VARIATIONS IN WOOD DENSITY AND MECHANICAL PROPERTIES OF *Manglietia conifera* Dandy PLANTED IN NA RI, BAC KAN

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SUMMARY

The radial and axial variations in wood density and mechanical properties of 10-year-old *Manglietia conifera* Dandy planted at Na Ri district, Bac Kan province were investigated. Wood samples with dimesions of 20 × 20 × 320 mm (Radial × Tangential × Longitudinal) were collected from 10, 50, and 90% of the radial length from pith at 0.3, 1.3, 2.3, 3.3, and 4.3 m heights above the ground. The raidal variations from pith to bark and axial variations at different heights were investigated to clariy effect of radial and axial positions on wood density (WD) and mechnical properties of *Manglietia conifera.* The mean values of WD, modulus of rupture (MOR), and modulus of elasticity (MOE) at 10.71% moisture content were 0.45 g/cm^3, 54.09 MPa, and 6.12 GPa, respectively. The mean values of WD, MOR, and MOE within tree of *Manglietia conifera* increased significantly from pith to bark, while those in axial direction changed very small and no statistical significance. WD had a positive linear relationship with both MOR (r = 0.71, p < 0.001) and MOE (r = 0.69, p < 0.001). This suggests that WD is a good indicator to predicting the mechanical properties of *Manglietia conifera* wood.

Keywords: *Manglietia conifera* Dandy, modulus of elasticity, modulus of rupture, wood density.

1. INTRODUCTION

Wood is a highly variable material due to its biological origin (Zobel and Van Buijtenen, 1989). For a given species, the within-tree variation is further partitioned into variation from pith to bark (radial variation) and variation with position along the stem (axial variation). The large variability of wood characteristics makes it difficult to precisely predict its performance and therefore to efficiently process and utilize the material. Therefore, a better understanding of the wood variability within a tree is of value to both wood quality improvement and efficient wood processing and utilization (Koga and Zang, 2004; Duong and Matsumura, 2018b).

Mechanical properties are usually the most important characteristics of wood products for structural applications (Bowyer *et al*., 2007). Strength and stiffness of timber are primary considerations in the construction industry, for pallets and containers. Modulus of elasticity (MOE) is an indication of stiffness of board or structural member, while modulus of rupture (MOR) is an indication of strength. Wood density (WD) is a useful index for predicting the strength properties of clearwood, because it is a direct measure of the amount of cell wall material in a given volume (Walker *et al*., 1993). Therefore, the determination of mechanical properties (MOR and MOE) together with WD is important to understand their relationships.

Manglietia conifera Dandy is a fast-growing native tree species grown popularly in the northern mountainous provinces of Vietnam. It's wood is used to product veneer or other artifical boards. Besides, the local people have also used *Manglietia conifera* wood to make house and other structural purposes. However, until to now, studies on *Manglietia conifera* wood have been limited, especially those related to the variations in mechanical properties within stem of trees.

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Therefore, this study was carried out to investigate the variations in WD, MOR, and MOE from the pith to bark and along the stem of trees. From the results obtained, the correlations between WD and MOR; WD and MOE were also discussed.

2. MATERIALS AND METHODS

2.1. Sampling

The 10-year-old *Manglietia conifera* trees used in the present study were planted in a state-owned plantation in Duong Son commune, Na Ri district, Bac Kan province, Vietnam (22°03′18″N, 10°02′48″E). Three trees were chosen based on straightness, normal branching, and no signs of any diseases or pest symptoms to use in the present study (Table 1). 50 cm long logs were taken at different height levels (0.3, 1.3, 2.3, 3.3, and 4.3 m heights from above the ground). The north and south sides of each tree were marked before felling. From each log, specimens (20 × 20 × 320 mm, Radial × Tangential × Longitudinal) were cut at three distances from pith (10, 50, and 90 % of the radial length) on both sides (North and South) for measuring WD and static bending properties (Figure 1). MOR and MOE were assessed in accordance with Vietnamese Industrial Standards (TCVN). The total number of small clear wood specimens was 90 (30 specimens for each tree). The specimens were conditioned in a room at a constant temperature (20°C) and relative humidity (60%) to constant weight.

Table 1. Diameter and height of the sample trees

Tree	$D_{1.3}$ (cm)	H_{vn} (m)
1	22.0	24.5
2	27.0	24.0
3	31.5	28.0

$D_{1.3}$ - diameter at breast height (at 1.3 m above the ground), H_{vn} - tree height.

2.2. Wood density

Before measuring the MOR and MOE, WD was measured for each specimen. WD was assessed in according to TCVN 8048-2:2009 (ISO 3131:1975). Specimens were weighed to an accuracy of 0.01 g and their dimensions were measured exactly to 0.01 cm. WD was obtained as a percentage of the wood weight per wood volume.

$$\gamma = \frac{m}{V}$$

where: γ: wood density (g/cm^3); m: weight of specimen (g); V: volume of specimen (cm^3).

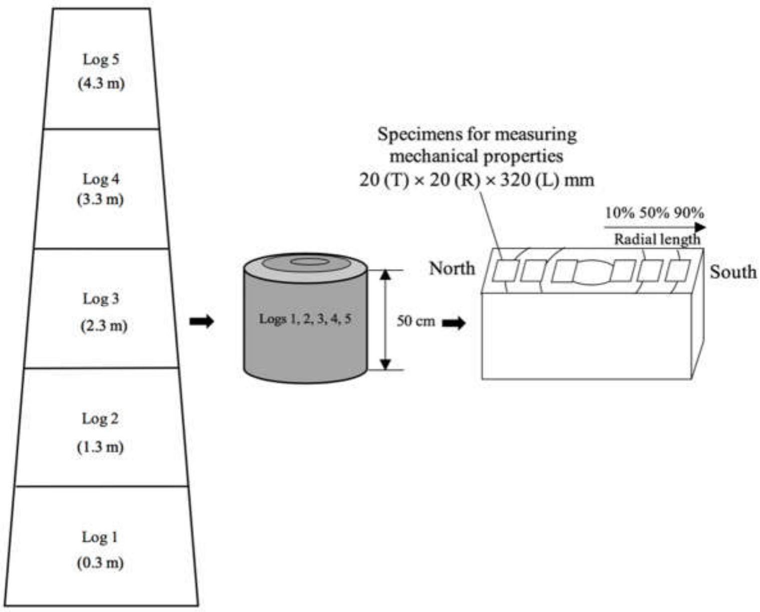


Figure 1. Method of cutting specimens for measuring mechanical properties from each tree.

2.3. MOR and MOE

MOR and MOE were assessed in according to TCVN 8048-3:2009 (ISO 3133:1975) and TCVN 8048-4:2009 (ISO 3349:1975), respectively. Specimens were subjected to bending test using Instron Tester over a span length of 280 mm. Load was applied to the center of the specimen at a constant speed of 5 mm per minute. MOR and MOE were calculated as:

$$MOR = \frac{3PL}{2bh^2} \quad ; \quad MOE = \frac{P_1L^3}{4d_1bh^3}$$

where: *MOR* is modulus of rupture; *MOE* is modulus of elasticity; *P* is maximum load (N); P_1 is load at the limit of proportionality (N); *L* is span length (mm); *b* is width of the specimen (mm); *h* is thickness of the specimen (mm); and d_1 is the deflection at the limit of proportionality (mm).

Specimens for measuring moisture content (MC) with dimensions of 20 (R) × 20 (T) × 20 (L) mm were sampled from the ends of the bending specimens after failure, if no mechanical damage was observed. MC was determined at test by the oven dry method just after strength testing. The average MC of the test pieces was 10.71 ± 0.16%.

2.4. Data analysis

The variations in WD and mechanical properties within stem were evaluated using the R software (2016) version 3.2.2. The differences in WD, MOR, and MOE among radial and height positions within stem were examined by Tukey-Kramer HSD test.

3. RESULTS AND DISCUSSIONS

3.1. WD and mechanical properties

Table 2 presents the descriptive statistics (means, standard errors, and analysis of variances) obtained for WD, MOR, and MOE within stem of *Manglietia conifera* wood. The overall values of WD, MOR, and MOE at 10.71% moisture contetnt in the three trees averaged over the stem heights are 0.45 g/cm^3, 54.09 MPa, and 6.12 GPa, respectively. Thu (2012) reported that the mean values of WD and MOR in 15-year-old *Manglietia conifera* at 12% MC were 0.44 g/cm^3 and 47.8 MPa.

Table 2. Variations in wood density (WD), modulus of rupture (MOR) and modulus of elasticity (MOE) within stem of *Manglietia conifera*

Variable	Description	WD (g/cm^3)	MOR (MPa)	MOE (GPa)
Radial position from pith (%)	10	0.42 ± 0.01^c	42.83 ± 1.48^c	5.04 ± 0.17^c
	50	0.45 ± 0.01^b	56.13 ± 1.04^b	6.27 ± 0.15^b
	90	0.49 ± 0.01^a	63.30 ± 0.78^a	7.06 ± 0.12^a
Height above the ground (m)	0.3	0.46 ± 0.01^a	54.66 ± 2.40^a	6.45 ± 0.23^a
	1.3	0.45 ± 0.01^a	57.59 ± 1.70^a	6.16 ± 0.28^a
	2.3	0.45 ± 0.01^a	51.31 ± 2.18^a	5.50 ± 0.26^a
	3.3	0.45 ± 0.01^a	53.61 ± 2.89^a	6.28 ± 0.25^a
	4.3	0.46 ± 0.01^a	53.25 ± 3.02^a	6.22 ± 0.30^a
Mean		0.45 ± 0.01	54.09 ±1.11	6.12 ± 0.16

Variation along radial direction is the best known and most studied within-tree variability in wood, which is generally reflected as radial pattern of change in wood characteristics of core wood and outer wood, juvenile and mature wood (Anoop *et al*., 2014). The wood properties observed in this study showed that WD, MOR, and MOE increased gradually from 10 to 90% of the radial length from pith to bark in radial direction (Figures 2, 3, and 4). However, the variations of these wood properties with height were very small and no statistical significance (Table 2). These results were compatible with those found in the literature. Machado *et al*. (2014) and Duong and Matsumura (2018a) reported that height level was not a significant source, while radial position was highly significant source of variation in the mechanical properties of *Acacia melanoxylon* and *Melia azedarach*, respectively.

The increasing of WD of *Manglietia conifera* wood from pith to bark could be explained by earlywood – latewood proportion. In the inner part of the stem (near the pith) the earlywood proportion in each growth ring is larger than it in the outer part of the stem (near the bark). The earlywood usually contains larger vessels, fewer fibers, and thinner fiber wall thickness than in the latewood. Therefore, the WD in the inner part is lower than in the outer part of the stem. Further experiments will be clearly needed to determine the variation in cell morphology as well as earlywood – latewood proportion from pith to bark in wood of *Manglietia conifera.*

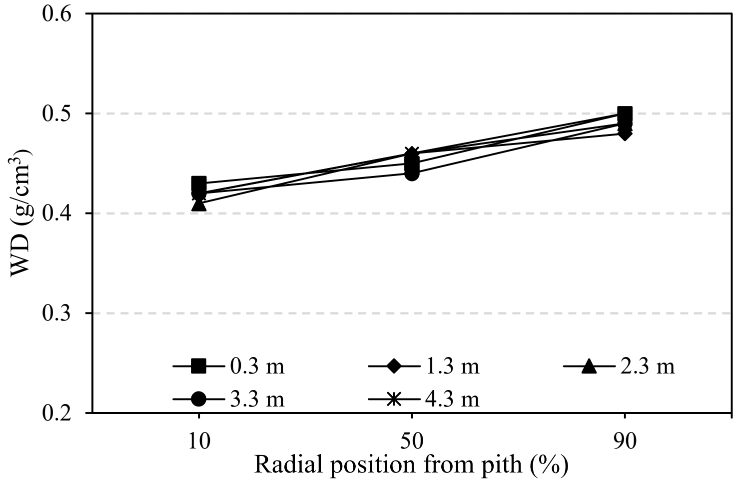


Figure 2. Radial and axial variations in wood density (WD) of *Manglietia conifera*

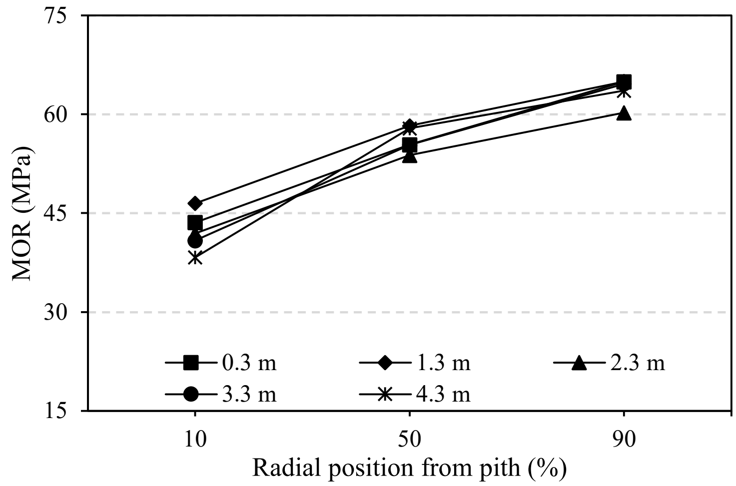


Figure 3. Radial and axial variations in modulus of rupture (MOR) of *Manglietia conifera*

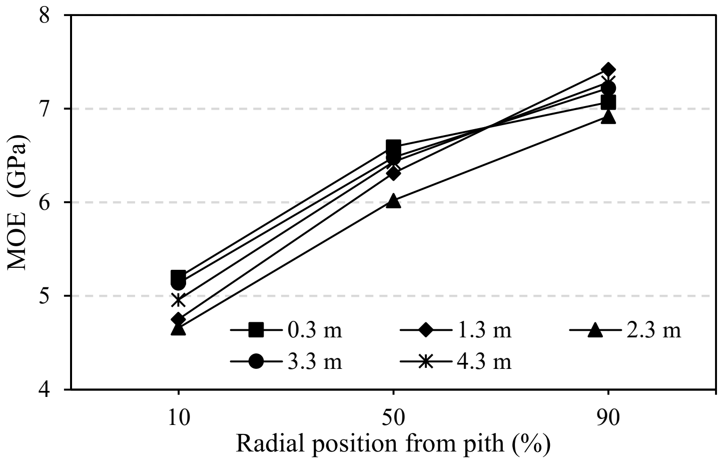
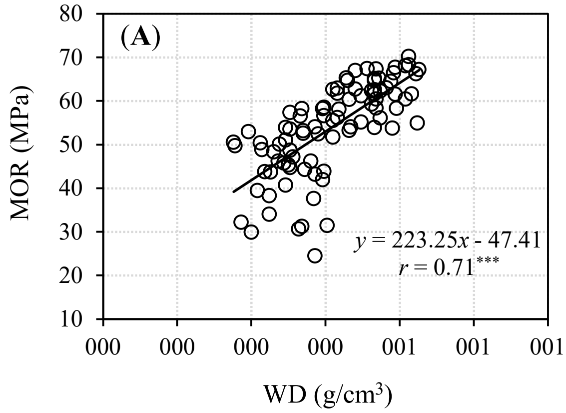


Figure 4. Radial and axial variations in modulus of elasticity (MOE) of *Manglietia conifera*

3.2. Relationships between WD and MOR, MOE

The degree of correlation between WD and mechanical properties of *Manglietia conifera* wood was evaluated by linear regression analysis. The results are presented in Figure 5. WD had significant positive linear correlations with both MOR (r = 0.71) and MOE (r = 0.69) at the 0.001 confidence level. These results suggest that WD could be used as a good indicator to predict the static bending properties of *Manglietia conifera*. Therefore, the improving WD which can be obtained by tree breeding programs, growth conditions, or selection for high wood density parts, etc. would have a positive impact on mechanical properties of *Manglietia conifera*. The positive linear relationship between WD and mechanical properties also found in other hardwood species as *Tectona grandis* (Izekor *et al*., 2010), *Eucaplytus tereticornis* (Sharma *et al*., 2005), *Acacia melanoxylon* (Machado *et al*., 2014), and *Melia azedarach* (Duong and Matsumura, 2018a).



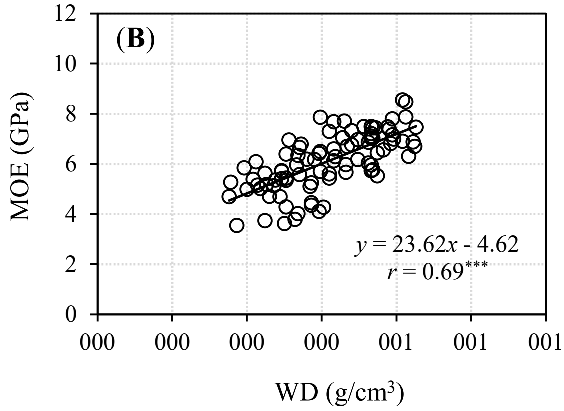


Figure 5. Relationships between wood density (WD) and modulus of rupture (MOR) (A); wood density (WD) and modulus of elasticity (MOE) (B). (***: p < 0.001)

4. CONCLUSIONS

In the present study, the mechanical properties of *Manglietia conifera* wood were measured in the radial and axial directions. The results obtained are as follows:

- The radial variations in WD, MOR, and MOE were highly significant and these mean values increased gradually from pith to bark.

- The variations in WD, MOR, and MOE with height were very small and no statistical significance.

- WD had significant positive linear correlations with both MOR and MOE at the 0.001 confidence level. This suggests that controlling WD would have a positive impact on static bending properties of *Manglietia conifera* wood.

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NHỮNG BIẾN ĐỔI KHỐI LƯỢNG THỂ TÍCH VÀ TÍNH CHẤT CƠ HỌC TRONG THÂN CÂY GỖ MỠ (*Manglietia conifera* Dandy) TRỒNG TẠI HUYỆN NA RÌ, TỈNH BẮC KẠN

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TÓM TẮT

Nghiên cứu này đã tiến hành đánh giá sự biến đổi khối lượng thể tích và các tính chất cơ học trong thân cây gỗ Mỡ ở rừng trồng 10 tuổi trồng tại huyện Na Rì, tỉnh Bắc Kạn theo hướng từ tâm ra vỏ và từ gốc đến ngọn. Các mẫu gỗ nghiên cứu có kích thước 20 × 20 × 320 mm (Xuyên tâm × Tiếp tuyến × Dọc thớ) được cắt tại các vị trí 10, 50, và 90% chiều bán kính theo hướng từ tâm ra vỏ và tại các vị trí chiều cao cây: 0,3, 1,3, 2,3, 3,3 và 4,3 m tính từ mặt đất. Những biến đổi tính chất gỗ theo hướng bán kính từ tâm ra vỏ và theo hướng dọc thân cây tại các vị trí khác nhau được điều tra để làm rõ ảnh hưởng của vị trí lấy mẫu đến tính chất khối lượng thể tích và các tính chất cơ học của gỗ Mỡ. Kết quả nghiên cứu cho thấy khối lượng thể tích, độ bền uốn tĩnh và mô đun đàn hồi uốn tĩnh của gỗ Mỡ tại độ ẩm 10,71% lần lượt là 0,45 g/cm^3, 54,09 MPa và 6,12 GPa. Các tính chất cơ học của gỗ Mỡ có xu hướng tăng dần từ tâm ra vỏ nhưng không có sự khác biệt giữa các vị trí chiều cao trong thân. Khối lượng thể tích có mối quan hệ tuyến tính với cả độ bền uốn tĩnh (r = 0,71, p < 0,001) và mô đun đàn hồi uốn tĩnh (r = 0,69, p < 0,001). Điều này cho thấy khối lượng thể tích là một chỉ số quan trọng có thể được sử dụng để dự đoán tính chất cơ học của gỗ Mỡ.

Từ khoá: Độ bền uốn tĩnh, gỗ Mỡ, khối lượng thể tích, mô đun đàn hồi uốn tĩnh.

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