Evaluation of growth and quality parameters of germplasm of *Dendrocalamus stocksii*

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Abstract: The study aimed at evaluating germplasm of *Dendrocalamus stocksii* for growth and material quality parameters using non-destructive technique. In the study, ultrasonic pulse propagation method for evaluating modulus of elasticity of bamboo material and assessing hollowness was explored. There was significant variation in internode length and diameter in mature culms of clumps from the 36 accessions in the germplasm bank. The ultrasonic pulse velocity varied from 2.74 to 4.05 km/s among the clumps indicating more than two folds variation in modulus of elasticity of bamboo material. Ultrasonic pulse velocity across the diameter of less than 0.85km/s indicated hollowness in the culm. The growth parameters in combination with non-destructive ultrasonic pulse propagation method can effectively be used for screening of superior accession or genotypes of bamboo species in future improvement programmes in *D.stocksii.*

Keywords: Bamboo, *Dendrocalamus stocksii,* germplasm, growth, stiffness, ultrasonic

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Introduction

Being a biological material, bamboos exhibit large variation in their physical and mechanical properties. This variability provides an opportunity for selection of elite material for specific end-use application in bamboo improvement programme. It is therefore important to capture these inherent variations in seemingly identical materials for the efficient processing and utilization of bamboo resources.

Dendrocalamus stocksii is an extremely manageable bamboo species with great economic potential finding application in scaffoldings, crafts, construction, furniture, etc. The species is mostly confined to the banks of streams and requires a well-drained deep soil. The species is widely distributed in Karnataka, Goa, Maharashtra and Kerala all along the Western Ghats. The mature culms (4-5 years old culms) attain height up to 9-10 m and diameter of 2.5-6 cm with internodal length ranging from 15-29 cm. The culms are generally solid at the base and are reported to be up to half-length of culm height and are hollow towards the tip of the culm. The species is distributed along a gradient of various ecological and climatic conditions of the coastal belts of Western Ghats and the variability in morphological characters have been recorded in this species (Lewis *et al*., 2010, Battacharya *et al*., 2006).

The economic potential of this species is immense considering its wide scope for value addition. The species is one of the priority species of the National

Bamboo Mission for mass cultivation in Karnataka and Maharashtra (Haridasan and Tiwari, 2008). The major primary requirements for the bamboo for its application in structural and high value furniture products are straightness, stiffness, good density and solidness along with high culm diameter (more than 50 mm). Understanding the variability in commercially important traits in the available genetic resources becomes crucial for the improvement of the species as per the industrial requirement.

In an attempt to document the distribution and diversity in species, Viswanath (2015) studied morphological, physiological and genetic variability in this species along the area of its distribution and found significant variation in culm and clump characteristics among different phenotypes of the species. Further, as part of the study, a germplasm bank of the species was established, collecting accessions from central Western Ghats (from Kasargod in Kerala to Ratnagiri in Maharashtra) covering a distance of 850 kms, at Gottipura field station of the Institute of Wood Science and Technology, Bengaluru. This germplasm bank provided an opportunity to assess the variability in bamboo material quality along with growth parameters for identification of superior clump.

The study adopted ultrasonic pulse propagation method *in-situ* to assess modulus of elasticity (MoE) of bamboo, which is probably the first of its kind. MoE is an important parameter for suitability of any material for structural or semi-structural application. Substantial research has been carried out on non-destructive assessment of wood properties particularly in trees using a range of tools and techniques like penetrometer, acoustic, near infra-red spectroscopy, etc. for quick and reliable screening of genotypes (Walker, 2006; Schimleck *et al*., 2001; Raymond *et al*., 2009). Acoustics has been recognized as an important tool to quickly screen and segregate round wood according to their processing characteristics and also have shown potential in selecting elite material particularly for MoE in breeding programmes of tree species (Blackburn *et al*., 2014; Lenz *et al*., 2013; Dickson *et al*., 2003). Acoustic method has been proved to be a simple and an effective method in segregating wood for stiffness (Grabianowski *et al*., 2004), fibre length (Albert *et al*., 2002), energy consumption in mechanical pulping (Bradley

Fig 1. Germplasm bank of *D. stocksii* used for evaluation

Table 1. Properties of 3rd and 5th internodes in 18 clumps (3 culms per clump)

Properties	3rd internode		5th internode	
	Mean (CV%)	Range	Mean (CV%)	Range
Internode length (cm)	24.02 (14.26)	14-32.30	29.06 (12.05)	20.00-36.90
Internode diameter (mm)	31.20 (9.56)	24.25-39.65	27.33 (9.47)	21.41-33.50
Ultrasonic velocity along the length (km/s)	3.02 (11.82)	2.32 – 3.74	3.40 (8.07)	2.92- 4.02
Ultrasonic velocity across the diameter (km/s)	0.96 (10.92)	0.79 – 1.41	0.90 (16.77)	0.59 – 1.48

et al., 2005) and capturing intrinsic properties like microfibril angle in few softwood species (Huang *et al*., 2003).

Theoretically, speed of sound in any material is a function of modulus of elasticity and density of the material (eq.1) and therefore is the basis of non-destructive testing of materials including wood.

MoE = density × stress wave velocity^2…… eq. 1

The stress wave velocity can be determined by different methods like resonance, stress wave propagation or ultrasonic pulse propagation. In this study, ultrasonic pulse propagation method was used to measure the pulse velocity (along the length) within bamboo. The pulse velocity depends on the frequency, stem characteristics, flaws, moisture etc. The method is more appropriate when the velocity is to be determined over short distances. In case of bamboo, the velocity can be determined between two internodes and therefore material MoE can be determined. Application of ultrasonic method can help in screening or identifying clumps/accession with superior MoE. The MoE determined by ultrasonic method has been reported to have very high correlation (>0.90) with the MoE determined by conventional three-point bending method in wood samples (Chauhan and Sethy, 2016) and, therefore is known to provide a reliable method for segregating wood based on stiffness. Recently, Ribeio *et al*., (2017) used stress wave timer for non-destructive evaluation of stiffness of *Bambusa vulgaris*.

The study aimed at assessing the natural variation in growth and quality of the assembled genotypes of *D. stocksii* with a purpose of identification of superior genotypes in the germplasm bank. Based on the quality parameters, attempts are made to identify superior genotypes.

Materials and Methods

Material for the study was drawn from germplasm bank established at Gottipura (Bengaluru) where 36 accessions were found to be having bamboo culms of more than one year old (Fig 1). The germplasm bank is situated in a semi-arid region and maintenance is poor in terms of watering and clump management.

Three culms (one year old) per clump were identified and culm diameter, internode length and height of the culm were recorded. The selected culms were measured for ultrasonic pulse transit time. Fakopp make ultrasonic timer was used to measure transit time of ultrasonic pulse in bamboo *in–situ* (Fig 2). The tool consists of two probes with sharp point. The probes were inserted in the bamboo culm (15 cm apart) with the thumb pressure and the system was switched on. A short ultrasonic impulse of 90 kHz is generated by electronic excitation of the transducer and at the same time,

Fig 2. Ultrasonic measurement and field data collection (A- scheme of ultrasonic measurement, B- probes used for measurement, C- measurement for hollowness, D – along the length measurementof ultrasonic velocity, E- Ultrasonic data recording, F- culm assessment)

timer starts running. The pulse propagates in the material and signal of the second (receiver) transducer stop the timer, when the signal reaches the threshold level (0.12 V) which marks the arrival of the pulse at the second transducer. The attenuation of the signal in green bamboo is high, comparing to dry material and therefore the transducers were kept only 15 cm apart. Transit time was recorded and a time correction factor of 12 microseconds was subtracted from the obtained value. Transit time was also recorded across the bamboo stem at the mid-point of 5th internode. The process of ultrasonic measurement and field data collection is shown in Fig 2.

The data on intermodal length and culm diameter were recorded, and complete data was analyzed using SPSS for significant differences between clumps and ranking of clumps based on growth and quality parameters.

Table 2. Descriptive statistics of measured parameters in Gottipura germplasm bank

Sl No.	Quality parameter	Mean (CV%)	Range
1	Total number of culms/clump	31 (9.76)	8-49
2	Internode length (cm)	28.40 (11.90)	18.00-36.90
3	Internode diameter (mm)	26.85 (10.15)	20.61-33.50
4	Ultrasonic velocity along the length (km/s)	3.43 (8.20)	2.74-4.05
5	Ultrasonic velocity across the diameter (km/s)	0.98 (16.68)	0.59 -1.48

Results and discussion

In the initial part of the study, the growth data and ultrasonic velocity were measured in 18 clumps (3 culms per clump) at both 3rd and 5th internodes to assess the variation in the measured parameters between nodes. The growth of bamboo was average with height ranging from 12-15 ft of the tallest in a clump and large number of culms per clump were observed.

In the case of bamboo, generally the properties of 5th internode are determined as an indicator of the overall properties of bamboo (Viswanath, 2015). The descriptive statistics of 18 clumps are given in Table 1. The average length of 3rd and 5th internode was 24.02 cm and 29.06 cm, respectively. The length of both 3rd and 5th internode was varying nearly two folds in the sample. Internode diameter of 5th internode was about 12.5% lower than of 3rd internode. The variability (coefficient of variation) in internode diameter was much smaller than internode length. The 3rd internode diameter ranged from 24.25 mm to 39.65 mm and 5th internode diameter ranged from 21.41 to 33.50 mm.

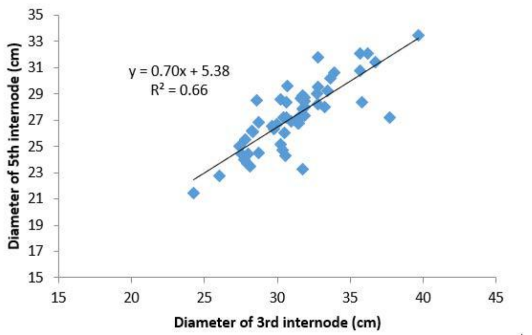

Fig 3. Relationship of diameter of 5th internode with diameter of 3rd internode

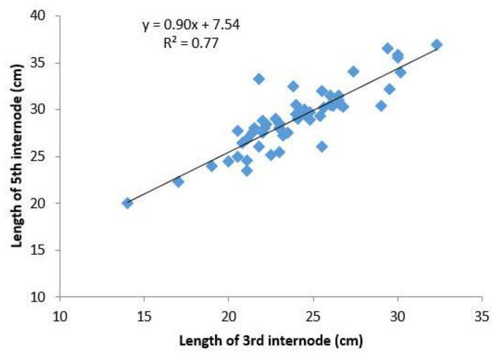

Fig 4. Relationship of length of 5th internode with the length of 3rd internode

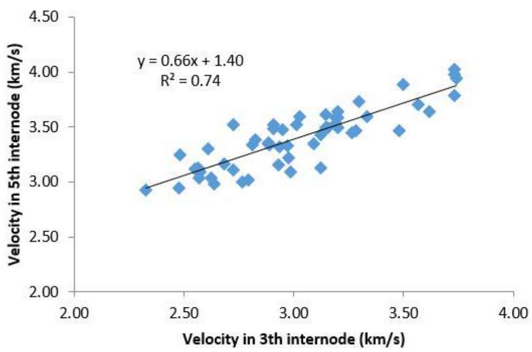

Fig 5. Relationship of ultrasonic velocity along the length of 5th internode with the velocity of 3rd internode

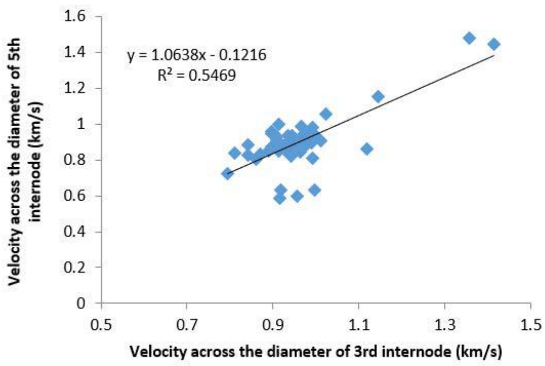

Fig 6. Relationship of ultrasonic velocity across the diameter in 5th and 3rd internode

Ultrasonic velocity along the height and across the diameter was measured. The ultrasonic velocity in 5th internode was 13.16% higher than in 3rd internode suggesting that the 5th internode is stiffer than 3rd internode. 13% difference in acoustic velocity implies about 26% difference in their stiffness. The coefficient of variation in ultrasonic velocity along the length was 11.82% in 3rd internode and 8.07% in 5th internode. Across the diameter, the velocity in 3rd and 5th internode exhibited similar range, however, variability was high in 5th internode.

The relationships of bamboo quality parameter of 3rd and 5th internode are shown in Figures 3, 4, 5 and 6. It is evident that internode length, diameter and ultrasonic velocity along the length have exhibited strong linear association which is on the expected lines as internode length tends to increase and diameter tends to decrease with the increasing height. The coefficient of determination for diameter, internode lengths and acoustic velocity was 0.66, 0.77 and 0.74, respectively. The relationship in ultrasonic velocity across the diameter was moderate ($R^2 = 0.55$) and was influenced by two extreme data points. This relatively poor relationship is attributed to the uncertainty in presence of hollowness in 5th internode. There is a possibility that the 3rd internode may be solid but the 5th internode could be hollow.

The strong association of 3rd and 5th internode in quality parameters was significant in all further measurements. Since it is much easier to carry out *in-situ* measurements in 5th internode due to easy accessibility and openness of the clump at higher height levels, for all further testing, measurements were carried out only at 5th internode as the average representation of the culm.

Measurements with other clumps in the germplasm bank were continued. The descriptive statistics across all clumps is given in Table 2.

The values for different parameters were in close agreement with the observed in 18 clumps in the initial part of the study. Ultrasonic velocity along the length was the least variable and across the diameter was the most variable parameter. The main aim of the project was to understand the differences between clumps and identification of superior clumps based on growth and material quality. A one-way analysis of variance was carried out to

Table 3. Analysis of variance for different parameters for Gottipura germplasm bank

Parameter	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Internode Length	Between clump	773.510	35	22.100	2.653	.000
	Within clump	566.470	68	8.330		
Internode diameter	Between clump	470.706	35	13.449	3.267	.000
	Within clump	279.930	68	4.117		
Ultrasonic velocity along the length	Between clump	5.255	35	.150	3.497	.000
	Within clump	2.877	67	.043		
Ultrasonic velocity across the diameter	Between clump	1.713	35	.049	2.979	.000
	Within clump	1.101	67	.016		

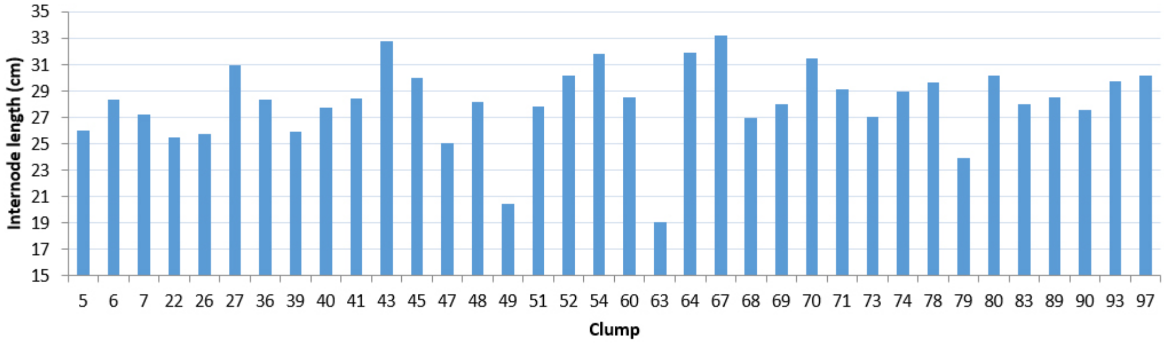

Fig 7. Variability in 5th internode length of culms in different clumps

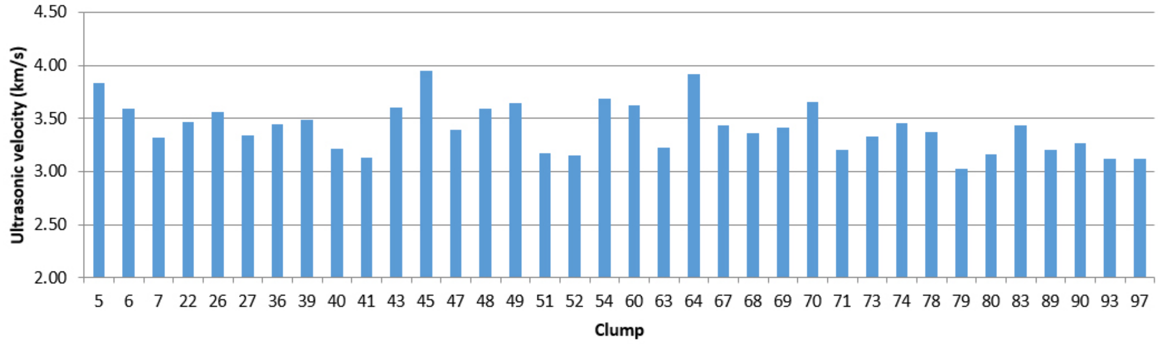

Fig 8. Variability in diameter of 5th internode of culms in different clumps

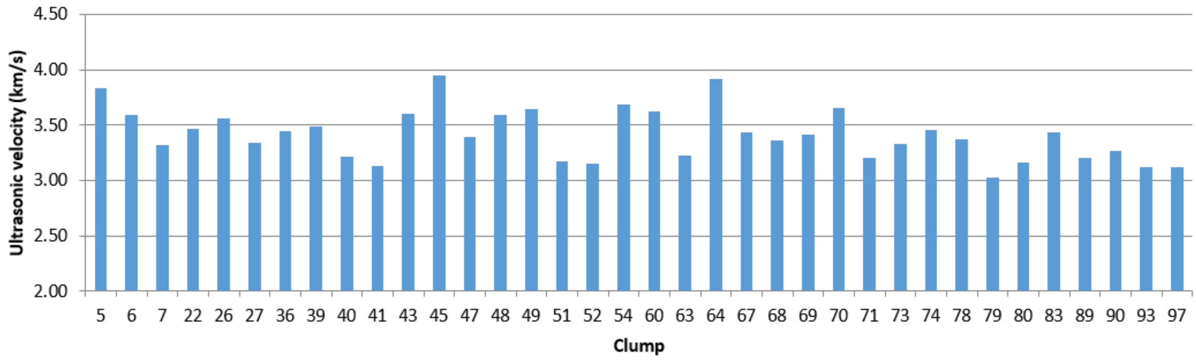

Fig 9. Variability in ultrasonic velocity of 5th internode of culms in different clumps

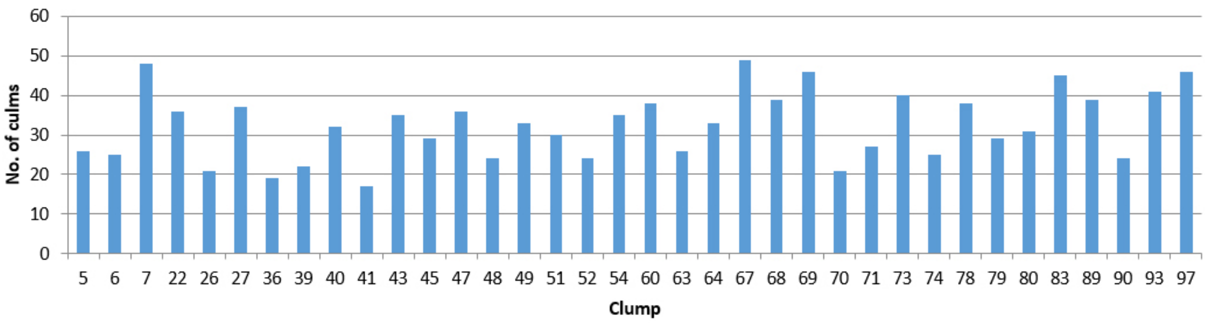

Fig 10. Number of culms per clump in different clumps

Table 4. Top 10 ranked clumps/accessions for different parameters for Gottipura germplasm bank

No.of clumps	Internode length	Internode diameter	Ultrasonic velocity along the length	Ultrasonic velocity across the diameter
67	67	69	45	63
7	43	67	64	49
69	64	54	5	60
97	54	27	54	6
83	70	52	70	69
93	27	68	49	89
73	52	43	60	43
68	97	64	43	7
89	80	7	6	79
60	45	63	48	54

see the significant differences between clumps in all the parameters (Table 3).

The analysis of variance indicated statistically significant differences in the quality parameters of different accessions/clumps. Duncan's test was performed to identify the significantly different clumps. In the case of internode length of the 5th internode, 36 clumps were divided in 8 distinct sub-groups and clumps 63, 49 and 79 were found to have the smallest internodal length. Internode diameter was divided in 10 sub-groups and clumps 27, 54, 67 and 69 exhibiting diameter of more than 30 mm. Ultrasonic velocity along the length had 11 sub-groups and 11 clumps were having velocity of more than 3.53 km/s and formed the homogeneous group. Overall, the velocity ranged from 3.02 km/s to 3.94 km/s across different clumps.The average values of 5th internode length, diameter and ultrasonic velocity along the length and no. of culms per clump for all the accessions in this germplasm bank are shown in Fig 7, 8, 9 and 10 respectively.

The clumps in this germplasm banks were ranked as per the number of culms, internode length, internode diameter and ultrasonic velocity. Best ten clumps for each parameter are shown in Table 4.

As far as the growth potential is concerned, clump no. 27, 43, 45, 52, 54, 64, 67, 69, 70, 83, and 93 were found to be more suitable for location like Gottipura. These clumps had good internodal length, high diameter and also a greater number of culms per clumps. These genotypes belonged to Uttar Karnataka, Kasargoad, North Goa, Kolhapur, Belgaum, South Goa and Ratnagiri area. Among these selected clumps, genotype code 43, 45, 54, 64 and 70 were also found to have high ultrasonic velocity i.e. high stiffness. All these clumps were found to be solid in nature. An interesting outcome of the study was the identification of hollowness in bamboo using ultrasonic method. When pulse propagation was recorded across the diameter, large transit time was an indication of hollowness. It was observed that when ultrasonic pulse velocity was less than 0.85 km/s, the culm was hollow. This was validated with few solid and hollow culms by extracting them. The hollowness varies from bottom to the top and the same was observed in many culms. In Gottipura,samples only 4 clumps were found to be hollow at 5th internode. However, this needs thorough investigations.

Conclusion

The study aimed at evaluating germplasm of *Dendrocalamus stocksii* for growth and material quality parameters using non-destructive techniques. In the study, the potential of ultrasonic pulse propagation method for evaluating modulus of elasticity of bamboo material and assessing hollowness was explored. This study is first of-its-kind wherein non-destructive acoustic method has been adopted to assess stiffness of bamboo culm and to identify superior genotypes with high productivity and superior properties. This approach requires further validation and testing for its efficacy and large-scale adoption by the researchers, bamboo grower and bamboo user.

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