Original Article

e-ISSN: 2581-0545 - https://journal.itera.ac.id/index.php/jsat/

Received 30th September 2025
Accepted 19th June 2026
Published 30th June 2026

Open Access

DOI: 10.35472/jsat.v10i1.2440

Quality Improvement of Simalambuo Wood (*Lophopetalum* spp.) through Thermal Impregnation of Liquid Smoke for Structural Reinforcement and Termite Repellency

Liver Zai *, Hestina, Erdiana, Vivi Purwandari, Rizky Saragih

Department of Chemistry, Faculty of Science, Technology, and Information, Universitas Sari Mutiara Indonesia, Indonesia

** Corresponding E-mail:* liverzai@sari-mutiara.ac.id

Abstract: This study aims to examine the effect of thermal impregnation using liquid smoke on the physical, mechanical, and biological properties of Simalambuo wood (*Lophopetalum* spp.). The wood samples were impregnated with liquid smoke at a pressure of 2.5 bar and subsequently subjected to thermal treatment at temperatures of 130, 150, 170, and 190 °C. The observed physical properties included color, specific gravity, and water absorption, while the mechanical properties tested included the modulus of elasticity (MoE) and modulus of rupture (MoR). A termite resistance test was conducted to evaluate the effectiveness of the treatment. The results showed that thermal impregnation with liquid smoke caused the wood color to become darker, increased specific gravity at lower treatment temperatures, decreased water absorption, and enhanced resistance to termite attacks. However, an increase in treatment temperature led to a decrease in the mechanical properties of the wood, namely the MoE and MoR values. Overall, thermal impregnation using liquid smoke improved the dimensional stability and biological resistance of Simalambuo wood, despite being accompanied by a partial reduction in its mechanical strength. These findings indicate that this eco-friendly method has the potential to enhance wood performance for structural and other applications.

Keywords: *liquid smoke impregnation, mechanical properties, physical properties, Simalambuo wood, thermal treatment*

Introduction

Wood is one of the most widely used materials due to its workability, high mechanical strength-to-density ratio, and status as a renewable natural resource [1]. In addition, its natural texture provides high aesthetic value, making wood a popular material in construction and even considered a symbol of luxury in various countries [2]. However, excessive forest exploitation has led to deforestation, which remains a serious global issue to date [3].

The growing population and the increasing demand for construction materials have driven higher wood consumption, while the availability of wood from natural forests is no longer able to meet these demands. This situation has led to a shift in wood utilization towards fast-growing tree species. However, wood from fast-growing trees generally possesses several drawbacks, such as high water absorption and susceptibility to decay [4], low density, and inadequate mechanical strength [5]. Consequently, this type of wood is more prone to physical damage, such as cracking, fracturing, and warping induced by changes in environmental moisture content [6].

One effort to overcome these weaknesses is through wood modification techniques, particularly impregnation, which is considered more eco-friendly compared to other treatment methods [7]. Previous research demonstrated that Simalambuo wood (*Lophopetalum* spp.) modified through thermal treatment using coconut oil experienced a decrease in water absorption from 162% to 16% and an improvement in dimensional stability from 8.4% to 4.2%. The process was carried out by immersing the wood in coconut oil at temperatures of 130–210 °C for six hours, with an oil absorption rate reaching 174%. The results of this study indicated that impregnation using coconut oil is effective in enhancing the wood's resistance to water and deformation [8].

In general, wood modification aims to improve dimensional stability, durability, and weathering resistance [9][10]. The impregnation technique itself is performed by filling the wood pores with specific substances to improve its physical properties and enhance its durability [11][12]. In this study, liquid smoke was selected as the impregnating agent. Liquid smoke is a byproduct of the pyrolysis of organic materials, such as wood and coconut shells, which contains various active compounds, including phenols, organic acids, and carbonyls. These compounds are known to act as natural preservatives that can enhance wood resistance against microorganisms and termites, reduce hygroscopicity, and improve the dimensional stability of the wood [13].

Therefore, the application of thermal impregnation using liquid smoke is expected to improve the quality of Simalambuo wood (*Lophopetalum* spp.), making it more resistant to water and termite attacks. This quality enhancement has the potential to make Simalambuo wood a more optimal alternative material for structural components as well as various other applications.

Method

Simalambuo wood (*Lophopetalum* spp.) samples were prepared in dimensions of 30 × 2 × 2 cm and 2 × 2 × 2 cm in accordance with the British Standard BS 373:1957, as well as 2.5 × 2.5 × 0.5 cm in accordance with SNI 01-7207-2006. The samples were then oven-dried to a constant weight and cooled in a desiccator for 2 hours. Subsequently, the samples were weighed using a digital balance, and their volumes were measured using a digital caliper to obtain the initial data.

The liquid smoke used in this study was derived from the pyrolysis of coconut shells with a concentration of 100% (v/v) as the impregnation medium. The characteristics of the liquid smoke, which is rich in phenolic compounds, organic acids, and carbonyls, are expected to improve the physical, mechanical, and biological resistance properties of the wood.

The impregnation process was carried out by immersing 30 replicate samples into the liquid smoke solution within an impregnation chamber. A constant pressure of 2.5 bar was applied for 2 hours to allow the liquid smoke to optimally penetrate the wood structure. After the impregnation process was completed, the samples were oven-dried again until a constant weight was reached. In the polymerization stage, the samples were wrapped in aluminum foil and heated at temperatures of 130 °C, 150 °C, 170 °C, and 190 °C for 4 hours.

The characterization of physical properties was conducted through color, specific gravity, and water absorption tests. Mechanical properties were evaluated through the testing of the modulus of elasticity (MOE) and modulus of rupture (MOR). Additionally, a termite resistance test was performed to assess the effectiveness of the applied treatments. The research data were statistically analyzed by comparing the physical and mechanical properties of the wood before and after treatment, as well as evaluating the effect of temperature variations on dimensional stability, structural strength, and wood resistance against termite attacks.

Results And Discussion

Color Change Analysis of Simalambuo Wood Following Thermal Impregnation with Liquid Smoke

The thermal impregnation treatment using liquid smoke had a significant effect on the color changes of Simalambuo wood. In **Figure 1**, the wood color exhibited a darkening trend from the control sample (A) up to the treatment at a temperature of 190 °C (E).

Figure 1. Color changes of Simalambuo wood from the control (A) to treatments at 130 °C (B), 150 °C (C), 170 °C (D), and 190 °C (E).

Quantitative color measurements (**Table 1**) showed that the lightness value (L*) decreased from 41.54 in the control to 30.36 at 190 °C. The decrease in the L* value indicates that the wood color became darker with increasing treatment temperatures. The a* value increased at 130 °C (14.30), then decreased to 4.08 at 190 °C. Meanwhile, the b* value decreased from 19.88 in the control to 2.48 at 190 °C, indicating a reduction in the yellow color intensity of the wood.

The total color difference (ΔE*) value, calculated based on the differences in the L*, a*, and b* parameters relative to the control sample, showed an increasing trend along with the rise in treatment temperature. The ΔE* values were 9.61, 11.98, 14.29, and 21.43 for the 130, 150, 170, and 190 °C treatments, respectively. The highest ΔE* value was obtained at 190 °C, indicating that this treatment produced the greatest color change compared to the control wood. Based on the color difference classification, all treatments had a ΔE* > 6, which indicates that the color changes are classified as high to very contrasting and can be clearly observed visually.

Table 1. Color measurement results of the control Simalambuo wood and after liquid smoke impregnation at various treatment temperatures.

Color Parameter	Control	Temperature (°C)			
		130	150	170	190
L*	41,54	39,56	37,04	34,48	30,36
a*	9,88	14,3	11,86	9,06	4,08
b*	19,88	10,94	9,48	5,84	2,48
ΔE*	0,00	10,17	12,95	15,32	21,48

The research results indicated that thermal treatment using liquid smoke caused a significant color change in Simalambuo wood. The decrease in the L*, a*, and b* values, as well as the increase in the ΔE* value, corresponds to the formation of a darker color resulting from hemicellulose degradation, oxidation reactions, and changes in the lignin structure during the heating process. Furthermore, the phenolic compounds contained in the liquid smoke can undergo condensation and form chromophores, which contribute to the darkening of the wood color. These findings are consistent with previous research reporting that heat treatment can cause wood to become darker due to internal chemical modifications within the wood structure [14].

Specific Gravity Evaluation of Simalambuo Wood Following Thermal Impregnation with Liquid Smoke

The specific gravity test was conducted to determine the density level of Simalambuo wood after the thermal impregnation treatment using liquid smoke. Specific gravity serves as one of the key indicators of wood quality, as a higher specific gravity value indicates that the wood structure tends to be denser, stronger, and more stable.

Table 2. Specific gravity of the control Simalambuo wood and after liquid smoke impregnation at various treatment temperatures.

Treatment	Specific Gravity (g/cm³) ± SD
Control	0,6609 ± 0,0057
130 °C	0,7235 ± 0,0039
150 °C	0,7459 ± 0,0108
170 °C	0,6937 ± 0,0057
190 °C	0,6801 ± 0,0110

Table 2 shows that the control wood had a specific gravity of 0.6609 g/cm³. After the thermal impregnation treatment, this value increased to 0.7235 g/cm³ at 130 °C and reached its highest value at 150 °C, which was 0.7459 g/cm³. However, at higher temperatures (170 °C and 190 °C), the specific gravity decreased to 0.6937 g/cm³ and 0.6801 g/cm³, respectively.

The increase in specific gravity at temperatures of 130–150 °C indicates that the compounds contained in the liquid smoke successfully penetrated and filled the wood cell cavities, thereby increasing the mass and density of the wood. This phenomenon demonstrates the effectiveness of the impregnation process in improving the internal structure of the wood.

Conversely, the decrease in specific gravity at 170 °C and 190 °C is attributed to the thermal degradation of the wood's structural components, particularly hemicellulose, which has lower thermal stability compared to cellulose and lignin. This degradation leads to mass loss due to the release of volatile compounds, thereby reducing the specific gravity of the wood. These results are consistent with various studies on the thermal modification of wood, which show that an increase in treatment temperature can cause mass loss due to the decomposition of the wood's organic constituents [15].

Water Absorption Evaluation of Simalambuo Wood Following Thermal Impregnation with Liquid Smoke

The water absorption test results (**Figure 2**) clearly demonstrate the difference between the control wood and the wood treated with thermal impregnation using liquid smoke. The control wood exhibited very high water absorption, exceeding 140% after 196 hours of immersion, which indicates the hygroscopic nature of the wood's natural pores.

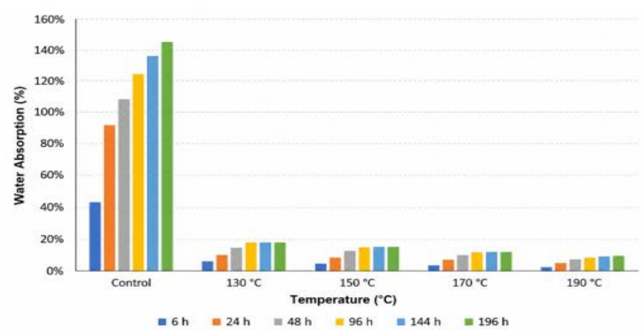

Figure 2. The effect of thermal impregnation using liquid smoke on the water absorption of Simalambuo wood at various treatment temperatures of 130, 150, 170, and 190 °C compared to the control (measurement interval: 6–196 hours).

Published by: Lembaga Penelitian dan Pengabdian Masyarakat (LPPM)
Institut Teknologi Sumatera, Lampung Selatan, Indonesia

Conversely, the samples treated at temperatures of 130–190 °C showed a significant decrease in water absorption, with values remaining below 20%, even after prolonged immersion. As the treatment temperature increased, water absorption tended to decrease, indicating that the impregnation process and thermal transformation enhanced the wood's resistance to water.

This phenomenon is consistent with literature stating that heat treatment causes a reduction in hydroxyl groups (-OH) through the degradation of hemicellulose and the formation of cross-links between lignin and extractive compounds, thereby reducing the wood's ability to absorb water [16]. Furthermore, previous studies noted that the thermal modification of wood causes changes in its chemical structure and reduces its hygroscopic properties, including water absorption, within a suitable temperature range for the modification process [17].

Thus, the results of this study support that the thermal impregnation method using liquid smoke is effective in reducing the water absorption of the wood, thereby improving the dimensional stability and potential durability of Simalambuo wood.

Modulus of Elasticity (MoE) Evaluation of Simalambuo Wood Following Thermal Impregnation with Liquid Smoke

The Modulus of Elasticity (MoE) test results of Simalambuo wood are shown in **Figure 3**. The control wood exhibited the highest MoE value, which was approximately 1.6 GPa, whereas the wood subjected to thermal treatment showed a decrease in elasticity. At 130 °C, the MoE value decreased to approximately 1.3 GPa and continued to decline to around 1.1 GPa at 150 °C. However, at 170 °C, the MoE value slightly increased to approximately 1.4 GPa, before decreasing again to around 1.2 GPa at 190 °C.

The decrease in the MoE value indicates that the thermal treatment affected the stiffness of the wood, although fluctuations occurred at specific temperatures. This finding is consistent with previous research reports stating that thermal treatment causes a reduction in MoE and MOR values due to the thermal degradation of cell wall components, particularly hemicellulose [18]. However, under certain moderate treatment conditions, an increase or stabilization of the MoE value may occur as a result of internal restructuring within the wood [19].

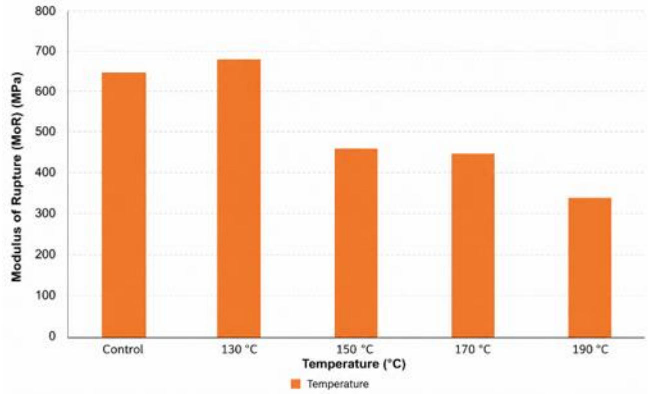

Figure 3. Static bending strength (MoE) values of the control Simalambuo wood and Simalambuo wood after thermal impregnation using liquid smoke at various treatment temperatures of 130, 150, 170, and 190 °C.

Modulus of Rupture (MoR) Discussion of Simalambuo Wood Following Thermal Impregnation

The Modulus of Rupture (MoR) values of Simalambuo wood, both for the control and after thermal impregnation at temperatures of 130 °C, 150 °C, 170 °C, and 190 °C, are presented in the **Figure 4**. The control wood exhibited an MoR value of approximately 650 MPa. A slight increase in the MoR value to around 690 MPa was observed at 130 °C, indicating that mild thermal treatment can enhance wood strength. This increase is likely due to the partial polymerization of extractive compounds and the improvement of bonds within the wood cell wall matrix.

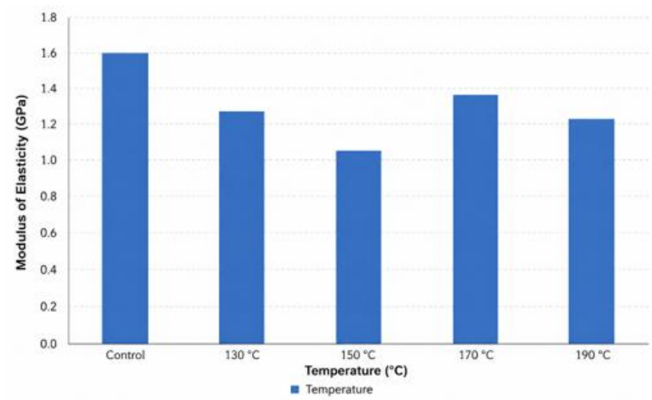

Figure 4. Modulus of Rupture (MoR) values of the control Simalambuo wood and Simalambuo wood after thermal impregnation at temperatures of 130, 150, 170, and 190 °C.

However, at higher temperatures of 150 °C and 170 °C, the MoR value decreased to approximately 460–450 MPa, and continued to decline to about 330 MPa at 190 °C. This trend indicates that thermal treatment at high temperatures tends to reduce the bending strength of Simalambuo wood. The decrease in the MoR value at high temperatures is consistent with previous research findings, which indicate that thermal treatment can cause the degradation of hemicellulose and amorphous cellulose, as well as changes in the lignin structure, ultimately leading to a reduction in the mechanical strength of the wood [14].

These results suggest that thermal impregnation at a moderate temperature (130 °C) can slightly increase wood strength. However, excessive thermal exposure can compromise the structural integrity of Simalambuo wood. Therefore, the optimization of treatment temperature is required to achieve a balance between dimensional stability, durability, and the mechanical performance of the wood.

Dry-Wood Termite Resistance Evaluation of Simalambuo Wood

Figure 5 shows the results of the dry-wood termite resistance test on Simalambuo wood based on the weight loss percentage after liquid smoke impregnation at temperatures of 130 °C, 150 °C, 170 °C, and 190 °C. The control sample experienced the highest weight loss, which was 7.72%, indicating a relatively high level of damage due to termite attacks. In contrast, the treated wood samples exhibited lower weight losses, specifically 3.6% at 130 °C, 3.9% at 150 °C, 4.1% at 170 °C, and the lowest value of 2.3% at 190 °C.

These results indicate that liquid smoke impregnation effectively increases the resistance of Simalambuo wood to termite attacks, with the highest effectiveness observed at the treatment temperature of 190 °C. Previous research demonstrated that smoke treatment on fast-growing tropical wood significantly increased resistance to *Coptotermes curvignathus* attacks due to the presence of phenolic compounds and organic acids that are toxic to termites [20].

In addition, previous studies found that liquid smoke derived from Bintangur wood at a concentration of 6–8% could cause up to 100% termite mortality, indicating that the chemical components in liquid smoke are effectively used as a natural bio-preservative [21].

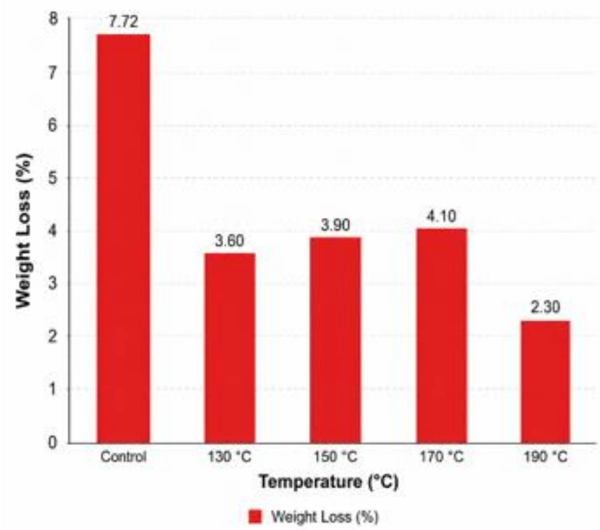

Figure 5. Dry-wood termite resistance test on control Simalambuo wood and Simalambuo wood after liquid smoke treatment at temperatures of 130, 150, 170, and 190 °C.

Thus, liquid smoke impregnation on Simalambuo wood can be considered an eco-friendly method to enhance wood durability against termite attacks while reducing reliance on synthetic chemical preservatives.

Based on the dry-wood termite resistance classification, the samples treated at 130, 150, and 170 °C, with weight losses ranging from 4.4–8.2%, are categorized into resistance class III (moderate). Meanwhile, the sample treated at 190 °C, with a weight loss of 2.3%, is categorized into resistance class II (resistant), which corresponds to the weight loss range of 2.0–4.4%.

Conclusions

The liquid smoke impregnation combined with thermal treatment on Simalambuo wood induced several alterations in the wood's properties, including color darkening, increased specific gravity at lower temperatures, decreased water absorption, and enhanced termite resistance. However, treatments at elevated temperatures tended to reduce the mechanical properties of the wood, affecting both the Modulus of Elasticity (MoE) and the Modulus of Rupture (MoR). Overall, the thermal treatment using liquid smoke effectively improved the dimensional stability and biological durability of the wood, albeit with a compromise in its mechanical strength.

Published by: Lembaga Penelitian dan Pengabdian Masyarakat (LPPM)
Institut Teknologi Sumatera, Lampung Selatan, Indonesia

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

The authors would like to express their gratitude to the Directorate of Research, Technology, and Community Service (DRTPM), Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) of the Republic of Indonesia for financially supporting this research through the BIMA grant scheme, fiscal year 2025.

References

[1] H. Sun, Z. Ren, T. Ji, H. Bi, and M. Xu, "Mechanically strong, cost-efficiency, and sustainable fully wood-derived structural material from fast-growing wood," J. Mater. Res. Technol., vol. 14, pp. 3043–3050, 2021.

[2] J. P. Cabral, B. Kafe, M. Subhani, J. Reiner, and M. Ashraf, "Densification of timber: a review on the process, material properties, and application," J. Wood Sci., vol. 68, no. 20, pp. 1–24, 2022.

[3] S. Chen, C. Woodcock, L. Dong, K. Tarrio, D. Mohammadi, and P. Olofsson, "Review of drivers of forest degradation and deforestation in Southeast Asia," Remote Sens. Appl.: Soc. Environ., vol. 33, p. 101129, 2024.

[4] I. Rahayu, A. S. M. Rohmatillah, E. Prihatini, W. Darmawan, G. D. Laksono, and V. J. Sitanggang, "Fast-growing wood-polymer nano composite characteristics through NaNo-SiO_2 impregnation," Wood Res. J., vol. 13, no. 2, pp. 69–78, 2022.

[5] T. Langella, M. Mikulijan, L. Han, M. Zouari, and D. B. DeVallance, "Modification of wood via biochar particle impregnation," Eur. J. Wood Wood Prod., vol. 82, pp. 773–783, 2024.

[6] X. Ma, Y. Zhang, P. Li, Y. Zhou, J. Yang, and Y. Zuo, "An eco-friendly strategy of cell wall stapling: In situ crosslinking of fast-growing poplar wood for enhanced dimensional stability and mechanical properties," Ind. Crops Prod., vol. 222, p. 119657, 2024.

[7] M. Tao, X. Liu, and W. Xu, "Effect of the vacuum impregnation process on water absorption and nail-holding power of silica sol-modified Chinese fir," Forests, vol. 15, no. 2, pp. 1–14, 2024.

[8] [8] L. I. P. Zai, S. Gea, Marpongahtun, Eddyanto, N. Azizah, and A. H. Siswanto, "Coconut oil effect on the hygroscopic properties of Simalambuo wood (Lophopetalum spp.)," Jurnal Natural, vol. 22, no. 2, pp. 78–84, 2022.

[9] I. Rahayu, A. Pratama, W. Darmawan, D. Nandika, and E. Prihatini, "Characteristics of impregnated wood by nano silica from betung bamboo leaves," IOP Conf. Ser.: Earth Environ. Sci., vol. 891, p. 012019, 2021.

[10] S. Xie et al., "Flame retardant modification of poplar wood based on sustainable impregnation solution with high biomass content," Ind. Crops Prod., vol. 215, p. 118616, 2024.

[11] E. Prihatini, I. Wahyuningtyas, I. S. Rahayu, and R. Ismail, "Modification of fast-growing wood into magnetic wood with impregnation method using Fe_3O_4 nanoparticles," Jurnal Sylva Lestari, vol. 11, no. 2, pp. 204–217, 2023.

[12] S. Gea, Kimia Kayu dan Modifikasi Kayu. Medan, Indonesia: USU Press, 2021.

[13] L. Alamsyah, S. P. A. Anggraini, and S. Yuniningsih, "Teknologi aplikasi asap cair grade 3 tempurung kelapa terhadap kualitas kayu meranti," in Pros. Semin. Nas. Teknologi Industri, Lingkungan dan Infrastruktur (SENTIKUIN), 2020, vol. 3, pp. C12.1–C12.7.

[14] C. Hill, M. Altgen, and L. Rautkari, "Thermal modification of wood—a review: chemical changes and hygroscopicity," J. Mater. Sci., vol. 56, no. 10, pp. 6581–6614, 2021, doi: 10.1007/s10853-020-05722-z.

[15] H. Liu, Z. Li, X. Zhang, B. Tang, C. Wan, and K. Wang, "The effect of different moderate thermal modification durations on the wood properties of American alder," Materials, vol. 15, no. 24, p. 8839, 2022, doi: 10.3390/ma15248839.

[16] A. Masoumi and B. H. Bond, "Dimensional stability and equilibrium moisture content of thermally modified hardwoods," BioResources, vol. 19, no. 1, pp. 1218–1228, 2024, doi: 10.15376/biores.19.1.1218-1228.

[17] V. Jančíková and M. Jablonský, "Thermal modification of wood—a review," Sustain. Chem., vol. 6, no. 3, p. 19, 2025, doi: 10.3390/suschem6030019.

[18] O. Bytner, M. Drożdżek, A. Laskowska, and J. Zawadzki, "Influence of thermal modification in nitrogen atmosphere on the selected mechanical properties of black poplar wood (Populus nigra L.)," Materials, vol. 15, no. 22, p. 7949, 2022, doi: 10.3390/ma15227949.

[19] F. Nhacila, E. Sitoe, E. Uetimane, A. Manhica, A. Egas, and V. Möttönen, "Effects of thermal modification on physical and mechanical properties of Mozambican Brachystegia spiciformis and Julbernardia globiflora wood," Eur. J. Wood Wood Prod., vol. 78, no. 5, pp. 871–878, 2020, doi: 10.1007/s00107-020-01576-z.

[20] Y. S. Hadi et al., "Color change and termite resistance of fast-growing tropical woods treated with kesambi (Schleichera oleosa) smoke," J. Wood Sci., vol. 66, p. 61, 2020, doi: 10.1186/s10086-020-01906-y.

[21] H. A. Oramahi, F. Diba, and Juanita, "Anti-termites properties of liquid smoke from bintangur wood," Jurnal Sylva Lestari, vol. 9, no. 3, pp. 400–410, 2021, doi: 10.23960/jsl.v9i3.515.