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Study on the correlation between the structure and properties of Dendrocalamus barbatus

Nguyen Viet Hung[1*], Pham Van Chuong[2], Nguyen Thi Tuyen[1]

Thai Nguyen University Agriculture and Forestry, Thai Nguyen University, Thai Nguyen 250000, Vietnam[1]
Vietnam National University of Forestry, Hanoi, 100000, Vietnam[2]

Corresponding Author: 1*

ABSTRACT— Correlation between the structure and some properties of Dendrocalamus barbatus is an important scientific basis for evaluating and explaining its variation with age and height position. This study has determined the correlation between the structure and some physical and mechanical properties. The template method was used to determine the density variation, bundle area, bundle size, and fiber dissociation method to determine fiber length. Also, the method of determining the mechanical properties of small samples was used to determine fluctuations in the physical and mechanical properties of Dendrocalamus barbatus. The results of experiments and correlation analysis showed that the variation in bundle density, bundle area, fiber length is similar to that of the physical and mechanical properties. The bundle area is a factor that correlates very closely with the properties with a significant correlation with the properties such as: density at 12% moisture (R^2 = 88.4%), basic density (R^2 = 88.6%), sample moisture (R^2 = 81.5%), grain longitudinal compressive strength (R^2 = 95.2%), modulus of rupture (MOR) (R^2 = 97.3%), modulus of elasticity (MOE) in static bending (R^2 = 67.2%), longitudinal shear strength (R^2 = 62.1%).

KEYWORDS: Dendrocalamus barbatus, bamboo, correlation, bundle area, density, modulus of elasticity, tree age, fiber

1. INTRODUCTION

The tree age and the height position have the effects on the variation of Dendrocalamus barbatus structure, leading to a variation in its properties. There have been many studies on bamboo, mainly focusing on the variation in structure and properties according to tree age and the height position. However, this topic is necessary to make further studies. In some previous studies, it was concluded on some bamboo species that the density of vascular bundles increased gradually from the base to the tip and decreased from outside to the inside. Phyllostachys pubescens [34], Bambusa blumeana [2], Bambusa rigida [16]. The ratio of bundle size in radial or tangential direction in some bamboo species decreased from the base to the tip of Bambusa rigida [16], [6], [14], Moso bamboo [15]. The strand length of some bamboo species varies with age and height position, increasing from the base to the tip, such as [36], Dendrocalamus sinicus [24], however, some other bamboo species fluctuate in the opposite direction like Bambusa blumeana and fiber length of the base and trunk is similar but decreases at the top like Gigantochloa scortechini [8], Bambusa rigida [16], Bambusa vulgaris [18]. Some species have fiber length that increases from age 1 to certain age and then decreases like Bambusa balcooa and Bambusa vulgaris [19], [36], Gigantochloa levis [22], B. vulgaris [7]. The fibrous cell walls thickness increases from age 1 to the certain age and decreases at the next age, increasing from the base to the tip like B. vulgaris var [7], [26], [7], [23], [33]; Bambusa rigida [16]. However, there are some species that fluctuate in the fibrous cell wall thickness increasing with the rise of age such as [36], Gigantochloa levis [22], Bambusa balcooa, Bambusa vulgaris [19]. Density of some species increases gradually as the rise of tree age and goes up from the base to the tip, such as B. vulgaris var, G. scortechinii [7], B. Wumeana b and G. scortechinii [15], [28], [6], [34], [23], Dendrocalamus strictus [32]; Bambusa bambos, Bambusa vulgaris var. vulgaris, Bambusa vulgaris var. striata, Bambusa balcooa, Bambusa tulda and Bambusa polymorpha [29], Dendrocalamus giganteus [3]. Shrinkage in some species decreases gradually as tree age increases and reduces from the base to the tip as stated in B. Wumeana b and G. scortechinii [15], B. blumeana. [6]. The shrinkage of some species decreases with increasing age, and, at a certain age, it tends to go up in the following age like B. blumeana [35]; Melocanna baccifera and Bambusa balcooa [28], [27].

Some species shrink gradually with the increase of age and rise from the base to the tip Dendrocalamus giganteus [3] Bambusa blumeana, B. vulgaris var, Gigantochloa scortechinii [7], B. blumeana [6] Phyllostachys pubescens [34]; Dendrocalamus strictus [32]. There are species of longitudinal compressive strength which increases gradually as the tree age increases, but at a certain age, it decreases at the next age and reduces from the base to the tip as Guadua angustifolia kunt [11], [4]. Modulus of rupture (MOR) in some bamboo species varies and increases gradually with the increasing age Bambusa blumeana, B. vulgaris var, Gigantochloa scortechinii [7], B. blumeana [6], Phyllostachys pubescens [34]; Bambusa tulda [17]. MOR of some species changes and tends to rise gradually with the increasing age and decreases to certain ages like B. blumeana [35]; Melocanna baccifera and Bambusa balcooa [28]; Bambusa balcooa [17], [4]. According to the height position of some species, MOR increased gradually from the base to the tip as shown in Melocanna baccifera and Bambusa balcooa [28]; Ph. Pubescens [10]; Phyllostachys pubescens [34]; Bambusa tulda age 4, Bambusa salarkhanii age 4, Melocanna baccifera age 3 [17], Guadua angustifolia kunt ages 2, 3 and 4 [11] Gigantochloa levis [22], Phyllostachys Pubesces [12]. MOE of some species increases gradually with age rise and goes up from the base to the tip: Bambusa blumeana, B. vulgaris var, Gigantochloa scortechinii [7], blumeana [6], Phyllostachys pubescens [34]; Bambusa balcooa, Bambusa tulda [17], Gigantochloa levis [22], Phyllostachys Pubesces [12]. MOE of some species varies with the age rise, and to a certain age it decreases or stabilizes at the next age: B. blumeana [35]; Melocanna baccifera and Bambusa balcooa [28], Guadua angustifolia kunt [11]. The longitudinal shear strength of some species has increased with the age and grows from the base to the tip: Bambusa blumeana, B. vulgaris var, Gigantochloa scortechinii [7], [6], and to a certain age it decreases: Guadua angustifolia [11]. From the literature study, the effects of tree age and height position on the structure and physical and mechanical properties of bamboo species, but there is very little information about the correlations between the structure and properties of bamboo, especially of Dendrocalamus barbatus. In this study, the correlations between structure and some physical and mechanical properties are investigated with the age and height position of Dendrocalamus barbatus in Vietnam.

2. Materials and Methods

The Dendrocalamus barbatus in this study is at the ages 1, 2, 3, 4 and 5, harvested in Quan Hoa district, Thanh Hoa province, Vietnam.

2.1 The selection method of sampling trees

Sampling plants were chosen according to GB/T 15780-1995 Standard [37]. In order to obtain the basic properties of certain bamboo materials, a test material that is representative of bamboo in the production area should be selected. For broadly distributed bamboo, it is necessary to base on different natural conditions such as soil, geographic location, climate, etc. At the sampling site, 5 highly representative trees for each age level are selected in the same cluster or 2 close clusters. However, the ages 1 - 5 are all taken from the same cluster, and the plants with defects are not chosen.

2.2 The method of selecting the position on the experimental tree

Experimental samples at tree positions were performed according to. The process of performing experiments of 5 years old at different positions on the trunk is conducted as follows: Starting from the second node from the bottom to the 31st node, divided into 3 parts representing the base (bottom), body (middle), tip (top). Each part consists of 10 nodes. In each section, the third node is used for physical identification and it is ensured that the positions are taken at the same age level [34].

2.3 Method of microscopic specimen capture to determine the structure of Dendrocalamus barbatus

For microscopic sample, the sampling location per tree age and height position were done according to GB/T 15780-1995 [37]. At locations to be determined on the cross-section of Dendrocalamus barbatus, they are divided into 4 directions East, West, South, and North. At the east position, it will be sampled to make microscopes for all age levels and height position. The sample used for cutting microscopic specimen with appropriate size (the length ranges 15 - 20mm, the thickness is equal to stem wall width, and the sample having 3 cross- sections (cross section, radial section, cross section tangent) must be ensured. In case of making many samples at the same time, it is necessary to mark or number for each sample to avoid confusion. The process of creating and scanning the template determines the bundle density, the area of the vascular bundle per 1 mm^2, the fiber diameter and the fiber cell wall thickness. Template cutting is performed on Microm HM440E with the thickness of 15-20 µm. Each sample is cut from 5 to 10 specimens. The process of capturing and measuring bundles of fibers on Olympus BX41 optical microscope with magnifications of 10x, 40x, 100x (eyepiece 10x) combined with Pax-it!2 software to measure.

Figure 1. Cutting and capture devices to determine the wall thickness of the fiber cell

2.4 Method of determining the fiber size

With the fibrillation method, the fiber length is measured randomly after the cells have been cleaved. The spinning process was carried out according to the method of [31]. The pieces of the shape and size of a matchstick (1.5 × 1.5 × 30 mm) are used. The steps of spinning process are carried out as follows:

- Fill the test tube with a sufficient amount of water, and heat it so that the test samples sink.
- Pour out water from the test tube, add a sufficient amount of HNO_3 (the ratio of HNO_3 and distilled water is 1:2), and continue to add 3 - 5g KCl.
- Heat the test tube containing the solution and the wood sample until there are air bubbles and the wood sample turns white (about 10 minutes).
- Use a glass rod to stir well to separate the wood fibers and wash the fibers carefully.
- Color the wood fiber separated by safranin and create temporary specimen to observe and take pictures with microscope connected to computer.

• Measure the yarn size on the captured image (the number of fibers to measure is about 50 fibers/position).
Randomly take 50 colored fibers onto two transparent glass slides (75 × 25mm). Using an optical microscope fitted with a measuring device (eyepiece microscope) measured the length and diameter of each fiber.

2.5 Method for determining the physical and mechanical properties of Dendrocalamus barbatus

Determining the physical and mechanical properties of Dendrocalamus barbatus is done with steps and formulas according to GB/T 15780-1995 standard). The determination of Dendrocalamus barbatus's mechanical properties was performed on the mechanical property tester QTEST/25.

Figure 2. The mechanical property tester QTEST/25

3. Results and Discussion

3.1 Correlation between structure and physical properties of Dendrocalamus barbatus

3.1.1 Correlation between the structure and the density of Dendrocalamus barbatus

From the correlation analysis results, it shows that Dendrocalamus barbatus's structure is correlated with density according to the tree age and the height position. The density of wood is determined by the porosity of the wood, and the smaller the porosity, the greater the density, and vice versa. Density also depends on the ratio of thick-walled cells, and the higher walled-wall ratio, the higher density will be, and vice versa [1]. Also for Dendrocalamus barbatus, anatomical results show that as the tree age increases, the proportion of stem structures also changes. The density of the vascular bundle, the area of the vascular bundle, the proportion of thick-walled cells, and the average size of the bundle increase. The fiber cell wall thickness of Dendrocalamus barbatus in the vascular bundle grows according to the tree age and from the base to the tip. Hence, the density of Dendrocalamus barbatus also fluctuates with those factors. On the other hand, according to [2], [34], in bamboo trunk, the vascular is one of the deciding organizations on the density and properties due to the increase in the vascular bundle as the tree age changes and the different hieght positions. The thickening of the cell walls of the bamboo fibers mainly in the vascular bundle will cause the density to change. The largest density of Dendrocalamus barbatus at the age of 4 and declines at the age of 5 but not much is due to the fact that at the ages of 3 and 4, it is in the maturity stage and the maximum density reaches. The vascular density, bundle area, and fibrous cell wall thickness reach the highest values in these ages [3], [9], [30]. Through the analysis of the correlation between the structure and density of Dendrocalamus barbatus, it is shown that the bundle area per 1 mm2 cross section is strongly correlated with the density, while other factors are less relevant. The correlation analysis results showed that the bundle area and density at 12% moisture have the relationship with correlation coefficient of 94.0%, reliability 99.9%. Also, it is shown through the regression equation (1) and Figure 3

$$\rho_w = 0.244 + 0.735 * S \qquad R^2 = 88.4\% \qquad (1)$$

Where: ρ_w- density at 12% moisture, g/cm^3;

S- bundle area, mm^2.

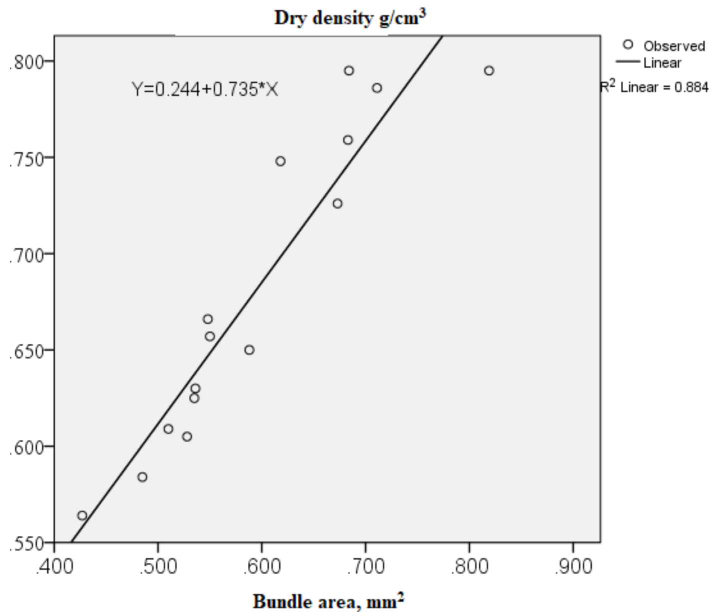

Figure 3. Relation between bundle area and dry density (at 12% moisture)

The basic density is also influenced by the bundle area. The correlation analysis results show that the bundle area and the basic density have their correlation with the correlation coefficient of 93.0%, reliability 99.9%. Regression analysis results are reflected through the regression equation 2 and Figure 4.

$$\rho_y = 0.140 + 0.660 * S \qquad R^2 = 88.6\% \qquad (02)$$

Where: ρ_y - Basic density, g/cm^3

S- Bundle area per 1mm^2, mm^2

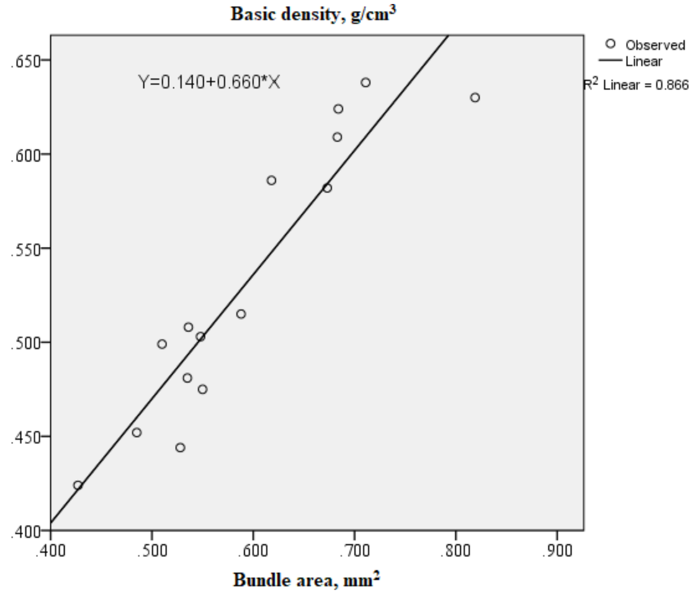

Figure 4. Relation between bundle area and basic density

The analysis results show that the area of the vascular bundle is a strongest factor affecting the density, because most of the bamboo fibers are mainly concentrated in the vascular bundle. The area of the vascular bundle is large, meaning that the ratio of soft tissue cells is less, the bamboo porosity is smaller, and the thick wall cell ratio increases. The large area of vascular bundles leads to a high proportion of fibers, which increase the density [13].

3.1.2 Correlation between the structure and humidity of Dendrocalamus barbatus

The variation in moisture content of Dendrocalamus barbatus is due to the porosity of the node wall. The porosity is differences in the proportion of soft tissue cells and the number of vascular bundles. The increasing porosity contributes to improve the water holding capacity, leading to increase humidity. The variation in humidity can also be explained by the variation in bamboo fiber cell wall thickness (i.e The small cell wall thickness means large fibrous lumen, resulting in increased moisture. The vascular density that affects the moisture of bamboo was also explained by some authors when seeing the variation in moisture of some types of bamboo as the age of the tree changes [25], [30]. The fluctuation of moisture is also due to the variation in the density of the vascular bundles, the area of the vascular bundles on the trunk. The density and area of the vascular bundles increases, and the soft tissue cell ratio decreases and leads to reduce the moisture. Moreover, the density and area of Dendrocalamus barbatus increase from the ages of 1 to 3 and 4, and decrease at the age of 5. This makes the moisture decrease from the ages of 1 to 3 and 4, and go up at the age of 5. The density and area of vascular bundles in all ages increases gradually from the base to the tip, thereby making the humidity decrease gradually from the base to the tip. On the other hand, the cell walls thickness increases from the ages of 1 to 4 and stabilizes at the age of 5, which also affects the moisture content of Dendrocalamus barbatus. As the wall thickness increases, it means that the intestinal Lumen cell, the space in the vascular bundle, and the moisture content decrease. The results of correlation analysis between the density of the vascular bundles, the area of the vascular bundles, and the fiber cell wall thickness of Dendrocalamus barbatus and the moisture of Dendrocalamus barbatus according to the tree age and the height position show that: The area of vascular bundles per 1mm2 is the strongest factor affecting the moisture, or in other words, the porosity in the cross section of the node wall affects the moisture content of Dendrocalamus barbatus.

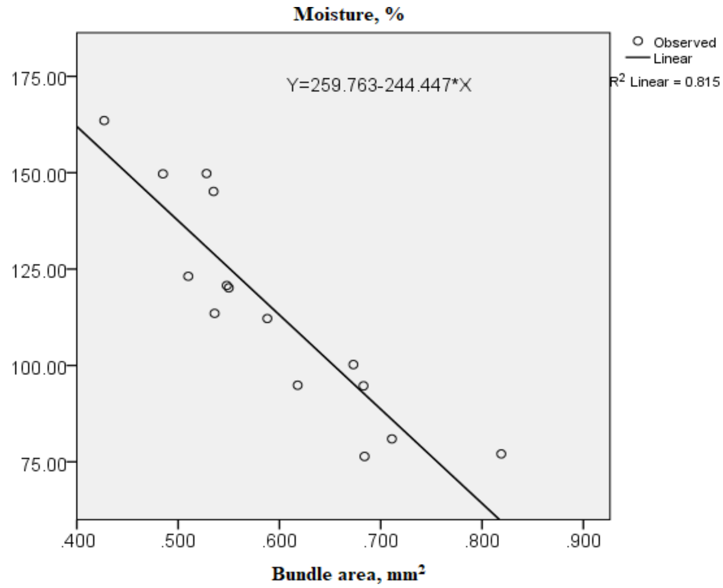

Figure 5. Correlation of bundle area and moisture

The results of correlation analysis between moisture and bundle area are shown in the linear regression equation (4) and Figure 5.

$$MC = 259.763 - 244.447 * S \qquad R^2 = 81.5\% \qquad (04)$$

Where: MC- Moisture, %;

S- Bundle area, mm^2

The above results can be explained that the increased bundle area also means that the cross-sectional surface porosity area decreases and vice versa. The porosity on the cross- sectional surface decreases, resulting in the increase in moisture content of Dendrocalamus barbatus and vice versa.

3.2 Correlation between some factors and some mechanical properties of Dendrocalamus barbatus

3.2.1 Correlation between some factors and the longitudinal compression strength

The longitudinal compression strength is an important and common mechanical criterion in practice. It is often used to study the relationship between the factors affecting the force resistance of wood. During the growing process, the structure of bamboo changes the arrangement of cells and distribution of vascular bundles in the stem. Specifically, for Dendrocalamus barbatus, the structural analysis results show that the density and area of vascular bundle increase from the base to the tip. Moreover, the cellulose content increases from the base to the tip, which thereby leads to the increasing proportion of microfibers. The density also increases from the base to the tip. This distribution and variation are closely related to the longitudinal compressive strength according to height positions. For bamboo, cell arrangement and distribution of vascular bundles in trunks are two main factors affecting the mechanical properties [2]. To evaluate the impact on the variation in the longitudinal compression strength of Dendrocalamus barbatus with age and height position, a correlation analysis of some factors affecting the longitudinal compressive strength is conducted. The results showed that the bundle area and the density correlate closely to the longitudinal compression strength.

3.2.1.1 Correlation between the bundle area with the longitudinal compression strength

The vascular bundle area per 1 mm2 increases the variation from the base to the tip, rises from the ages of 1 to 4 and decreases at the age of 5. This variation is similar to the variation in the longitudinal compression strength. The correlation analysis results showed that the longitudinal compression strength is correlated with the bundle area with the very tight correlation (r = 97.6%), 99% confidence level, shown in the regression equation (5) and Figure 6.

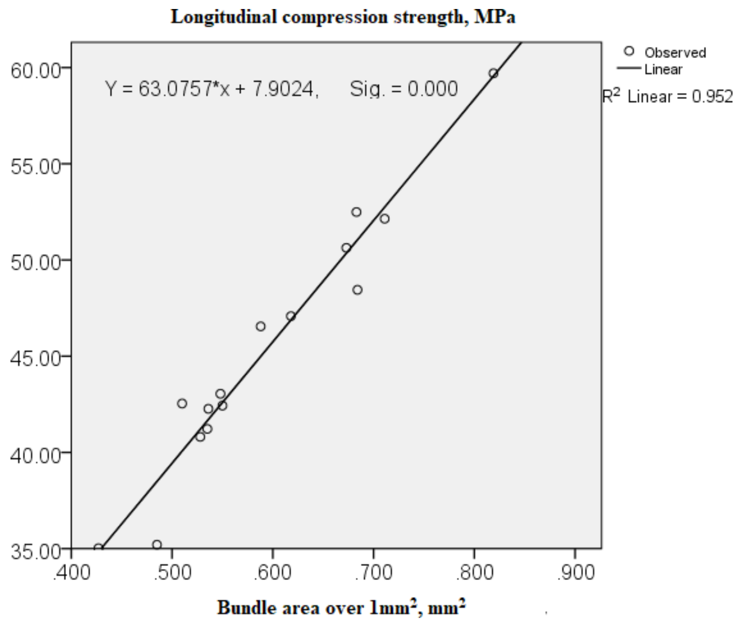

Figure 6. Correlation between bundle area and longitudinal compression strength

$$\sigma_{12} = 63.0757 * S + 7.9024 \qquad R^2 = 95.2\% \qquad (5)$$

Where: σ_{12}- the longitudinal compression strength with the sample moisture of 12%, MPa;

S- Bundle area, mm^2.

3.2.1.2 Correlation between the density and the longitudinal compression strength

The density fluctuates from the base to the tip, increases from the ages of 1 to 4 and decreases slightly at the age of 5. This result is similar to the variation of the longitudinal compression strength. The correlation analysis results between the density and the longitudinal compression strength are shown in the regression equations (6) and Figure 7.

$$\sigma_{12} = 63.0757 * \rho + 7.9024 \qquad R^2 = 81.6\% \qquad (6)$$

Where: σ_{12}- the longitudinal compression strength with the sample moisture of 12%, MPa;

ρ- the density with the sample moisture of 12%, g/cm^3.

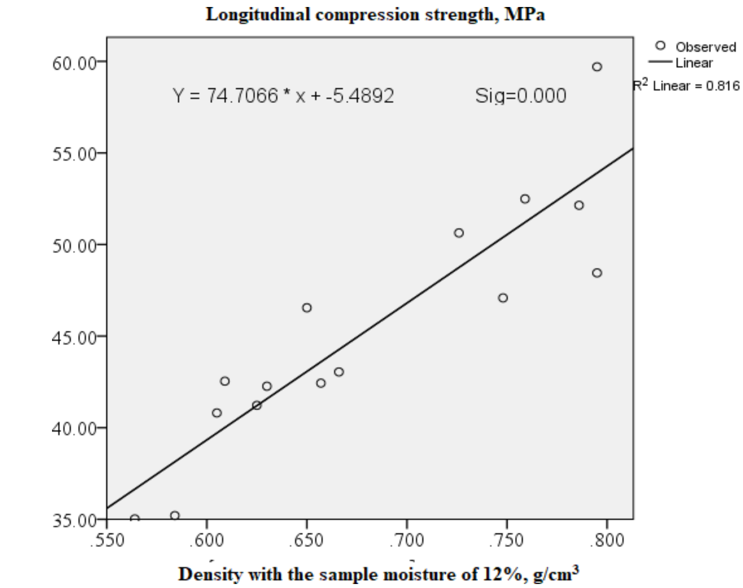

Figure 7. Correlation between the density and the longitudinal compression Strength

3.2.2 Correlation between several factors to the static flexural strength

The variation in MOR of Dendrocalamus barbatus with age and height position is due to the different variations in bundle density, bundle area, fiber length, cellulose content, and the density from the base to the tip. The variation of these factors is proportional with microfibers. Increasing the microfibers will improve some of the general mechanical properties including MOR of Dendrocalamus barbatus. For the tree age, when the tree reaches a certain age, the density, the bundle area, the fiber length, and the density also reach certain values, so the MOR of Dendrocalamus barbatus also fluctuates.

3.2.2.1 Correlation of bundle area with MOR

The vascular area rises with the variation from the base to the tip, the ages from 1 to 4 and decreases at the age of 5. This variation is similar to MOR variation of Dendrocalamus barbatus. To observe the correlation between the area of vascular bundles with MOR with the tree age and the height position, the obtained experimental results were analyzed.

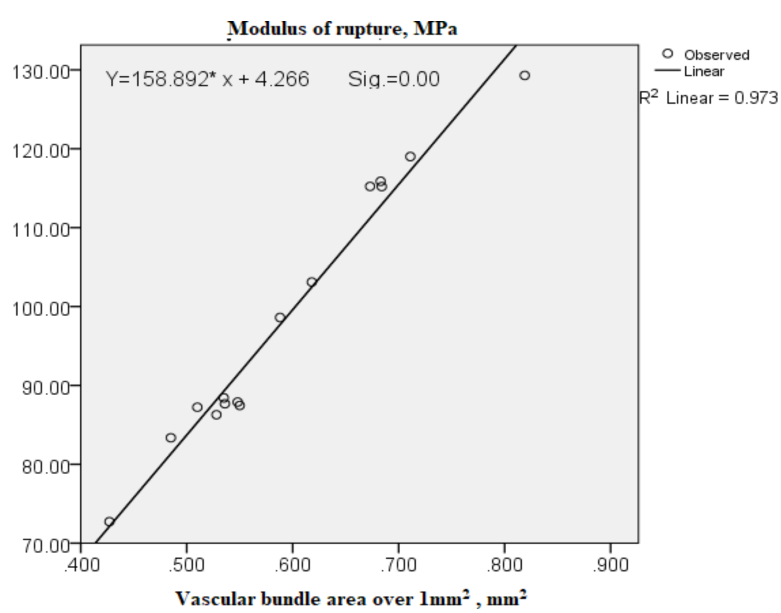

Figure 8. Correlation between bundle area and MOR

The correlation analysis results showed that the vascular bundle area and MOR correlated with each other, with the correlation level (r = 98.6%), 99% confidence. The correlation is shown in the regression equation 7 and Figure 8.

$$MOR = 158.892 * S + 4.266 \qquad R^2 = 97.3\% \qquad (7)$$

Where: MOR- static flexural strength when the sample moisture is 12%, MPa S - vascular bundle area, mm^2

3.2.2.2 Correlation of the density with MOR

The results of this study show that the density of Dendrocalamus barbatus tends to increase from the base to the tip and from the ages of 1 to 4, and decreases slightly at the age of 5. That variation is similar to that of MOR. The correlation analysis results showed that the density and MOR have correlation with each other, with the close correlation (r = 94.4%) and 99% confidence. The correlation is shown by the regression equation 8 and Figure 9.

$$MOR = 194.691 * \rho - 33.8877 \qquad R^2 = 89.2\% \qquad (8)$$

Where: MOR- Static flexural strength when the sample moisture is 12%, MPa ρ- the density when the sample moisture is 12%, g/cm^3.

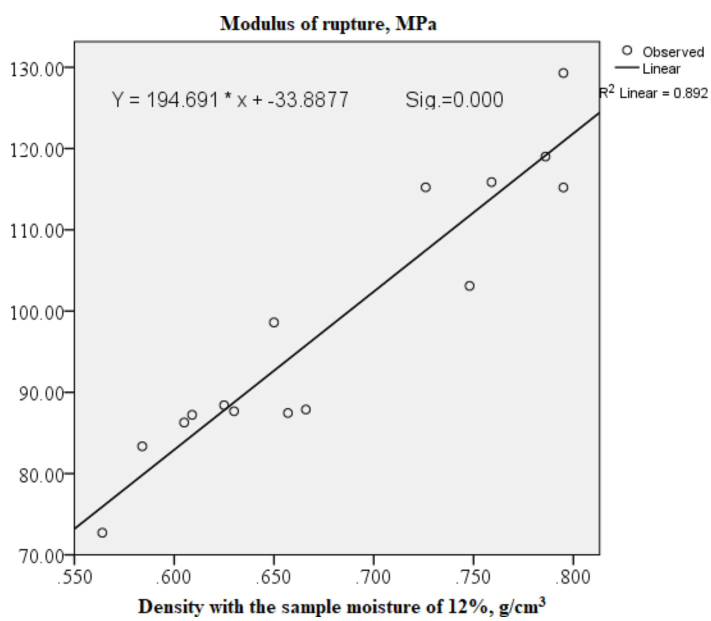

Figure 9. Correlation of the density with MOR

3.2.3 Correlation between several factors to the static flexural modulus

The variation of the elastic modulus according to the tree age, the height positions of some other bamboo species is also explained by some authors due to the variation in the number of vascular bundles and the density [22], and due to fluctuations of the strands on the bamboo wall [28]. The variation in bundle size (radial/tangent) and fiber length is proportional to MOE [5]. MOE is proportional to the variation in cell wall thickness with increasing tree age [7], [8], [20]. The results of correlation analysis between factors influencing

Dendrocalamus barbatus's MOE showed that such factors as: bundle density, vascular area, cell wall thickness, density and cellulose content are correlated with MOE variation.

3.2.3.1 Correlation between bundle density with MOE

According to the research results on the structure, it shows that the density of the vascular bundle varies with the tree age and the height position, similar to the variation of MOE. Results of analyzing the correlation between bundle density with MOE according to the regression equation 9 and Figure 10.

$$MOE = 2014.702 * X + 1721.754 \qquad R^2 = 90.1\% \qquad (9)$$

Where: MOE- Modulus of elasticity in static bending when the sample moisture is 12%, MPa;

X- the density of the vascular bundle, bundle/mm^2.

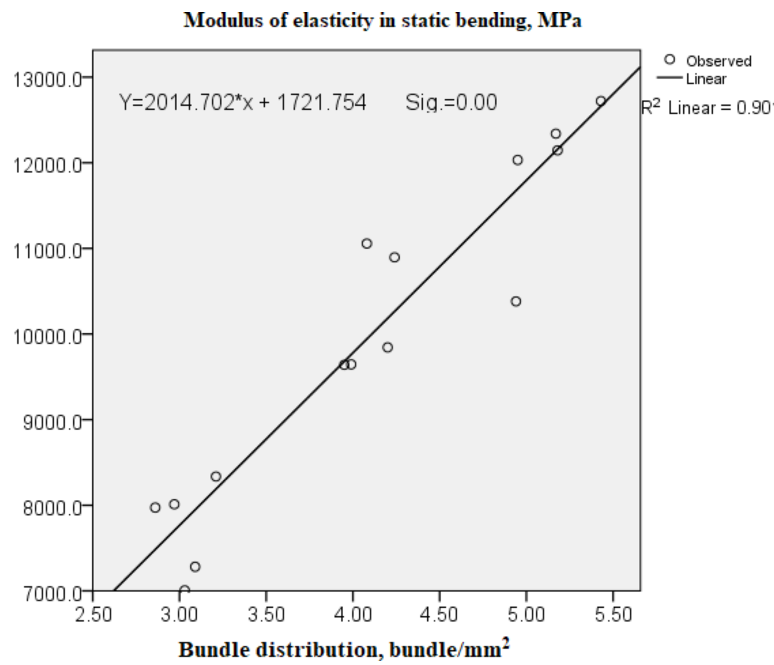

Figure 10. Correlation diagram between bundle distribution and MOE

3.2.3.2 Correlation between the area of the bundle and MOE

From the correlation analysis results, it shows that the area of the vascular bundle and MOE is correlated with each other, with a significance level of 82.0%, 99% confidence. The correlation is shown by the regression equation 10 and Figure 11.

$$MOE = 15168.171 * S + 959.101 \qquad R^2 = 67.2\% \qquad (10)$$

Where: MOE- Modulus of elasticity in static bending when sample moisture content is 12%, MPa;

S- vascular bundle area, mm^2.

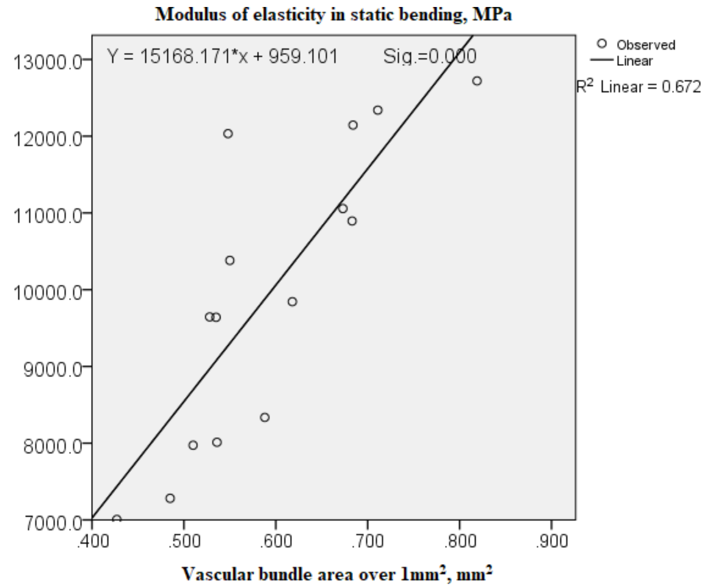

Figure 11. Correlation diagram between bundle area and MOE

3.2.3.3 Correlation between the density and MOE

Density is an important indicator affecting most general mechanical properties. Density affects MOE of bamboo [22]. From the results of the regression analysis, it shows that the density has a strong correlation with MOE according to the age of Dendrocalamus barbatus. The correlation is shown by the regression equation 11 and Figure 12.

$$MOE = 20042.0681 * \rho - 3673.4443 \qquad R^2 = 71.6\% \qquad (11)$$

Where: MOE- Modulus of elasticity in static bending when sample moisture content is 12%, MPa;

ρ- Density when sample moisture content is 12%, g/cm^3

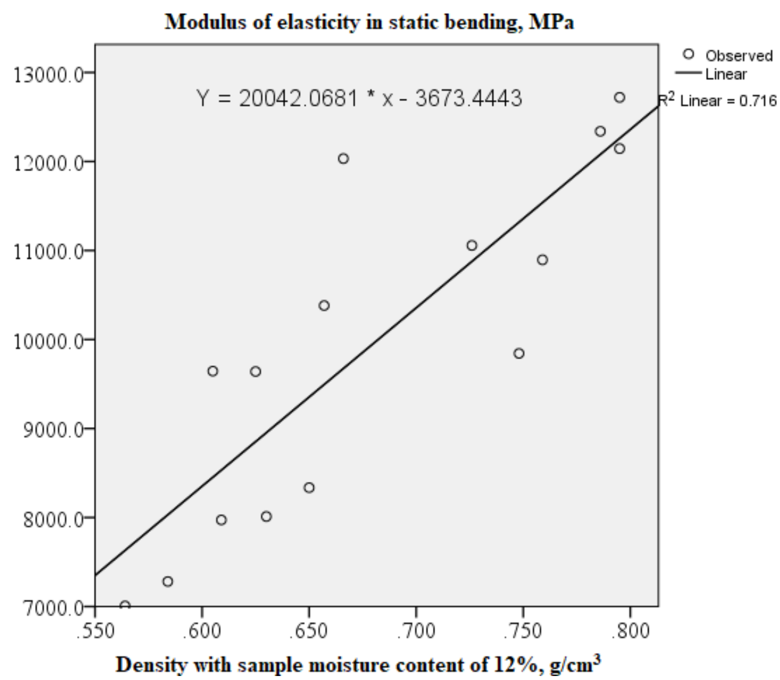

Figure 12. Correlation diagram between the density and MOE

3.2.4 Correlation between some factors to the longitudinal shear strength

The variation in compressive strength along the fiber is due to the influence of fluctuations in density, bundle density, bundle area, cellulose content and especially the link between cellulose and lignin in Dendrocalamus barbatus's vascular bundles (lignin is an adhesive on the cellulose flank, thus creating solidity for wood) [1], [2]. Therefore, the high content of cellulose and lignin in wood will also increase the shear strength in the wood. The variation in the longitudinal shear strength of some bamboo species is explained by the variation in the bundle density of bamboo [6], and the variation in longitudinal shear strength is caused by fiber ratio of bundle [11]. According to [7], it showed that the longitudinal shear strength was related to the fiber length and the fiber diameter. Among the factors affecting the longitudinal shear strength, there are closely correlated factors, but some have low correlation. The analysis results of the correlation between the longitudinal shear strength of the fiber with some influencing factors show that, such factors as vascular area and density are closely correlated with the longitudinal shear strength.

3.2.4.1 Correlation between bundle area with longitudinal shear strength

The vascular area increases from the base to the tip and from the ages of 1 to 3 and 4, and decreases at the age of 5. From that, it shows that the area of vascular bundles has the similarity to the variation in longitudinal shear strength.

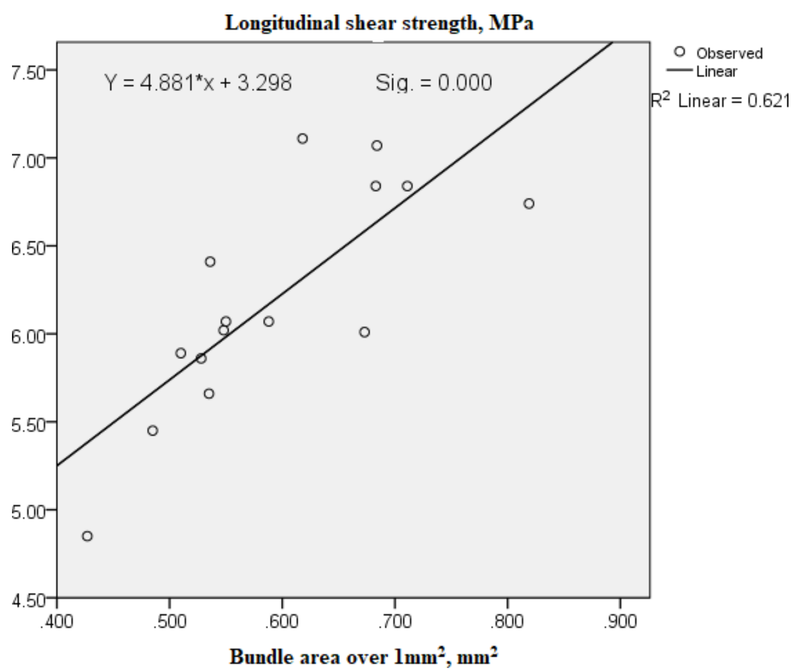

Figure 13. Correlation diagram between bundle area and longitudinal shear strength

The correlation analysis results showed that the area of bundles and longitudinal shear strength has their interaction, with a significance level of 78.6%, reliability 99%. The results of regression analysis showed that the variation of longitudinal shear strength according to the area of the bundle is expressed in Equation 12 and Figure 13.

$$\tau = 4.881 * S + 3.298 \qquad R^2 = 62.1\% \qquad (12)$$

Where: τ- longitudinal shear strength when sample moisture content is 12%, MPa;

S- bundle area over $1mm^2$, mm^2.

3.2.4.2 Correlation of density with longitudinal shear strength

The results of regression correlation analysis showed that the variation of the longitudinal shear strength according to the density are expressed in Equation 13 and Figure 14.

$$\tau = 7.0204 * \rho + 1.4228 \qquad R^2 = 77.9\% \qquad (13)$$

Where: τ- longitudinal shear strength when sample moisture content is 12%, MPa;

ρ- density with sample moisture content of 12%, g/cm^3.

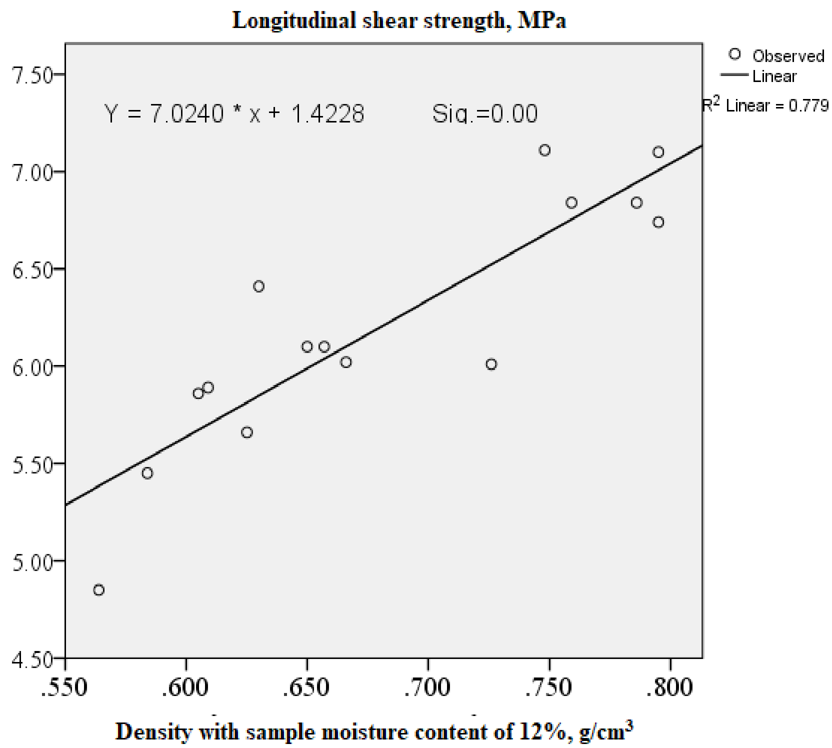

Figure 14. Correlation chart between density and longitudinal shear strength

4. Conclusion

In this study, the correlations between structure and some physical and mechanical properties of Dendrocalamus barbatus are investigated with the age and height position. The main contributions can be summarized as follows:

The vascular area is strongly correlated with most of Dendrocalamus barbatus's properties by ages and height positions including density, sample moisture, longitudinal compressive strength, static flexural strength, elastic modulus when static bending, longitudinal shear strength. The vascular bundle distribution is closely correlated with the elastic modulus in static bending with age and height position. Density is strongly correlated with the mechanical properties of Dendrocalamus barbatus such as longitudinal compressive strength, static flexural strength, static flexural modulus, longitudinal shear strength according to tree age and height position.

5. Acknowledgements

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