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RESEARCH ARTICLE

Guadua angustifolia Kunth: Effect of age on growth, culm morphology, and biomass production

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Abstract: The present study was investigated to document the effect of age on growth, culm morphology, and biomass production in *Guadua angustifolia* Kunth, a commercially important bamboo species, at the ICFRE - Institute of Wood Science and Technology (ICFRE-IWST), Bengaluru, in 2023. Five different-aged culms, viz., 1-, 2-, 3-, 4-, and 5-year-old culm in the 10-year-old clump were used in this study. The results showed that culm age significantly influenced various parameters. The 1-year-old culms had the highest commercial height and mean leaf breadth, while the 2-year-old culms exhibited the maximum total culm height. The 3-year-old culms had the highest mean leaf length and branch diameter. In contrast, the 5-year-old culms displayed the lowest values for total culm height, commercial height, mean leaf length, leaf breadth, and branch diameter. The 1-year-old culms had the maximum number of nodes per culm and wall thickness at the base, while the 3-year-old culms showed the highest node diameter and wall thickness at the 5th node. The 5-year-old culms exhibited the highest internodal length at the 5th node. Total culm biomass was maximum in 1-year-old culms (28.4 kg) and minimum in 5-year-old culms (11.02 kg). Leaf and branch biomass followed a similar trend. A strong negative correlation between bamboo parameters was observed, and best-fit regression models were developed for all parameters, including significant linear relationships between culm green weight and culm solid volume for all culm age classes.

Keywords: Guadua, age, growth, morphology, biomass

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Introduction

The common name for the perennial grass with a lar ge, woody culm is bamboo. In total, there are about 1662 species of bamboo in 121 genera. (Canavan *et al*., 2017). About 148 species and 4 varieties in 29 genera of bamboo are found in India (Sharma and Nirmala, 2015). A small number of bamboo species from the genera, *Phyllostachys*, *Guadua*, *Dendrocalamus*, and *Bambusa* are widely used in construction (Jayanetti *et al*., 1998). Bamboo is a naturally occurring composite material that grows abundantly in most tropical countries (Lakkad and Patel, 1981). Bamboo has a very long history with mankind, and it is the oldest building material used by mankind (Mohmod *et al*., 1990). *G. angustifolia* Kunth, which belongs to the Poaceae, is one of the 18 economically important commercial bamboo species in India (NMBA 2011; and Benton, 2015). *G. angustifolia* mostly adapts to the climate of tropical life zones and humid sub-tropical forests (Marulanda *et al*., 2005), with open clumping of growth habitat and new shoots coming far apart from mother culms. It is one of the most important (Sowmya and Viswanath, 2015) and strongest bamboo woody species in nature, and it has two varieties, viz., *G. angustifolia* var *bicolor* and *G. angustifolia* var *nigra* (Londono, 2002). It is commonly referred to as the thickest bamboo, giant bamboo (Gutiérrez *et al.,* 2016), Guadua, Colombian timber bamboo (Mesquita *et al.,* 2023), and American narrow-leaved and vegetal steel (Borah *et al., 2021*). The genus Guadua has thorny, clumping bamboo and large varieties of 30 bamboo species (Young *et al., 1992*). It is native to South America, parts of Venezuela, Peru, Colombia, and Ecuador, and it's widely grown in the southeast and south parts of Brazil (Lobovikov *et al.,* 2005), northern South America, parts of Guyana and southern South America, parts of Argentina, Paraguay, and Uruguay (Young *et al.,* 1992), Panama, Nicaragua (Londono, 2002), and extending from Mexico to Argentina (Benton, 2015). New culms emerge during July to August from rhizomes produced the previous year. It is introduced and commercially grown in the tropical humid zones of Karnataka and Kerala in India (Viswanath, 2012). In Karnataka, it is mostly found in hilly zone of Uttar Kannada, Belgaum, Dharwad, Haveri, Shimoga, Chikmagalur, Coorg, Hassan, and coastal zone areas of Udupi, Dakshina Kannada, and Uttara Kannada (nbm.nic.in/PPT/Karnataka.pdf) because of its fast growth, high carbon sequestration ability, and other ecological benefits (Gonzalo, 2013). Its field performance trials were established in Karnataka and Kerala (Viswanath, 2012). The study of bamboo culm characteristics across various ages and diameter classes aids in identifying plus clumps or culms that enhance a species' commercial viability, (Inoue *et al.,* 2013). *G. angustifolia* is an important species for both people and the earth. It is commonly used for construction purposes due to its strength and durability (Borah *et al.,* 2021) and also used for furniture, handicrafts, houses, agglomerates, veneers, and flooring (Garcia and Arango, 2015), woven articles, pulp, boards (Benton, 2015), musical instruments, soil conservation (Rao *et al.,* 1998), its root systems prevent soil erosion, it has environmental benefits like absorbing large amount of carbon dioxide from the atmosphere, paper production, and it is used for food and medicine like various culinary dishes. It contains silica that helps treat skin diseases. These shoots are edible in South America (Riano *et al.,* 2002). Overall, it is an important resource for many industries and applications. Because of its quick growth, it is a good choice for reforestation and eco-friendly building projects in many countries (Hector, 2012). Generally, bamboo culms mature and reach maximum strength in 2–3 years (Liese and Weiner, 1996), but this general agreement does not apply to all bamboo species and their applications because the nature and properties of the culm vary with age. The earlier studies reported that the morphological, physio-chemical, and mechanical properties of bamboo species varied significantly with age and location (Anon, 2021). In the present study, the effect of age on growth, morphology, and biomass production was investigated.

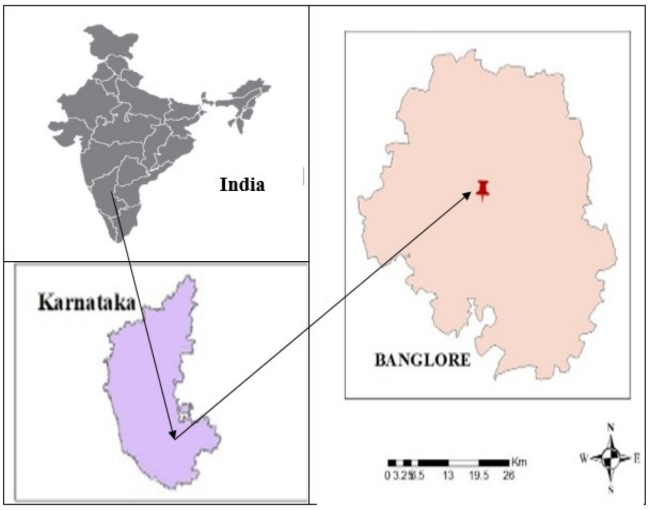

Fig 1. Location of the study area in IWST, Bengaluru, Karnataka.

Fig 2. Clumps of 10-years old (2A) and 4-years (2B) of *G. angustifolia*

Materials & methods

Study area

The present study was conducted at the Central Research Nursery, ICFRE-Institute of Wood Science and Technology, Bengaluru (13^0 01' N and 77^0 57' E) during the period of April-May 2023 (Fig. 1). The climate is tropically humid, with a mean annual rainfall of 550–2000 mm. The mean maximum and minimum temperature are 21.0° C and 33.0° C, respectively. *G. angustifolia* was introduced in India only a decade ago by the late N.S. Adkoli and Shri. A.C. Lakshmana, Bamboo Society of India, Aranya Bhavan, Bangalore, Karnataka. A clonally propagated *G. angustifolia* was planted in the Central Research Nursery, ICFRE-IWST, Bangalore, in 2005. With branch cuttings of this mother plant, more than 3000 plants were produced and supplied to farmers and other stakeholders. From this stock, two seedlings were planted in the Central Research Nursery, IWST, in 2016 and are being well maintained for mass propagation. The age of one clump of *G. angustifolia* is 10 years (Fig. 2A), and two clumps are 4-years old (Fig. 2B).

Plant material

The age of emerging new culms was marked every year with a permanent marker in the 10-year-old clump at ICFRE-IWST campus (Fig. 2) for this study since 2018 onwards. There were five different aged culms in the 10-year-old clump. viz., 1-, 2-, 3-, 4-, and 5-year-old culms were selected randomly. The selected culms were harvested using hand saws in April 2023 for this study. A completely randomized block design (RCBD) with five treatments and three replications was adopted.

Characterization of culm, branch and leaf traits

Culm characterization

Growth traits of harvested different aged culms, *viz.,* total culm height (m), commercial culm height (m), number of branches, branch diameter (mm), leaf length (cm), and leaf breadth (cm), were measured. Culms were harvested at about 1 meter according to the methods and standards described in the BIS Standard, IS 6874:2008. A measuring tape was used to measure the overall culm height of different aged culms from the base to the tip, and the results were expressed in metres. Commercial culm height was measured from the base to the point at which the diameter is 2 cm using measuring tape, and values were expressed in meters. The number of internodes per culm, diameter at the culm base, diameter at the 5^{th} internode, wall thickness at the base and 5^{th} internodes,

Fig. 3. Different parts of *Guadua* bamboo.

and node width at the 5th node was measured. All five-year-old culms have their internodes counted from the bottom to the top, age-wise. Diameters at the base and 5th internode of all culms of each age were measured with the help of a digital caliper, and values were expressed in millimeters. From the base, node at the 5th internode length was measured with the help of a measuring scale, and values were expressed in centimeters. Whereas the wall thickness at the base and 5th internode was measured with the help of a digital caliper, and values were expressed in millimeters. From the base, node at the 5th internode was measured with the help of a measuring scale, and values were expressed in centimeters. All of the culms internodal lengths were measured in centimetres from the base to the tip using a measuring scale, and the length of the internode was then averaged. A digital Vernier caliper was used to measure the diameter of the culm in millimeters (mm) from base to top portion of the culm, then average the diameter of the internode was calculated. The taperness of the culms of different ages was calculated by measuring the girth in the middle of each internode from base to top. Then we found taperness in the culm and values expressed in percentage. For measuring hollowness at the base and fifth internode, initially we took the diameter and wall thickness of the internode portion of both sides. Then we removed the wall thickness values from the diameter. Then we found the culm hollowness at the base and fifth internode, with values expressed in percentage.

Branch and leaf characterization

A total of 25 fully mature leaves from the selected culm of each age were randomly collected, and the length and breadth of the leaves were measured using a measuring scale, with values expressed in centi-meters. The diameter of branches of different aged culms was measured with the help of Vernier caliper, and values were expressed in millimeters.

Biomass production of different aged culm

The harvested culms were made into three equal pieces, viz., the bottom, middle, and top portions of the culm (segments), using a machine saw. The fresh weight of the bottom, middle, and top portions of different aged culms was recorded. After measuring the fresh weight of the above-said segments, they were subjected to oven dry at 103±2ºC for 24 hours. until a constant weight is attained, and then the dry weight of the same is noted. Similarly, the leaves and branches were separated from the culms, and the fresh weight of the same was weighed. A 100 g of leaf and branch samples were oven dried at 60±20 °C for 24 hrs., separately. until a constant weight and oven dry weight of the same was recorded. Then, the fresh-weight biomass of leaves and branches was converted into dry-weight biomass based on oven dry weight.

Statistical analysis

The descriptive statistics of morphological traits were done using MS Excel, and the results were expressed in terms of mean values and standard deviation. Correlation and principal component analysis were analyzed between different growth parameters of all five years' age of culms using R-Studio. The significance level for all the values was tested using R-Studio software (*version 4.3.2*). Additionally, regression equations for the following relationships were created. 1) Culm age and height, 2) commercial height and culm age, 3) number of internodes per culm and culm age, 4) internodal length at 5^{th} and culm age, 5) diameter at bottom and culm age, 6) diameter at 5^{th} internode and culm age, 7) wall thickness at base and culm age, 8) wall thickness at fifth and culm age, 9) dry weight per culm and culm age. These regression analysis was done using MS Excel.

Result and Discussions

Effect of age on culm growth traits

The effect of age on growth traits is given in Table 1. Although row spacing, the prevailing environment, and management methods have each had an effect on culm height, the genetic composition of the species is the main factor influencing it. The results showed that the total culm height significantly differed with the age of the culms. The total culm height ranged from 9.57m to 16.6m. Further, we observed that total culm height followed a decreasing trend from the 2nd year, and the difference between 1- and 2-year-old culms was insignificant. The findings of the present study are in consonance with earlier studies. For instance, the total culm height of *G. angustifolia* culm varied between 16.7m (Riano *et al.,* 2002) with a mean height of 13.47m and 23.65m (Londono, 2022). The mean culm height of 3-, 4-, and 5-year-old culms was 14.78, 10.00, and 9.57m. Viswanath (2012) observed that the culm height of 3-, 4-, and 5 -year-old culms was >13, 14, and >14m. The height and diameter at breast height of matured culms in a 5-7-year-old clump were higher, and if culms are not harvested after this point, the growth of bamboos is very slow and some of the species grow less than 0.5 m, while other species can grow over 30 m, with some species even growing up to 40 m (Banik, 2015). Earlier studies shown that decrease of culm height according to its ages 18.90, 18.29 and 17.38 meters at the ages of 1, 2 and 3 years old in *Bambusa blumeana* (Mohmod *et al.,* 2016). The commercial culm height of different aged culms was significantly different and ranged from 8.45 to 14.20 m, with an average of 11.21m. The data on variations in morphological traits of culms is presented in Table 1. The data revealed that the number of nodes and internodes per culm of different aged culms of *G. angustifolia* differed with age. The mean number of internodes in different aged culms ranged from 39 to 53, with an average of 45.4. In the present study, we counted 53 internodes in a 16.6-metre-long culm. However, it is reported that a 20-metre-long culm had 75 internodes (Schroder, 2024). Singnar *et al*., (2015) reported that number of internodes per culm ranged from 14 to 49 with a mean of 35. The diameter at the base and 5th internode of different aged culms showed significant variations. The diameter at the culm base was between 71.62 mm and 91.65 mm, with an average of 82.35 mm. Hector (2012) found that the diameter at the base was 22 cm, whereas Riano (2002) noted that the girth at the base was 84.07 mm. The girth at the 5^{th} internode of different aged culms ranges from 59.14 mm to 88.96 mm, with a mean of 75.32 mm. The 5^{th} internodal length of culms ranged between 14 cm and 18.5cm. The wall thickness at the base ranged from 18.08 mm to 24.06 mm, with a mean of 21.17 mm. Thus, the results of the present study are comparable with those of Londono (2022), who reported that the wall thickness was 1.82 cm at the base and the 5th internodal length ranged from 13.06 mm to 22.81 mm with a mean of 17.86 mm. Viswanath (2012) found that the wall thickness of 2-, 3-, 4-, and 5-year culms was 12.50, 13.59, 13.14, and 14.95 mm.

Table 1. Variations in growth traits of culm, branch and leaf and biomass production in *G. angustifolia*

Culm parameters						
Age (year)	**1**	**2**	**3**	**4**	**5**	**Mean ± SD**
CH (m)	16.40	16.60	14.78	10.00	9.57	13.47± 3.44
CCH: (m)	14.20	13.50	11.40	8.50	8.45	11.21±2.70
NI	53.00	51.00	44.00	39.00	40.00	45.4±6.34
DCB (mm)	91.65	84.86	81.84	81.79	71.62	82.3±7.21
D5I (mm)	88.96	79.84	81.23	67.47	59.14	75.3±11.88
IL5: (cm)	16.30	16.30	15.50	14.00	18.50	16.12±1.62
WTCB (mm)	24.06	20.74	23.70	19.29	18.08	21.17±2.65
WT5I (mm)	21.17	17.04	22.81	15.22	13.06	17.86± 4.06
NW5 (cm)	2.20	2.40	2.50	2.20	2.00	2.26±0.19
MIL (cm)	30.94	32.55	33.59	25.64	23.93	29.33±4.29
MID (mm)	73.59	70.64	68.54	56.07	45.97	62.96±11.61
CTBT (%)	59.02	52.6	47.01	33.03	25.02	43.33±14.02
CHB (%)	47.49	51.11	42.08	52.83	49.51	48.60±4.14
CHF (%)	52.40	57.31	44.57	54.88	55.83	52.99±5.03
Branch and leaf parameters						
LL (cm)	16. 43	15.83	16.93	16.63	15.37	16.24±0.63
LB (cm)	1.90	1.73	1.80	1.76	1.83	1.80±0.06
BD (mm)	9.04	10.27	10.60	9.28	7.28	9.294±1.3
Biomass production						
TFW (kg)	34.136	31.477	25.994	14.212	14.124	23.98±9.43
DW (kg)	28.37	25.99	20.44	11.30	11.02	19.42±8.07
FW (KgM^{-1})	2.08	1.89	1.75	1.42	1.47	1.72±0.27
ODW (KgM^{-1})	1.72	1.56	1.38	1.13	1.15	1.38±0.25
LBFW (g)	1414	1315	1237	1085	971	1204.4±177.45
LB ODW(g)	509.04	447.10	439.13	336.35	291.30	404.58±88.60
BBFW (g)	2720	2540	2180	1987	1647	2214.8± 429.0
BBDW (g)	2216.80	1955.80	1798.50	1748.56	1416.42	1827.22±293.8

CH: Culm Height, CCH: Commercial Culm height, NI: No. of internodes/culm, DCB: Diameter at Culm base, D5I: Diameter at 5th Internode, IL5: Internodal length at 5th internode, WTCB: Wall thickness at Culm base, WT5I: Wall thickness 5th Internode, NW5: Node width at 5th node, MIL: Mean internodal length, MID: Mean internodal diameter, CTBT: Culm Taperness from base to top, CHB: Culm Hollowness at base, CHF: Culm Hollowness at fifth internode, LL: Leaf length, LB: Leaf breadth, BD: Branch diameter, TFW: Total fresh culm Weight, DW: Dry culm Weight, FW/unit length: Fresh culm wt./unit length, ODW/ unit length: Oven dry culm wt./unit length, LB ODW(g) : Leaf biomass Oven dry culm wt, BBFW: Branch biomass Fresh culm wt, BBDW : Branch biomass dry culm wt.

Whereas, Guadua bamboo are 21 mm wall thickness reported earlier studies (Pozo Morales *et al.,* 2017). The node width of different aged culms ranged between 2.00 cm and 2.50 cm, with an average of 2.26 cm. The node width of this study is higher than that of Young (1992), who recorded a node width of 1-3 cm. The different ages of *Guadua* culms showed significant variation in internodal length. The mean internodal length was 33.59 cm, and a third-year-old showed the highest internodal length. followed by 32.55 cm in the second year, 30.94 cm in the first year, 25.64 cm in the fourth year, and 23.93 cm in the fifth year. Here, mean internodal length increases from young to up to third-year age, and then followed decrease trend from its fourth year. The average internodal length of the culm ranged from 23.93 to 33.59 cm. Similar findings were found with the current results of *Guadua* bamboo. The internode length of *Gigantochloa scortechinii* of range from 32.3 to 49.5 cm (Hisham *et al.,* 2006). All ages of culms showed significant differences in mean internodal diameter, which is presented in Table 4. The higher of mean internodal diameter was observed in one-year-old, followed by 70.64 mm in the second year, 68.54 mm in the third year, 56.07 mm in the fourth year, and 45.97 mm in the fifth year. Here, we observed that the diameter of the culm decreased with age. Whereas, *Guadua* bamboo are 90 mm internodal diameter reported earlier studies (Morales *et al.,* 2017). Here our results shown higher diameter in first year age culm and lower in five-year age culm among five culm age classes of *Melocanna baccifera*, three-year-old culms had the highest mean internode diameter, whereas current-year culms had the lowest (Singnar *et al.,* 2015). The culm taperness from base to top showed differences in all age culms. Higher taperness was observed in one-year-olds, and the lowest in fifth-year-olds (25.02%). Here, young culms have larger diameter at the base, and the top portion has smaller, thinner internodes. We observed that as age increased, the taperness of the culm decreased. Generally, internodal diameter and culm wall thickness were increased around the bottom parts and decreased towards the top of culms. Giant timber bamboo has properties like other bamboo species tapers from the base towards the tip decrease (Dessalegn *et al.,* 2020). Culms have a higher moisture content at early ages, and because of this moisture content, they show high wall thickness at culm internodes. This wall thickness covered a portion of the internode. The highest culm hollowness was 52.83% at base observed in fourth-year-old culms, followed by (51.11%) in 2-year-old culm, and the lowest culm hollowness was 42.08% at base observed in three-year-olds. The same higher culm hollowness at the fifth internode (57.31%) was observed in a second-year-old, while the lowest culm hollowness at the base (44.57%) was observed in a three-year-old culm.

Branch and leaf parameters of different aged culm of *G. angustifolia*

The leaf length of different aged culms ranged between 15.37 and 16.93cm with a mean 16.24 cm and leaf width between 1.73cm and 1.90cm with an average 1.80cm. Thus, significant variations were observed in length and breadth of leaves in different aged culms. Here, our results are comparable with earlier studies. Young (1992) reported that the leaf length of Guadua species was 10-25 cm long and 1-4 cm width. The branch diameter of different aged culms of this species ranged from 7.28 mm to 10.60 mm, with an average of 9.29 mm. Contrary to this, it is reported that the branch diameter of Guadua was 1.1 cm (Schroder, 2024). Local environment and genotype might be contributing factors to these variations.

Biomass production of different aged culm of *G. angustifolia*

The results of the fresh and dry weights of different aged culms are cited in Table 1. It revealed that the total fresh weight and over-dry weight of different aged culms ranged from 14.124 to 34.136 and 11.02 to 28.37 kg/culm, with an average of 23.98 and 19.42 kg/culm, respectively. The fresh and oven-dry weights of different aged 1-m length culm ranged from 1.42 to 2.08 kg and 1.13 to 1.72 kg, with an average of 1.72 and 1.38 kg, respectively. The total fresh and oven-dry leaf weight of different aged culms ranges from 1647 to 2720 and 291.30 to 509.04 g, with a mean of 1204.40 and 404.58 g/culm, respectively. The total fresh and oven-dry weight of branches of different aged culms lied between 971 and 1414 and 1416.42 and 2216.8 g/

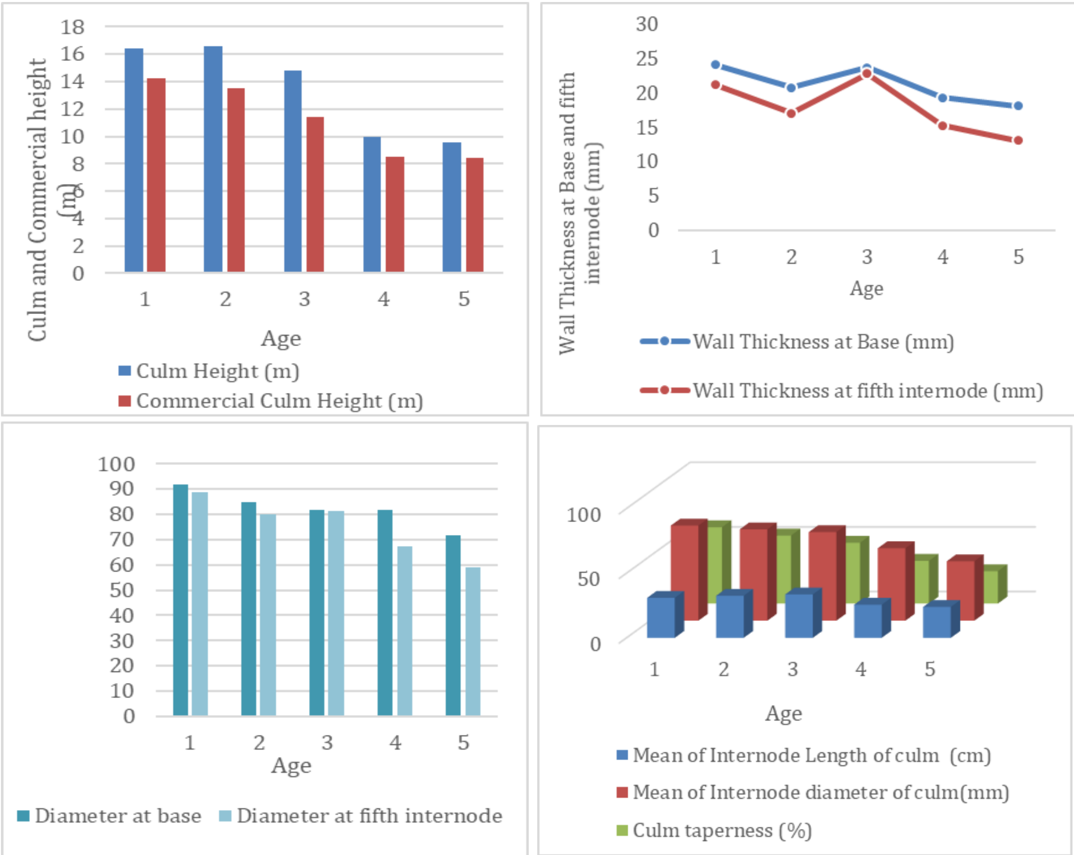

Fig 4. Variations in growth traits of different age of culms *G. angustifolia*

culm, with an average of 2214.8 and 1827.22 g/culm, respectively. On this line, Viswanath (2012) reported that the above-ground mass of the same species was 161.18 kg in a 5-year-old clump and 152.65 kg in a 4-year-old clump. The relation observed amongst the total length of the culm, fresh weight, and number of nodes suggested that the culm's length is not the sole determinant of its weight or biomass, additionally, the size and quantity of culms per clump determine the amount of biomass produced (Agarwal, 2020). Girth plays an important role in determining the biomass or weight of culms reported by (Agarwal and Purwar, 2016) (Fig. 4).

Correlation analysis of growth traits among different ages of *Guadua* bamboo

There are two methods for understanding how quantitative features relate to one another. First of all, it's useful to predict the other characters reactions when one is selected. The implications, positive or negative or no correlation, can help in the selection of suitable individuals for the formulation of appropriate selection procedures for simultaneous improvement of more than one character. Second, for complex compounds like biomass and yield, selection based on strongly correlated growth feature works better than direct selection (Singh *et al.,* 2018; Kumar and Dhillon, 2016). In the present study various parameters of *Guadua* bamboo of different aged culms were analyzed and significant differences were observed. Earlier studies have also been reported Significant differences in various bamboo species for many growth parameters (Kumari and Bhardwaj, 2017). The present results pertain that the culm height of different age of culms was significantly correlated with commercial culm height, number of internodes, diameter at bottom, diameter at fifth internode, wall thickness at bottom, wall thickness at fifth internode, dry weight and culm height negatively correlated with internode length (Table 2) Pathak *et al.* (2015) also recorded significant differences in culms height among seven bamboo species. And commercial culm height positively correlated with the all parameters but no linear relationship with internode length. Number of internodes was significantly correlated with the all parameters. Diameter at bottom positively correlated with the all parameters except internode length, it showed negative correlation with internode length (-0.46). Diameter at fifth positively correlated with the all parameters except internode length, it showed negative correlation with internode length (-0.28). internode length was significantly correlated with number of internodes (0.95), and no linear relationship with commercial culm height, and dry weight and negative correlated with remaining parameters. wall thickness at bottom and fifth internode positively correlated with the all parameters except internode length (-0.26, -0.31). Dry weight positively correlated with the all parameters but no linear relationship with internode length. Totey *et al.,* (1989) found highly significant positive correlations between different growth parameters in *D. strictus* seedlings (Fig. 5).

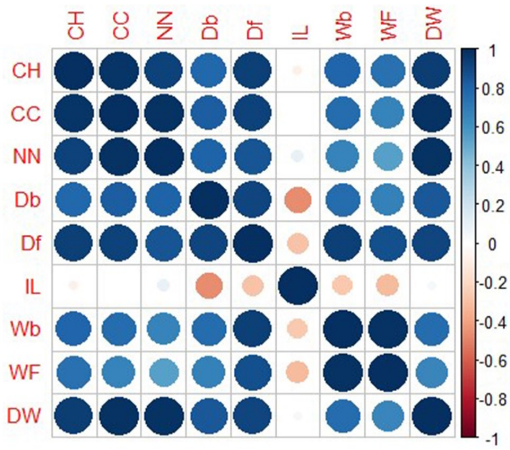

Fig 5. Correlation among different parameters of different age of bamboo culms

CH: culm height, CC: commercial culm height, NN: number of internodes, Db: diameter at bottom, Df: diameter at fifth internode, IL: internode length, Wb: wall thickness at bottom, Wf: wall thickness at fifth internode, DW: dry weight.

(Here we got the correlation plot whose color and size are mapped to the correlation coefficient values. The stronger the correlations are, the larger the circle is. Positive correlations are displayed in navy blue and negative correlations in crimson glory color. The Correlation Coefficients are overlaid on the circles.

Table 2. Correlation co-efficient among different parameters of *Guadua bamboo*

Bamboo traits	CH	CC	NN	Db	Df	IL	Wb	Wf	DW
CH	**1.00**	0.97	0.92	0.78	0.93	-0.07	0.79	0.74	0.94
CC	0.97	**1.00**	0.98	0.82	0.92	0.00	0.76	0.66	0.98
NN	0.92	0.98	**1.00**	0.8	0.85	0.95	0.66	0.54	0.98
Db	0.78	0.82	0.80	**1.00**	0.91	-0.46	0.76	0.67	0.84
Df	0.93	0.92	0.85	0.91	**1.00**	-0.28	0.93	0.87	0.91
IL	-0.07	0.00	0.95	-0.46	-0.28	**1.00**	-0.26	-0.31	0.04
Wb	0.79	0.76	0.66	0.76	0.93	-0.26	**1.00**	0.98	0.76
Wf	0.74	0.66	0.54	0.67	0.87	-0.31	0.98	**1.00**	0.65
DW	0.94	0.98	0.98	0.84	0.91	0.04	0.76	0.65	**1.00**

Significant at 5% ($P<0.05$)

CH: Culm height, CC: Commercial culm height, NN: number of internodes, Db: diameter at bottom, Df: diameter at fifth internode, IL: internode length, Wb: wall thickness at bottom, Wf: wall thickness at fifth internode, DW: dry weight.

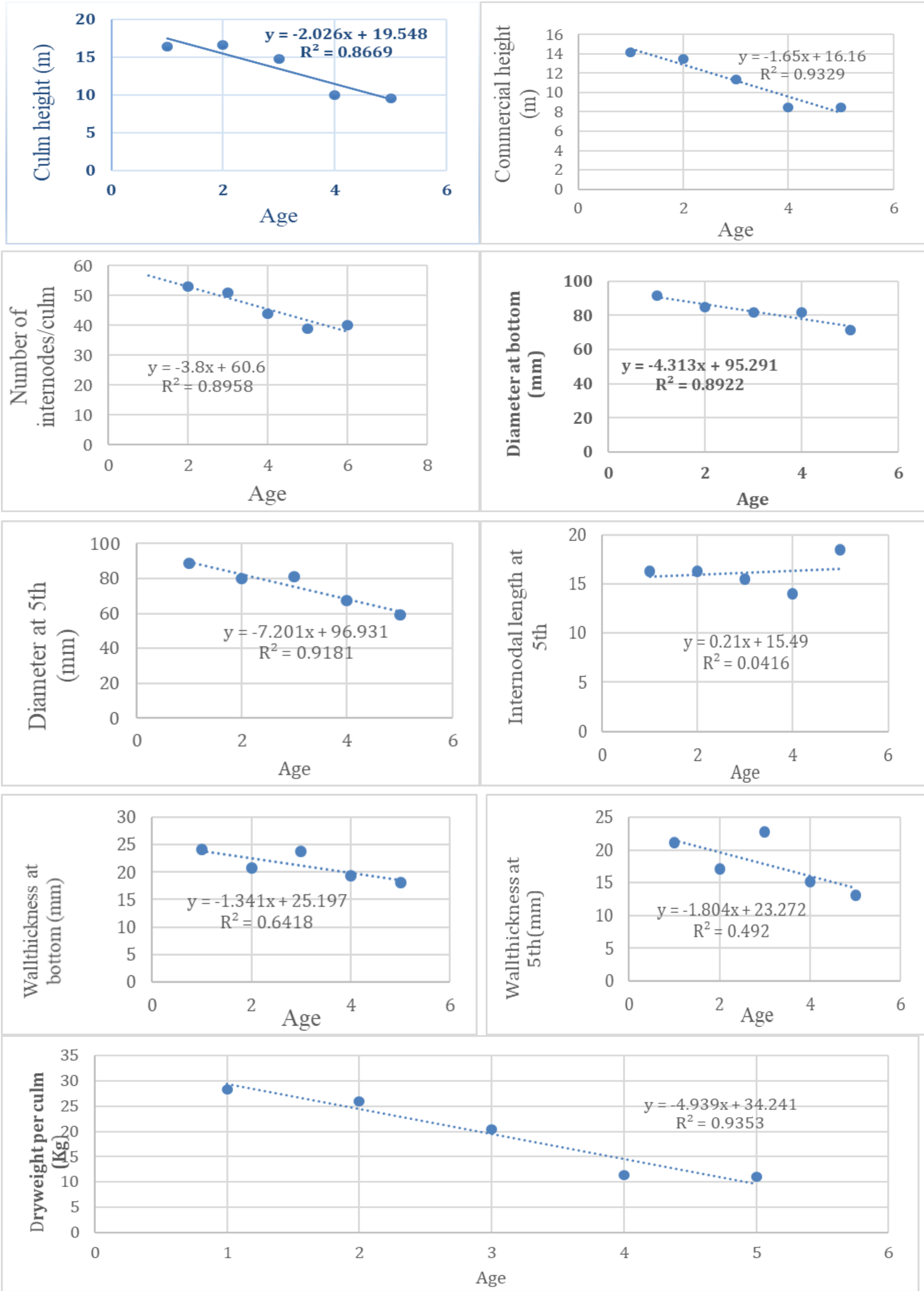

Fig 6. Scatter plots and Linear regression analysis for growth parameters of *Guadua* bamboo

Scatter plots and Linear regression analysis for growth parameters of Guadua bamboo species

Regression equations have been developed for the bamboo's important variables (Table 3) developed a linear regression that was the best match, with a correlation coefficient of R2, for key bamboo culm metrics. In social science research, an R-squared of 0.50 to 0.99 is considered appropriate, particularly when the majority of the explanatory factors exhibit statistical significance. A linear regression model best captured the link between age and major bamboo culm features in our study, and it was able to explain 0.0416–0.9353 of the variability in the key bamboo culm parameters. Here morphological traits are different variables with constant or dependent variable of age. The relationship between culm height and age was best represented by a linear regression model and the model explained (0.8669), commercial culm height (0.9329), Number of internodes (0.8958), Diameter at bottom (0.8922), Diameter at fifth internode (0.9181%), Wall thickness at bottom 0.6418), Dry weight (0.9353) of variability in the dependent, variables are statistically significant. But the Internode length at fifth internode (0.0416), Wall thickness at fifth internode (0.492), of variability in the dependent, variables are statistically non – significant (Fig 6).

Table 3. Regression equations for different aged culms

Morphological traits	Equation	R^2
Culm height	CV=2.026x+19.548	0.8669
Commercial culm height	CV=-1.65x+16.16	0.9329
Number of internodes	CV=-3.8x+60.6	0.8958
Diameter at bottom	CV=4.313x+95.291	0.8922
Diameter at fifth internode	CV=7.201x+96.931	0.9181
Internode length at fifth internode	CV=0.21x+15.49	0.0416
Wall thickness at bottom	CV=1.341x+25.197	0.6418
Wall thickness at fifth internode	CV=1.804x+23.272	0.492
Dry weight	CV=4.939x+34.241	0.9353

* Significant at $p < 0.01$ level.

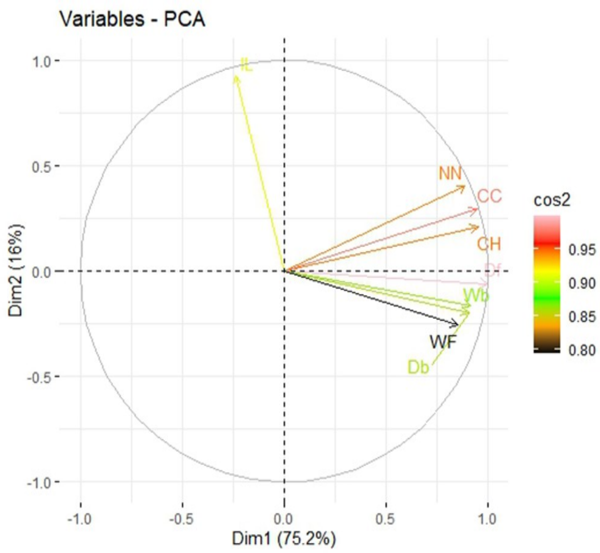

Fig 7. Principal component analysis biplot for important parameters of bamboo

CH: culm height, CC: commercial culm height, NN: number of internodes, Db: diameter at bottom, Df: diameter at fifth internode, IL: internode length, Wb: wall thickness at bottom, Wf: wall thickness at fifth internode, DW: dry weight

Principal component analysis for important parameters of bamboo

Principal component analysis was performed to assess the variation in the variables, to make selection on the basis of studied traits. There were two Principal components, PC1 and PC2 obtained, which 75.2 and 16% variation, respectively. These two Principal components together accounted for 91.2% of total variations in the variables. The first component of the study was highly loaded with the following variables: dry weight; culm height; commercial culm height; number of internodes; diameter at bottom; diameter at fifth internode; wall thickness at bottom; and wall thickness at fifth internode. Internode length had high loadings on the second component, (Fig 7). Culm height, commercial culm height, number of internodes, diameter at bottom, diameter at fifth internode, wall thickness at bottom, wall thickness at fifth internode, dry weight variables confirm the high positive correlation and internode length had high negative correlation.

Conclusion

The authors concluded that culm age had significant effect on growth traits, morphology, and biomass production of *G. angustifolia*. The total height, commercial height of culm, no of nodes per culm, wall thickness at both base and 5^{th} internode and biomass of culm, branch and leaf were shown decreasing trend with increasing age of culm except 2-year-old culm. Thus, age of culm influences the all-major growth traits viz., diameter, internodal length, and wall thickness of *G. angustifolia* and in turn, these growth traits may affect the physical, mechanical and working properties of bamboo species. Further, a detailed study on effect of culm age on physical and mechanical properties of *G. angustifolia* may be warranted for drawing conclusive inferences.

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