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RESEARCH ARTICLE

# Physical and mechanical properties of *Dendrocalamus giganteus* from difference zones in Long district, Phrae province, Thailand

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**Abstract**: This research compared physical and mechanical properties of *Dendrocalamus giganteus* from bamboo plantation and bamboo forest in Long district, Phrae province, Thailand. The experiment was a completely randomized design with 6 treatments involving 2 zones (Bamboo Plantation and Bamboo Forest) and three parts of bamboo (Top, middle and bottom), with five replicates of each for a total of 30 conditions. The optimal conditions for the physical and mechanical properties of *Dendrocalamus giganteus* were observed in the treatment with the Bamboo Plantation zone at the top part of the bamboo. These differences were all significant ($p < 0.05$). The results suggest that the top part of the bamboo is influenced by vascular bundles, which are denser in this region compared to the bottom part. Furthermore, bamboo plantations managed through silviculture with sustainable practices can significantly enhance the properties of bamboo

*Keywords:* Bamboo forest, bamboo plantation, bending, *Dendrocalamus giganteus*, moisture content

## Introduction

The preference for materials like steel and concrete has been replaced by bamboo due to their strength and durability, attributed to issues like global warming (Chamasemani *et al*., 2024; Estokova *et al*., 2022; Kim *et al*., 2022; Conejo *et al*., 2020; Davidovits, 1994). Nevertheless, sustainable structures and furniture have gained popularity (Yang and Vezzoli, 2024; Li *et al*., 2023; Zhu *et al*., 2023; Bumgardner and Nicholls, 2020; Kumar *et al*., 2020), and bamboo has emerged as an alternative material due to its ease of cultivation, rapid growth (Lombardo, 2022; Long *et al*., 2023; Chen *et al*., 2022), and ability to thrive in any climate and soil type (Ananfack *et al*., 2023; Ayer *et al*., 2023; Gaikwad *et al*., 2022). There are over 17 genera and more than 1,500 species of bamboo in world (Canavan *et al.,* 2016; Permkam, 2005). Some well-known bamboo species in Thailand include *Dendrocalamus asper, Bambusa blumeana,* and *Thyrso-stachys siamensis* (Mustafa *et al*., 2021; Pattarathitiwat *et al*., 2021; Leksungnoen, 2017; Sungkaew *et al*., 2021; Srivaro, 2017).

Long District, in Phrae Province, is one of the areas in the northern region of Thailand abundant in bamboo, especially *Dendrocalamus giganteus* (Tian, 2021). This species can grow very large, up to more than 20 cm in diameter. The culms are straight, beautiful, without thorns or hairs, reaching approximately 10-25 m in height. The wall thickness is not very thick, about 1.25 cm. The leaves are relatively small, with large shoots, sweet and crispy, suitable for consumption (Azadeh and Ghavami, 2018; Chang *et al*., 2015, Zhan *et al*., 2017). This type of bamboo is cultivated and grows well in both bamboo plantations and bamboo forests. Bamboo plantations are managed through silvicultural system,

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including planting, watering, and cutting, resulting different fertility compared to bamboo forests (Mulatu and Fetene, 2013).

Although the physical and mechanical properties of bamboo have been extensively studied (Bhonde *et al.,* 2014), the properties of *Dendrocalamus giganteus* bamboo should be further investigated due to variations in the growing environments across different regions (Ming *et al.,* 2017). Currently, local communities often use this type of bamboo inappropriately, such as for construction materials, buildings, and certain types of architectural works, which reduces the bamboo's lifespan (Zheng et al., 2023). Moreover, different parts of the bamboo also exhibit variations in their physical and mechanical properties.

Therefore, this study compared physical and mechanical properties of *Dendrocalamus giganteus* from bamboo plantation and bamboo forest in Long district, Phrae province, Thailand from using the ASTM D143 standard (2014) standards

## Materials and methods

### Study site

The study investigated *Dendrocalamus giganteus* in two zones (Bamboo Plantation and Bamboo Forest) at Long District, Phrae Province, Thailand, as shown in Fig 1.

### Preparation of wood test samples

*Dendrocalamus giganteus* aged four years were examined for their physical and mechanical properties based on the ASTM D143 standard (2014), from three parts of the bamboo (Top (To), middle (Mi), and bottom (Bo)), as illustrated in Figure 2, with 5 replications. Physical properties of samples included moisture content (MC), density (D), and specific gravity (SG). The sample size for MC, D, and SG was 30x20x10 mm. Mechanical properties tested were modulus of rupture (MOR), modulus of elasticity (MOE), compressive strength (CS), shear strength (SS), and tensile strength (TS). The sample size for MOR and MOE was 100x10x10 mm, for CS was 80x10x10 mm, for SS was 40x35x10 mm, and for TS was 120x12x3 mm. For estimation of mechanical property, samples were dried in an oven at 103±2°C for 24 hours, until the moisture content was around 12%.

### Experimental design

The experiment was a completely randomized design with 6 treatments comprising 2 zones (Bamboo Plantation and Bamboo Forest) and three


**Fig 1.** *Dendrocalamus giganteus* bamboo in each zone (A) Bamboo Plantation; (B) Bamboo Forest

parts of bamboo (Top, middle and bottom). With five replicates per treatment, there were a total of 30 conditions.

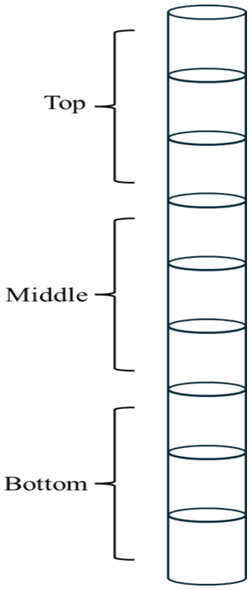


**Fig 2.** Top, middle and bottom parts of *Dendrocalamus giganteus* culm for testing

**Data collection**

The samples were dried at 103±2°C for 24 hours, until the moisture content reached approximately 12%. The change in moisture content was determined as the difference in the wood moisture content between before and after drying in oven. Moisture content, density, and specific gravity were calculated by weight and volume using the following Equation 1, Equation 2 and Equation 3:

$$\text{Moisture content (\%)} = (W_1 - W_2) / W_2 \times 100 \quad (1)$$

$$\text{Density (kg/m}^3) = (W_1 / V) \times 10^6 \quad (2)$$

$$\text{Specific gravity} = W_2 / (V \times r_w) \quad (3)$$

where $W_1$ and $W_2$ are the weights before and after treatment in grams, V is volume of sample in $mm^3$ and $r_w$ is density of water (=1 g/$mm^3$).

The specimen was assessed using a universal testing machine with an 80 mm span length. The loading rate was maintained at a constant 1.0 mm/min. The Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were determined using the following equation 4 and Equation 5:

$$\text{MOR (MPa)} = (3 \times P_{max} \times L) / (2 \times b \times h^2) \quad (4)$$

$$\text{MOE (MPa)} = (P \times L^3) / (4 \times D \times b \times h^3) \quad (5)$$

where P is load in N, $P_{max}$ is maximum load in N, L is span in mm, b is breadth in mm, h is depth of test specimen in mm and D is deflection at limit of proportionality in mm.

The compressive strength, shear strength, and tensile strength were determined by applying a vertical load to the sample. Their strengths were calculated using the following Equation 6, Equation 7 and Equation 8:

$$\text{Compressive strength (MPa)} = P/A \quad (6)$$

$$\text{Shear strength (Mpa)} = P/A \quad (7)$$

$$\text{Tensile strength (MPa)} = P/A \quad (8)$$

where P is maximum load in N and A is Cross-section area in $cm^2$.

**Data analysis**

Statistical difference in MC, D, SG, MOR, MOE, CS, SS, and TS were analysed using one-way analysis of variance (ANOVA) followed by Duncan's new multiple range test. The mechanical properties of *Dendrocalamus giganteus* were determined using SPSS for Windows (version 20.0) for the analyses.

## Result and discussions

### Moisture content, density, and specific gravity from *Dendrocalamus giganteus*

The moisture content, density and specific gravity varied depending on zone and part. The moisture content was consistently below 12%, with the lowest moisture content observed in treatment Bamboo $\text{Forest}_{Bo}$ (11.13±1.03%), followed by Bamboo $\text{Plantation}_{Mi}$ (11.23±0.43%), Bamboo $\text{Forest}_{To}$ (11.24±0.35 %), Bamboo $\text{Plantation}_{To}$ (11.71±0.74%), Bamboo $\text{Plantation}_{Bo}$ (11.82±0.54%), and Bamboo $\text{Forest}_{Mi}$ (11.90±0.69%) and the differences were not statistically significant p-value > 0.05(. Regarding density, the highest value was recorded in treatment Bamboo $\text{Plantation}_{To}$ (701.32±8.85 kg/$m^3$), followed by Bamboo

**Table 1.** Average percentage of moisture content, density and specific gravity from *Dendrocalamus giganteus*

| Treatment | MC (%) | D (kg/m$^3$) | SG |
|---|---|---|---|
| Bamboo Plantation$_{Bo}$ | 11.82±0.54 | 687.63±9.57$^{ab}$ | 0.69±0.01$^{a}$ |
| Bamboo Plantation$_{Mi}$ | 11.23±0.43 | 692.12±13.33$^{ab}$ | 0.70±0.02$^{a}$ |
| Bamboo Plantation$_{To}$ | 11.71±0.74 | 701.32±8.85$^{a}$ | 0.71±0.01$^{a}$ |
| Bamboo Forest$_{Bo}$ | 11.13±1.03 | 677.52±11.05$^{b}$ | 0.67±0.01$^{b}$ |
| Bamboo Forest$_{Mi}$ | 11.90±0.69 | 689.24±8.88$^{ab}$ | 0.69±0.02$^{ab}$ |
| Bamboo Forest$_{To}$ | 11.24±0.35 | 696.50±10.14$^{a}$ | 0.69±0.02$^{a}$ |
| Average | 11.51±0.63$^{ns}$ | 690.72±10.30 | 0.69±0.01 |

Data are shown as the mean ± SD.

Forest$_{To}$ (696.50±10.14 kg/m$^3$), Bamboo Plantation$_{Mi}$ (692.12±13.33 kg/m$^3$), Bamboo Forest$_{Mi}$ (689.24±8.88 kg/m$^3$), Bamboo Plantation$_{Bo}$ (687.63±9.57 kg/m$^3$) and Bamboo Forest$_{Bo}$ (677.52±11.05 kg/m$^3$). these density differences were statistically significant (p-value < 0.05). Similarly, specific gravity was highest in treatment Bamboo Plantation$_{Mi}$ (0.71±0.01), Bamboo Plantation$_{Mi}$ (0.70±0.02), Bamboo Plantation$_{Bo}$ (0.69±0.01). Bamboo Forest$_{Mi}$ (0.69±0.02), Bamboo Forest$_{To}$ (0.69±0.02), and Bamboo Forest$_{Bo}$ (0.67±0.01) these specific gravity differences were statistically significant (p-value < 0.05), as presented in Table 1 and Table 3. These results are similar to those of Hartono *et al*. (2022) and Krause *et al*. (2016). The density is in the range 700-860 kg/m$^3$. According to Brito *et al*. (2015), specific gravity ranges from 0.66-0.83. Shastry and Unnikrishnan (2017) emphasize the importance of moisture content, density, and specific gravity in determining the mechanical properties of bamboo, as also noted by Aguinsatan *et al*. (2019) and Neto *et al*. (2021).

## MOR, MOE, CS, SS and TS from *Dendrocalamus giganteus*

The highest MOR was with treatment Bamboo Plantation$_{To}$ (126.39±3.89 MPa), followed by Bamboo Forest$_{To}$ (123.66±2.69 MPa), Bamboo Plantation$_{Mi}$ (123.15±2.90 MPa), Bamboo Plantation$_{Bo}$ (118.83±3.75 MPa), Bamboo Forest$_{Mi}$ (118.65±3.00 MPa) and Bamboo Forest$_{Bo}$ (112.52±2.29 MPa). Similarly, the highest MOE was with treatment Bamboo Plantation$_{To}$ (17,654.59±64.99 MPa), followed by Bamboo Plantation$_{Mi}$ (17,618.86±44.02 MPa), Bamboo Plantation$_{Bo}$ (17,542.94±27.70 MPa), Bamboo Forest$_{To}$ (17,534.47±38.16 MPa), Bamboo Forest$_{Mi}$ (17,461.31±67.51 MPa) and Bamboo Forest$_{Bo}$ (17,421.67±39.83 MPa). Furthermore, the highest CS was observed in treatment Bamboo Plantation$_{To}$ (37.08±1.43 MPa), followed by Bamboo Plantation$_{Mi}$ (36.74±1.07 MPa), Bamboo Plantation$_{Bo}$ (35.11±1.54 MPa), Bamboo Forest$_{To}$ (33.24±1.17 MPa), Bamboo Forest$_{Mi}$ (30.33±2.40 MPa) and Bamboo Forest$_{Bo}$ (30.13±2.49 MPa). Similarly, the highest SS was recorded in treatment Bamboo Plantation$_{To}$ (4.50±0.12 MPa), followed by Bamboo Plantation$_{Mi}$ (4.48±0.08 MPa), Bamboo Forest$_{To}$ (4.45±0.10 MPa), Bamboo Plantation$_{Bo}$ (4.40±0.08 MPa), Bamboo Forest$_{Mi}$ (4.38±0.09 MPa) and Bamboo Forest$_{Bo}$ (4.30±0.04 MPa). Lastly, the highest TS was with treatment Bamboo Plantation$_{To}$ (219.34±3.64 MPa), followed by Bamboo Forest$_{To}$ (213.85±3.59 MPa), Bamboo Plantation$_{Mi}$ (212.94±6.86 MPa), Bamboo Plantation$_{Bo}$ (211.16±6.43 MPa), Bamboo Forest$_{Mi}$ (208.91±2.35 MPa) and Bamboo Forest$_{Bo}$ (208.60±7.03 MPa), as shown in Table 2. These differences were all significant (p < 0.05), as illustrated in Table 3. These results align with previous studies by Almeida *et al*. (2009), who reported MOR values ranging from 101-127 MPa and MOE around 15,400 MPa. Additionally, Thammapornram *et al*. (2018) found that *D. giganteus* can resist compression strengths of 29.74-43.79 MPa and tensile strengths of 159.38-257.68 MPa. Hung *et al*. (2021) report that the shear strength approximately 5.25 MPa. The bamboo from plantations tends to be stronger than that from forests, with the top part exhibiting higher mechanical property values than the middle and lower parts (Berndsen *et al*., 2014; Gao *et al*., 2022) Thereby, *Dendrocalamus giganteus* is deemed suitable for producing furniture or structures (Siam *et al*., 2019).

**Table 2.** Average percentage of MOR, MOE, CS, SS and TS from *Dendrocalamus giganteus*

| Treatment | MOR (MPa) | MOE (MPa) | CS (MPa) | SS (MPa) | TS (MPa) |
|---|---|---|---|---|---|
| Bamboo Plantation$_{Bo}$ | 118.83±3.75$^{b}$ | 17,542.94±27.70$^{b}$ | 35.11±1.54$^{ab}$ | 4.40±0.08$^{ab}$ | 211.16±6.43$^{b}$ |
| Bamboo Plantation$_{Mi}$ | 123.15±2.90$^{a}$ | 17,618.86±44.02$^{a}$ | 36.74±1.07$^{a}$ | 4.48±0.08$^{a}$ | 212.94±6.86$^{ab}$ |
| Bamboo Plantation$_{To}$ | 126.39±3.89$^{a}$ | 17,654.59±64.99$^{a}$ | 37.08±1.43$^{a}$ | 4.50±0.12$^{a}$ | 219.34±3.64$^{a}$ |
| Bamboo Forest$_{Bo}$ | 112.52±2.29$^{c}$ | 17,421.67±39.83$^{c}$ | 30.13±2.49$^{c}$ | 4.30±0.04$^{b}$ | 208.60±7.03$^{b}$ |
| Bamboo Forest$_{Mi}$ | 118.65±3.00$^{b}$ | 17,461.31±67.51$^{c}$ | 30.33±2.40$^{c}$ | 4.38±0.09$^{ab}$ | 208.91±2.35$^{b}$ |
| Bamboo Forest$_{To}$ | 123.66±2.69$^{a}$ | 17,534.47±38.16$^{b}$ | 33.24±1.17$^{b}$ | 4.45±0.10$^{a}$ | 213.85±3.59$^{ab}$ |
| Average | 120.53±3.09 | 17,538.97±43.70 | 33.77±1.68 | 4.42±0.09 | 212.47±4.98 |

Mean ± SD values with difference lowercase superscripts are significantly ($p < 0.05$) different

**Table 3.** Statistical analysis of MOR, MOE, CS, SS and TS from *Dendrocalamus giganteus*

| List | Group | Sum of squares | df | Mean square | F | P-value |
|---|---|---|---|---|---|---|
| MC | Between group | 2.973 | 5 | 0.595 | 1.317 | 0.290 |
| | Within group | 10.838 | 24 | 0.452 | | |
| | Total | 13.811 | 29 | | | |
| D | Between group | 1,668.049 | 5 | 333.610 | 3.074 | 0.028 |
| | Within group | 2,604.722 | 24 | 108.530 | | |
| | Total | 4,272.770 | 29 | | | |
| SG | Between group | 0.004 | 5 | 0.001 | 3.566 | 0.015 |
| | Within group | 0.005 | 24 | 0.000 | | |
| | Total | 0.008 | 29 | | | |
| MOR | Between group | 607.849 | 5 | 121.570 | 12.335 | 0.001 |
| | Within group | 236.538 | 24 | 9.856 | | |
| | Total | 844.388 | 29 | | | |
| MOE | Between group | 197,881.517 | 5 | 39,576.303 | 19.418 | 0.001 |
| | Within group | 48,916.210 | 24 | 2,038.175 | | |
| | Total | 246,797.728 | 29 | | | |
| CS | Between group | 234.492 | 5 | 46.898 | 14.933 | 0.001 |
| | Within group | 75.372 | 24 | 3.140 | | |
| | Total | 309.864 | 29 | | | |
| SS | Between group | 0.147 | 5 | 0.029 | 3.684 | 0.013 |
| | Within group | 0.192 | 24 | 0.008 | | |
| | Total | 0.339 | 29 | | | |
| TS | Between group | 393.322 | 5 | 78.664 | 2.784 | 0.040 |
| | Within group | 678.217 | 24 | 28.259 | | |
| | Total | 1,071.539 | 29 | | | |

## Conclusion

The optimal conditions for the physical and mechanical properties of *Dendrocalamus giganteus* were observed in the treatment with the Bamboo Plantation zone at the top part of the bamboo. These differences were all significant ($p < 0.05$). The results suggest that the top part of the bamboo is influenced by vascular bundles, which are denser in this region compared to the bottom part. Furthermore, bamboo plantations managed through silviculture with sustainable practices can significantly enhance the properties of bamboo

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