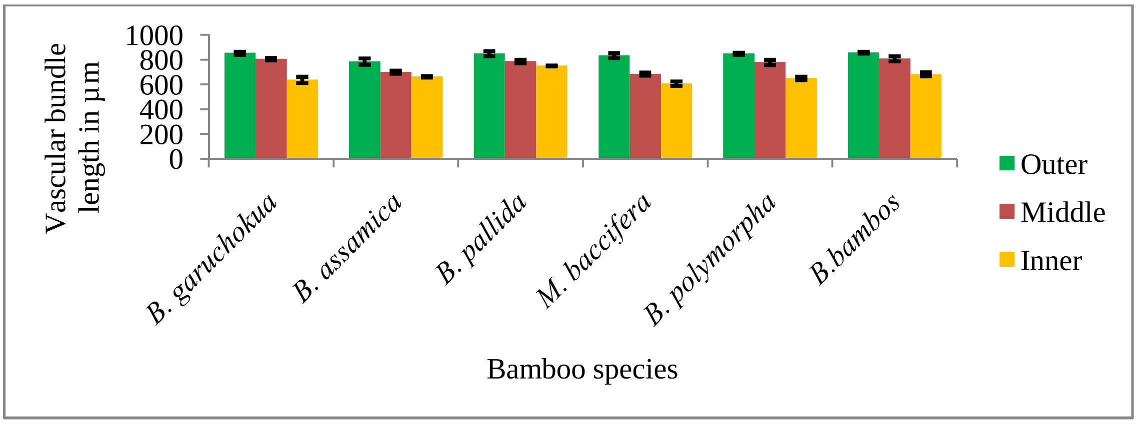


Figure 5.14: Vascular bundle length showing three cross sectional position outer, middle and inner in µm

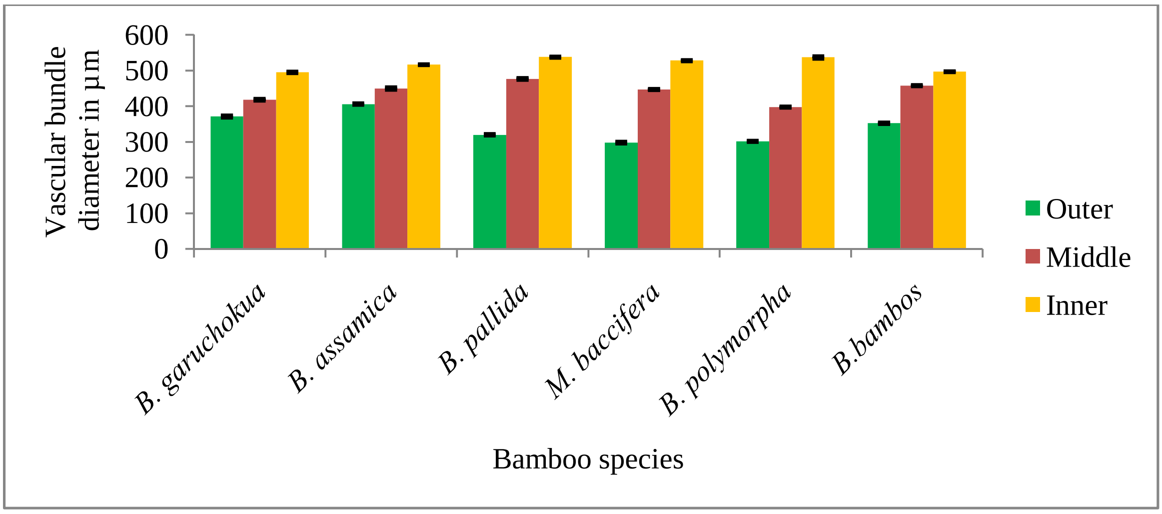


Figure 5.15: Vascular bundle diameter showing three cross sectional position outer, middle and inner in µm

5.4.2. Study of Fiber characters

Liese and Grosser (1972) gave important statement on fiber characters of bamboo. According to them, 60 to 70% of total tissue weight is constituted by fiber. Liese (1998); Fengel and Wegener (1984) determined the range of bamboo fiber length from 2 to 4 mm, which is very similar to the fiber length of certain softwood. The length of fiber is different in different species and within different location of the same culm. He mentioned about the fiber length of certain bamboos, *Phyllostachys edulis* (1.5 mm), *P. pubescens* (1.3 mm), *Dendrocalamus giganteus* (3.2 mm), *D. membranaceus* (4.3 mm), *Oxytenanthera nigrocilliata* (3.6 mm). Razak *et al*. (2012) studied fiber length characters of *G. scortechinii* and found differences in layers of same culm with outer 1698.52 µm, middle 2060.41 µm and inner 1861.35 µm. Regarding fiber length within bamboo culm, the same statement was given by Liese and Grosser (1972) that fiber length varies even within same culm. The result of the present study followed the same pattern of fiber length in outer, middle and inner position and satisfies the statement.

Kokutse *et al*. (2013) determined the fiber length of 4 numbers of bamboos, *Bambusa vulgaris* var. striata Lodd. ex Lindl., *B. vulgaris* Schrad ex J.C., *Oxytenanthera abyssinica* (A. Rich) Munro., and *Bambusa sp.* with 2.54±0.07, 2.58±0.08, 2.13±0.06 and 2.68±0.09 mm respectively. The result of their findings is close and comparable with the result of the fiber length of present study. The results of the present study follow the same pattern of fiber length characters across the culm wall position (outer, middle and inner) by having the highest fiber length in middle position than inner and outer as described by Kokutse *et al*. (2013). The result of the present study shows the highest fiber length in *B. assamica* with 2.3850±0.07 followed by *M. baccifera* with 2.3646±0.03. The *B. garuchokua* and *B. bambos* both shows close fiber length by having 2.2912±0.06 and 2.2928±0.12 respectively.

Fiber diameter of several bamboo species were studied by many workers. Fiber diameter range of 18.23 µm to 22.36 µm was reported from *Gigantochloa scortechinii* by Razak *et al*. (2012). Abd. Latif (1995) mentioned fiber length of *G. scortechinii* with 23 µm to 37 µm. The measurement of fiber diameter studied by different workers in genus Bambusa shows comparatively less. Ireana (2009) in his study found 12 µm fiber diameters in *B. blumeana*. Razak *et al*. (2010) found fiber diameter range of 16.9 µm to 18.0 µm in *B. valgaris*. Abd. Latif (1995) reported larger fiber diameter in *B. valgaris* with range of 20 µm to 42 µm. These results of fiber diameter in several bamboo species stated by different workers are comparable with the result of the present study.

The result of the fiber diameter in the cross section of the culm wall, outer, middle, inner in *G. scortechinii* were 18.49 µm, 22.36 µm and 19.56 µm respectively (Razak *et al*., 2012). The result of their study shows the middle layer with highest fiber diameter as compared with outer and inner layer.

The result of the fiber diameter in studied bamboo species shows the same pattern of having highest fiber diameter in middle layer as compared to outer and inner layer. Among the studied species *M. baccifera* have the highest fiber diameter (15.97±0.10 µm), followed by *B. polymorpha* with (15.96±0.19 µm) and the *B. bambos* with lowest fiber diameter (14.88±0.20 µm).

The result of the fiber length and diameter (L/D) µm/ µm ratio of studied bamboo satisfy the statement given by Wang *et al*. (2008) that the L/D ratio of 100µm/ µm and above are better pulp fiber for paper making. The present studied species shows the L/D ratio of *B. garuchokua* (149.75), *B. assamica* (149.92), *B. pallida* (147.71), *M. baccifera* (148.02), *B. polymorpha* (145.92), and *B. bambos* (154.12).

Table 5.18: Fiber length showing three cross sectional position outer, middle and inner in mm

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	1.9578 ±0.17	2.1242 ±0.15	1.9586 ±0.06	1.9968 ±0.08	1.8879 ±0.45	1.9362 ±0.08
Middle	2.2912 ±0.16	2.3850 ±0.07	2.3498 ±0.05	2.3646 ±0.03	2. 3290 ±0.19	2.2928 ±0.12
Inner	2.1064 ±0.02	2.1734 ±0.05	2.1433 ±0.15	2.0740 ±0.16	2.1028 ±0.11	2.1706 ±0.10

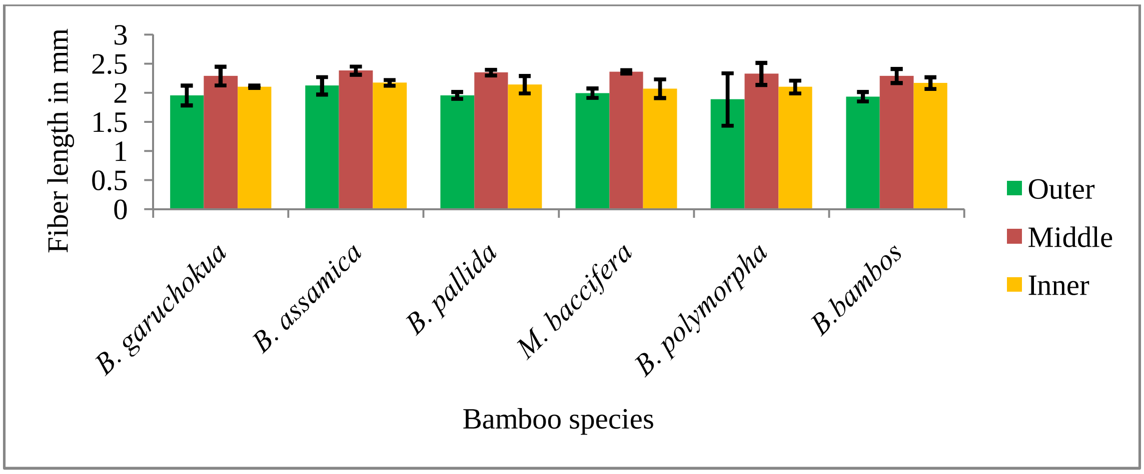


Figure 5.16: Fiber length showing three cross sectional position outer, middle and inner in mm

Table 5.19: Fiber diameter showing three cross sectional position outer, middle and inner in µm

Position	*Bambusa garuchokua*	*Bambusa assamica*	*Bambusa pallida*	*Melocanna baccifera*	*Bambusa polymorpha*	*Bambusa bambos*
Outer	13.678 ±0.46	13.372 ±0.09	12.234 ±0.24	14.076 ±0.23	12.798 ±0.17	9.938 ±0.12
Middle	15.3 ±0.23	15.032 ±0.13	15.908 ±0.10	15.974 ±0.10	15.96 ±0.19	14.876 ±0.20
Inner	14.958 ±0.37	13.963 ±0.24	15.03 ±0.06	14.806 ±0.19	15.172 ±0.43	12.968 ±0.27

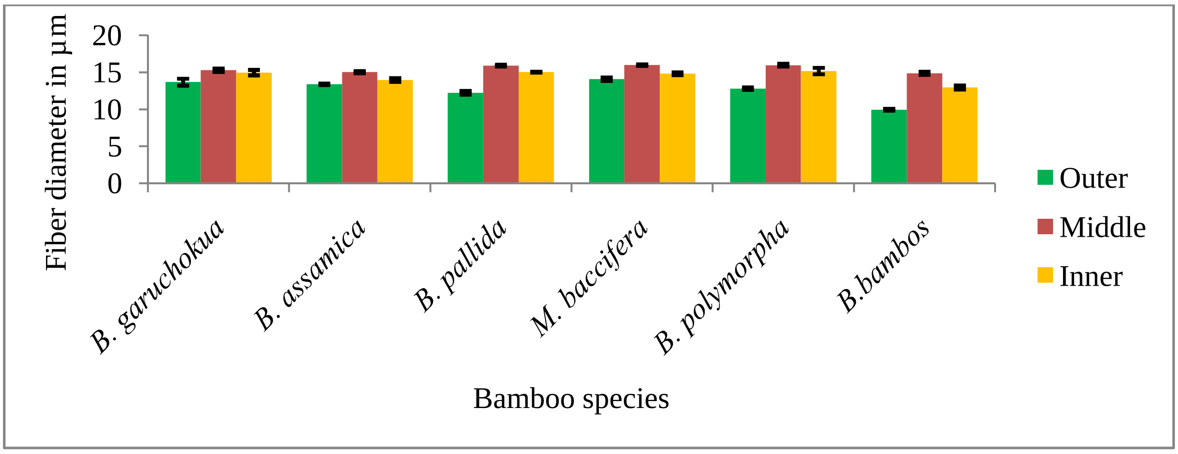
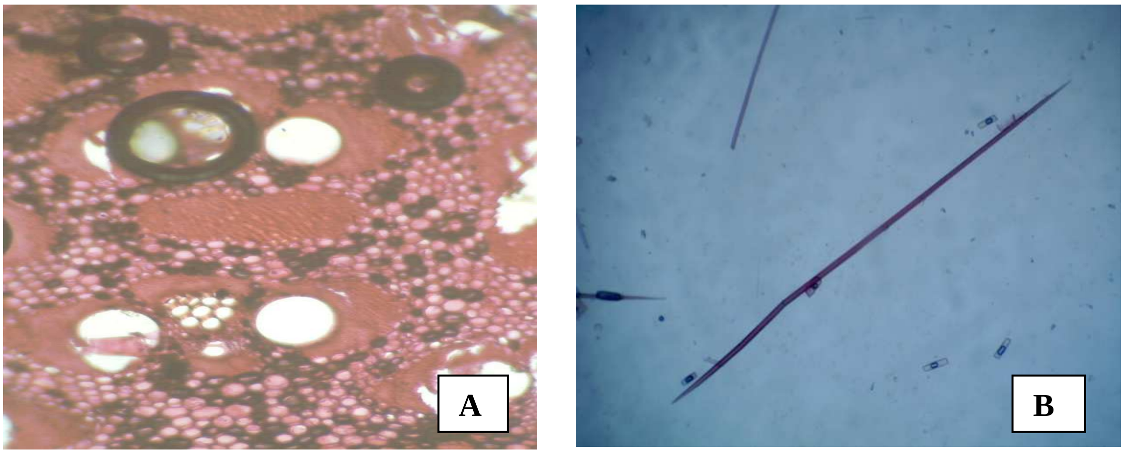


Figure 5.17: Fiber diameter showing three cross sectional position outer, middle and inner in µm

PLATE 5.7

Bambusa garuchokua Barooah *et* Borthakur., Anatomical structure

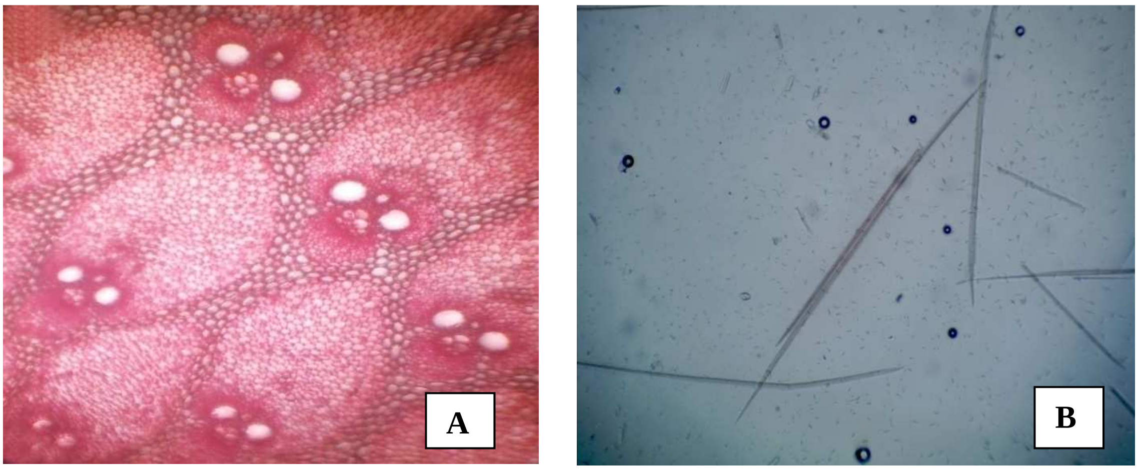


[A] - A view of the micro section of vascular bundle under microscope (100X magnification).

[B] - A view of macerated bamboo fiber under microscope (100X magnification).

PLATE 5.8

Bambusa assamica Barooah *et* Borthakur., Anatomical structure

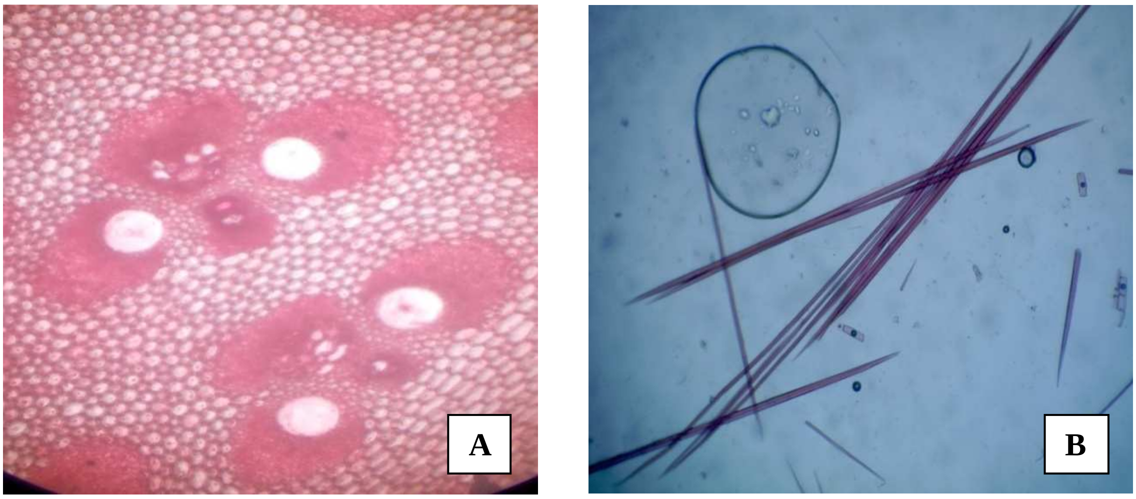


[A] - A view of the micro section of vascular bundle under microscope (100X magnification).

[B] - A view of macerated bamboo fiber under microscope (100X magnification).

PLATE 5.9

Bambusa pallida Munro., Anatomical structure

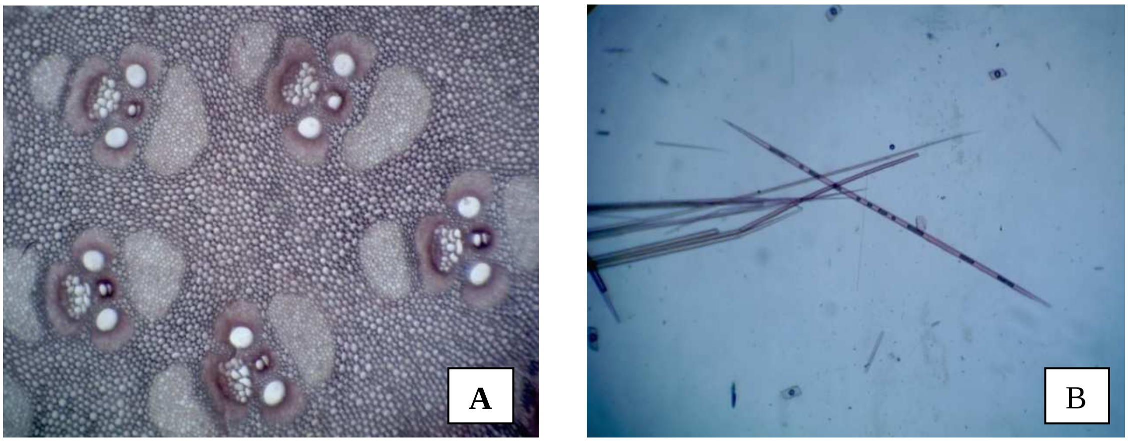


[A] - A view of the micro section of vascular bundle under microscope (100X magnification).

[B] - A view of macerated bamboo fiber under microscope (100X magnification).

PLATE 5.10

Melocanna baccifera (Roxb.) Kurz., Anatomical structure

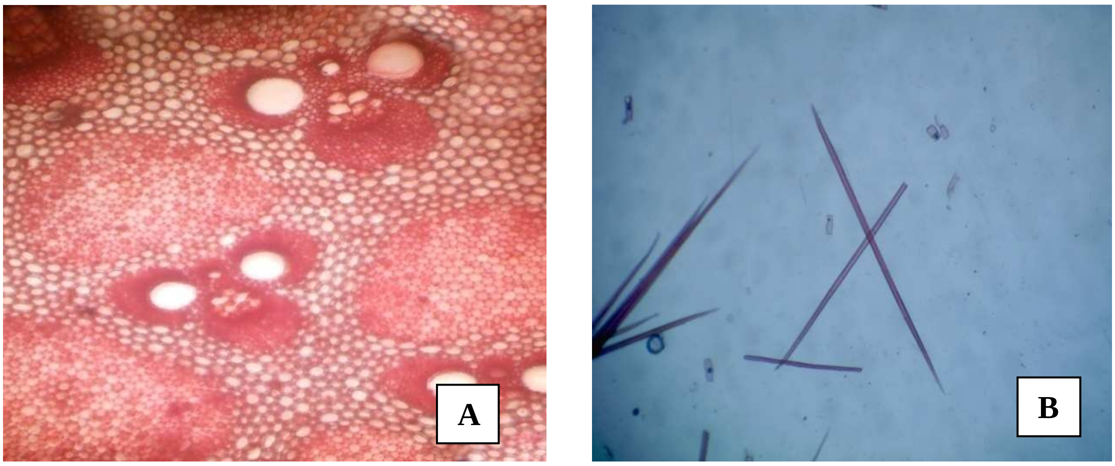


[A] - A view of the micro section of vascular bundle under microscope (100X magnification).

[B] - A view of macerated bamboo fiber under microscope (100X magnification).

PLATE 5.11

Bambusa polymorpha Munro., Anatomical structure

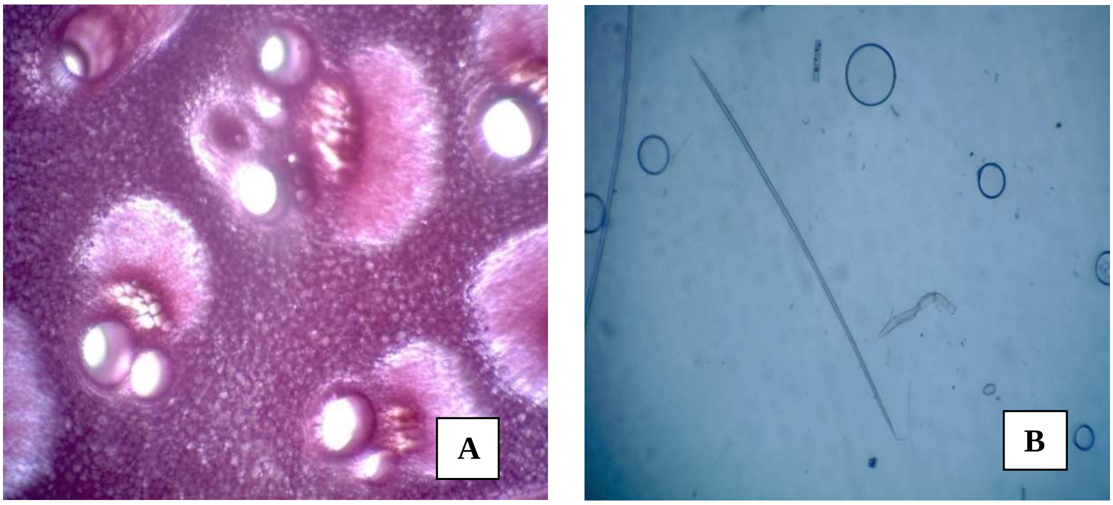


[A] - A view of the micro section of vascular bundle under microscope (100X magnification).

[B] - A view of macerated bamboo fiber under microscope (100X magnification).

PLATE 5.12

Bambusa bambos (L.) Voss., Anatomical structure



[A] - A view of the micro section of vascular bundle under microscope (100X magnification).

[B] - A view of macerated bamboo fiber under microscope (100X magnification).

4.2.8 Corelation of chemical, physical and anatomical properties

The correlations between chemical content and vascular bundle characters of six selected bamboo species have been studied. The result shows the relation of alcohol-toluene solubility and hot water solubility with vascular bundle concentration. Among the selected bamboo species, most of the bamboo species showed negative relation with hot water solubility.

The result of the present study indicates the significant correlation of vascular bundle concentration with lignin content. This shows higher vascular bundle concentration with higher lignin content. The length and diameter of vascular bundle show weak correlation with lignin content.

The result of the correlation studied among the selected bamboo species shows no relation of lignin content with fiber length, where as there is a relation of lignin with fiber diameter. The result shows that the lignin content is more with the smaller fiber diameter. These result of the present study satisfied the theory of requirement of higher amount of lignin content to bind smaller diameter fiber.

All the present studied bamboo species shows the similar pattern of positive correlation of holocellulose and α-cellulose with vascular bundle concentration. The holocellulose and α-cellulose shows negative relation with length and diameter of vascular bundle. The ash content shows negative relation with vascular bundle characters and fiber morphology.

Based from the results, *B. bambos*, *B. garuchokua*, *B. pallida*, was found to have a considerably less specific gravity (SG) than *B. assamica*, *M. baccifera* and *B. polymorpha* which is associated with higher moisture content and shrinkage percentage. With regards to their anatomical structure, *B. bambos*, *B. garuchokua*, *B. pallida*, *B. polymorpha* have higher vascular bundle concentration and lesser fiber dimensions in compared to *B. assamica*, *M. baccifera.*

Table 5.20: Correlation coefficient of different physical properties with studied anatomical structure of *B. garuchokua*

	Vascular bundle concentration	**Fiber length**	**Fiber Diameter**	**Vascular bundle length**	**Vascular bundle diameter**
Moisture content (MC)	-0.2013	-0.8755	-0.654	0.4700	-0.8727
Specific gravity (SG)	0.1268	-0.7515	0.2922	0.5738	-0.2946
Tangential shrinkage	0.3180	0.0435	0.5307	0.3360	0.1391
Radial shrinkage	0.5924	0.3598	-0.5902	0.0610	-0.3333
Longitudinal shrinkage	0.4833	-0.2057	0.5637	0.1980	0.2766
Modulus of elasticity (MOE)	0.9048	0.6161	0.4172	0.3593	0.4981
Modulus of rupture (MOR)	-0.6561	-0.1560	-0.2437	-0.6125	0.0167
Longitudinal compression	0.5387	0.3832	-0.5591	0.4340	-0.3159
Tangential compression	-0.4754	0.5280	-0.0271	-0.8835	0.4790

Table 5.21: Correlation coefficient of different physical properties with studied anatomical structure of *B. assamica*

	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Moisture content (MC)	0.4907	0.5383	-0.1323	0.5669	0.4192
Specific gravity (SG)	0.3656	0.7044	0.0735	0.4643	0.6592
Tangential shrinkage	0.0119	-0.4911	-0.7116	-0.1138	-0.5803
Radial shrinkage	-0.5432	-0.3332	0.4243	-0.5688	-0.2570
Longitudinal shrinkage	0.1843	-0.4649	-0.3624	0.1405	-0.8167
Modulus of elasticity (MOE)	0.1130	-0.5883	0.1540	0.1049	-0.5393
Modulus of rupture (MOR)	-0.5511	-0.0923	0.5115	-0.5288	-0.4268
Longitudinal compression	-0.7766	-0.9544	0.9712	-0.6711	0.4555
Tangential compression	-0.2152	-0.4559	0.6976	-0.0747	0.8903

Table 5.22: Correlation coefficient of different physical properties with studied anatomical structure of *B. pallida*

	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Moisture content (MC)	-0.5540	-0.2487	0.0550	0.7650	0.0717
Specific gravity (SG)	0.1882	0.5799	-0.2992	-0.5663	0.2219
Tangential shrinkage	0.5314	-0.2883	-0.8934	-0.1258	-0.5670
Radial shrinkage	-0.7638	-0.2426	0.3127	0.1709	0.1927
Longitudinal shrinkage	-0.9478	0.6030	0.9066	-0.0610	0.9145
Modulus of elasticity (MOE)	-0.8392	0.3818	0.4917	0.3899	0.6575
Modulus of rupture (MOR)	-0.7660	-0.0914	0.2612	0.5521	0.2867
Longitudinal compression	0.1061	0.3284	-0.1690	-0.9012	0.1127
Tangential compression	0.1035	-0.2077	0.3807	-0.2364	-0.0927

Table 5.24: Correlation coefficient of different physical properties with studied anatomical structure of *M. baccifera*

	Vascular bundle concentration	**Fiber length**	**Fiber Diameter**	**Vascular bundle length**	**Vascular bundle diameter**
Moisture content (MC)	0.5281	0.2283	-0.8541	0.7837	-0.2617
Specific gravity (SG)	0.0842	-0.5628	-0.3370	0.5928	-0.8021
Tangential shrinkage	-0.6748	0.2379	-0.1687	-0.5856	0.4468
Radial shrinkage	-0.4012	-0.3188	0.9748	-0.6591	0.7014
Longitudinal shrinkage	0.8969	0.2546	-0.6360	0.9418	-0.7269
Modulus of elasticity (MOE)	0.0042	-0.6368	0.6911	-0.0317	-0.0638
Modulus of rupture (MOR)	-0.3096	0.6117	-0.6062	-0.3297	0.1847
Longitudinal compression	-0.0840	-0.7592	0.3932	0.2041	-0.2852
Tangential compression	-0.1621	-0.5938	0.2258	0.1426	-0.2192

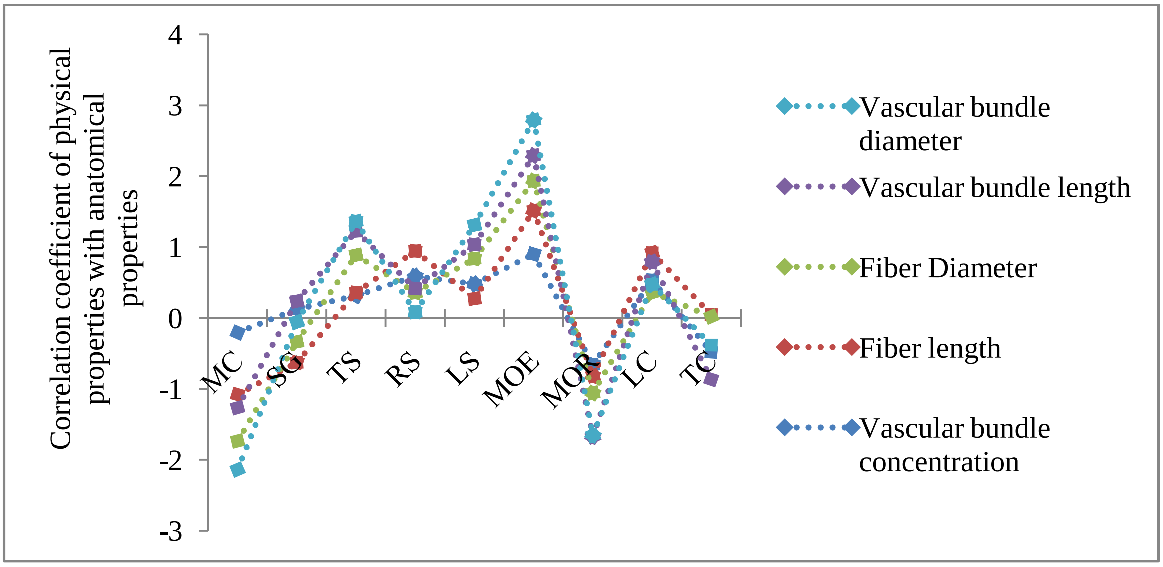
Table 5.25: Correlation coefficient of different physical properties with studied anatomical structure of *B. polymorpha*

	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Moisture content (MC)	0.8805	0.3797	-0.5728	0.6312	0.1599
Specific gravity (SG)	-0.5516	-0.8823	-0.1365	-0.3797	-0.6986
Tangential shrinkage	0.8170	0.5025	-0.5222	0.6606	0.0923
Radial shrinkage	0.0724	0.0735	0.1377	0.4494	-0.5560
Longitudinal shrinkage	-0.5147	0.0372	0.8147	-0.2812	0.1391
Modulus of elasticity (MOE)	-0.2053	0.1560	0.3674	0.1515	-0.3144
Modulus of rupture (MOR)	-0.4675	-0.7972	-0.1257	-0.2269	-0.7854
Longitudinal compression	-0.0110	0.2319	0.1724	0.3014	-0.3394
Tangential compression	0.7440	0.7556	-0.1199	0.5067	0.5832

Table 5.26: Correlation coefficient of different physical properties with studied anatomical structure of *B. bambos*

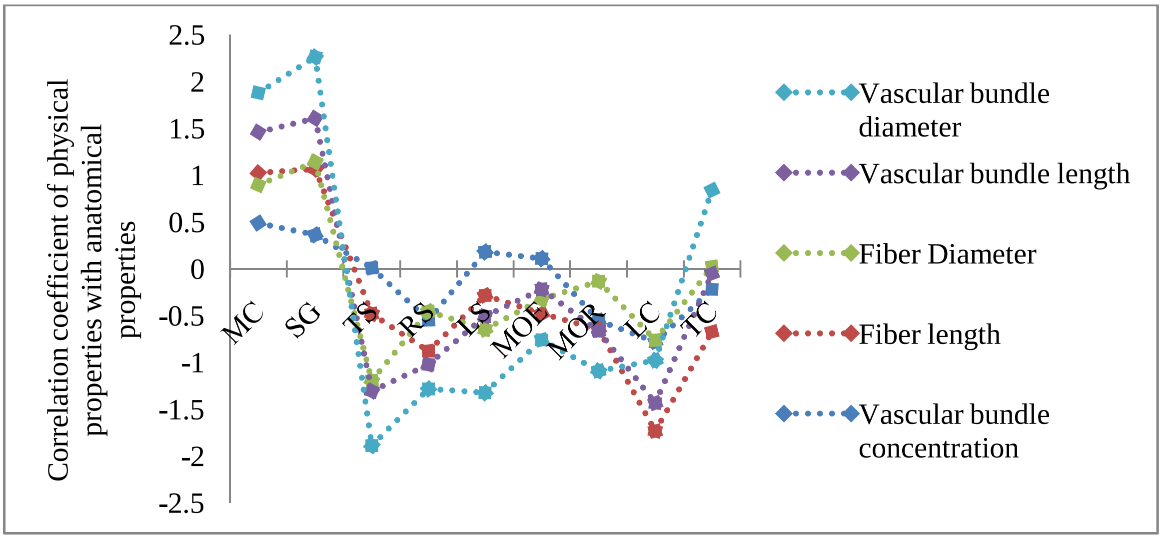
	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Moisture content (MC)	-0.3663	-0.3140	0.2938	-0.2712	0.4867
Specific gravity (SG)	0.3216	0.3041	-0.9432	0.2026	-0.6178
Tangential shrinkage	-0.2571	-0.2984	0.8300	-0.1553	0.7002
Radial shrinkage	-0.3631	-0.0365	0.7108	-0.3234	0.3449
Longitudinal shrinkage	0.3941	-0.7809	-0.4344	0.6762	-0.8356
Modulus of elasticity (MOE)	0.7961	0.5455	0.0865	0.5781	0.2301
Modulus of rupture (MOR)	0.2926	-0.7455	0.2703	0.5511	-0.0946
Longitudinal compression	0.8600	0.3594	-0.1093	0.7314	-0.3150
Tangential compression	-0.1166	0.9142	-0.1707	-0.4543	0.4054

Figure 5.18: Correlation coefficient of different physical properties with studied anatomical structure of *B. garuchakua*



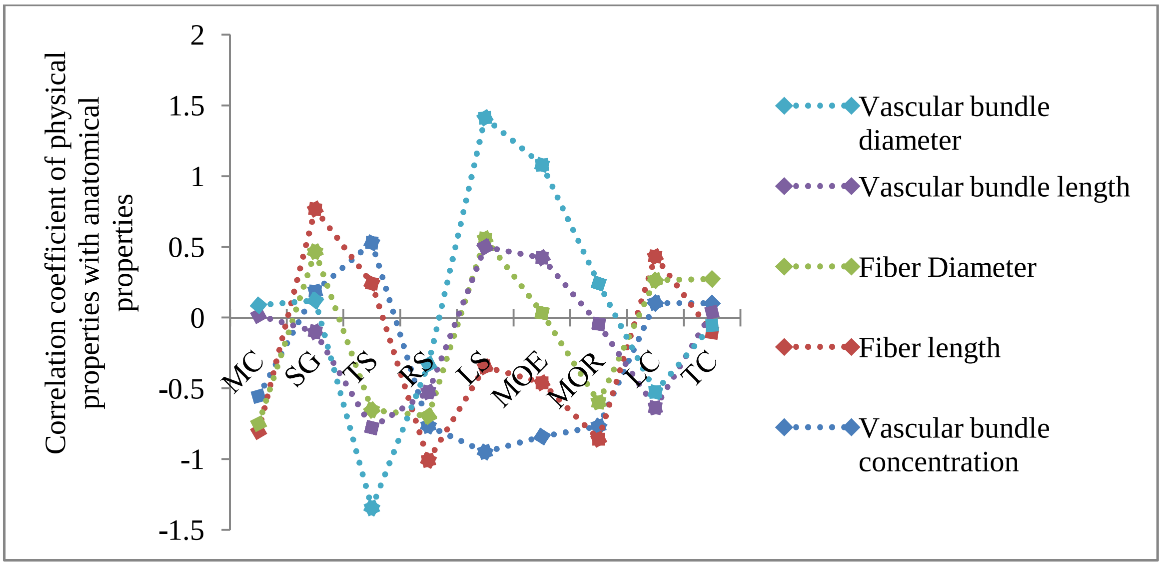
MC = Moisture content, SG = Specific gravity, TS = Tangential shrinkage, RS = Radial shrinkage, LS = Longitudinal shrinkage, MOE = Modulus of elasticity, MOR = Modulus of rupture, LC = Longitudinal compression, TC = Tangential compression.

Figure 5.19: Correlation coefficient of different physical properties with studied anatomical structure of *B. assamica*



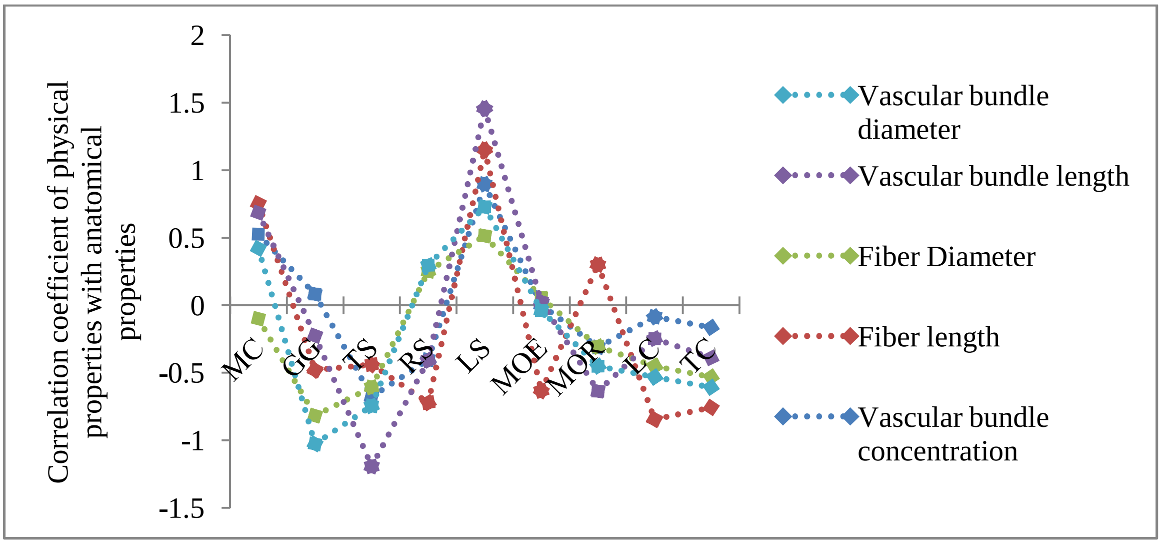
MC = Moisture content, SG = Specific gravity, TS = Tangential shrinkage, RS = Radial shrinkage, LS = Longitudinal shrinkage, MOE = Modulus of elasticity, MOR = Modulus of rupture, LC = Longitudinal compression, TC = Tangential compression.

Figure 5.20: Correlation coefficient of different physical properties with studied anatomical structure of *B. pallida*



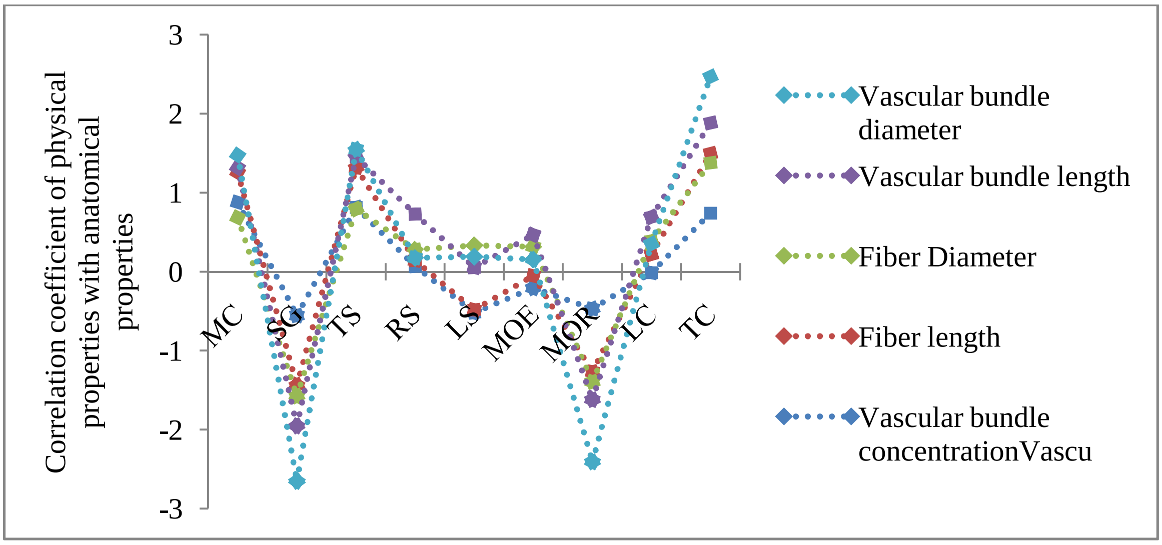
MC = Moisture content, SG = Specific gravity, TS = Tangential shrinkage, RS = Radial shrinkage, LS = Longitudinal shrinkage, MOE = Modulus of elasticity, MOR = Modulus of rupture, LC = Longitudinal compression, TC = Tangential compression.

Figure 5.21: Correlation coefficient of different physical properties with studied anatomical structure of *M. baccifera*



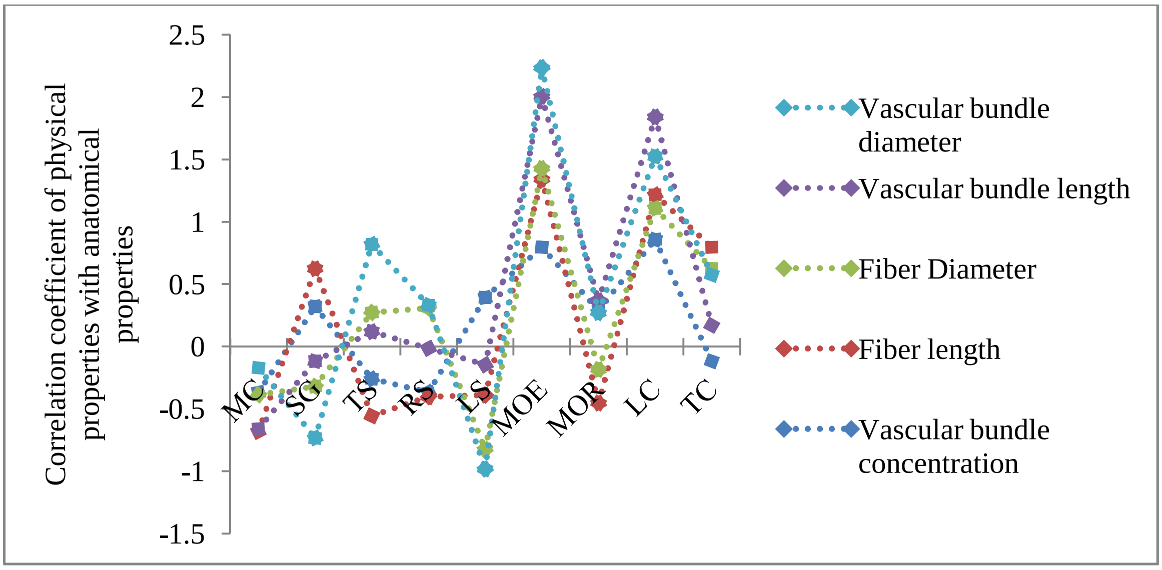
MC = Moisture content, SG = Specific gravity, TS = Tangential shrinkage, RS = Radial shrinkage, LS = Longitudinal shrinkage, MOE = Modulus of elasticity, MOR = Modulus of rupture, LC = Longitudinal compression, TC = Tangential compression.

Figure 5.22: Correlation coefficient of different physical properties with studied anatomical structure of *B. polymorpha*



MC = Moisture content, SG = Specific gravity, TS = Tangential shrinkage, RS = Radial shrinkage, LS = Longitudinal shrinkage, MOE = Modulus of elasticity, MOR = Modulus of rupture, LC = Longitudinal compression, TC = Tangential compression.

Figure 5.23: Correlation coefficient of different physical properties with studied anatomical structure of *B. bambos*

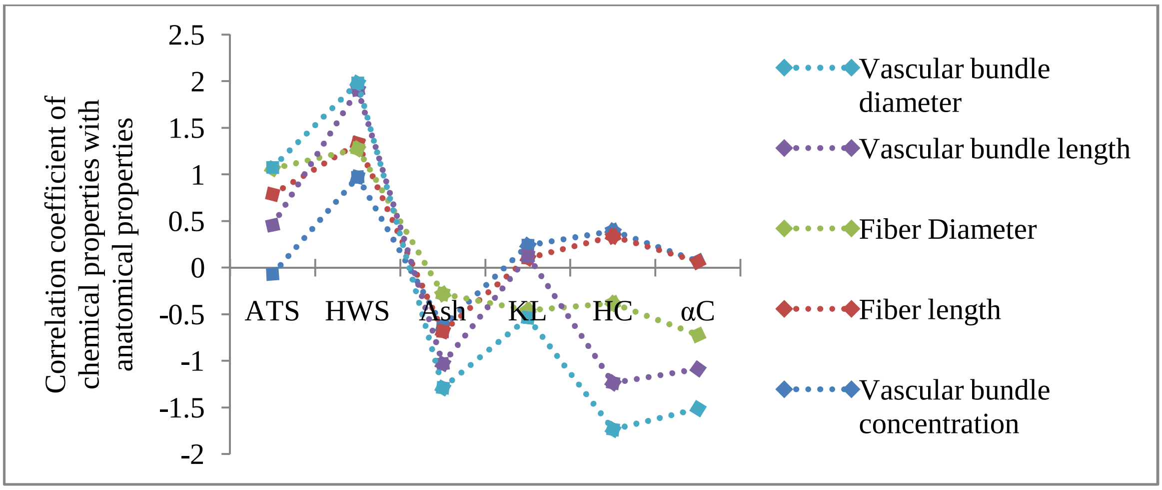


MC = Moisture content, SG = Specific gravity, TS = Tangential shrinkage, RS = Radial shrinkage, LS = Longitudinal shrinkage, MOE = Modulus of elasticity, MOR = Modulus of rupture, LC = Longitudinal compression, TC = Tangential compression.

Table 5.27: Correlation coefficient of different chemical composition with studied anatomical properties of *B. garuchokua*

	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Alcohol-toluene solubitity	-0.0662	0.8554	0.2737	-0.6024	0.6156
Hot water solubility	0.9737	0.3634	-0.0600	0.6346	0.0723
Ash content	-0.6291	-0.0535	0.4037	-0.7502	-0.2602
Klason lignin	0.2438	-0.1381	-0.5616	0.5809	-0.6609
Holocellulose	0.3962	-0.0592	-0.7187	-0.8529	-0.4995
α-cellulose	0.0705	-0.0045	-0.7862	-0.3633	-0.4266

Figure 5.24: Correlation coefficient of different chemical composition with studied anatomical properties of *B. garuchokua*

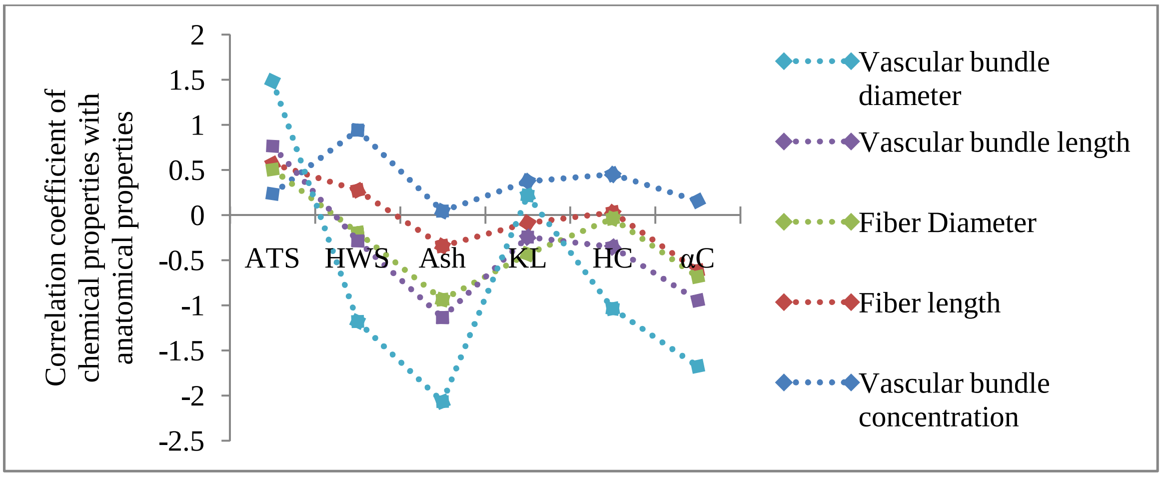


ATS = Alcohol - toluene solubility; HWS = Hot water solubility; Ash = Ash content; KL = Klason lignin; HC = Holocellulose; αC = α-cellulose.

Table 5.28: Correlation coefficient of different chemical composition with studied anatomical properties of *B. assamica*

	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Alcohol-toluene solubitity	0.2393	0.3322	-0.0624	0.2591	0.7201
Hot water solubility	0.9440	-0.6654	-0.4701	-0.0918	-0.8950
Ash content	0.0463	-0.3869	-0.5944	-0.1985	-0.9324
Klason lignin	0.3766	-0.4620	-0.3448	0.1877	0.4615
Holocellulose	0.4540	-0.4202	-0.0674	-0.3158	-0.6860
α-cellulose	0.1591	-0.7703	-0.0690	-0.2637	-0.7285

Figure 5.25: Correlation coefficient of different chemical composition with studied anatomical properties of *B. assamica*

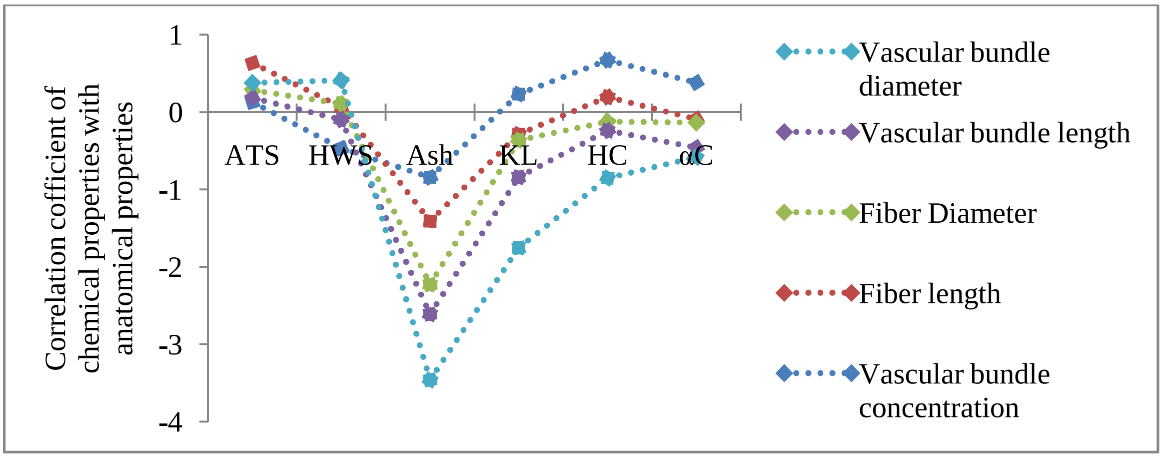


ATS = Alcohol - toluene solubility; HWS = Hot water solubility; Ash = Ash content; KL = Klason lignin; HC = Holocellulose; αC = α-cellulose.

Table 5.29: Correlation coefficient of different chemical composition with studied anatomical properties of *B. pallida*

	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Alcohol-toluene solubitity	0.1332	0.5050	-0.3533	-0.0981	0.1934
Hot water solubility	-0.4649	0.5367	0.0387	-0.2068	0.5117
Ash content	-0.8400	-0.5655	-0.8196	-0.3827	-0.8488
Klason lignin	0.2347	-0.5184	-0.0750	-0.4757	-0.9163
Holocellulose	0.6737	-0.4734	-0.3204	-0.1170	-0.6107
α-cellulose	0.3851	-0.4720	-0.0451	-0.3242	-0.1255

Figure 5.26: Correlation coefficient of different chemical composition with studied anatomical properties of *B. pallida*

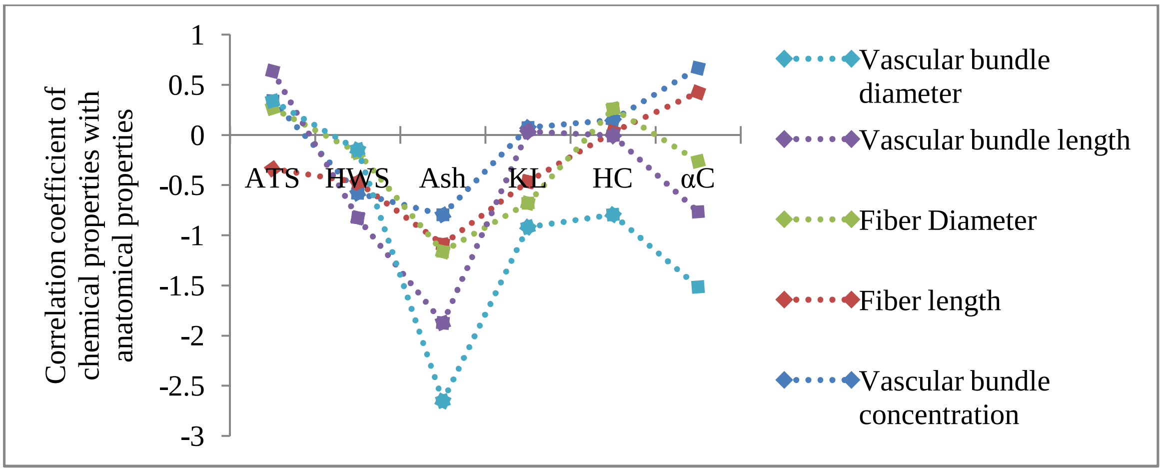


ATS = Alcohol - toluene solubility; HWS = Hot water solubility; Ash = Ash content; KL = Klason lignin; HC = Holocellulose; αC = α-cellulose.

Table 5.30: Correlation coefficient of different chemical composition with studied anatomical properties of *M. baccifera*

	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Alcohol-toluene solubitity	0.3439	-0.6808	0.6062	0.3670	-0.2961
Hot water solubility	-0.5786	0.1071	0.3011	-0.6545	0.6808
Ash content	-0.7934	-0.2953	-0.0725	-0.7108	-0.7797
Klason lignin	0.0742	-0.5370	-0.2140	0.7131	-0.9520
Holocellulose	0.1526	-0.1216	0.2340	-0.2690	-0.7874
α-cellulose	0.6689	-0.2435	-0.6849	-0.5033	-0.7517

Figure 5.27: Correlation coefficient of different chemical composition with studied anatomical properties of *M. baccifera*

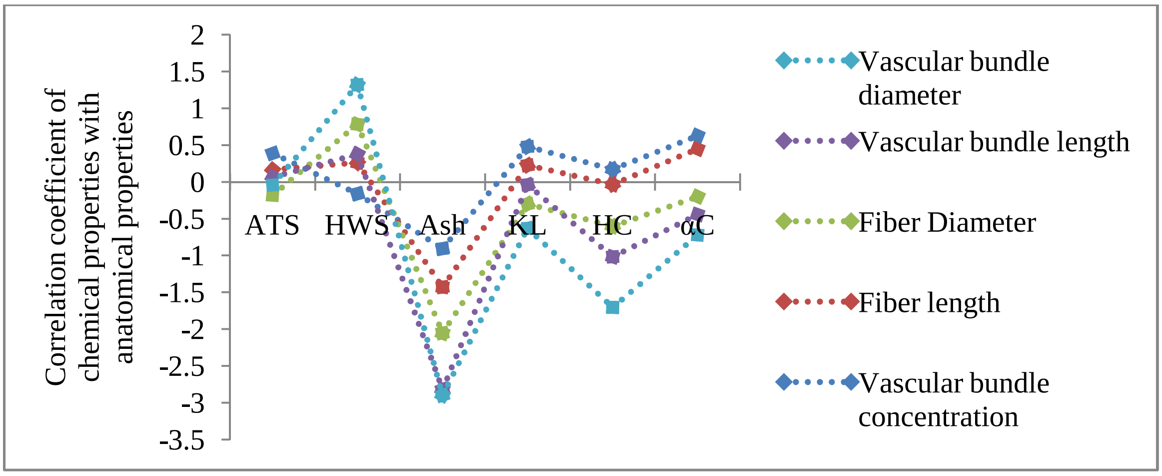


ATS = Alcohol - toluene solubility; HWS = Hot water solubility; Ash = Ash content; KL = Klason lignin; HC = Holocellulose; αC = α-cellulose.

Table 5.31: Correlation coefficient of different chemical composition with studied anatomical properties of *B. polymorpha*

	Vascular bundle concentration	Fiber length	Fiber Diameter	Vascular bundle length	Vascular bundle diameter
Alcohol-toluene solubitity	0.3905	-0.2205	-0.3501	0.2489	-0.1072
Hot water solubility	-0.1589	0.4221	0.5249	-0.4108	0.9468
Ash content	-0.9037	-0.5234	-0.6257	-0.7656	-0.0772
Klason lignin	0.4819	-0.2507	-0.5290	0.2616	-0.5900
Holocellulose	0.1717	-0.2016	-0.5698	-0.4141	-0.6904
α-cellulose	0.6314	-0.1798	-0.6496	-0.2429	-0.2767

Figure 5.28: Correlation coefficient of different chemical composition with studied anatomical properties of *B. polymorpha*

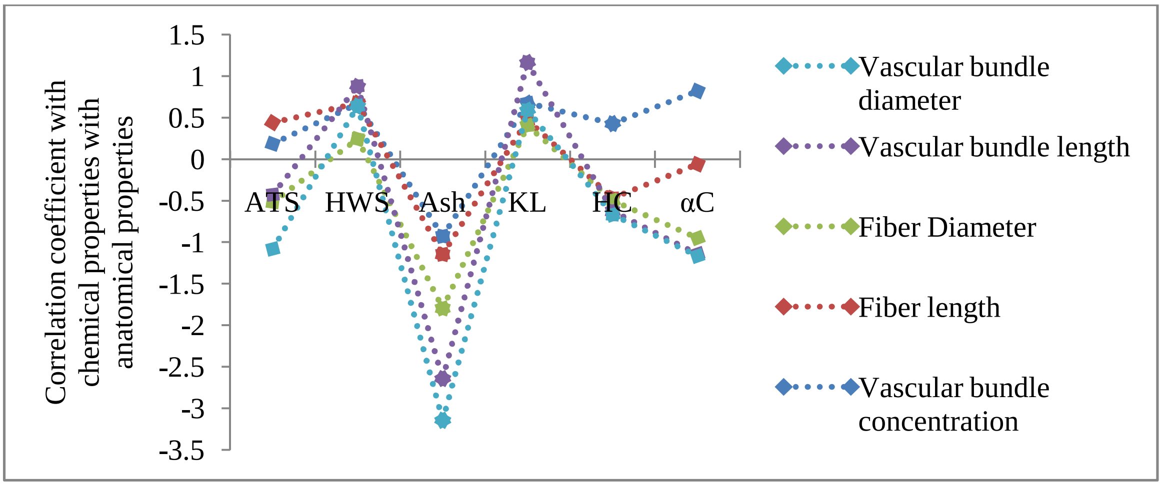


ATS = Alcohol - toluene solubility; HWS = Hot water solubility; Ash = Ash content; KL = Klason lignin; HC = Holocellulose; αC = α-cellulose.

Table 5.32: Correlation coefficient of different chemical composition with studied anatomical properties of *B. bambos*

	Vascular bundle concentration	**Fiber length**	**Fiber Diameter**	**Vascular bundle length**	**Vascular bundle diameter**
Alcohol-toluene solubitity	0.1894	0.2521	-0.9586	0.0942	-0.6539
Hot water solubility	0.6687	0.0094	-0.4332	0.6362	-0.2386
Ash content	-0.9251	-0.2178	-0.6511	-0.8448	-0.5028
Klason lignin	0.6758	-0.2008	-0.0672	0.7579	-0.5740
Holocelluloe	0.4298	-0.8959	-0.0310	-0.1258	-0.0422
α-cellulose	0.8248	-0.8814	-0.8907	-0.1921	-0.0217

Figure 5.29: Correlation coefficient of different chemical composition with studied anatomical properties of *B. bambos*



ATS = Alcohol - toluene solubility; HWS = Hot water solubility; Ash = Ash content; KL = Klason lignin; HC = Holocellulose; αC = α-cellulose.