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Studies on Anatomical and Physico-Mechanical Properties of Candidate Plus Culms (CPCs) of *Dendrocalamus strictus* for Planting Stock Improvement Programme

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Abstract

Five candidate plus culms (CPCs) of about 2-year-old *Dendrocalamus strictus* (namely 16, 17, 21, 55 and 110) were collected from Sirsi, Karnataka, India, for investigations on anatomical, physical and mechanical properties. Various morphological (inter-nodal length, culm diameter and culm wall thickness), anatomical (fibre length, fibre diameter, fibre lumen diameter, fibre wall thickness and vascular bundles), physical (moisture content and specific gravity) and mechanical (fibre stress at elastic limit-FS at EL, modulus of rupture-MOR and modulus of elasticity-MOE) properties were evaluated for inter-comparison among the CPCs. Among all the CPCs, specific gravity was maximum in CPC 55 and minimum in CPC 17. A comparison of different properties was carried out at 2nd and 4th internode for all the five CPCs. The results indicate that the internodal length was lower in 2nd than 4th internodes with maximum and minimum values observed in CPC 55 and CPC 16 respectively. The culm diameter and culm wall thickness was higher in the 2nd internode than 4th internode. The maximum value of culm wall thickness was observed in CPC 110 and minimum in CPC 21 whereas culm diameter was maximum in CPC 16 and minimum in CPC 17. The fibre morphology did not show significant variation between 2nd and 4th internode among all CPCs. However, vascular bundles remained more

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in 4th internode of all the CPCs compared to 2nd internode. While FS at EL was maximum in CPC 55, the minimum corresponding values were found in CPC 110. Similarly, the MOR was maximum in CPC 55 and minimum in CPC 110. The maximum value of MOE was observed in CPC 55 while minimum values were in CPC 16. The data analysis shows that CPCs 55 having superior strength properties is comparatively more suitable for structural applications. CPCs 16 showed most of the anatomical parameters in the higher range and may be utilized for general applications including pulp and paper. The data generated on CPCs may be of use for bamboo improvement program and bamboo plantations which can produce quality product.

Keywords: Anatomy; Bamboo; CPCs; *Dendrocalamus strictus*; Strength Properties.

1. Introduction

Bamboo has traditionally been in use in construction from times immemorial. The important uses being housing, scaffolding, fence posts, tent poles, ladders, bridges, bullock cart and other agricultural implements [1]. In housing, it has been reported to have been used in foundation, frames, floors, walls, partitions, ceilings, doors and windows, roofs, pipes, troughs and for reinforcement in cement concrete [2]. Bamboo is a cultural feature of South Eastern Asia. Its plethora of essential uses has led to the use of terms such as 'bamboo culture' 'green gold' 'poor man's timber, 'bamboo friend of the people' and 'cradle to coffin timber'. Bamboo substitutes timber in many respects. As a material, bamboo ranks potentially higher than juvenile wood having less variability in structure and more favourable properties for making reconstituted panel products [3]. Bamboo is extensively propagated in national afforestation programmes to meet industrial and rural requirements for wood products and to check erosion and conserve soil. One third of the human race at least uses bamboo for several purposes. Besides its use in construction and handicrafts, bamboo is an important paper pulp source in India [4].

In view of the multifarious uses, lots of work have been carried out to generate scientific data on morphology [5,6], leaf epidermal studies for identification [7,8], strength properties [9,21], engineered uses [10,11], fibre morphology [12,13] and pulp sheet properties [14]. Preliminary studies on physico-mechanical and anatomical properties of candidate-plus-culms of *Bambusa Bambos* (L.) Voss, Besch Syn. *B. arundinacea* (Retz.) Willd. have been carried out in India [15]. Various studies mentioned above are basically meant for utilization and develop classification and grading. However, no attempt has been made to use the data for bamboo (species) improvement programme. Since selection and collection of CPC's have already been made for *D. strictus* [16], the young progeny trials were made available for evaluation of the "wood quality" of *D. strictus* with reference to anatomical as well as strength parameters (within culm and between culm variation) to create the database and recommend for various uses as alternative to wood. In view of above, the studies have been carried out to find variations in young selected CPCs of *D. strictus* from Sirsi, Karnataka, India.

2. Materials and methods

Matured culms of about 2-year-old *D. strictus* (CPC No. 16, 17, 21, 55 and 110) were collected from Bambusatum raised at College of Forestry, Sirsi, Karnataka, India. These culms were studied for various anatomical, physical and mechanical properties as detailed below.

2.1 Anatomical Properties

Morphological properties like internodal length, girth and culm wall thickness was measured with metric scale and digimatic calipers. For microscopy, the samples were made into two pieces, the first half was used for maceration to study the fibre length, fibre diameter, fibre lumen diameter, fibre wall thickness. The second half was used for section cutting to study the vascular bundles. About 20 µm thick sections were cut using Reichest sliding microtome. The vascular bundles were measured for entire section from pith to bark side and the measurements were then calculated for cm^2.

Slivers of material were taken in a test tube, boiled with water till it settled down. 30% HNO_3 and a pinch of potassium chlorate was added and further boiled till the material was colourless. Extra acid was drained and washed with plenty of water. The cooked material was taken on a slide, spread across for measurements. Fifty measurements were taken for each of fibre length, fibre diameter and fibre lumen diameter using Leica labourlux microscope. Using Image Analysis System (Quantimet 500 C), the images of the cross sections of the culms were captured.

2.2 Physical Properties

Small samples of 2.5 x 2.5 cm from intermodal region (2nd and 4th internodes) were taken to find the specific gravity. Specific gravity was determined by oven dry weight/volume at test as per IS: 6874 (1973) [17].

2.3 Strength Properties

The fibre stress at elastic limit (FS at EL), modulus of rupture (MOR) and modulus of elasticity (MOE) properties were obtained from 3-point static bending tests drawn on full diameter bamboo specimen free from any defect like cracks and crookedness. The load was applied at center internode of the specimen. The tests were conducted on 100 kN capacity of Testometric Universal Testing machine attached with computer, programmed with different type of tests. The specimen is mounted on a rig and load was applied through the loading block at the center. The specimen was freely supported to follow the bending action. The load was applied continuously throughout the test such that the moveable head of the testing machine moves at a constant rate of 2.5 mm per minute. The testing machine was programmed to stop automatically when the specimen starts cracking indicating that it will not bear any further load. The properties were obtained by using the following formulae [17].

$$FS\ at\ EL\ (N/mm^2) = \frac{178.18\ PD}{D^4 - D_1^4} \quad (1)$$

$$MOR\ (N/mm^2) = \frac{178.18\ P'D}{D^4 - D_1^4} \quad (2)$$

$$MOE\ (\times 10^3\ N/mm^2) = \frac{145.515\ P}{(D^4 - D_1^4)\ \Delta} \quad (3)$$

Where, P is load in kg at the limit of proportionality which was taken as the point in load deflection-curve which the graph deviates from the straight line, P' is maximum load in kg, D is outer diameter at mid span in cm, D_1 is inner diameter at mid span in cm and Δ is deflection at the limit of proportionality in cm.

3. Results and discussion

3.1 Morphology and anatomical features

Five CPCs of 2-year-old *D. strictus* were investigated for morphological and anatomical properties at their 2nd and 4th internodes. The cross-sectional views of all the CPCs are shown in Figure 1. Average values of different morphological and anatomical parameters of all the CPCs measured at 2nd and 4th internodes are presented in Table 1. The results, as shown in Figure 2, indicate that the internodal length was less in the 2nd than the 4th except in one CPC, the culm diameter and culm wall thickness was more in the 2nd internode than 4th internode. There was no definite trend in the fibre length between 2nd and 4th internode (Figure 3). The fibre morphology showed slight variation in fibre diameter and its wall thickness between 2nd and 4th internode in CPC 110. The number of vascular bundles, however, remained higher in 4th internode of all the CPCs (Figure 3).

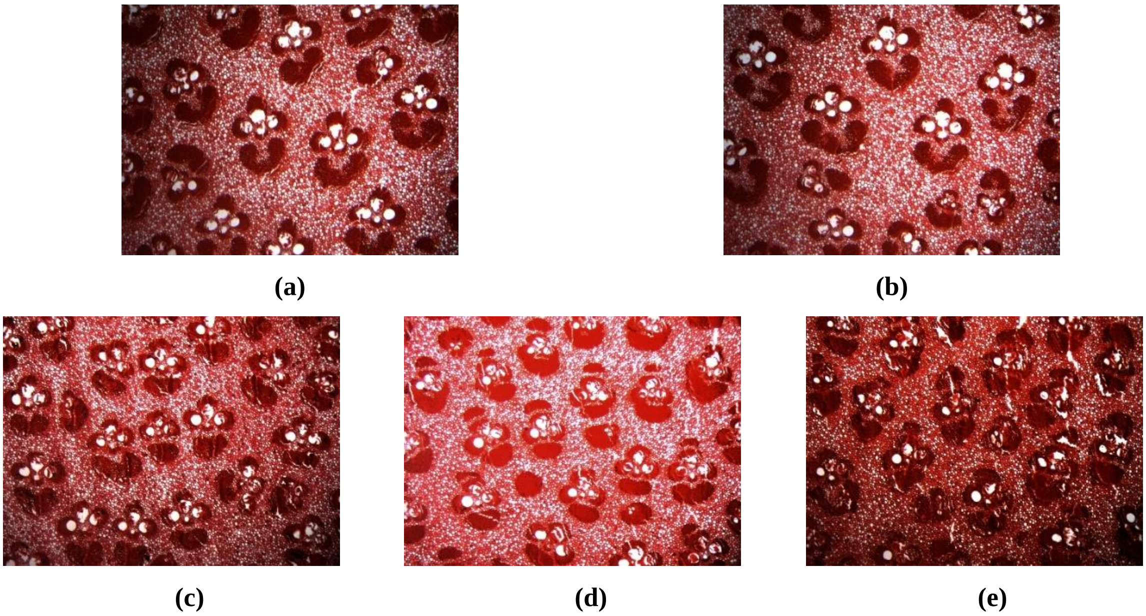
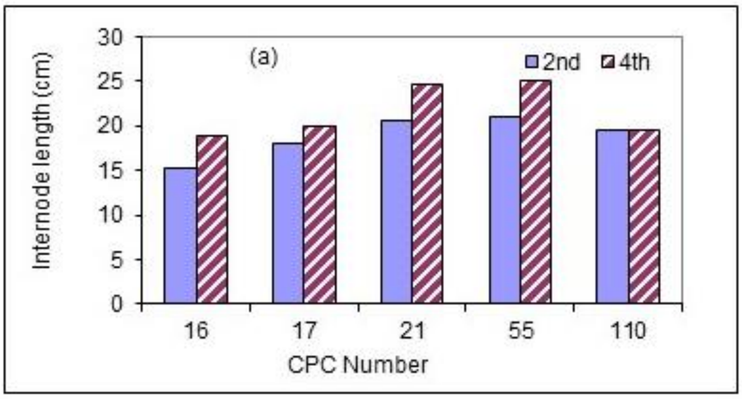


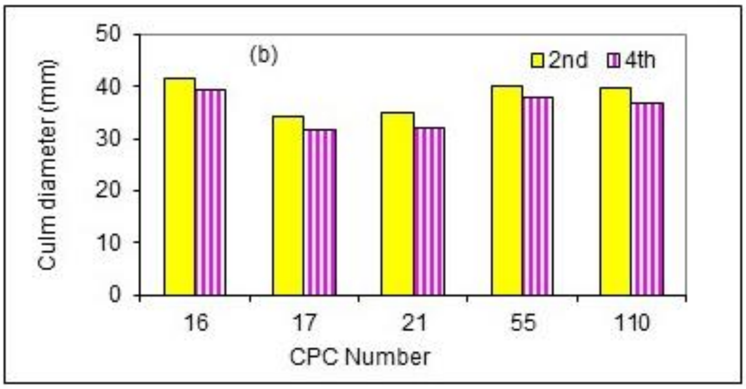
Figure 1: Cross sections of *D. strictus* CPCs 16 (a), CPC 17 (b), CPC 55 (b) and CPC 110 (d)

A comparison of range of variation based on average values of 2nd and 4th internode obtained in both the genera indicate (Table 2) that the maximum internode length was found in CPC No. 55. Similarly the maximum culm wall diameter and wall thickness was observed in CPC 110. Similarly the fibre length showed wide variation in CPC 16 and CPC 110. The lowest fibre wall thickness was found in CPC 17. While maximum number of vascular bundles were found in CPC 21, the minimum was found in CPC 17. Studies made on fibre morphology of matured culms of *D. strictus* [18] showed that fibre length ranged from 2.24 to 2.79 mm and 2.45-2.17 mm in the respective genera. The fibre diameter (14.51-13.63) is found to be less than the CPCs [14] suggesting that young CPCs have potential for its use in paper and pulp industry. Similar types of variation in fibre morphology with respect to internode number in these two genera have also been reported by other researchers [12].

Table 1: Average values of different morphological and anatomical parameters of CPCs measured at 2nd and 4th internodes.

Property	CPCs Number									
	16	**17**	**21**	**55**	**110**	**16**	**17**	**21**	**55**	**110**
	2nd Internode					4th Internode				
Internode length (cm)	**15.3**	18.0	20.5	**21.0**	19.5	**19.0**	20.0	24.7	**25.0**	19.5
Culm diameter (mm)	**41.52**	**34.54**	34.78	40.17	39.68	**39.19**	**31.76**	32.16	37.89	36.90
Culm wall thickness (mm)	19.72	15.28	14.64	17.59	19.84	17.45	13.30	12.44	17.13	18.45
Fibre length (mm)	2.9	2.9	3.2	3.2	3.0	2.8	3.1	3.0	3.1	3.1
Fibre diameter (µm)	22.46	17.24	19.59	19.11	16.20	23.90	17.21	18.56	18.90	18.7
Fibre lumen diameter (µm)	9.60	6.16	8.38	595	4.60	9.68	6.23	7.24	5.97	5.70
Fibre wall thickness (µm)	12.90	11.08	11.21	13.17	11.51	14.21	10.98	11.33	12.92	12.97
Vascular bundles (/cm^2)	212	220	236	213	228	291	253	322	260	298





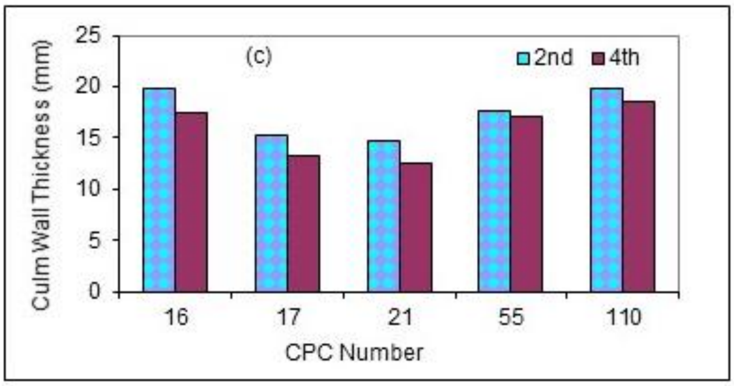
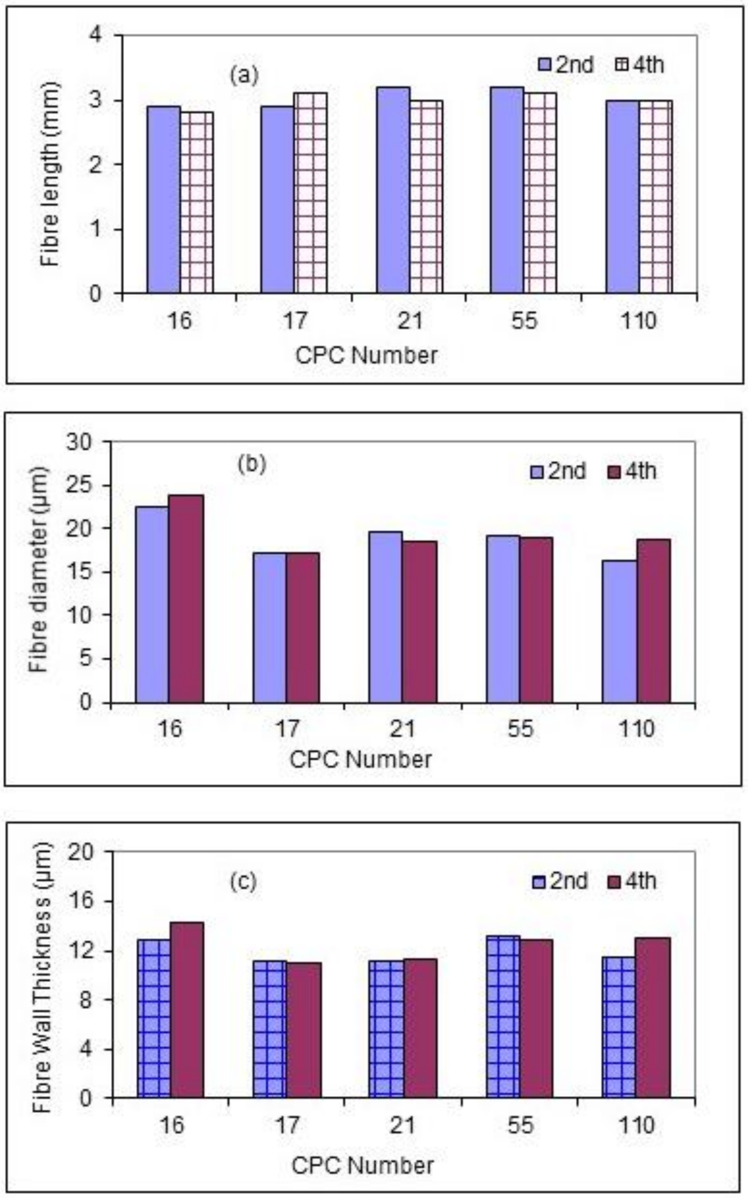


Figure 2: Variation in (a) internode length, (b) culm diameter and (c) culm wall thickness at 2nd and 4th internodes of different CPCs.



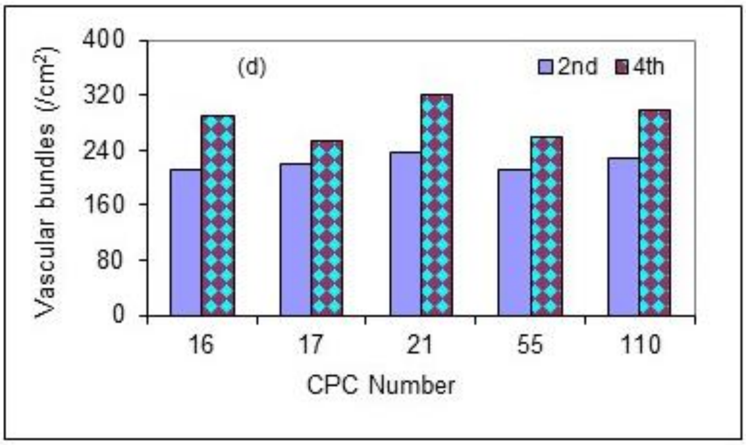


Figure 3: Variation in (a) fibre length, (b) fibre diameter, (c) fibre wall thickness and (d) vascular bundles at 2nd and 4th internodes of different CPCs.

Table 2: Range of variation in various properties among CPCs at 2nd and 4th Internode.

Properties	**Range of variation**	
	2nd Internode	**4th Internode**
Internodal length (cm)	15.3 (CPC 16) — 21 (CPC55)	19 (CPC 16) — 25 (CPC55)
Culm diameter (mm)	34.54 (CPC17) — 41.52 (CPC 16)	31.76 (CPC17) — 39.19 (CPC 16)
Culm wall thickness (mm)	14.64 (CPC 21) — 19.84 (CPC 110)	12.44 (CPC 21) — 18.4 (CPC 110)
Fibre length (mm)	2.9 (CPC16,17) — 3.2 (CPC 21,55)	2.8 (CPC16) — 3.1 (CPC 17,55,110)
Fibre diameter (µm)	16.2 (CPC 110) — 22.46 (CPC 16)	17.21 (CPC 17) — 23.52 (CPC 16)
Fibre lumen diameter (µm)	4.6 (CPC 110) — 9.6 (CPC 16)	5.7 (CPC 110) — 9.68 (CPC 16)
Fibre wall thickness (µm)	11.08 (CPC 17) — 12.9 (CPC 16)	10.98 (CPC 17) — 14 (CPC 16)
Vascular bundles (/cm^2)	212 (CPC 16) — 236 (CPC 21)	253 (CPC 17) — 322 (CPC 21)

3.2 Physical and Mechanical Properties

Physical and mechanical properties of CPCs of *D. strictus* have been evaluated for their moisture content, specific gravity, FS at EL, MOR and MOE (Table 3). The higher values in each of the property indicate superiority over the others in the respective CPCs.

The results indicate only minor difference in moisture content of different CPCs. Among all the CPCs, specific gravity was maximum in CPC 55 and minimum in CPC 17 respectively. While FS at EL was maximum in CPC 55, the minimum values were found in CPC No. 110. The MOR was at its maximum in CPC 17 while MOE was maximum in CPC 55 followed by CPC 21. The data (Table 3) shows that CPC 55 having superior strength

Table 3: Physical and mechanical properties of different CPCs of *D. strictus*

Property	CPCs Number				
	16	**17**	**21**	**55**	**110**
Moisture content (%)	9.3	8.0	8.8	9.1	11.0
Specific gravity	0.661	0.610	0.702	0.732	0.673
FS at EL (kg/cm^2)	684	976	973	1002	570
MOR (kg/cm^2)	811	1585	1127	1297	641
MOE (×10^3 kg/cm^2)	221.8	308.6	352.1	365.4	232.8

properties is comparatively more suitable for structural applications whereas CPC 16 showed most of the anatomical parameters in the higher range (Table 1) and may be utilized for general applications including pulp and paper The data generated on CPCs may be of use for bamboo improvement program and bamboo plantations which can produce quality product. However, large number of CPCs of different bamboo species need to be studied for selecting better CPCs for large scale production aiming different end use applications.

4. Conclusions

Various morphological (inter-nodal length, culm diameter and culm wall thickness), anatomical (fibre length, fibre diameter, fibre lumen diameter, fibre wall thickness and vascular bundles), physical (moisture content and specific gravity) and mechanical (fibre stress at elastic limit-FS at EL, modulus of rupture-MOR and modulus of elasticity-MOE) properties of five CPCs of 2-year-old *D. strictus* were evaluated for inter-comparison among the CPCs. Among all the CPCs, specific gravity was maximum in CPC 55 and minimum in CPC 17. A comparison of different properties was carried out at 2nd and 4th internode for all the five CPCs. The results indicate that the internodal length was lower in 2nd than 4th internodes with maximum and minimum values observed in CPC 55 and CPC 16 respectively. The culm diameter and culm wall thickness was more in the 2nd internode than 4th internode. The maximum value of culm wall thickness was observed in CPC 110 and minimum in CPC 21 whereas culm diameter was maximum in CPC 16 and minimum in CPC 17. The fibre morphology did not show significant variation between 2nd and 4th internode among all the CPCs. However, the number of vascular bundles remained more in 4th internode of all the CPCs compared to 2nd internode. While FS at EL was maximum in CPC 55, the minimum corresponding values were found in CPC 110. Similarly, the MOR was maximum in CPC 17 and minimum in CPC 110. The maximum value of MOE was observed in CPC 55 while minimum values was in CPC 16. The data analysis shows that CPCs 55 having superior strength properties is comparatively more suitable for structural applications. CPCs 16 showed most of the anatomical parameters in the higher range and may be utilized for general applications including pulp and paper. The data generated on CPCs may be of use for bamboo improvement program and bamboo plantations which can produce quality product.

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