Vol. 13(1): 317-331, January 2025

DOI: https://doi.org/10.23960/jsl.v13i1.1072

Jurnal Sylva Lestari

P-ISSN: 2339-0913
E-ISSN: 2549-5747

Journal homepage: https://sylvalestari.fp.unila.ac.id

Full Length Research Article

Bending Strengths of Large-leaf Mahogany (*Swietenia macrophylla* King) and Mangium (*Acacia mangium* Willd) Commercial Lumbers in Northeastern Mindanao, Philippines

Rey Naldoza Cossid[1,2], Jan Michael Ampong Torralba[1], John Harold Merantes Clemente[1], Chary Joyce Gabriel Villaflor[1], Catherine Mhae Buctuan Jandug[1], Cornelio Sacquiap Casilac Jr[1,*]

[1] College of Forestry and Environmental Science, Department of Forestry, Caraga State University, Butuan, Philippines
[2] DOST-FPRDI Regional Forest Products Innovation and Training Center, College of Forestry and Environmental Science, Caraga State University, Butuan, Philippines
[*] Corresponding Author. E-mail address: corneliocasilac@gmail.com

ARTICLE HISTORY:

Received: 6 September 2024
Peer review completed: 30 December 2024
Received in revised form: 17 January 2025
Accepted: 3 February 2025

KEYWORDS:

3-point test jig
Load deflection
Mahogany
Modulus of elasticity
Modulus of rupture

ABSTRACT

Large-leaf mahogany (*Swietenia macrophylla* King) and mangium (*Acacia mangium* Willd) have been the preferred wood for furniture and cabinets for ages. *S. macrophylla* is famous around the world for the wood it provides. This study investigated the bending strength (modulus of rupture (MOR) and modulus of elasticity (MOE)) of *S. macrophylla* and *A. mangium* commercially available lumbers sold at roadside lumber dealers in northeastern Mindanao (Provinces of Agusan del Norte, Agusan del Sur and Misamis Oriental), Philippines. Four lumbers were acquired for each species in every province. A total of 12 lumbers per species were collected from the three provinces, or 24 sampled lumbers. These lumbers were further processed into a nominal dimension of 1.5 cm × 1.5 cm × 27.6 cm. All samples were oven-dried at 105 ± 3°C for 24 hours inside a laboratory oven until no more moisture could be removed. The 3-point test jig was fabricated and adapted to a kidizen science-free design but modified for this study. The results show no significant differences in bending strength at a 0.01 significance level among the three provinces and between species. Overall, bending strength is comparable across provinces and species. For *S. macrophylla* and *A. mangium*, Agusan del Norte obtained the highest MOR and MOE (54.707 MPa, 63.002 MPa). The MOE of *S. macrophylla* in Agusan del Norte was also high (6,825 MPa), but for *A. mangium*, Misamis Oriental province was the highest.

1. Introduction

Large-leaf mahogany (*Swietenia macrophylla* King) is an exotic tree classified as a broad-leaved species introduced in the Philippines. It is known for its fast growth and wood quality. The particular name ‘macrophylla’ comes from the Greek word macros (big) and ‘phyllon’ (leaf) (Telrandhe et al. 2022). It is a large tree, reaching a height of up to 40 m and a diameter of up to 2.0 m (Krishna and Maurya 2018). This species is also commercially important in the neotropical forests (Anoop et al. 2014). To meet the increasing demand for timber, sustainable tree plantations of fast-growing species are the best option (Gilbero et al. 2022). These trees are typically large, about 60 to 80 feet tall. Exotic to the Country, *S. macrophylla* is a fast-growing, deciduous tree native to the dry tropical forests of Mexico down to Bolivia (Grogan et al. 2014). It was first planted in Manila, Philippines in 1907 and at Mt. Makiling, Laguna in 1913 (Baguinon et al. 2005). Until 2011, it was the most planted tree as a resource for the country's pulp and timber needs (Tulod et al. 2017). The reddish-brown color of this tree makes it unique compared to other trees.

For the tropical lowlands, *Acacia mangium* Willd is a significant multifunctional tree. It is a fast-growing tree native to parts of Indonesia, Papua New Guinea and Australia. It has been cultivated outside its native environment and introduced into humid tropical lowland regions of Asia, South America and Africa over the last few decades (Koutika and Richardson 2019). This species can be the choice of hardwood species for cross-laminated timber (CLT) (Hariz et al. 2023). The wood is also suitable for light structural works, agricultural implements, boxes, crates (Awang and Bhuimibhanon 1993), and decorative veneers (Hegde et al. 2013). It has also attained naturalization in other places like Puerto Rico and Brazil. These two species are highly valuable not only locally but also internationally. From furniture production to environmental conservation, the Philippines' economy depends heavily on the availability and use of *S. macrophylla* and *A. mangium* when making fine furniture, musical instruments, and decorative things; *S. macrophylla* wood is in high demand. Similarly, the nation's plantation and forestry sectors have made *A. mangium* a mainstay thanks to its quick growth and adaptable wood qualities. Its timber is used in building, paper manufacturing, and even as a raw material for wood chips, giving many towns a steady stream of cash. Calculating the modulus of rupture (MOR) and modulus of elasticity (MOE) is crucial because it enables standardization of product quality, facilitates structural design and engineering, enhances market access and trade opportunities, and drives research and development efforts to improve wood properties and sustainability. In addition, it also helps assess the strength, stiffness, and overall quality of the wood. Ensuring these lumbers' suitability for various applications is essential.

The 3-point jig test is a fundamental method used to evaluate the mechanical properties of wood, providing valuable insights into its strength and stiffness characteristics (McGavin et al. 2019). There are three types of flexural test methods: three-point, four-point, and biaxial flexural (Ilie et al. 2017). The concept of the three-point bending test has been adapted and improved upon by various individuals and organizations over the years. Its origins can be traced back to the early days of materials science and engineering. In modern times, organizations like ASTM International (American Standards for Testing and Materials) and the International Organization for Standardization (ISO) have established standardized procedures and specifications for conducting the three-point bending test, which includes guidelines for the design and use of the test jig. In this study, the researchers aimed to conduct 3-point jig tests on wood samples obtained from two distinct species: *S. macrophylla* and *A. mangium*. By subjecting these samples to controlled loading conditions, we seek to compare and analyze the mechanical performance of these two species, offering insights into their suitability for various applications in construction, furniture manufacturing, and other industries. The three provinces were chosen in this study because these three provinces have a plantation of *S. macrophylla* and *A. mangium*.

2. Materials and Methods

2.1. Location of the Study

The location of the study is northeastern Mindanao, covering the Provinces of Agusan Del Norte, Agusan Del Sur and Misamis Oriental (**Fig. 1**). All acquired commercial woods, brought from commercial lumber dealers, were delivered to Caraga State University College of Forestry (CoFES) workshop.

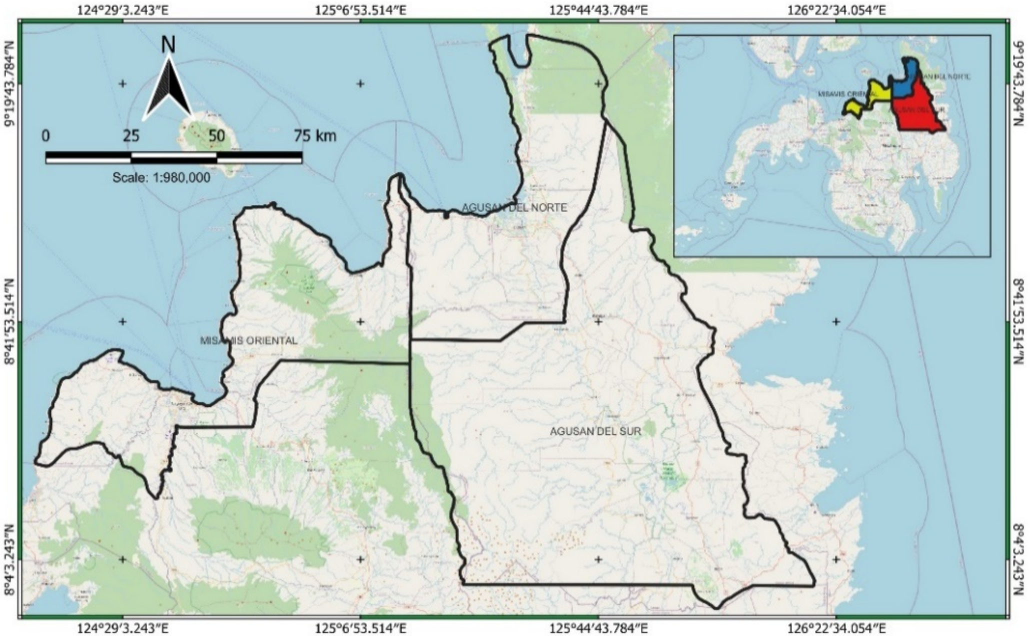


Fig. 1. Location of the study.

2.2. Data Collection

The researchers purchased available commercial lumbers of *S. macrophylla* and *A. mangium* from commercial lumber dealers in the three provinces. Four (4) lumbers were acquired for each species in every province. A total of 12 lumbers per species were collected from the three provinces, or 24 sampled lumbers (**Fig. 2**). These lumbers were further processed into a nominal dimension of 1.5 cm × 1.5 cm × 27.6 cm, actual dimensions were used in the computation as adopted by DIN (52186-78) with modification for rectangular solid wood. All samples were oven-dried at 105 ± 3°C for 24 hours inside a laboratory oven until no more moisture could be removed. The three-point testing jig was fabricated at the CoFES workshop. The jig was fabricated by adapting a kidizen science-free design but modified for this study. The kidizen uses a 3-point method utilizing wooden lumbers as support; the third point is the force or load hanging to the wood sample. (**Fig. 3a**). Illustration of the 3-point test jig. (**Fig. 3b**).

Fig. 2. Twenty-four (24) wood samples for testing.

2.3. Data Analysis

Fig. 3 illustrates the fabricated modified 3-point test jig used with a static load applied at the center. The modified jig uses a 3-point method utilizing wooden lumbers as support, and the third point is tangentially hanging force or load to the wood sample. Bending strength was calculated using Equations 1, 2, 3 and 4.

$$MOR = M/S \tag{1}$$

where M is a moment of modulus, and S is a section of modulus.

$$M = (P)(L)/4 \tag{2}$$

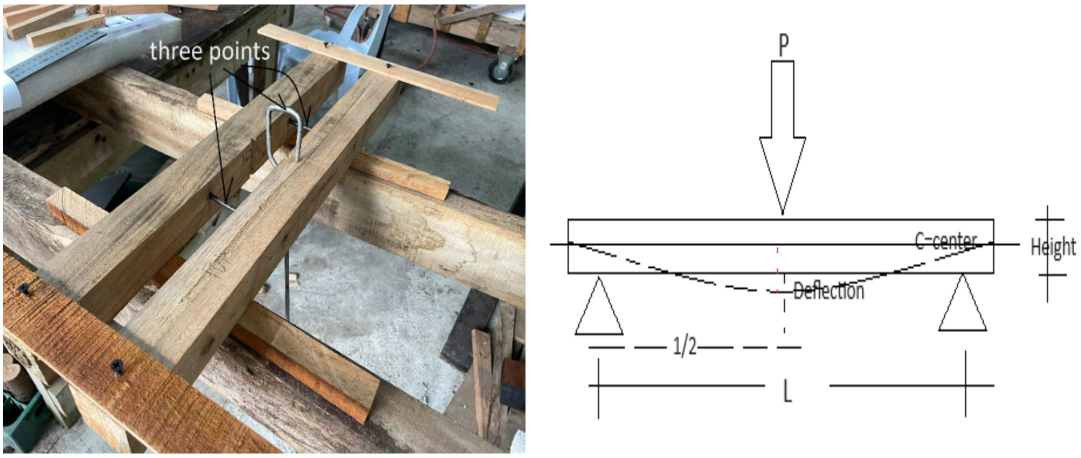
where M is a moment of modulus, P is the maximum point of load at the center, and L is the length of wood samples as supported by points 1 and 3.

$$S = b^2\,(t)\,/16 \tag{3}$$

where S is the section of modulus, b is the depth or height of the beam, and t is the width of the beam.

$$MOE = P(L)^3/48\,(E)\,(I) \tag{4}$$

The dimensions of b and t are based on actual measurements using a vernier caliper rather than from the nominal dimension. ANOVA – RCBD was used through Microsoft Excel's data analysis toolpack for ANOVA to test significant differences of means. Treatments were *S. macrophylla* and *A. mangium*; blocks were the three provinces with four samples for each species per province. Tukey's Honestly Significant Difference (HSD) post-hoc test was used.



a **b**

Fig. 3. Fabricated 3-point test jig (a), Illustration of the 3-point test method (b).

3. Results and Discussion

3.1. Modulus of Rupture of S. macrophylla and A. mangium

Modulus of rupture (MOR) measures the strength of *S. macrophylla* and *A. mangium*, commercially available in three provinces. It is crucial for determining the maximum load they can withstand. Shukla (2023) stated that the presence of knots, cellular makeup, cell wall deposition, extractives, and even growth characteristics all affect the wood's ability to bend. **Table 1** shows the data on the Modulus of rupture (MOR) of *S. macrophylla* and *A. mangium* in three provinces. The modulus of rupture (MOR) refers to the maximum stress a material can withstand during bending before breaking. This parameter measures the wood's strength and resilience under load. The highest MOR among *S. macrophylla* is in Agusan del Norte province, with an average value of 54.71 MPa. In comparison, Misamis Oriental obtained the lowest MOR with an average value of 42.67 MPa.

For comparison, the average MOR value for *S. macrophylla* reported in previous studies is 766.01 kg/cm^2, as studied by Anoop et al. (2014). The strength classification grades of wood put large *S. macrophylla* at an average of moderately low strength (ranging from moderately low to medium), having 5.80–9.13 psi (Tesoro et al. 1990). For the MOR of *A. mangium,* Agusan Del Norte province got the highest mean of 63.00 MPa; the lowest MOR is in Agusan Del Sur, which obtained a mean of 35.97 MPa (**Table 1**). Other researchers found that the MOR of a 10-year-old *A. mangium* is higher than that of a 13-year-old (Yahya et al. 2023). In Malaysia, the MOR of *A. mangium* (second generation) was 55 MPa (Jusoh et al. 2014).

Table 1. Results of the modulus of rupture (MOR) of *S. macrophylla* and *A. mangium* in three provinces in Northeastern Mindanao

Wood Species	Province				
	Agusan del Sur (MPa)	Agusan del Norte (MPa)	Misamis Oriental (MPa)	Total	Mean
S. macrophylla	37.58	53.04	33.50		
	49.15	52.99	52.96		
	70.01	53.39	52.96		
	50.86	59.39	31.27		
Total	207.59	218.83	170.69	597.11	199.04
Mean	51.89^a	54.71^a	42.67^a	149.28	49.76^a
A. mangium	30.65	85.53	46.50		
	29.77	31.27	14.59		
	26.67	64.14	48.17		
	56.77	71.07	46.46		
Total	143.87	252.01	155.73	551.61	183.87
Mean	35.97^a	63.00^a	38.93^a	137.90	45.96^a

Note: Means with the same letter are not significantly different at the 0.01 level.

The modified strength classification used by Tesoro et al. (1990) put *A. mangium* at medium strength of 7,297 MPa. *A. mangium* has a low specific gravity of 0.46–0.52, a strength class of III (Somadona et al. 2020), and a durability class of IV (Febrianto et al. 2015). The Analysis of variance (ANOVA) test indicates no significant differences in bending strength among provinces and species. The lack of significant differences in MOR in the three provinces and species of *S. macrophylla* and *A. mangium* may be relatively consistent. This could be attributed to similar growth conditions and environmental factors. In this study, the ages of the *S. macrophylla* and *A. mangium* wood samples are unknown, as they were sourced from the lumber available in the three provinces. The highest MOR values observed for both wood types in Agusan del Norte might suggest favorable environmental conditions such as rainfall. Rainfall in this province is pronounced throughout the year, with maximum rainfall from November to January (Casilac and Tulod 2024). These factors might contribute to higher mechanical properties, aligning with studies that link water availability to improved wood properties. Vieira et al. (2021) concluded that water availability can influence tree growth, anatomical properties and wood density.

3.2. Modulus of Elasticity of S. macrophylla and A. mangium

The modulus of elasticity (MOE) measures the stiffness of a material. It indicates the elasticity and suitability of wood for load-bearing applications. **Table 2** shows the Modulus of Elasticity (MOE) result of *S. macrophylla* and *A. mangium* samples in three provinces. ANOVA test shows no significant difference among provinces, and between species among the three provinces, Agusan del Norte obtained the highest MOE of *S. macrophylla* with a mean of 6,825 MPa. However, Misamis Oriental has the lowest MOE with a mean of 5,189 Mpa. Several authors also studied the MOE of *S. macrophylla* present in different countries. Amarasinghe and Muthumala (2019) recorded the MOE of *S. macrophylla* 4,809 Mpa in Sri Lanka. Langbour et al. (2011) also studied the MOE of *S. macrophylla* in Brazil, Peru, and Mexico compared to species in Martinique and showed no significant difference. This may imply that the mechanical properties of *S. macrophylla* do not vary from where it was grown; it may be because the site has the same latitudes. According to Van Der Maaten-Theunissen et al. (2013) and Rossi et al. (2015), there is a downward trend in the wood density of *Pinus sylvestris* with increasing latitude.

Table 2. Results of the modulus of elasticity (MOE) of *S. macrophylla* and *A. mangium* in three provinces in Northeastern Mindanao

Wood species	**Province**				
	Agusan del Sur (MPa)	**Agusan del Norte (MPa)**	**Misamis Oriental (MPa)**	**Total (MPa**	**Mean (MPa)**
S. macrophylla	6,782	8,482	6,030	21,295	
	5,898	6,355	5,447	17,700	
	6,300	7,123	4,776	18,190	
	6,102	5,342	4,502	15,947	
Total	25,084	27,303	20,756	73,134	
Mean	6,271^a	6,825^a	5,189^a	18,283	4,765^a
A. mangium	5,911	7,698	7,048	20,657	
	4,763	5,628	3,624	14,016	
	4,965	7,696	12,388	25,050	
	10,219	8,977	8,651	27,847	
Total	25,860	29,999	31,711	85571	
Mean	6,465^a	7,499^a	7,927^a	21,892	7,297^a

Note: Means with the same letter are not significantly different at the 0.01 level.

The study of Anoop et al. (2014) found that *S. macrophylla* in South India has a MOE of 72,641 kg/cm^2 or 7,123 MPa; it has a higher MOE compared to the study. It may be because the lumber sold commercially may not have reached full maturity when harvested. According to Anoop et al. (2014), the harvesting of *S. macrophylla* at Dhoni is over 88 years old at the time of felling, which results in higher MOE. Rokeya et al. (2014) reported the strength properties of *S. macrophylla,* showing a similar MOE (5,785 MPa). By comparison, the findings of this research *S. Macrophylla* MOE of 4,765 MPa is similarly near to the National Structural Code of the Philippines (2010) properties of Philippine Woods, at 80% stress grade of 4.66 GPa, or 4,660 MPa, under the "Group II-moderately high strength group", and way higher than 50% stress grade which is of 2.99 GPa or 2,990 MPa.

For *A. mangium*, the highest MOE is in Misamis Oriental, with a mean of 7,927 MPa, while Agusan Del Sur registered the lowest MOE with 6,465 MPa. Among the two species studies, *A.*

mangium has the highest MOE of 7,297 MPa. This study explains that MOR and MOE of A. mangium show non-linear relationships. The MOR results of *A. mangium* were highest in Agusan del Norte, but for the MOE, the highest was obtained in Misamis Oriental. This means that wood with higher MOR does not necessarily have proportionally higher MOE because of other factors like anatomical variation, environmental influences, and defects in wood. Ei-Osta et al. (2007) studied six hardwood species in Egypt and reported that two out of six showed a non-linear relationship between MOR and MOE. The study of Yang et al. (2017) for southern pine lumber shows a moderate correlation of MOE with MOR, and various nondestructive testing methods demonstrate lower correlations in predicting MOR. These findings highlight the complexity of wood properties and the challenges in accurately predicting strength characteristics. Wahab et al. (2017) found that Malaysia's modulus of elasticity (MOE) of oil-treated *A. mangium* wood was 6,992 N/mm². Alipon et al. (2017) conducted a study of the properties of *A. mangium* in different sites in Caraga Region Brgy. Nongnong, Butuan City and Las Nieves, Agusan Del Norte show no significant differences in their MOE results. However, the third site–Patin-ay, Agusan Del Sur–shows significant differences in *A. mangium*. Sahri et al. (1998) study of *A. mangium* from different provenances in Indonesia, Malaysia and Thailand indicates that MOE is not significantly different at 0.05 significance level ranging from 6,168 MPa to 6,728 MPa. While some studies found significant differences in modulus of elasticity (MOE) between provenances (Van Duong and Hasegawa 2021), other authors reported no significant correlation between mechanical properties and growth characteristics of *A. mangium*, except for modulus of rupture (MOR) (Nurhasybi and Sudrajat 2019). Jajo (2015) evaluated the provenance of *A. mangium* for growth and wood traits in India and showed no significant results in MOE. *A. mangium* is not listed in the National Structural Code of the Philippines (NSCP); however, *A. crassicarpa* is listed by NSCP Table 615.2-1 with MOE at 80% grade to be 6.78 GPa and at 50% grade, 4.24 GPa, putting the finding's 7.29 GPa similarly comparable. The study of Alipon et al. (2017) suggests that harvesting should be prolonged from 4 to 6 or 8 years old due to remarkable improvement in the mechanical properties of *A. mangium*.

3.3. Load-Deflection of S. macrophylla in the Three Provinces

Fig. 4 shows the load-deflection of *S. macrophylla* in Agusan del Norte; four wood samples undergo the 3-point test jig. Sample 1 exhibited a proportional limit of 52.16 kg and a corresponding deflection of 1.90 mm, while sample 2 exhibited a proportional limit of 16.78 kg. A deflection of 1 mm, sample 3 proportional limit is 39.86 kg and a corresponding deflection of 2.01 mm. Lastly, the proportional limit of sample 4 is 16.78 kg with a deflection of 1 mm. Samples 1 and 3 demonstrated higher proportional limits, suggesting that greater loads should withstand before experiencing plastic deformation. Still, they are less stiff and may deform readily under a given load base in higher deflections, 1.90 mm and 2.01 mm. In addition, samples 2 and 4 had identical proportional limits, suggesting they might have similar properties.

Fig. 5 also shows the load-deflection of *S. macrophylla* in Agusan del Sur. Based on the results, sample 1 has a proportional limit of 31.75 kg with a deflection of 1.5 mm, sample 2 has a proportional limit of 16.78 kg and deflection of 1 mm, sample 3 has a proportional limit of 31.75 kg with a deflection 2 mm and for sample 4 has a proportional limit of 39.88 kg with a deflection of 2.49 mm. The data shows that sample 4 exhibited the highest proportional limit while sample 2 had the lowest. For the deflection, sample 2 obtained the lowest deflection of 1 mm, and sample 4 received the highest deflection of 2.49 mm. The impact of loading direction on wood strength varies among species, with some showing significant differences between radial and tangential directions, while others exhibit minimal variation (Borůvka et al. 2020).

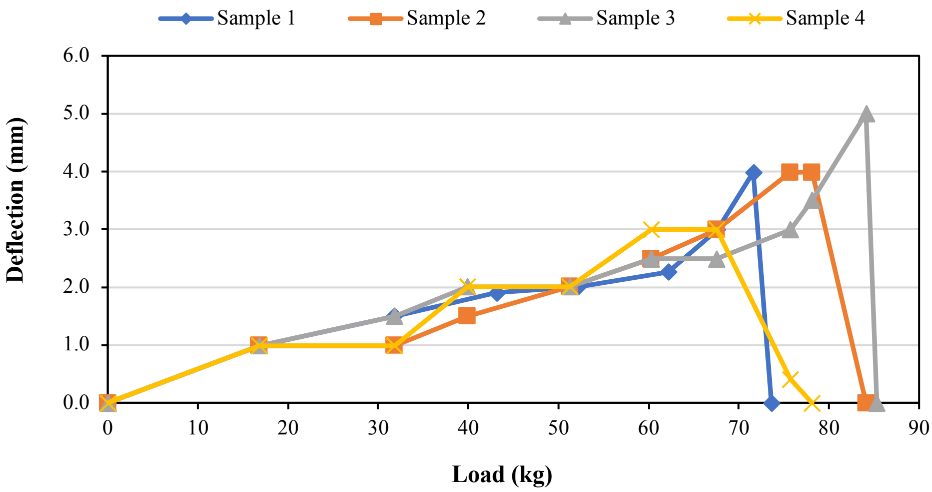


Fig. 4. The load-deflection variation of *S. macrophylla* commercial lumbers during the 3-point jig test in Agusan del Norte.

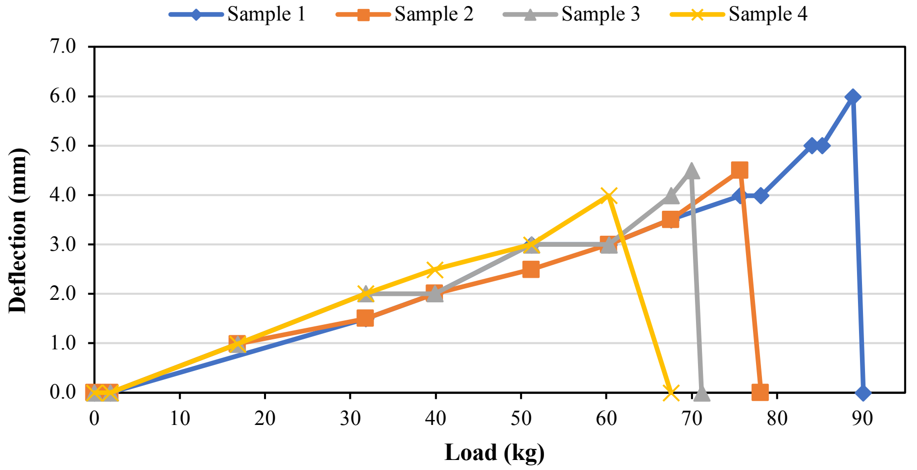


Fig. 5. The load-deflection variation of *S. macrophylla* commercial lumbers during the 3-point jig test in Agusan del Sur.

Fig. 6 shows the load-deflection of *S. macrophylla* in Misamis Oriental. Sample 1 and sample 2 showed a proportional limit of 39.46 kg with a corresponding deflection of 2 mm, sample 3 had a proportional limit of 31.75 kg with a deflection of 2 mm, and the proportional limit of sample 4 was of 39.46 kg with a deflection of 2.49 mm. The samples exhibited consistent proportional limits, suggesting a relatively predictable response to increasing loads up to a certain point. Materials initially exhibit a linear relationship between stress and strain, but beyond the proportional limit, they undergo plastic deformation, resulting in permanent changes in shape (Roylance 2001; Svoboda et al. 2017). In **Fig. 4–6**, the wood requires an ever-increasing stress or load to continue straining before it breaks. Beyond the proportional limit, materials exhibit strain hardening, requiring increasing stress to maintain deformation, while exceeding the elastic limit results in permanent deformation (Roylance 2001; Svoboda et al. 2017). If the stress exceeds the elastic limit, the material will retain a residual strain after removing the load (Gaf et al. 2015; Igaz et al. 2015; Igaz et al. 2016). The variations in the proportional limits and deflections among the four *S. macrophylla* samples, despite being from the same species and sampling locations, may be attributed to several factors like natural wood variability, minor climate variation, water availability, processing of lumber and moisture content. According to Kretschmann (2010), variation is common to all materials, especially "wood'' because it is a natural material and is subject to many changing influences, for example, wood moisture and can cause variation in its properties. Studies have shown that wood deflection is influenced by species, densification degree, material thickness, and loading cycles (Sikora et al. 2017).

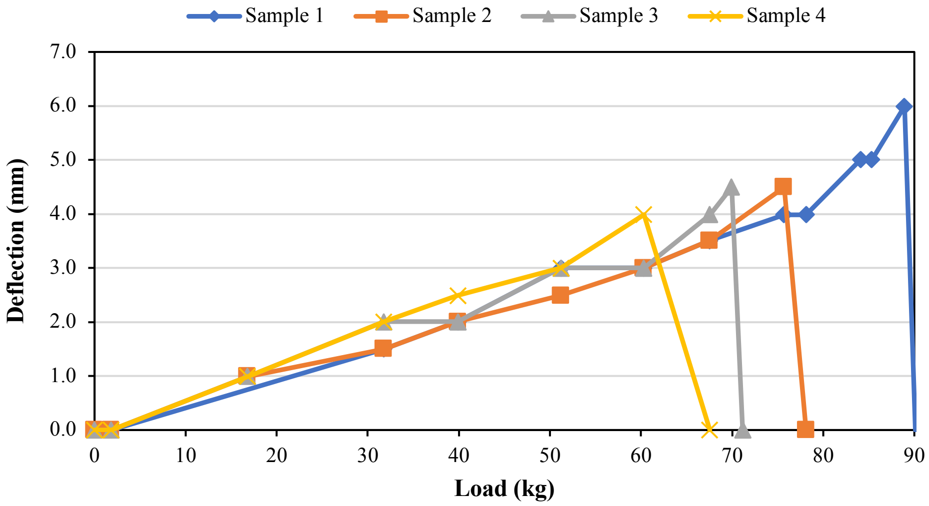


Fig. 6. The load-deflection variation of *S. macrophylla* commercial lumbers during the 3-point jig test in Misamis Oriental.

The wood samples from Misamis Oriental province obtained the highest mean deflection of 2.13 mm, showing that the samples are more flexible and less stiff. However, the samples from Agusan del Norte had the lowest average deflection of 1.47 mm, indicating greater stiffness and less deformation under load. In this study, the higher average deflection of wood samples from Misamis Oriental samples may be due to variations in environmental factors, water availability and other factors that can influence wood density and fiber alignment. The study of Shepherd et al. (2014) concluded that this variability is attributed to factors such as moisture content, grain orientation, and processing conditions.

3.4. Load-Deflection of A. mangium in the Three Provinces

Fig. 7 shows the load-deflection of *A. mangium* in Agusan del Norte; four wood samples undergo the 3-point test jig. Sample 1 exhibited a proportional limit of 53.52 kg with a deflection of 2 mm, the proportional limit of sample 2 was 39.47 kg with a deflection of 2 mm, samples 3 and 4 showed a proportional limit of 81.64 kg and deflection of (3 mm and 3.5 mm) respectively. As shown in **Fig. 8,** samples 1 and 3 exhibit a proportional limit of 31.75 kg with a corresponding deflection of 2 mm. Sample 4 obtained the highest proportional limit of the four samples of *A. mangium* in Agusan del Sur. **Fig. 9** for Misamis Oriental samples 1, 3 and 4 has a proportional limit of 53.52 kg with a deflection of (2.5 mm, 1.5 mm, and 2 mm). These results suggest that *A. mangium* is a versatile species, but carefully considering individual tree properties is crucial to ensure its suitability for specific purposes. Baskara et al. (2022) stated that *A. mangium* species are unsuitable for solid wood use. It is commonly used for non-structural purposes and has low added value (Marwanto et al. 2018). In this study, the wood samples partially exhibit linear relationships, and the ultimate strength of the wood samples can be seen before they break. Materials initially exhibit a linear relationship between stress and strain, but beyond the proportional limit, they undergo plastic deformation, resulting in permanent changes in shape (Roylance 2001; Svoboda et al. 2017). According to Svoboda et al. (2017), a force beyond the proportionality limit causes the development of elastic deformation over time and plastic deformation. **Fig. 7–9** show the wood sample exhibits plasticity (changing its shape without breaking). The degree of plasticity under mechanical stress is called plastic deformation (Svoboda et al. 2017). The wood samples of *A. mangium* from Agusan del Norte had the highest average deflection (2.62 mm), while Misamis Oriental had the lowest average deflection (2 mm).

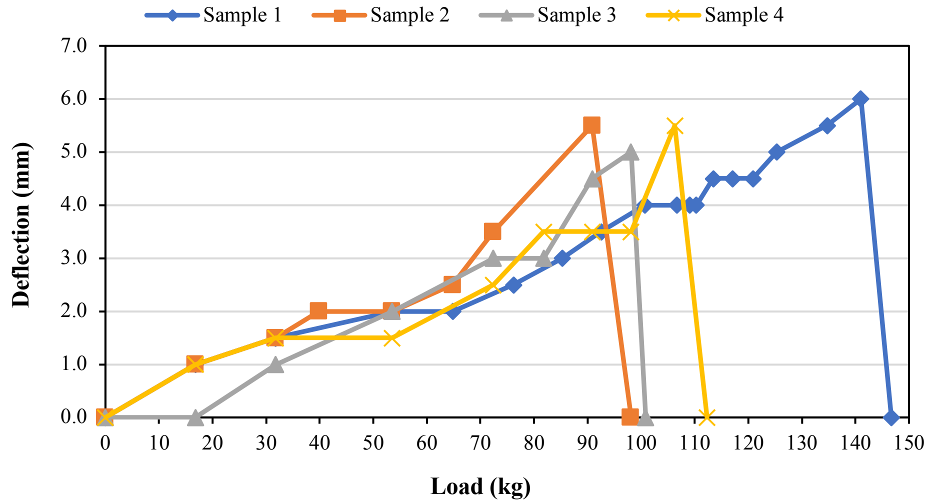


Fig. 7. The load-deflection variation of *A. mangium* commercial lumbers during the 3-point jig test in Agusan del Norte.

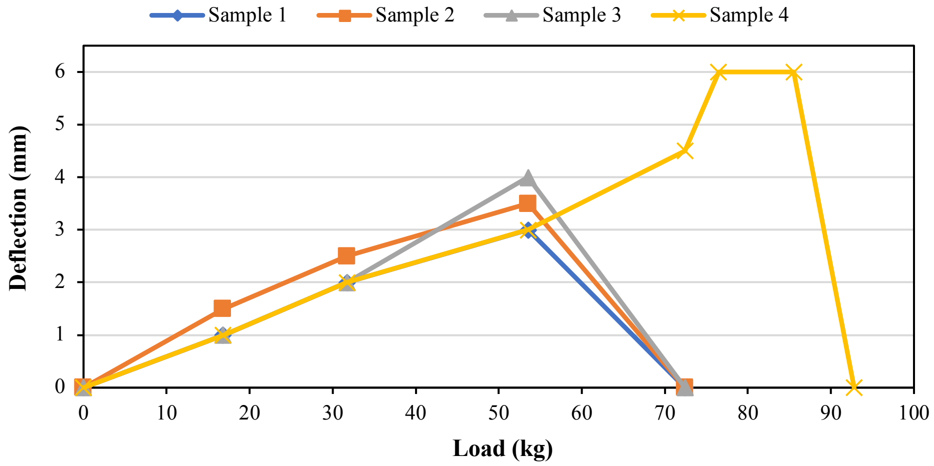


Fig. 8. The load-deflection variation of *A. mangium* commercial lumbers during the 3-point jig test in Agusan del Sur.

A. mangium has been extensively studied for its potential as a structural timber. Research indicates that *A. mangium* can be suitable for light frame timber construction systems and manufacturing cabinets and furniture, agricultural tools, boxes and crates (Nadhari et al. 2014). At green condition, *A. mangium* is classified under-strength group SG6, with a higher modulus of rupture than tensile strength (Ismaili et al. 2011). The physical and mechanical properties of *A. mangium* are influenced by provenance, with samples from Papua New Guinea and Queensland, Australia showing varying performance (Sahri et al. 1998). Provenance trials have identified several superior sources for solid wood production, including Kini WP, Keru Village WP, and Derideri R. Morehead of Papua New Guinea, which exhibit desirable traits in productivity, stem form, branching habit, and crown form (Nirsatmanto 2012). The study by Kachaka et al. (2021) conducted in Congo also shows that *A. mangium* originating from Papua New Guinea, Australia, Malaysia, Vietnam, China, Fiji, including the Philippines, has better performance for provenances. These findings suggest carefully selecting *A. mangium* provenances can optimize its use in forest plantations for construction and furniture materials. Both species demonstrated potential for use in construction when processed into laminated veneer lumber (LVL), meeting relevant standards (Alamsyah et al. 2023).

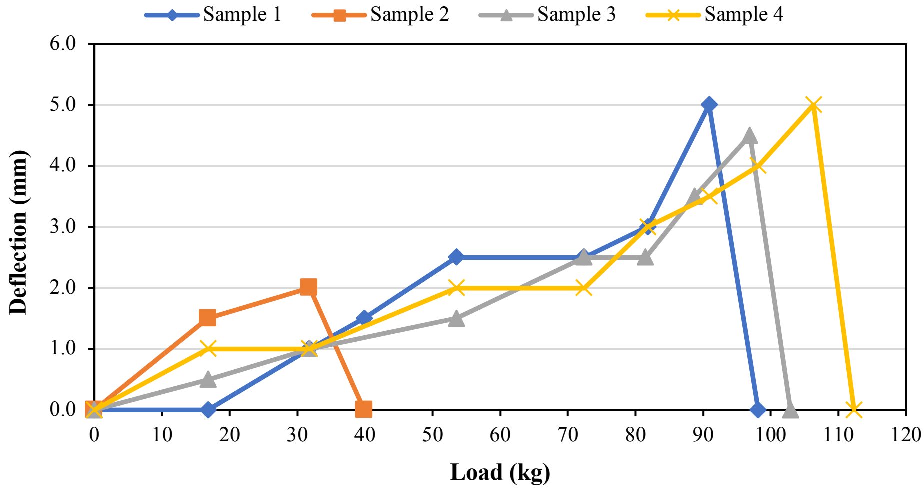


Fig. 9. The load-deflection variation of *A. mangium* commercial lumbers during the 3-point jig test in Misamis Oriental.

4. Conclusions

Calculating the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of *S. macrophylla* and *A. mangium* lumbers in the Philippines is crucial because it helps assess the wood's strength, stiffness, and overall quality. This is essential for ensuring the suitability of these lumbers for various applications, such as construction and furniture making. Study shows that wood samples of commercial lumber in three provincial sites do not show differences in their bending strengths, both MOR and MOE. Their respective bending strengths do not differ significantly between *S. macrophylla* and *A. mangium*. Regarding the MOR value result of the three provinces compared, Agusan Del Norte has the highest for both species. *A. mangium* also has the highest MOR. While for MOE, wood samples from Agusan del Norte registered the highest among the three provinces, *A. mangium* from Misamis Oriental registered the highest MOE. The provinces' proximity to each other may be less varied, so the result showed no differences. It is recommended that further study be made to consider sites that are farther away, have different latitudes, and have varying soil characteristics and rainfall patterns. Also, more wood samples to research. Overall, the results of this study conclude that *S. macrophylla* exhibits superior mechanical properties compared to *A. mangium*, making it potentially more suitable for high-strength construction.

Acknowledgments

The authors would like to express gratitude to the College of Forestry and Environmental Science, Department of Forestry, Caraga State University, for their invaluable support in completing this study.

References

Alamsyah, E. M., Darwis, A., Sutrisno, Y. S., Munawar, S. S., Malik, J. and Sumardi, I., 2023. Modified Grain Orientation of Laminated Veneer Lumber Characteristics of Three Fast-Growing Tropical Wood Species. *BioResources* 18(3). DOI: 10.15376/biores.18.3.6132-6141

Alipon, M. A., Alcachupas, P. L., Bondad, E. O., and Cortiguerra, E. C. 2017. Properties and Utilization of Acacia Mangium Willd. Timber at Different Ages and Sites in Caraga Region, Philippines. *Lignocellulose* 6(2): 74–87.

Amarasinghe, W. V. T. D., and Muthumala, C. K. 2019. A Comparison of Mechanical and Physical Wood Properties of Big-Leaf Mahogany (*Swieteniam acrophylla*) and African Mahogany (*Khaya senegalensis*) of Sri Lanka. *Proceedings of International Forestry and Environment Symposium*. DOI: 10.31357/fesympo.v24i0.4331

Anoop, E. V., Jijeesh, C. M., Sindhumathi, C. R. and Jayasree, C. E. 2014. Wood Physical, Anatomical and Mechanical Properties of Big Leaf Mahogany (*Swietenia macrophylla* Roxb) a Potential Exotic for South India. *Research Journal of Agriculture and Forestry Sciences* 2(8): 7–13.

Awang, K., and Bhuimibhanon, P. 1993. *Genetics and Tree Improvement Acacia mangium, Growing and Utilization*. Winrock International and The Food and Agriculture Organization (FAO) of United Nations. Bangkok, Thailand.

Baguinon, N. T., Quimado, M., and Francisco, G. 2005. *Country Report on Forest Invasive Species in the Philippines*. Food and Agriculture Organization (FAO) of the United Nations. Bangkok, Thailand.

Baskara, M. I. A., Hapsoro, D., Maulana, M. I., Prasetia, D., Hidayat, W., Lubis, M. A. R., and Febrianto, F. 2022. Physical and Mechanical Properties of Oriented Strand Board from Three Species of Plantation Forests at Various Resin Contents. *Jurnal Sylva Lestari* 10(1): 49–62. DOI: 10.23960/jsl.v10i1.519

Borůvka, V., Novák, D. and Šedivka, P., 2020. Comparison and Analysis of Radial and Tangential Bending of Softwood and Hardwood at Static and Dynamic Loading. *Forests* 11(8): 896. DOI: 10.3390/f11080896

Casilac Jr, C. and Tulod, A. 2024. Biophysical Factors Influencing The Height and Diameter Structures of Falcata (*Falcataria falcata* (L.) Greuter & R. Rankin) in Agusan del Norte, Philippines. *International Journal of Biosciences* 24(3): 202–211. DOI: 10.2139/ssrn.4853852

DIN 52186. 1978. *Testing of Wood; Bending Test*. German Institute for Standardisation.

Ei-Osta, M.L., Badran, O., and El-Wakeel, A. O. 2007. Prediction of Modulus of Rupture from Modulus of Elasticity for Some Egyptian Hardwoods. *Wood and Fiber Science* 11: 147–154.

Febrianto, F., Pranata, A. Z., Septiana, D., Arinana, Gumilang, A., Hidayat, W., Jang, J. H., Lee, S. H., Hwang, W. J. and Kim, N. H. 2015. Termite Resistance of Less Known Tropical Woods Species Grown in West Java, Indonesia. *Journal Korean Wood Science Technology* 43(2): 248–257. DOI: 10.5658/wood.2015.43.2.248

Ismaili, G., Bakar, B. H. A. and Rahim, K. K. A. 2011. Evaluation of *Acacia mangium* in Structural Size at Green Condition. *Journal of Civil Engineering, Science and Technology* 2(2):17–22. DOI: 10.33736/jcest.90.2011

Gaff, M., Gašparík, M., Borůvka, V. and Haviarová, E. 2015. Stress Simulation in Layered Wood-Based Materials under Mechanical Loading. *Materials and Design* 87(3): 1065–1071. DOI: 10.1016/j.matdes.2015.08.128

Gilbero, D.M., Abasolo, W.P., Matsuo, M. and Yamamoto, H. 2022. Lateral Growth Affects Xylem Maturation Properties of 8-Year-Old Big-Leaf Mahogany (*Swietenia macrophylla*). *Journal of Tropical Forest Science* 34(1): 1–10.

Grogan, J., Landis, R. M., Free, C. M., Schulze, M. D., Lentini, M., and Ashton, M. S. 2014. Big-Leaf Mahogany *Swietenia macrophylla* Population Dynamics and Implications for Sustainable Management. *Journal of Applied Ecology* 51(3): 664–674. DOI: 10.1111/1365 2664.12210

Hariz, T. M. R., Hadi, Y. S., Lubis, M. A. R., Maulana, M. I., Sari, R. K. and Hidayat, W. 2023. Physical and Mechanical Properties of Cross-Laminated Timber Made of a Combination of Mangium-Puspa Wood and Polyurethane Adhesive. *Jurnal Sylva Lestari* 11(1): 37–65. DOI: 10.23960/jsl.v11i1.645

Hegde, M., Palanisamy, K. and Yi, J.S. 2013. *Acacia mangium* Willd.-A Fast Growing Tree for Tropical Plantation. *Journal of Forest and Environmental Science* 29(1): 1–14. DOI: 10.7747/jfs.2013.29.1.1

Igaz, R., Krišťák, L.U., Ružiak, I., Réh, R. and Danihelová, Z. 2016. Heat Transfer during Pressing of 3D Moulded Veneer Plywood Composite Materials. *Key Engineering Materials* 688: 131–137. DOI: 10.4028/www.scientific.net/kem.688.131

Igaz, R., Ruziak, I., Kristak, L'ubos, Reh, R., Izdinsky, J. and Siagiova, P. 2015. Optimization of Pressing Parameters of Crosswise Bonded Timber Formwork Sheets. *Acta Facultatis Xylologiae Zvolen* 57(1): 83–88.

Ilie, N., Hilton, T. J., Heintze, S. D., Hickel, R., Watts, D. C., Silikas, N., Stansbury, J. W., Cadenaro, M. and Ferracane, J. L. 2017. Academy of Dental Materials Guidance—Resin Composites: Part I—Mechanical Properties. *Dental Materials* 33(8): 880–894. DOI: 10.1016/j.dental.2017.04.013

Jajo, R. 2015. *Provenance Evaluation of Acacia mangium Wild for Growth and Wood.* College of Forestry. Vellanikkara, India.

Jusoh, I., Abu Zaharin, F., and Adam, N. S. 2014. Wood Quality of Acacia Hybrid and Second-Generation *Acacia mangium*. *BioResources* 9(1). DOI: 10.15376/biores.9.1.150-160

Kachaka, E. Y., Poirier, V., Munson, A. D. and Khasa, D. P. 2021. Evaluation of an *Acacia mangium* Provenance Trial After Seven Years, on The Ibi-Batéké Plateau, Democratic Republic of the Congo. *Tropicultura* 39(1). DOI: 10.25518/2295-8010.1740

Koutika, L. S. and Richardson, D. M. 2019. *Acacia mangium* Willd: benefits and Threats Associated with its Increasing Use Around The World. *Forest Ecosystems* 6(2): 1–13. DOI: 10.1186/s40663-019-0159-1

Kretschmann, D. 2010. *Mechanical Properties of Wood. Wood handbook: Wood as an Engineering Material: Chapter 5.* General Technical Report FPL; GTR-190. Department of Agriculture, Forest Service, Forest Products Laboratory. The US.

Krishna, S. and Maurya, H. 2018. A Review on Favorable Approaches of *Swietenia macrophylla* Plant for the Human Ailments. *Indian Journal of Pharmaceutical and Biological Research* 6(03): 60–65. DOI: 10.30750/ijpbr.6.3.10

Langbour, P., Gérard, J., Roda, J. M., Fauzi, P. A. and Guibal, D. 2011. Comparison of Wood Properties of Planted Big-Leaf Mahogany (*Swietenia macrophylla*) in Martinique Island with Naturally Grown Mahogany from Brazil, Mexico and Peru. *Journal of Tropical Forest Science* 23(3): 252 –259.

Marwanto, M., Maulana, S., Maulana, M. I., Wistara, N. J., Nikmatin, S., and Febrianto, F. 2018. Peningkatan Sifat Papan Partikel Sengon dengan Perlakuan Perendaman Air Dingin. *Jurnal Ilmu dan Teknologi Kayu Tropis* 16(2): 150–158. DOI: 10.51850/jitkt.v16i2.450

McGavin, R. L., Nguyen, H. H., Gilbert, B. P., Dakin, T., and Faircloth, A. 2019. A Comparative Study on The Mechanical Properties of Laminated Veneer Lumber (LVL) Produced from Blending Various Wood Veneers. *BioResources* 14(4): 9064–9081. DOI: 10.15376/biores.14.4.9064-9081

Nadhari, W. N. A. W., Hashim, R., Hiziroglu, S., Sulaiman, O., Boon, J. G., Salleh, K. M., Awalludin, M. F., Sato, M. and Sugimoto, T. 2014. Measurement of Some Properties of Binderless Composites Manufactured from Oil Palm Trunks and *Acacia mangium*. *Measurement* 50: 250–254. DOI: 10.1016/j.measurement.2014.01.002

National Structural Code of the Philippines. 2010. *Association of Structural Engineers of The Philippines*. Quezon City, Philippines.

Nirsatmanto, A. 2012. Genetic Variation Observed in Composite Seedling Seed Orchard of *Acacia mangium* Willd. at Central Java, Indonesia: Implications for Increasing Genetic Gain and Seed Production. *Indonesian Journal of Forestry Research* 9(2): 91–99. DOI: 10.20886/ijfr.2012.9.2.91-99

Nurhasybi, N., and Sudrajat, D. J. 2019. Growth Performance of *Acacia mangium* Provenances in Parung Panjang, Bogor and its Correlation with Physical and Mechanical Wood Properties. *IOP Conference Series: Earth and Environmental Science* 359(1): 012003.

Rokeya, U. K., Rahman, M. A. and Hossain, M. A. 2021. Effect of Heat Treatment on Physical and Mechanical Properties of Mahogany (*Swietenia macrophylla* King) and Acacia Hybrid (*Mangium* × *Auriculiformis*) Wood. *Bangladesh Journal of Forest Science* 37(2): 45–55.

Rossi, S., Cairo, E., Krause, C., and Deslauriers, A. 2015. Growth and Basic Wood Properties of Black Spruce along an Alti-Latitudinal Gradient in Quebec, Canada. *Annals of Forest Science* 72(1): 77–87. DOI: 10.1007/s13595-014-0399-8

Tulod, A. M., Casas, J. V., Marin, R. A. and Ejoc, J. A. B. 2017. Diversity of Native Woody Regeneration in Exotic Tree Plantations and Natural Forest in Southern Philippines. *Forest Science and Technology* 13(1): 31–40. DOI: 10.1080/21580103.2017.1292958

Roylance, D. 2001. *Stress-Strain Curves*. Massachusetts Institute of Technology Study. Cambridge, UK.

Sahri, M. H., Ashaari, Z., Kader, R. A. and Mohmod, A. L. 1998. Physical And Mechanical Properties of *Acacia mangium* and *Acacia Auriculiformis* from Different Provenances. *Pertanika Journal of Tropical Agricultural Science* 21(2): 73–81.

Shepherd, M.R., Hambric, S.A. and Wess, D.B. 2014. The Effects of Wood Variability on The Free Vibration of an Acoustic Guitar Top Plate. *The Journal of The Acoustical Society of America* 136(5): el357–el361. DOI: 10.1121/1.4898740

Shukla, M. 2023. *Studies on Wood Quality Characteristics of Melia Species*. [Thesis]. College of Forestry, India.

Sikora, A., Gaffová, Z., Rajnoha, R., Šatanová, A. and Kminiak, R. 2017. Deflection of Densified Beech and Aspen Woods as a Function of Selected Factors. *BioResources* 12(2): 3192–3210. DOI: 10.15376/biores.12.2.3192-3210

Somadona, S., Sribudiani, E., Valencia, D. E. 2020. Karakteristik Balok Laminasi Kayu Akasia (*Acacia mangium*) dan Meranti (*Shorea leprosula*) berdasarkan Susunan Lamina dan Berat Labur Perekat Styrofoam. *Jurnal Kehutanan Wahana Foresta* 15(2): 54–64. DOI: 10.31849/forestra.v15i2.5039

Svoboda, T., Gaffová, Z., Rajnoha, R., Šatanová, A. and Kminiak, R. 2017. Bending Forces at The Proportionality Limit and the Maximum–Technological Innovations for Better Performance in Wood Processing Companies. *BioResources* 12(2): 4146–4165. DOI: 10.15376/biores.12.2.4146-4165

Telrandhe, U. B., Kosalge, S. B., Parihar, S., Sharma, D. and Hemalatha, S. 2022. Collection and Cultivation of *Swietenia macrophylla* King. *Scholars Academic Journal of Pharmacy* 11(1): 13–19. DOI: 10.36347/sajp.2022.v11i01.003

Tesoro, F. O., and Aday, J. U. 1990. *Properties and Uses of Some Philippine Woods*. Forest Products Research and Development Institute, DOST, College, Laguna.

Van Der Maaten-Theunissen, M., Boden, S., Van Der Maaten, E. 2013. Wood Density Variations of Norway Spruce (*Picea abies* L. Karst.) under Contrasting Climate Conditions in Southwestern Germany. *Annals of Forest Research* 56(1): 91–103. DOI: 10.15287/afr.2013.46

Van Duong, D. and Hasegawa, M. 2021. Predicting Mechanical Properties of Clear Wood from *Acacia Mangium* Provenances using Ultrasound. *BioResources* 16(4): 8309–8319. DOI: 10.15376/biores.16.4.8309-8319

Vieira, W. D. L., Amorim, E. P., Correa, C. C., Freitas, M. L. M., Ballarin, A.W., Tomazello-Filho, M., Guerrini, I. A., Rossi, M. and Longui, E. L. 2021. Effect of Soil Type on Mean Annual Increment, Wood Anatomy and Properties of 33-Year-Old *Corymbia citriodora* (Hook.), KD Hill, and LAS Johnson. *Research, Society and Development* 10(10): 1–22. DOI: 10.33448/rsd-v10i10.19004.

Wahab, R., Ghani, R.S.M., Samsi, H.W. and Rasat, M.S.M. 2017. Colour, Strength and Chemical Alteration of *Acacia mangium* Wood Treated in Oil Heat Treatment. *Canadian Journal of Pure and Applied Sciences* 11: 4169–4181.

Yang, B.Z., Seale, R.D., Shmulsky, R., Dahlen, J. and Wang, X. 2017. Comparison of Nondestructive Testing Methods for Evaluating No. 2 Southern Pine Lumber: Part B, Modulus of Rupture. *Wood and Fiber Science* 47(4): 375–384.