**12th World Bamboo Congress**

**Taiwan, 18-22 April, 2024**

www.worldbamboo.net

# Potential utilization of climbing bamboo species in the Philippines

Elvina O. Bondad*, Oliver S. Marasigan, Marina A. Alipon, and Shereyl A. Daguinod

*Physics and Mechanics Section, Material Science Division Forest Products Research and Development Institute (FPRDI) Department of Science and Technology (DOST) College, Los Baños, Laguna 4031 Philippines*

## Abstract

The study was conducted to determine the physical and mechanical properties of 12 species of climbing bamboo collected from Luzon, Island Philippines. The physical and mechanical characteristics were determined using the ASTM D143. For physical properties, luzon bikal, bukawe, bagtok, and baitu showed the lowest green MC (64.26%, 91.96%, 93.40%, and 94.25%, respectively) but gave the highest relative density (0.777, 0.603, 0.630, and 0.619, respectively). Baguisan, on the other hand, showed the highest tangential (11.99%), radial (14.28%), and volumetric shrinkage (24.24%). For longitudinal shrinkage, yaho (0.91%) gave the highest value. From the bottom to the top portion, a decrease in MC and an increase in RD were observed. Various trends in mechanical properties at green condition, highest fiber stress at elastic limit (FSEL), modulus of rupture (MOR), and modulus of elasticity (MOE) were observed on luzon bikal (46.48 MPa, 70.07 MPa, and 11.50 GPa, respectively) and bagtok (40.69 MPa, 79.05 MPa, and 11.36 GPa, respectively). Similarly, these species showed the highest compression parallel-to-grain with node (56.11 MPa and 42.66, respectively) and without node (58.52 MPa and 44.60 MPa). On the other hand, the highest shear strength with and without node was observed in bagtok (13.22 MPa and 8.68 MPa, respectively) and baitu (10.16 MPa and 7.53 MPa, respectively). Based on the DOST-FPRDI strength classification, baitu, luzon bikal, bikal baboy, bagtok, yaho, puser, and bukawe are suited to applications where the large diameter is not required such as construction, high-grade furniture, and flooring where both strength and durability are required. The improved utilization of climbing bamboos can give bamboo growers a wider range of options for plantation establishment and bamboo products manufacturers more choices for their raw materials.

**Keywords** Bamboo, climbing bamboo, mechanical properties, physical properties, utilization

**Corresponding Author: Elvina O. Bondad, Department of Science and Technology (DOST) College, Los Baños, Laguna 4031 Philippines*

## 1. Introduction

Bamboo is recognized as one of the fastest-growing plants on earth and the best alternative as raw material to replace timber in the future. Culms complete their growth both in diameter and height in only 80 to 110 days and become ready for harvest in about three years (Wahab et al. 2009). Moreover, culms have a higher strength-weight ratio, which makes bamboo an ideal substitute for wood (Baja-Lapis 2016). In the Philippines, bamboo production and use have been focused on erect species. According to DENR-ERDB (2016), of the climbing bamboo, only puser (*Cyrtochloa puser*) was identified as an economically important species. Climbing bamboos encompass 32% of all bamboos in the Philippines (Virtucio 2008) and are distributed under three genera, viz., *Dinochloa*, *Cyrtochloa*, and *Cephalostachyum*. According to Escobin (2005) climbing bamboos under the genera *Cyrtochloa* and *Dinochloa* include the scrambling, trailing, clambering, and scandent types. On the other hand, bamboos under *C.* are those whose culms grow to a considerable height and bear many branches at each node. The upper part then cannot support itself and scrambles or leans on nearby vegetation. Among the climbing bamboos in the Philippines are bolo [*C. fenixii* (Gamble) S. Dransf], baitu (*C. hirsuta* S. Dransf. comb. nov.), luzon bikal [*C. luzonica* (Gamble) S. Dransf], bikal baboy [*C. major* (Pilg.) S. Dransf. comb. nov.], puser [*C. puser* (Gamble) S. Dransf. comb. nov.], bukawe [*C. toppingii* (Gamble) Dransf.], bikal [*D. acutiflora* (Munro) S. Dransf. comb. nov.], tagisi (*D. dielsiana* Pilger), elmer bikal (*D. elmeri* Gamble), baguisan (*D. pubiramea* Gamble), bagtok (sterile) (*C. mindorense* Gamble), and yaho (fertile/flowering) (*C. mindorense* Gamble). According to Maruzzo et al. (2005), climbing bamboos can become a potential source of raw materials for handicrafts production. Homologous to rattan, climbing bamboos can also be combined with vines and other materials and may be used for handles of high-end baskets. They have received little attention among bamboo growers and processors due to a lack of information about their properties and utilization.

Previous studies have assessed the distribution and some properties of climbing bamboos to determine their possible end-uses. Escobin (2005) and Virtucio (2008) documented 17 species found in the Philippines. Maruzzo et al. (2005), on the other hand, assessed the morphological and anatomical properties of these species and found them suitable for handicrafts and furniture. In 2019, Marasigan et al. suggested that *C. puser* can be used as materials for furniture, weaving, handicrafts, and tool handles, and in construction applications where a large diameter bamboo was not required (e.g., door panels, floorings, and window frames) and engineered bamboo products. With the growing bamboo industry in the Philippines, the utilization of climbing bamboos can help augment the raw material supply, and widen the options of the plantation owners, and reforestation project managers. Previous studies on climbing bamboos, however, merely focused on their morphological and anatomical properties. Other properties, such as physical and mechanical are also important to determine their potential, promote their optimum use, and support the current and future scenarios in bamboo raw materials in the Philippines. This study was thus conducted to determine the possible end-uses of climbing bamboo in the Philippines based on their physical and mechanical properties.

## 2. Materials and methods

### 2.1. Sample preparation and testing

Twelve species of climbing bamboo were collected from seven provinces located in Luzon Island, Philippines viz., Zambales, Ilocos Norte, Rizal, Bataan, Abra, Occidental Mindoro, and Laguna (Table 1). These 12 species belong to three genera viz., *Cyrtochloa* (6), *Cephalostachyum* (2), and *Dinochloa* (4). Five mature culms with age between 4-5 years old were collected from five different clumps per species at about 30 cm above the ground. The length of the culms was measured and then the culms were equally segmented into three portions – namely bottom, middle, and top. Figure 1. shows the sampling scheme used in the study.

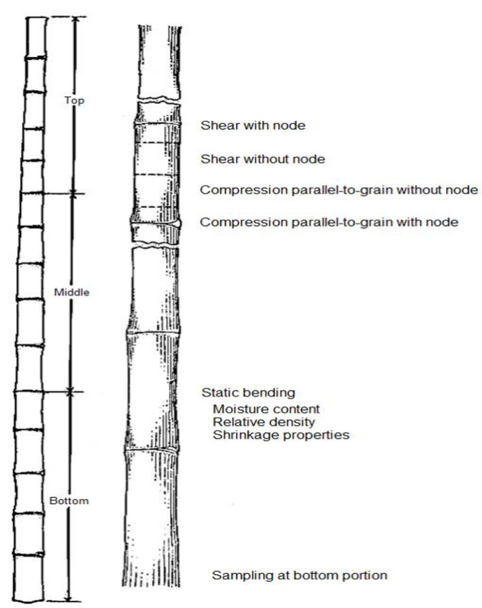


**Figure 1. Sampling scheme for the determination of the physical and mechanical properties of climbing bamboo at different height levels.**

**Table 1. Comparison of the physical properties of climbing and erect bamboo species in the Philippines**

| Common name | Scientific name/type of bamboo | Locality | Moisture content (%) | Relative density | Shrinkage (%) | |
|---|---|---|---|---|---|---|
| | | | | | Radial | Tangential |
| **CLIMBING BAMBOO** | | | | | | |
| Bolo | *C. fenixii* | Nueva Era, Ilocos Norte | 176.03 | 0.42 | 6.60 | 2.83 |
| Baitu | *C. hirsuta* | Brgy. San Pablo, Dinalupihan, Bataan | 94.25 | 0.62 | 5.26 | 3.38 |
| Luzon bikal | *C. luzonica* | Masinloc, Zambales | 64.26 | 0.78 | 5.96 | 4.51 |
| Bikal baboy | *C. major* | Brgy. San Pablo, Dinalupihan, Bataan | 98.06 | 0.57 | 6.52 | 3.23 |
| Bagtok | *C. mindorense* | Brgy. Inhobol, Mamburao, Occidental Mindoro | 93.40 | 0.63 | 9.00 | 5.13 |
| Yaho | *C. mindorense* | Brgy. Inhobol, Mamburao, Occidental Mindoro | 109.36 | 0.56 | 4.65 | 2.75 |
| Puser | *C. puser* | Batiwtiw, Tayum, Abra | 102.48 | 0.59 | 5.67 | 3.50 |
| Bukawe | *C. toppingii* | Brgy. Aldea, Tanay, Rizal | 91.96 | 0.60 | 6.96 | 4.93 |
| Bikal | *D. acutiflora* | Brgy. Tala, Rizal, Laguna | 203.83 | 0.38 | 5.90 | 2.20 |
| Tagisi | *D. dielsiana* | Masinloc, Zambales | 180.17 | 0.41 | 4.96 | 3.96 |
| Elmer bikal | *D. elmeri* | Masinloc, Zambales | 166.30 | 0.43 | 3.76 | 3.66 |
| Baguisan | *D. pubiramea* | Batiwtiw, Tayum, Abra | 184.84 | 0.38 | 14.28 | 11.99 |
| **Erect Bamboo** | | | | | | |
| Iron bamboo | *Guadua angustifolia** | Los Baños, Laguna | 81.80 | 0.63 | 18.37 | 8.33 |
| Kawayan tinik | *Bambusa blumeana*** | - | 92.80 | 0.64 | 12.00 | 8.50 |
| Kawayan kiling | *B. vulgaris*** | - | 95.50 | 0.64 | 14.10 | 11.90 |
| Bolo | *Gigantocholoa levis*** | - | 117.30 | 0.54 | 11.00 | 6.60 |
| Giant bamboo | *Dendrocalamus asper*** | - | 119.20 | 0.55 | 14.70 | 7.50 |
| Bayog | *D. merrillianus*** | - | 106.20 | 0.60 | 12.00 | 8.10 |
| Buho | *Schizostachyum lumampao*** | - | 173.70 | 0.48 | 18.70 | 5.90 |

*Source: * - Villareal et al. 2020; ** - Espilloy (1996)*

## 2.2. Physical properties

The moisture content, relative density, and shrinkage properties were determined following the ASTM D143 (2014) with modification in sample size. The 125 mm high culm ring was then split using a sharp bolo to give two slats measuring 25 mm × culm wall thickness (CWT) × 125 mm.

From each slat, a sample measuring 25 mm × 25 mm × CWT was prepared for MC and RD determination. The remaining slat measuring 25 mm × CWT × 100 mm was used for shrinkage properties determination. A total of 30 samples per species were collected. The MC and RD were computed using Equations 1 and 2 and shrinkage properties were computed using Equations 3 to 6.

1. $MC = \left(\frac{W_i - W_o}{W_o}\right) x100$

Where: MC = % Moisture content

$W_i$ = Initial weight (g)

$W_o$ = Oven dry weight (g)

2. $RD = \frac{W_o}{W_d}$

Where: RD = Relative density

$W_o$ = Oven dry weight (g)

$W_d$ = Weight of displaced water (g)

3. $\% \, RS = \frac{Di - Df}{Di} \, x \, 100$

4. $\% \, TS = \frac{Di - Df}{Di} \, x \, 100$

5. $\% \, LS = \frac{Di - Df}{Di} \, x \, 100$

6. $\% \, VS = \frac{Di - Df}{Di} \, x \, 100$

Where:

- % RS = Radial shrinkage
- % VS = Volumetric shrinkage
- % TS = Tangential shrinkage
- Di = Initial measurement
- % LS = Longitudinal shrinkage
- Df = Final measurement

**2.3. Mechanical properties**

The mechanical properties were tested using the standard procedure of the American Society for Testing Materials (ASTM D143, 2014) with slight medication adopting the procedure by Alipon et al. (2009) in the absence yet of the standard for bamboo during the conduct of this study. A total of 15 samples per species were prepared for each test.

**2.3.1. Static bending.** The bending strength was determined through a three-point bending test. The outer diameter of the culms was multiplied by 14 resulting in the free span of the specimen. On each side of the culm, two wood saddle supports were placed. The load was applied at the midspan/mid of the specimen at a uniform rate of motion of the movable crosshead.

**2.3.2. Compression Parallel-to-Grain.** Two sets of samples (with and without nodes) were prepared. The specimens' length was 10 × CWT. Special care was taken to ensure a precise cut at the end planes that was perpendicular to the grain and a vertically centered placement of the specimen.

**2.3.3. Shear strength.** Two sets of samples (with and without nodes) were also prepared. The shear strength along the fibers was tested using specimens with lengths equal to their diameters. Special care was taken to ensure a precise cut at the end planes perpendicular to the grain and a vertically centered placement of the specimen.

### 2.4. Statistical Analysis

A two-factor factorial analysis of variance (ANOVA) in randomized complete block design (RCBD) was performed on the species and height levels at a 95% confidence level. Further analysis was conducted using Tukey`s Honestly Significant Difference Test. All the statistical analyses were done using R-studio ver. 3.6.0 (R Core Team, 2019).

## 3. Results and discussion

### 3.1. Physical properties

#### 3.1.1. Moisture content and relative density

The green moisture content (MC) of the climbing bamboos ranges from 64.26% to 203.83% where the bikal recorded the highest value and luzon bikal the lowest (Fig. 2.). A significant difference ($p$ = <2e-16) in MC was found among the species. On the other hand, relative density (RD) ranged from 0.378 to 0.777 where the highest values were observed in luzon bikal and the lowest in bikal and baguisan (Figure 2). A significant difference ($p$ = <2e-16) in RD values among species was also found. Moreover, RD was negatively correlated with MC (Figure 3). The result indicates that bikal could had better mechanical properties than other species with low RD. It is interesting that the green MC and RD of the luzon bikal were lower and higher, respectively, than those of the *Guadua angustifolia* and bamboo species observed by Espiloy (1996) (Table 1). Moreover, the green MC of baitu (94.25%), bukawe (91.96%), puser (102.49%), bikal baboy (98.06%), and yaho (109.36%) was lower than that of erect bamboos such as *Gigantochloa levis* (117.30%), *Dendrocalamus asper* (119.20%), *Dendrocalamus merrillianus* (106.20%), *and Schizostachyum lumampao* (173.70%). This implies that luzon bikal could have better mechanical properties than economically important bamboo species and can be used for structural applications where a large diameter is not important.

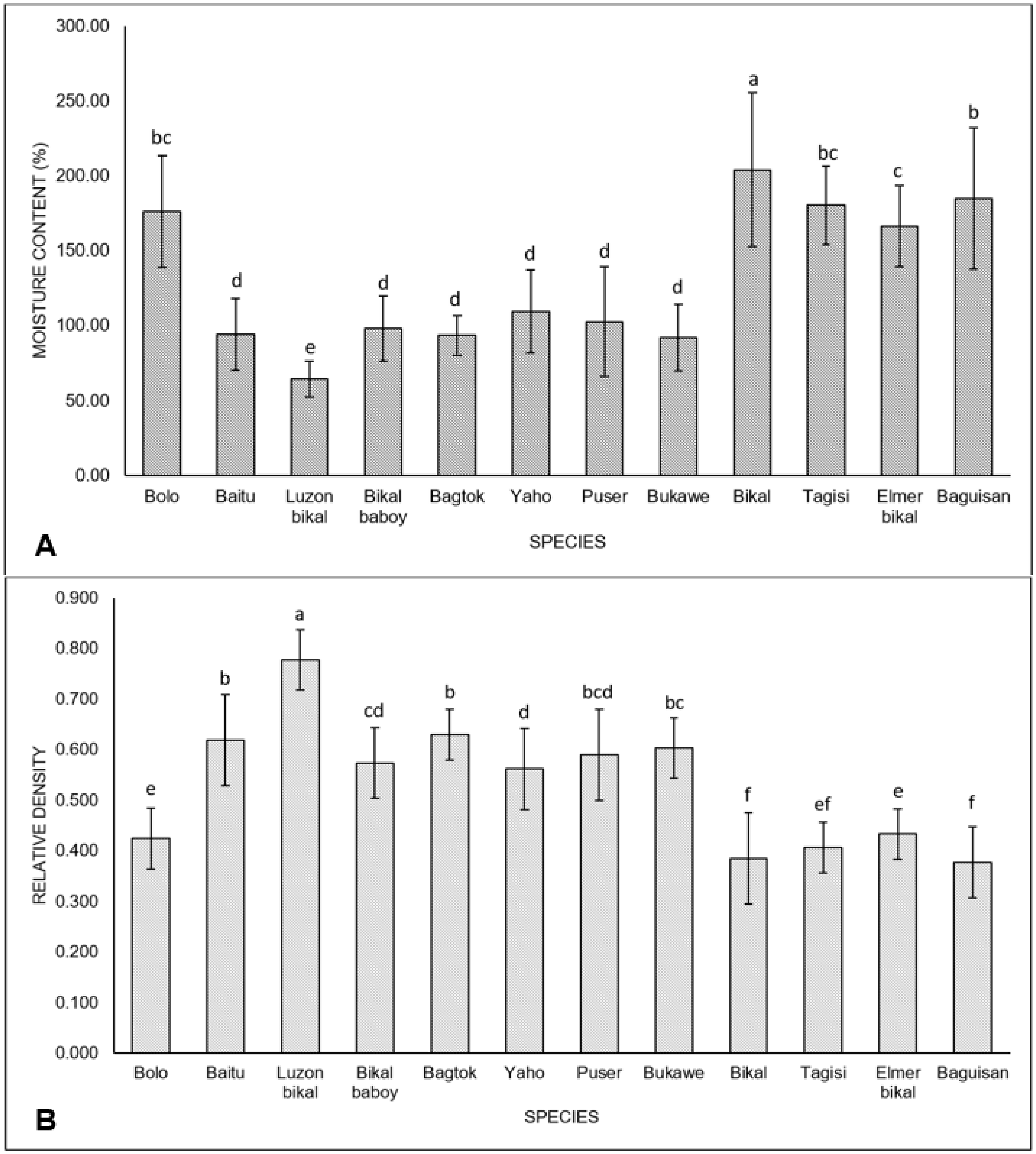


**Figure 2.** Moisture content (A) and relative density (B) of climbing bamboo. Means with the same letter are not significantly different (a, f – highest, lowest value)

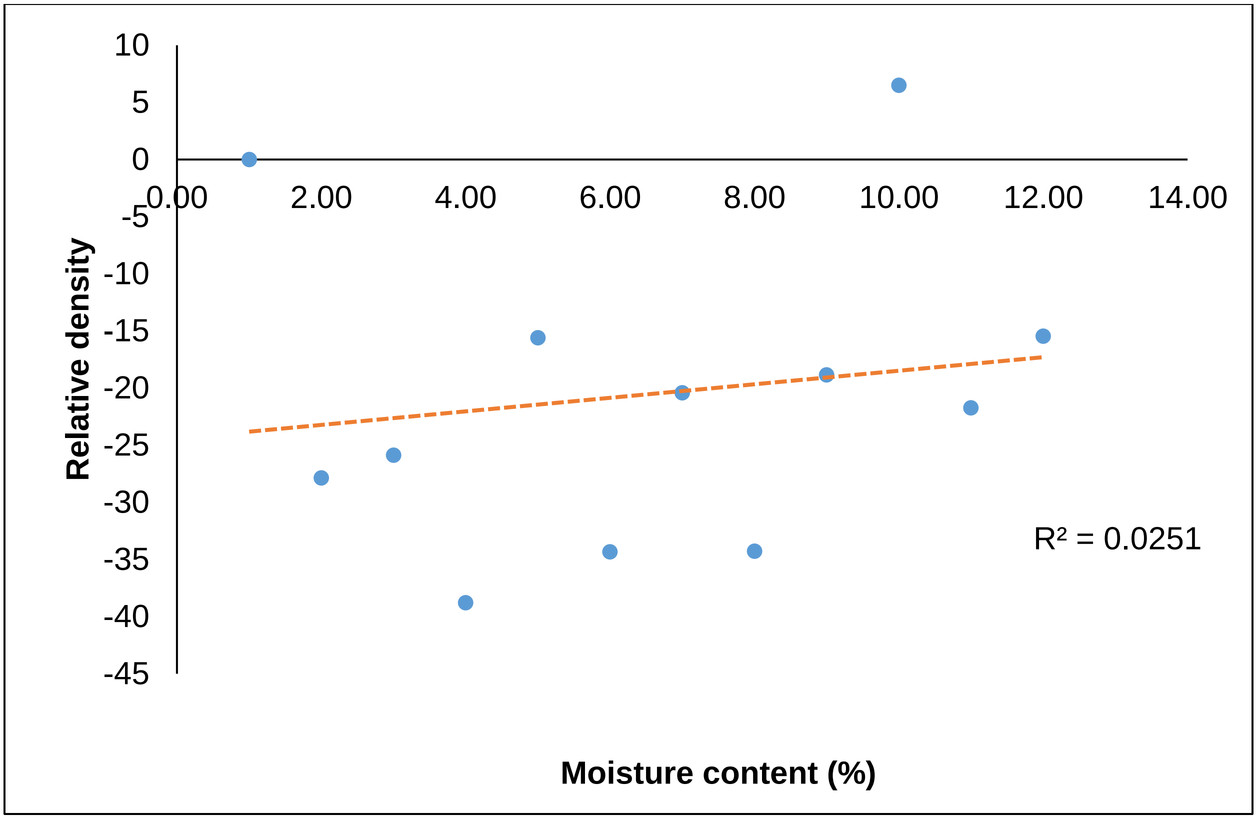


**Figure 3.** Relationship between moisture content and relative density of climbing bamboo

The significant difference in green MC and RD among the climbing bamboos can be associated with the difference in morphological and anatomical properties. According to Villareal et al. (2020), MC is positively correlated with cell wall thickness and CWT but negatively correlated with internode length, vascular bundles, and lumen diameter. On the other hand, RD is positively correlated with internode length and vascular bundles but negatively with culm diameter, CWT, and most anatomical properties (fiber length, lumen diameter, and cell wall thickness). Kamruzzaman et al. (2008), Nordahlia et al. (2011), and Siam et al. (2019) also observed a similar relationship among these properties in different bamboo species. According to Maruzzo et al. (2005) the luzon bikal had a short internode (15.0 cm), small culm diameter (1.36 cm), thin CWT (3.0 mm), and small vessel width (150 um). However, it had more vascular bundles (4.0 no/mm$^2$), shorter fiber length (2.324 mm), and a thicker cell wall (0.015 um). On the other hand, bikal and baguisan had larger culm diameter (3.22 cm and 2.30 cm, respectively), cell wall thickness (7.98 mm and 11.57 mm, respectively), vessel width (251 um and 277, respectively), and fiber length (2.927 mm and 2.967 mm, respectively). On average, vascular bundles of these species were 4.0 no/mm$^2$ for bikal and 5.0 no/mm$^2$ for baguisan.

### 3.1.2. Shrinkage properties

The tangential shrinkage (TS), radial shrinkage (RS), longitudinal shrinkage (LS), and volumetric shrinkage (VS) of the climbing bamboo ranged from 2.20% to 4.78%, 2.47% to 5.91%, 0.038% to 0.906%, and 7.28% to 24.24%, respectively (Figure 4). For the TS and RS, the highest values were observed in bagtok and bukawe, respectively, while the lowest was observed in bikal (RS) and baguisan (TS). On the other hand, for VS, the highest value was obtained from baguisan and the lowest from yaho. For LS, yaho gave the highest value and bukawe the lowest. A significant difference in shrinkage properties (i.e., TS, RS, LS, VS) ($p$ = <2e-16) was observed. The high TS, RS, and VS of baguisan can be attributed to its high CWT (11.57 mm) and fiber length (2.967 mm) which was reported by Maruzzo et al. (2005). On the other hand, the low TS, RS, and VS of bikal, elmer bikal, and yaho may be attributed to the difference in morphological and anatomical properties. According to Maruzzo et al. (2005) the bikal, elmer bikal, and yaho have low CWT (7.98 mm, 9.16 mm, and 3.89 mm, respectively) and shorter fiber lengths (2.927 mm, 2.544mm, and 2.866 mm, respectively). In erect bamboo species, the RS, TS, and VS are positively correlated with culm diameter, CWT, and fiber length (Villareal et al. 2020; Siam et al. 2019; Razak et al. 2013). Moreover, a negative correlation between RS, TS, and VS and vascular bundles was observed in erect bamboos (Villareal et al. 2020; Siam et al. 2019; Kamruzzaman et al. 2018; Nordahlia et al. 2011). Furthermore, the high LS observed in yaho could probably be due to the high microfibril angle (MFA) at the $S_2$ layer (Shmulsky and Jones, 2019). Moreover, according to the findings of Villareal et al. (2020), there is a negative relationship between LS and CWT and cell wall thickness. The results of the present study suggest that baguisan and bagtok are dimensionally unstable and cannot be used in applications where dimensional stability is a concern. On the other hand, yaho is not recommended for applications where LS is important.

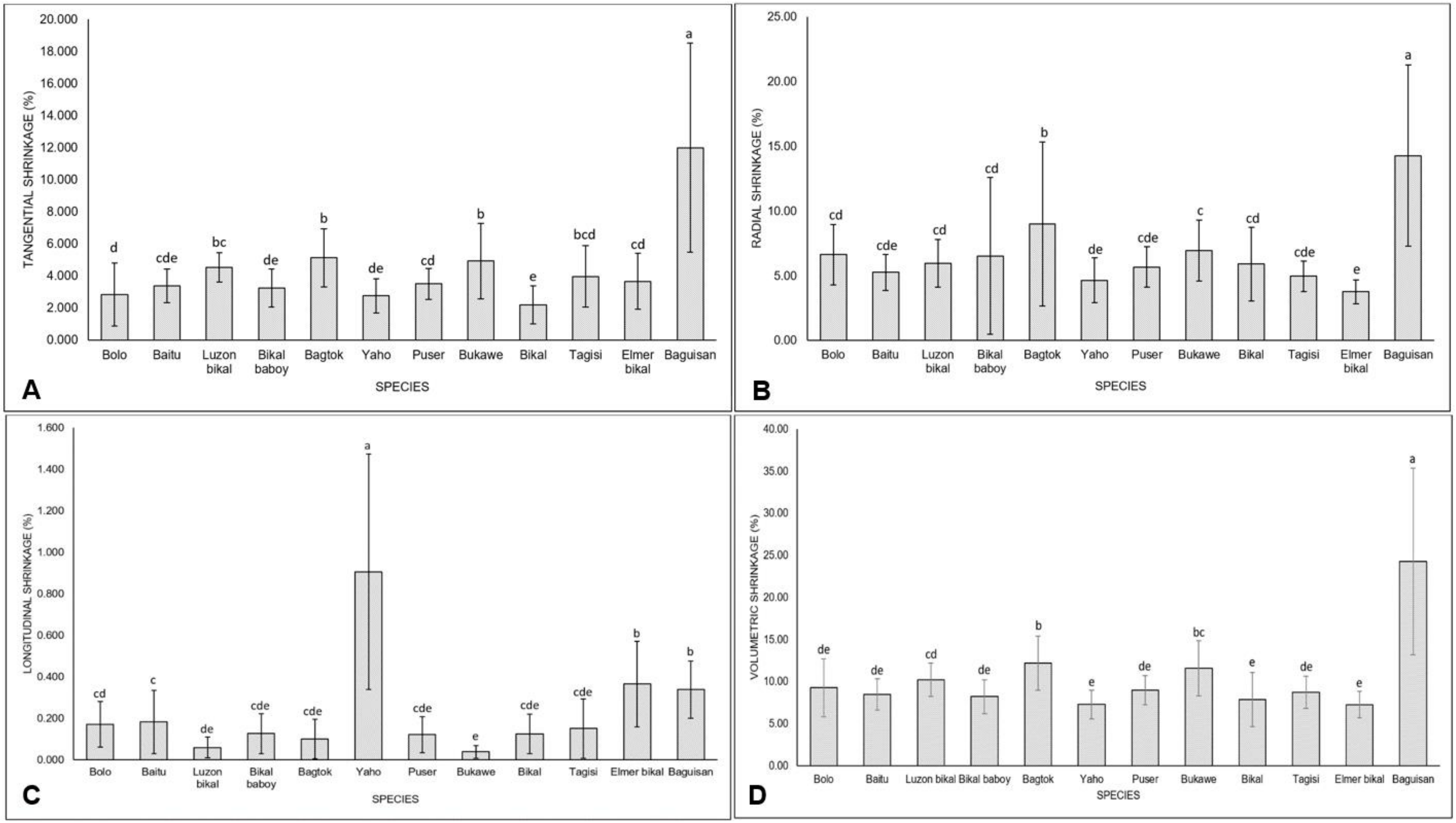


**Figure 4.** Tangential (A), radial (B), longitudinal (C), and volumetric shrinkage (D) properties of climbing bamboo. Means with the same letter are not significantly different (a, e – highest, lowest value)

### 3.1.3. Mechanical properties

Significant differences in fiber stress at elastic limit (FSEL) ($p$ = <2e-16), modulus of rupture (MOR) ($p$ = <2e-16), and modulus of elasticity (MOE) ($p$ = <2e-16) were observed among the climbing bamboos studied. FSEL ranged from 11.54 to 46.48 MPa with luzon bikal having the highest value and bikal the lowest (Table 2). MOR, on the other hand, ranged from 26.64 to 79.05 MPa where the highest values were observed in bagtok and the lowest in bolo. Meanwhile, luzon bikal, bagktok, and bikal baboy gave the highest MOE (11.50 GPa, 11.36 GPa, and 11.12 GPa, respectively) and bikal and tagisi the lowest (4.05 GPa and 3.85 GPa, respectively). For the compression parallel-to-grain with node and without node, the values ranged from 15.11 to 56.11 MPa and 13.82 to 58.52 MPa (Table 2). The highest values came from luzon bikal (56.11 and 58.52 MPa, respectively) and the lowest from tagisi (15.99 and 15.86 MPa, respectively) and baguisan (15.11 and 13.82 MPa, respectively). A significant difference was observed among the bamboos both with node ($p$ = 2e-16) and without node ($p$ = 2e-16). For the shear strength with node and without node, values ranged from 1.62 to 13.22 MPa and 1.79 to 8.68 MPa, respectively with bagtok having the highest and baguisan. The samples with node ($p$ = 2e-16) and without node ($p$ = 2e-16) differed significantly. Except for MOE, bamboo species with high RD tended to have higher mechanical properties (Figure 5). A similar relationship between RD and mechanical properties was observed in 13 species of Malaysian bamboo (Siam et al. 2019), *Gigantochloa scortechinii* (Hamdan et al. 2009), *D. latiflorus, D. merrillanus, Bambusa vulgaris* (Leoncio 2017), and *D. strictus* (Bhonde et al. 2014). Likewise, mechanical properties improved as the vascular bundles of bamboo increased. According to Correal and Arbelaez (2010) and Archila-Santos et al. (2014), the increase in mechanical strength is due to a higher RD which is associated with a higher number of vascular bundles. Furthermore, according to Bahari and Ahmad (2009), cell wall thickness also affects the mechanical properties of bamboo, bamboo with longer fiber and thick cell walls likely to have higher mechanical properties. Similar observations were observed in *G. scortechinii* (Razak et al. 2012), *G. levis* (Razak et al. 2013), and *S. brachycladum* (Nordahlia et al. 2011). The presence of lignin and cellulose fibers also affects the mechanical properties of bamboo (Nordahlia et al. 2011). A difference in compression parallel-to-grain and shear strength was observed between bamboo samples with node and without node (Table 3). From with node to without node, a decrease in strength was recorded in bolo (9.29%), baguisan (8.54%), baitu (6.91%), yaho (1.22%), and tagisi (0.81%). On the other hand, an increase in compression strength was shown by in bikal (20.18%), elmer bikal (7.64%), bikal baboy (6.70%), puser (4.66%), bagtok (4.55%), luzon bikal (4.30%), and bukawe (3,98%). For the shear strength, a decrease was observed in all species except for bikal (6.51%) and baguisan (10.49%). The highest and lowest decreases in shear strength came from luzon bikal (38.77%) and elmer bikal (15.45%).

**Table 2. Mechanical properties of climbing bamboo**

| | Mechanical properties | | | | | | |
|---|---|---|---|---|---|---|---|
| | Static bending | | | Compression parallel-to-grain (MPa) | | Shear strength (MPa) | |
| **Bamboo** | **FSEL (MPa)** | **MOR (MPa)** | **MOE (GPa)** | **With node** | **Without node** | **With node** | **Without node** |
| Bolo | 14.71gh | 26.64g | 4.69de | 22.81e | 20.69f | 8.72cd | 6.29cde |
| Baitu | 15.20fgh | 33.40fg | 8.31b | 35.59cd | 33.13d | 10.16bc | 7.53abc |
| Luzon bikal | 46.48a | 70.07b | 11.50a | 56.11a | 58.52a | 9.93bc | 6.08de |
| Bikal baboy | 22.38cd | 62.52bc | 11.12a | 36.88bcd | 39.46bc | 7.76de | 6.55cde |
| Bagtok | 40.69b | 79.05a | 11.36a | 42.66b | 44.60b | 13.22a | 8.68a |
| Yaho | 21.57de | 44.30de | 8.56b | 31.19d | 30.81de | 9.35c | 7.44bc |
| Puser | 16.32efgh | 40.97def | 8.21b | 39.09bc | 40.91bc | 10.94b | 7.19bcd |
| Bukawe | 27.42c | 45.01de | 7.45bc | 34.95cd | 36.34cd | 10.29bc | 8.35ab |
| Bikal | 11.54h | 43.07de | 4.02e | 16.90f | 20.31f | 5.07f | 5.40e |
| Tagisi | 19.72defg | 37.86ef | 3.85e | 15.99f | 15.86fg | 6.90e | 5.40e |
| Elmer bikal | 20.69def | 61.69c | 5.97cd | 25.27e | 27.20e | 7.51de | 6.35cde |
| Baguisan | 16.22efgh | 49.64d | 5.70cde | 15.11f | 13.82g | 1.62g | 1.79f |

**Table 3. Percent difference in compression parallel-to-grain and shear strength between climbing bamboo with node and without node.**

| Mechanical Properties | | |
|---|---|---|
| **Bamboo sp.** | **Compression parallel-to-grain (MPa)** | **Shear strength (MPa)** |
| Bolo | -9.294 | -27.867 |
| Baitu | -6.912 | -25.886 |
| Luzon bikal | 4.295 | -38.771 |
| Bikal baboy | 6.996 | -15.593 |
| Bagtok | 4.548 | -34.342 |

| | | |
|---|---|---|
| Yaho | -1.218 | -20.428 |
| Puser | 4.656 | -34.278 |
| Bukawe | 3.977 | -18.853 |
| Bikal | 20.178 | 6.509 |
| Tagisi | -0.813 | -21.739 |
| Elmer bikal | 7.638 | -15.446 |
| Baguisan | -8.537 | 10.494 |

The decrease in strength in some species from with to without nodes can be attributed to the short fiber, high lignin, and a high number of truncated vascular bundles at the nodal region (Liese, 1998). High-strength properties in bamboo with nodes were also reported in *Gigantochloa scortechinii* (Hamdan et al. 2009) and *Phyllostachys edulis* (Liu et al. 2021). On the other hand, Jimenez et al. (2021) observed higher compression strength in *B. blumeana* and *D. asper* without nodes than in samples with nodes. However, the difference was not significant. Variation in shear strength in bamboo specimens with and without nodes was also documented by Bautista et al. (2021), Salzer et al. (2018), and Oka et al. (2014). They observed higher shear strength in the specimens without nodes for *G. apus, B. philippinensis, B. vulgaris, B. blumeana,* and *G. atroviolaceae.* On the other hand, Bautistia et al. (2021) reported higher strength in *D. asper* specimens with nodes. The variation in strength properties among the bamboo species may be due to the different sources of bamboo and cell structure (Salzer et al. 2018; Oka et al. 2014). Based on DOST-FPRDI strength classification (Alipon and Bondad, 2008), baitu, luzon bikal, bikal baboy, bagtok, yaho, puser, and bukawe belong to the C1 group (high strength) which is suited for application where the large diameter is not required such as construction, high-grade furniture, and flooring where both strength and durability are required. On the other hand, bolo, tagisi, and elmer bikal belong to the C3 (medium strength) which is suitable for high-grade furniture, paneling, automobile bodies, and bodies of musical instruments. Lastly, bikal and baguisan fell under C4 (moderately low strength) which is best for pulp and paper, and low-grade furniture where strength is not of critical importance.

### 3.2. Effect of Height Levels on the Properties of Bamboo

#### 3.2.1. Physical properties

**3.2.1.1. Moisture content.** Height level (i.e., bottom, middle, and top) had a significant influence ($p = 0.0031$) on the MC only of luzon bikal where the bottom and middle portions were significantly higher than the top (Table 4). A decreasing trend in MC from bottom to top was observed among the bamboos except for the bagtok and elmer bikal. The same trend was observed in different bamboo species (Razak et al. 2010; Nordahlia et al. 2011; Siam et al. 2019). This trend may be due to the difference in anatomical properties along the height levels. Nordahlia et al.

(2011) found in their study a negative relationship between MC and vascular bundles frequency of *S. brachycladum.* Siam et al. (2019) reported that the percentage of parenchyma cells contributes to the culm`s water storage capacity and the increase of these cells results in higher MC.

#### 3.2.1.2. Relative density

Height level had a significant ($p = 0.0257$) influence on the RD of puser only where the bottom portion was significantly lower than the middle and top (Table 4). Numerous trends of RD along the height levels of the bamboo species were observed namely increasing trend from bottom to top (bolo, yaho, puser, and baguisan), decreasing trend from bottom to top (bagtok, bukawe, and tagisi) and decreasing trend from bottom to middle and increased from middle to top (baitu, luzon bikal, and elmer bikal) (Table 4). The increase in RD towards the top of the bamboo culm was also reported in *D. pendulus, D. asper, G. levis, G. scortechinii* (Zakikhani et al. 2017), *G. angustifolia* (Villareal et al. 2020), and *D. strictus* (Bhonde et al. 2014). According to Wang et al. (2016) and Villareal et al. (2020), this trend is associated with low CWT and higher vascular bundles, coupled with an increase in silica content. Correal and Arbelaez (2010) also mentioned that a high amount of sclerenchyma fibers at the top portion can also contribute to high RD at this level.

**Table 4. Physical properties of climbing bamboo at different height levels**

| Physical properties | Height levels | Bolo | Baitu | Luzon bikal | Bikal baboy | Bagtok | Yaho | Puser | Bukawe | Bikal | Tagisi | Elmer bikal | Baguisan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moisture content (%) | Bottom | 191.10$^{a}$ | 103.88$^{a}$ | 69.50$^{a}$ | 100.29$^{a}$ | 88.39$^{a}$ | 122.51$^{a}$ | 122.13$^{a}$ | 93.40$^{a}$ | 219.18$^{a}$ | 167.80$^{a}$ | 165.43$^{a}$ | 205.21$^{a}$ |
| | Middle | 171.20$^{a}$ | 93.90$^{a}$ | 67.60$^{a}$ | 103.26$^{a}$ | 91.73$^{a}$ | 104.73$^{a}$ | 97.92$^{a}$ | 89.50$^{a}$ | 198.91$^{a}$ | 185.68$^{a}$ | 167.36$^{a}$ | 188.49$^{a}$ |
| | Top | 165.80$^{a}$ | 87.98$^{a}$ | 55.70$^{b}$ | 94.68$^{a}$ | 100.09$^{a}$ | 100.84$^{a}$ | 87.42$^{a}$ | 93.00$^{a}$ | 193.40$^{a}$ | 187.05$^{a}$ | 166.14$^{a}$ | 160.83$^{a}$ |
| Relative density | Bottom | 0.39$^{a}$ | 0.58$^{a}$ | 0.78$^{a}$ | 0.57$^{a}$ | 0.64$^{a}$ | 0.53$^{a}$ | 0.54$^{a}$ | 0.61$^{a}$ | 0.36$^{a}$ | 0.43$^{a}$ | 0.44$^{a}$ | 0.36$^{a}$ |
| | Middle | 0.43$^{a}$ | 0.52$^{a}$ | 0.76$^{a}$ | 0.56$^{a}$ | 0.64$^{a}$ | 0.58$^{a}$ | 0.60$^{b}$ | 0.61$^{a}$ | 0.39$^{a}$ | 0.40$^{a}$ | 0.43$^{a}$ | 0.37$^{a}$ |
| | Top | 0.45$^{a}$ | 0.66$^{a}$ | 0.78$^{a}$ | 0.58$^{a}$ | 0.61$^{a}$ | 0.58$^{a}$ | 0.63$^{b}$ | 0.59$^{a}$ | 0.40$^{a}$ | 0.39$^{a}$ | 0.44$^{a}$ | 0.41$^{a}$ |
| Tangential shrinkage (%) | Bottom | 3.51$^{a}$ | 4.03$^{a}$ | 4.65$^{a}$ | 3.30$^{a}$ | 5.66$^{a}$ | 2.65$^{a}$ | 3.78$^{a}$ | 6.19$^{a}$ | 2.90$^{a}$ | 3.80$^{a}$ | 3.27$^{a}$ | 16.13$^{a}$ |
| | Middle | 3.44$^{a}$ | 3.40$^{ab}$ | 4.28$^{a}$ | 3.01$^{a}$ | 4.60$^{a}$ | 3.03$^{a}$ | 3.45$^{a}$ | 4.79$^{a}$ | 2.01$^{a}$ | 3.93$^{a}$ | 3.25$^{a}$ | 11.87$^{ab}$ |
| | Top | 1.55$^{a}$ | 2.74$^{b}$ | 4.61$^{a}$ | 3.30$^{a}$ | 5.13$^{a}$ | 2.59$^{a}$ | 3.27$^{a}$ | 3.81$^{a}$ | 1.70$^{a}$ | 4.17$^{a}$ | 4.48$^{a}$ | 7.99$^{b}$ |
| Radial shrinkage (%) | Bottom | 7.80$^{a}$ | 5.07$^{a}$ | 5.17$^{a}$ | 6.52$^{a}$ | 8.88$^{a}$ | 5.14$^{a}$ | 5.56$^{ab}$ | 7.41$^{a}$ | 6.18$^{a}$ | 5.39$^{a}$ | 3.99$^{a}$ | 17.59$^{a}$ |
| | Middle | 6.88$^{ab}$ | 5.60$^{a}$ | 6.15$^{a}$ | 8.07$^{a}$ | 11.79$^{a}$ | 4.29$^{a}$ | 4.90$^{b}$ | 7.30$^{a}$ | 5.63$^{a}$ | 4.64$^{a}$ | 3.30$^{a}$ | 15.75$^{ab}$ |
| | Top | 5.22$^{b}$ | 5.11$^{a}$ | 6.57$^{a}$ | 4.97$^{a}$ | 9.00$^{b}$ | 4.54$^{a}$ | 6.57$^{a}$ | 6.19$^{a}$ | 5.91$^{a}$ | 4.86$^{a}$ | 3.99$^{a}$ | 9.51$^{b}$ |
| Longitudinal shrinkage (%) | Bottom | 0.16$^{a}$ | 0.18$^{a}$ | 0.08$^{a}$ | 0.12$^{a}$ | 0.07$^{a}$ | 0.96$^{a}$ | 0.12$^{a}$ | 0.04$^{a}$ | 0.20$^{a}$ | 0.19$^{a}$ | 0.34$^{a}$ | 0.32$^{a}$ |
| | Middle | 0.20$^{a}$ | 0.12$^{a}$ | 0.02$^{a}$ | 0.13$^{a}$ | 0.13$^{a}$ | 1.10$^{a}$ | 0.15$^{a}$ | 0.03$^{a}$ | 0.09$^{a}$ | 0.10$^{a}$ | 0.32$^{a}$ | 0.37$^{a}$ |
| | Top | 0.15a | 0.24a | 0.07a | 0.15a | 0.10a | 0.65a | 0.09a | 0.05a | 0.08a | 0.17a | 0.43a | 0.33a |
| Volumetric shrinkage (%) | Bottom | 11.02a | 9.18a | 9.57a | 8.86a | 14.02a | 7.65a | 9.13a | 13.16a | 8.80a | 8.98a | 7.14ab | 30.54a |
| | Middle | 10.06a | 9.07a | 10.16a | 7.64a | 11.40a | 7.19a | 8.19a | 11.80ab | 7.29a | 8.39a | 6.44b | 25.52ab |
| | Top | 6.68b | 7.12b | 10.89a | 8.11a | 11.14a | 7.02a | 9.64a | 9.76b | 7.50a | 8.84a | 8.18a | 16.68b |

Note: Means with the same letter are not significantly different (a, b – highest, lowest value).

**3.2.1.3. Shrinkage properties.** The TS (*p* = 0.0001), RS (*p* = 0.0079), and VS (*p* = 1.64e-05) of the samples were significantly affected by height level. For TS, a notable difference was observed between baitu and baguisan where the bottom portion was significantly higher than the top but not the middle portion. For RS, bolo, puser, and baguisan varied significantly, while for VS, bolo, baitu, bukawe, elmer bikal, and baguisan were notably different (Table 4.). Several TS, RS, LS, and VS trends were observed among the bamboos (Table 4.). For TS, a decreasing trend from the bottom to the top was recorded for bolo, baitu, puser, bukawe, bikal, and baguisan. For luzon bikal, bikal baboy, bagok, and elmer bikal a decreased in TS from the bottom to the middle and increased from the middle to the top was observed. Tagisi, meanwhile showed an increasing trend. From the bottom to the top, RS of bolo and baguisan decreased while that of luzon bikal increased. On the other hand, from the bottom to the middle the RS decreased and increased from the middle to the top in yaho, puser, bukawe, bikal, tagisi, and elmer bikal. Baitu, bikal baboy, and bagtok meanwhile showed an increasing trend of RS from bottom to middle and decreasing from middle to top. Moreover, from the bottom to the top, LS of bikal decreased while that of bikal baboy increased. For bolo, bagtok, yaho, baguisan, and puser an increased in LS from the bottom to the middle and decreased from the middle to the top was noted. On the other hand, a decreasing LS from the bottom to the middle and increasing from the middle to the top was observed in baitu, luzon bikal, bukawe, tagisi and elmer bikal. For VS, an increasing trend towards the top was observed in bikal whereas for bolo, baitu, bagtok, yaho, bukawe and baguisan a decreasing trend was recorded. Bikal baboy, puser, bikal, tagisi, and elmer bikal the VS decreased from the bottom to middle and then increased towards the top. The decreasing trend of shrinkage properties from the bottom to the top portion of some of the climbing bamboos can be attributed to its morphological and anatomical properties. According to Villareal et al. (2020) the RS, TS, and VS were positively correlated with culm diameter and CWT but negatively correlated with vascular bundles frequency. On the other hand, LS was negatively correlated with culm diameter, CWT, and cell wall thickness. A similar decreasing trend of shrinkage properties from the bottom to the top portion of bamboo was also observed in some erect bamboo species (Nordahlia et al. 2021; Siam et al. 2019; Villareal et al. 2020; Kamruzzaman et al. 2008). The high shrinkage properties observed in the bottom portion of the bamboos can also be attributed to the higher amount of parenchyma cells, which contributes to water storage, resulting in higher initial MC and a low proportion of vascular bundles (Razak et al. 2012). On the other hand, the low shrinkage observed at the top portion can be associated with the presence of shorter fibers and relatively higher RD (Khabir et al. 1995) compared to other parts of the culm. Moreover, high LS value observed at different height levels could be due to the decreasing cell wall thickness (Villareal et al. 2020) and the arrangement of microfibril angle in the S2 layers of the cells (Shmulsky and Jones, 2019).

#### 3.2.2. Mechanical Properties

**3.2.2.1. Static bending.** The mechanical properties of climbing bamboos such as FSEL ($p$ = 0.0018) and MOR ($p$ = 4.77e-09) were significantly affected by the height levels. For FSEL, the bottom of baitu and luzon bukal had significantly higher values than the middle and top (Table 5.). On the other hand, a decreasing FSEL from the bottom to the top was observed in bolo, luzon bikal, bagtok, and puser. On the contrary, an increasing trend from the bottom to the top was shown by baguisan. Baitu, bikal, yaho, bukawe, bikal, tagisi, and elmer bikal exhibited a decreased in FSEL from the bottom to middle then increased towards the top. A significant difference in MOR along the height levels was also observed in luzon bikal, bagtok, yaho, and bukawe (Table 5). MOR decreased from the bottom to the top of bolo, baitu, luzon bikal, bikal baboy, bagtok, bukawe and elmer bikal but increased in baguisan. For yaho, puser, bikal, and tagisi, however, MOR decreased from the bottom to the middle and then increased towards the top. For the MOE, an increasing trend along the height levels was observed in bikal and baguisan and a decreasing trend was observed in luzon bikal, bikal baboy, and bagtok. For the elmer bikal, bolo, and baitu, an increase in MOE from the bottom to middle portion and then decreased towards the top portion. On the other hand, a decreasing strength from bottom to middle and then increased towards the top portion was observed in yaho, puser, bukawe, and tagisi (Table 5.). The various trends of FSEL, MOR, and MOE were also observed in erect bamboo species. Espiloy and Espiloy (1992) reported a decreasing FSEL, MOR, and MOE along the height levels of *B. blumeana, B. vulgaris, G. levis, D. asper. D. merrillianus,* and *S. lumampao.* On the other hand, Salzer et al. (2018), Siam et al. (2019), and Correal and Arbelaez (2010) documented an increasing trend of MOR and MOE along the height levels of *B. blumeana,* 13 species of bamboo in Malaysia, and 3 to 5 years old *G. angustifolia,* respectively. According to Kamruzzaman et al. (2008), the increase in the MOE of the bamboo is associated with the decreasing culm diameter towards the top portion and vice versa. The variation in FSEL, MOR, and MOE can also be attributed to the difference in vascular bundles and RD. As shown in Figure 5, a direct relationship exists between mechanical properties and RD, consistent with the findings of other studies (Kamruzzaman et al. 2008; Siam et al. 2019; Wakchaure and Kute 2012; Espiloy and Espiloy 1992; Correal and Arbelaez 2010). Moreover, varied mechanical properties may also be due to differences in location and age of bamboo (Razak et al. 2012; Kamruzzaman et al. 2008).

**3.2.2.2. Compression parallel-to-grain.** Height level had a significant influence to the compression parallel-to-grain without node ($p = 0.0269$) of baitu, yaho, and puser (Table 5.). For bolo, bikal, elmer bikal and baguisan, an increasing trend was observed from the bottom to the top while decreasing trend was recorded in bagtok. Puser and bukawe, on the other hand, increased from the bottom to middle and then decreased towards the top. Meanwhile, bikal baboy, tagisi, and luzon bikal showed a decreasing strength from the bottom to middle and then increasing towards the top. For compression parallel-to-grain with node, the strength increased towards the top portion of luzon bikal, elmer bikal, and baguisan but for bikal baboy, bukawe and tagisi the strength decreased along the height (Table 5.). Puser, bagtok, and yaho displayed an increasing strength from the bottom to the middle and decreasing towards the top. Baitu and bikal, on the other hand, recorded an increased in strength from bottom to middle but decreased towards the top portion. However, the difference in strength along the height levels was not significant ($p = 0.443$) (Table 5.). A similar increasing trend of compression parallel-to-grain in bamboo culms with and without nodes was also observed in *Gigantochloa atroviolacea* (Oka et al. 2014), 3-to-5-years old *G. angustifolia* (Correal and Albelaez, 2010), *B. blumeana, B. vulgaris, G. levis, D. asper. D. merrillianus*, and *S. lumampao* (Espiloy and Espiloy, 1992). In contrast, a decreasing trend of compression parallel-to-grain along the height of 2-year-old *G. angustifolia* was reported (Correal and Albelaez 2010).

A positive correlation between relative density and compression strength was observed by Kenneth and Uzodimma (2021) and Chaowana et al. (2015) in different erect bamboo species. They found that the positive correlation between relative density and compression strength was due to the uneven distribution of vascular bundles, chemical composition, and cell structure across the bamboo culm`s height and position. Moreover, the variation in the trend of compression strength along the culm of the climbing bamboo can also be attributed to the difference in location and age (Correal and Albelaez 2010; Kamruzzaman et al. 2008). However, the effect of these factors was not assessed in the present study.

**Table 5. Mechanical properties of climbing bamboo at different height levels**

| Mechanical properties | Height levels | Bolo | Baitu | Luzon bikal | Bikal baboy | Bagtok | Yaho | Puser | Bukawe | Bikal | Tagisi | Elmer bikal | Baguisan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FSEL (MPa) | Bottom | $15.71^{a}$ | $19.13^{a}$ | $51.97^{a}$ | $22.34^{a}$ | $46.98^{a}$ | $25.78^{a}$ | $22.47^{a}$ | $30.11^{a}$ | $13.02^{a}$ | $21.51^{a}$ | $21.60^{a}$ | $14.93^{a}$ |
| | Middle | $14.30^{a}$ | $12.60^{b}$ | $44.43^{b}$ | $21.18^{a}$ | $43.71^{a}$ | $19.19^{a}$ | $16.03^{a}$ | $25.83^{a}$ | $9.45^{a}$ | $18.20^{a}$ | $19.32^{a}$ | $15.19^{a}$ |
| | Top | $14.12^{a}$ | $13.98^{b}$ | $43.04^{b}$ | $23.64^{a}$ | $31.39^{a}$ | $19.77^{a}$ | $10.47^{a}$ | $26.62^{a}$ | $12.16^{a}$ | $19.48^{a}$ | $21.16^{a}$ | $18.56^{a}$ |
| MOR (MPa) | Bottom | $30.40^{a}$ | $39.38^{a}$ | $83.91^{a}$ | $69.58^{a}$ | $97.09^{a}$ | $60.08^{a}$ | $49.74^{a}$ | $56.42^{a}$ | $50.75^{a}$ | $39.70^{a}$ | $62.88^{a}$ | $45.63^{a}$ |
| | Middle | $26.19^{a}$ | $30.79^{a}$ | $63.87^{b}$ | $59.90^{a}$ | $80.93^{a}$ | $35.53^{b}$ | $33.81^{a}$ | $39.68^{b}$ | $38.47^{a}$ | $36.32^{a}$ | $60.20^{a}$ | $49.82^{a}$ |
| | Top | $23.35^{a}$ | $30.04^{a}$ | $62.43^{b}$ | $58.08^{a}$ | $59.15^{b}$ | $37.30^{b}$ | $39.37^{a}$ | $38.94^{b}$ | $40.01^{a}$ | $37.58^{a}$ | $62.01^{a}$ | $53.47^{a}$ |
| MOE (GPa) | Bottom | $4.94^{a}$ | $8.04^{a}$ | $11.90^{a}$ | $14.06^{a}$ | $12.69^{a}$ | $9.94^{a}$ | $8.49^{a}$ | $7.81^{a}$ | $3.75^{a}$ | $3.92^{a}$ | $5.87^{a}$ | $4.47^{b}$ |
| | Middle | $5.04^{a}$ | $8.94^{a}$ | $11.85^{a}$ | $10.15^{a}$ | $12.10^{a}$ | $7.70^{a}$ | $8.04^{a}$ | $6.88^{a}$ | $4.14^{a}$ | $3.70^{a}$ | $6.07^{a}$ | $5.55^{b}$ |
| | Top | $4.09^{a}$ | $7.98^{a}$ | $10.76^{a}$ | $9.18^{a}$ | $9.31^{a}$ | $8.05^{a}$ | $8.11^{a}$ | $7.68^{a}$ | $4.18^{a}$ | $3.95^{a}$ | $5.98^{a}$ | $7.06^{b}$ |
| Compression parallel-to-grain (with node) (MPa) | Bottom | $22.45^{a}$ | $36.17^{a}$ | $52.15^{a}$ | $41.07^{a}$ | $43.48^{a}$ | $31.42^{a}$ | $38.48^{a}$ | $37.01^{a}$ | $16.33^{a}$ | $16.56^{a}$ | $24.51^{a}$ | $12.39^{b}$ |
| | Middle | $26.35^{a}$ | $35.13^{a}$ | $57.72^{a}$ | $35.97^{a}$ | $47.92^{a}$ | $29.72^{a}$ | $42.42^{a}$ | $35.45^{a}$ | $17.34^{a}$ | $16.17^{a}$ | $24.74^{a}$ | $15.34^{ab}$ |
| | Top | $19.65^{a}$ | $35.47^{a}$ | $58.47^{a}$ | $33.61^{a}$ | $36.58^{a}$ | $32.44^{a}$ | $36.39^{a}$ | $32.39^{a}$ | $17.05^{a}$ | $15.26^{a}$ | $26.56^{a}$ | $17.62^{a}$ |
| Compression parallel-to-grain (without node) | Bottom | $18.70^{a}$ | $26.79^{b}$ | $54.54^{b}$ | $42.35^{a}$ | $46.87^{a}$ | $29.09^{b}$ | $38.27^{b}$ | $34.46^{a}$ | $18.49^{a}$ | $15.28^{a}$ | $24.63^{a}$ | $12.32^{a}$ |
| | Middle | $20.94^{a}$ | $34.95^{a}$ | $50.78^{b}$ | $37.59^{a}$ | $44.92^{a}$ | $29.22^{b}$ | $44.41^{a}$ | $38.39^{a}$ | $20.85^{a}$ | $14.67^{a}$ | $26.36^{a}$ | $13.30^{a}$ |
| | Top | $22.46^{a}$ | $37.67^{a}$ | $70.26^{a}$ | $38.47^{a}$ | $42.03^{a}$ | $34.13^{a}$ | $40.07^{b}$ | $36.17^{a}$ | $21.59^{a}$ | $17.63^{a}$ | $30.63^{a}$ | $15.85^{a}$ |
| Shear strength (with node) | Bottom | $7.94^{a}$ | $10.56^{a}$ | $9.40^{a}$ | $7.95^{a}$ | $12.19^{b}$ | $9.29^{a}$ | $12.50^{a}$ | $10.17^{a}$ | $4.90^{a}$ | $7.49^{a}$ | $7.89^{a}$ | $1.75^{a}$ |
| | Middle | $9.58^{a}$ | $10.61^{a}$ | $10.56^{a}$ | $8.03^{a}$ | $14.64^{a}$ | $8.99^{a}$ | $11.78^{a}$ | $10.93^{a}$ | $5.22^{a}$ | $7.22^{a}$ | $6.67^{a}$ | $1.58^{a}$ |
| | Top | $8.62^{a}$ | $9.62^{a}$ | $9.84^{a}$ | $7.31^{a}$ | $12.84^{ab}$ | $9.79^{a}$ | $8.55^{a}$ | $9.79^{a}$ | $5.09^{a}$ | $6.02^{a}$ | $7.99^{a}$ | $1.56^{a}$ |
| Shear strength (without node) | Bottom | $5.15^{a}$ | $7.80^{a}$ | $8.07^{a}$ | $6.94^{a}$ | $8.99^{a}$ | $6.96^{a}$ | $7.48^{a}$ | $7.67^{a}$ | $5.21^{a}$ | $5.65^{a}$ | $6.25^{a}$ | $1.79^{a}$ |
| | Middle | $7.14^{a}$ | $7.99^{a}$ | $5.37^{a}$ | $6.21^{a}$ | $8.56^{a}$ | $7.62^{a}$ | $8.04^{a}$ | $8.78^{a}$ | $5.46^{a}$ | $5.75^{a}$ | $6.23^{a}$ | $1.83^{a}$ |
| | Top | $6.59^{a}$ | $6.81^{a}$ | $4.81^{a}$ | $6.52^{a}$ | $8.48^{a}$ | $7.76^{a}$ | $6.05^{a}$ | $8.62^{a}$ | $5.54^{a}$ | $4.81^{a}$ | $6.58^{a}$ | $1.78^{a}$ |

Note: Means with the same letter are not significantly different (a, b – highest, lowest value).

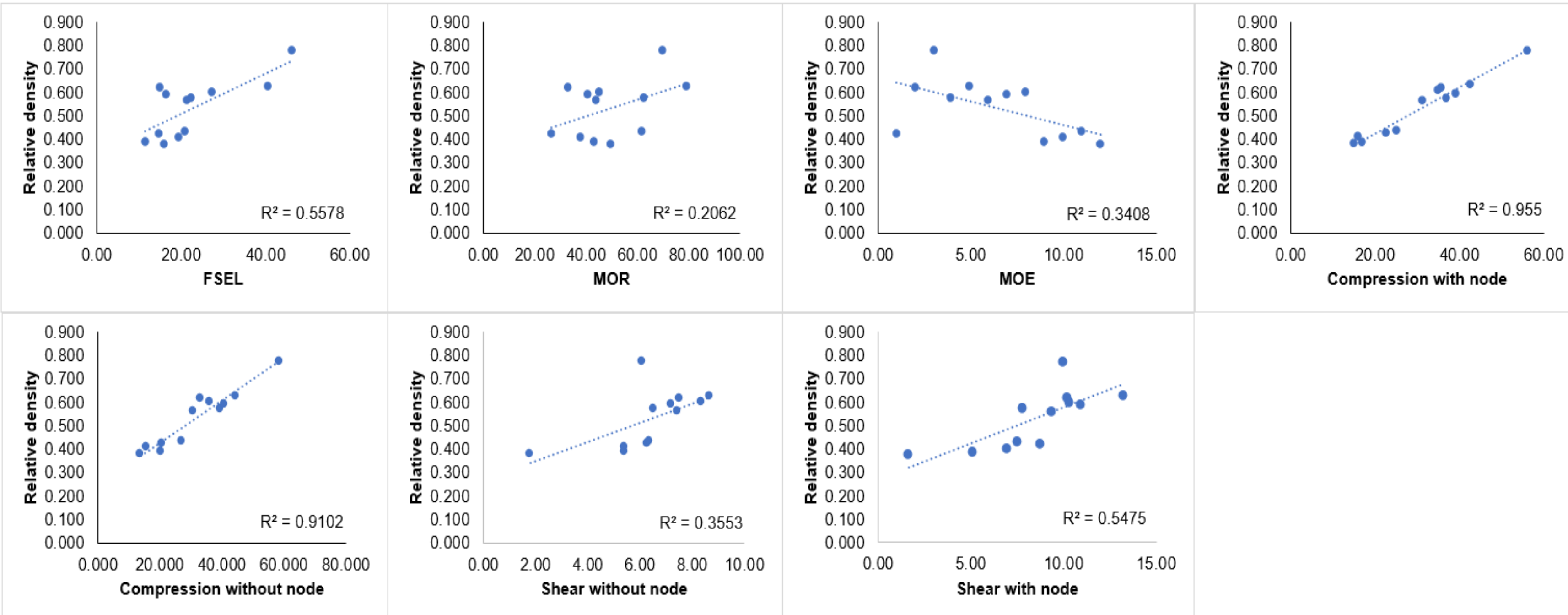


**Figure 5.** Relationship of relative density and mechanical properties of climbing bamboo

**3.2.2.3. Shear strength.** For the shear strength with node, an increased in strength along the height levels was recorded in puser and tagisi (Table 5.). Bolo, baitu, luzon bikal, baguisan, bikal baboy, bagtok, bukawe, and bikal, on the other hand, showed an increasing strength from the bottom to the middle and decreasing from the middle to the top. A decreased in strength from the bottom to the middle and then increased towards the top was observed in elmer bikal. However, the difference in strength along the height of the bamboos was not significant ($p$ = 0.109) (Table 5.). For shear strength without node, an increased in strength along the height was noted in yaho and bikal while luzon bikal and bagtok exhibited a decreased (Table 5.). Bolo, baitu, puser, bukawe, tagisi, and baguisan showed an increased in strength from the bottom to middle and then decreased towards the top. Bikal and bikal baboy, on the other hand, recorded a decreasing strength from the bottom to middle and increasing from the middle to the top. However, the differences in strength along the height was not significant ($p$ = 0.367) (Table 5.). In erect bamboo species, Correal and Arbelaez (2010) observed an increasing shear strength from the bottom to middle portion and then decreased towards the top portion on 2 to 5 years old *G. angustifolia*. On the other hand, Oka et al. (2014) and Salzer et al. (2018) observed an increasing trend along the height of *G. atroviolaceae* and *B. blumeana* for bamboo with node and without node, respectively. According to Oka et al. (2014), the difference in shear strength along the height level of the bamboo can be attributed to the difference in vascular bundles and relative density. This was further supported by Correal and Albelaez (2010), who also stated that the increase in shear strength was correlated with the RD and the number of vascular bundles.

## Conclusion

The results of the present study on the physical and mechanical properties of climbing bamboos suggest that the local bamboo industries can consider using them as raw materials for different products. Baitu, luzon bikal, bikal baboy, bagtok, yaho, puser and bukawe can be considered as possible alternative raw materials for applications where large diameter is not required such as for construction, high-grade furniture, and flooring where both strength and durability are required. Bolo, tagisi, and elmer bikal can be utilized for high-grade furniture, paneling, automobile bodies, and bodies of musical instruments. Lastly, bikal and baguisan are recommended to be used for pulp and paper and low-grade furniture. Furthermore, a significant difference in physical and mechanical properties was observed among the climbing bamboo species. Height levels significantly affected these properties. Hence, for optimum utilization the recommended end-uses of the species based on the physical and mechanical properties should be considered.

**Acknowledgment**

The authors are grateful to the DOST-Forest Products Research and Development Institute non-wood collection team for their assistance in the collection of the climbing bamboo poles. Also, to the Department of Environment and Natural Resources for the assistance provided during the conduct of the study. Special thanks are due to Mr. MA. Mundin, Mr. R. Dimapilis, and Ms. F. Talatala of the Physical and Mechanical Section of the DOST-FPRDI for providing technical assistance in conducting this research.

**Conflict of interest**

Authors declare there is no conflict of interest.

**References**

American Society for Testing Materials (ASTM) 2014. Methods of testing small clear specimens of timber. ASTM Designation: D143-52. In: Book of ASTM Standards, Part 16. Philadelphia, PA: 30.

Department of Environment and Natural Resources – Ecosystem Research and Development Bureau (DENR – ERDB) 2016. Sustaining our Bamboos. Ecosystem Research and Development Bureau of the Department of Environment and Natural Resources, Canopy International 42 (1): 2.

Alipon MA, Bondad EO. 2008. Strength grouping of Philippine timbers for various uses. Forest Product Research and Development Institute Journal. College, Laguna, Philippines.

Archila-Santos HF, Ansell MP, And Walker P. 2014. Elastic properties of thermos-hydro-mechanically modified bamboo (*Guadua angustifolia* Kunth) measured in tension. Key Engineering Materials 600: 111-120. 10.4028/www.scientific.net/KEM.600.111.

Baja-Lapis, A.C., 2016. *Bamboo: the grass of hope*. Philippine Bamboo Foundation.

Bautista, B.E., Garciano, L.E. and Lopez, L.F., 2021. Comparative analysis of shear strength parallel to fiber of different local bamboo species in the Philippines. *Sustainability*, *13*(15), p.8164.

Bhonde, D., Nagarnaik, P.B., Parbat, D.K. and Waghe, U.P., 2014. Physical and Mechanical properties of bamboo (Dendrocalmus strictus). *Int. J. Sci. Eng. Res*, *5*(1), pp.455-459.

Chaowana, K., Wisadsatorn, S. and Chaowana, P., 2021. Bamboo as a sustainable building material—culm characteristics and properties. *Sustainability*, *13*(13), p.7376.

Correal D, J.F. and Arbeláez C, J., 2010. Influence of age and height position on Colombian Guadua angustifolia bamboo mechanical properties. *Maderas. Ciencia y tecnología*, *12*(2), pp.105-113.

Escobin, R.P., 2005. *Identification manual on Philippine climbing bamboos*. Forest Products Research and Development Institute, Department of Sciene and Technology.

Espiloy ZB. 1996. Properties and Utilization of Philippine Bamboos. FPRDI Research Chair Paper presentation, 04 Jul 1996.

Espiloy, Z.B., Espiloy Jr, E.B. and Moran, M.S.R., 1999. Basic properties of two lesser-used bamboo species: laak (Bambusa sp.) and kayali (Gigantochloa atter). *Forest Products Research and Development Institute (FPRDI) Journal*, *25*, pp.1-18.

Hamdan, H.U.M.K., Anwar, U.M.K., Zaidon, A. and Tamizi, M.M., 2009. Mechanical properties and failure behaviour of Gigantochloa scortechinii. *Journal of Tropical Forest Science*, pp.336-344.

Jimenez Jr, J.P., Macalinao, M.G.M. and Sapin, G.N., 2021. Physico-mechanical Properties of Two Philippine Bamboos Thermally Modified in a Steam Environment. *Philippine Journal of Science*, *150*(1).

Kamruzzaman, M., Saha, S.K., Bose, A.K. and Islam, M.N., 2008. Effects of age and height on physical and mechanical properties of bamboo. *Journal of Tropical Forest Science*, pp.211-217.

Kenneth, O.I. and Uzodimma, U.O., 2021. Evaluation of the Compressive Strength of Bamboo Culms under Node and Internode Conditions. *Saudi J. Civ. Eng*, *5*, pp.251-258.

Kabir, M.F., Bhattacharjee, D.K. and Sattar, M.A., 1995, June. Physical properties of node and internode of culm and branch of Dendrocalamus hamiltonii. In *Bamboo, People and the Environment. Proceedings of the 5th International Bamboo Workshop and the 4th International Bamboo Congress. Ubud, Bali, Indonesia* (pp. 19-22)..

Leoncio MCA. 2017. Comparative mechanical properties of selected bamboo species. International Journal of Precious Engineering Research and Application 2(1): 1-8.

Liese W. 1998. The Anatomy of Bamboo Culms. INBAR. Technical Report 18. Beijing, China.

Liu, P., Zhou, Q., Fu, F. and Li, W., 2021. Effect of bamboo nodes on the mechanical properties of P. edulis (Phyllostachys edulis) bamboo. *Forests*, *12*(10), p.1309.

Marasigan OS, Villareal JF, and Mendoza RC. 2019. Comparative Anatomical Properties of Erect and Climbing Portion of Two-Year-Old Puser Bamboo (*Crythocloa puser* S. Dransfield). In: *1st ASEAN Bamboo Congress for Climate Change Adaptation towards Environmental Sustainability and Economic Resiliency,* August 12 – 16, 2019, Iloilo International Convention Center.

Maruzzo MM, Escobin RP, and America WM. 2005. Anatomical Structure and Properties of Climbing Bamboos. FPRDI Journal 31: 50 – 69.

Nordahlia, A.S., Anwar, U.M.K., Hamdan, H., Latif, M.A. and Mahanim, S.M.A., 2011. Anatomical, physical and strength properties of Shizostachyum brachycladum (Buluh lemang). *Journal of Bamboo and Rattan*, *10*(3&4), pp.111-22.

Oka, G.M., Triwiyono, A., Awaludin, A. and Siswosukarto, S., 2014. Effects of node, internode and height position on the mechanical properties of Gigantochloa atroviolacea bamboo. *Procedia Engineering*, *95*, pp.31-37.

Wahab, R., Mohamed, A., Mustafa, M.T. and Hassan, A., 2009. Physical characteristics and anatomical properties of cultivated bamboo (Bambusa vulgaris Schrad.) culms. *Journal of Biological Sciences*, *9*(7), pp.753-759.

Wahab, R., Mustapa, M.T., Sulaiman, O., Mohamed, A., Hassan, A. and Khalid, I., 2010. Anatomical and physical properties of cultivated two-and four-year-old Bambusa vulgaris. *Sains Malaysiana*, *39*(4), pp.571-579.

Wahab, R, Mustafa MT, Amini MHM, And Rasat MSM. 2013. Anatomy and Strength Properties Between Tropical Bamboo *Gigantochloa levis* and *G. scortechinii*. In: 2nd International Conference on Kenaf and Allied Fibers 2013 (ICKAF 2013).

Razak, W., Mohd, T.M., Shafiqur, R., Mohammed, A.S., Othman, S., Mahmud, S. and Mohd, S., 2012. Relationship between physical, anatomical and strength properties of 3-year-old cultivated tropical bamboo Gigantochloa scortechinii. *Journal of Agricultural and Biological Science*, *7*(10), pp.782-791.

Wahab, R., Mustapa, M.T., Sulaiman, O., Mohamed, A., Hassan, A. and Khalid, I., 2010. Anatomical and physical properties of cultivated two-and four-year-old Bambusa vulgaris. *Sains Malaysiana*, *39*(4), pp.571-579.

Salzer, C., Wallbaum, H., Alipon, M. and Lopez, L.F., 2018. Determining material suitability for Low-Rise housing in the Philippines: Physical and mechanical properties of the bamboo species Bambusa blumeana. *BioResources*, *13*(1), pp.346-369.

Bahari, S.A. and Ahmad, M., 2009. Effects of culm height levels and node presence on mechanical properties and fracture modes of Gigantochloa scortechinii strips loaded in shear parallel to grain. *Bamboo Sci Cult*, *22*(1), pp.41-44.

Shmulsky, R. and Jones, P.D., 2019. Forest products and wood science: an introduction.

Siam, N.A., Uyup, M.K.A., Husain, H. and Awalludin, M.F., 2019. Anatomical, physical, and mechanical properties of thirteen Malaysian bamboo species. *BioResources*, *14*(2), pp.3925-3943.

Villareal, J.F., Marasigan, O.S., Mendoza, R.C., Alipon, M.A. and Abasolo, W.P., 2020. Morphological, Anatomical, and Physical Properties of Iron Bamboo (Guadua angustifolia Kunt.) Grown in the Philippines. *Philippine Journal of Science*, *149*.

Virtucio F. 2008. Assessment of Bamboo Resources of the Philippines. Paper presented at the National Bamboo Forum. October 2008. Philippine Trade Training Center, Pasay City, Metro Manila.

Wakchaure, M.R. and Kute, S.Y., 2012. Effect of moisture content on physical and mechanical properties of bamboo.

Wang, Y., Zhan, H., Ding, Y., Wang, S. and Lin, S., 2016. Variability of anatomical and chemical properties with age and height in Dendrocalamus brandisii. *BioResources*, *11*(1), pp.1202-1213.

Zakikhani, P., Zahari, R., Sultan, M.T.B.H.H. and Majid, D.L.A.A., 2017. Morphological, mechanical, and physical properties of four bamboo species. *BioResources*, *12*(2), pp.2479-2495.