Belangke Bamboo (*Gigantochloa pruriens*) Laminated Board Modified with Polystyrene, Citric, and Boric Acid: Resistance from Termite and Decay Attacks

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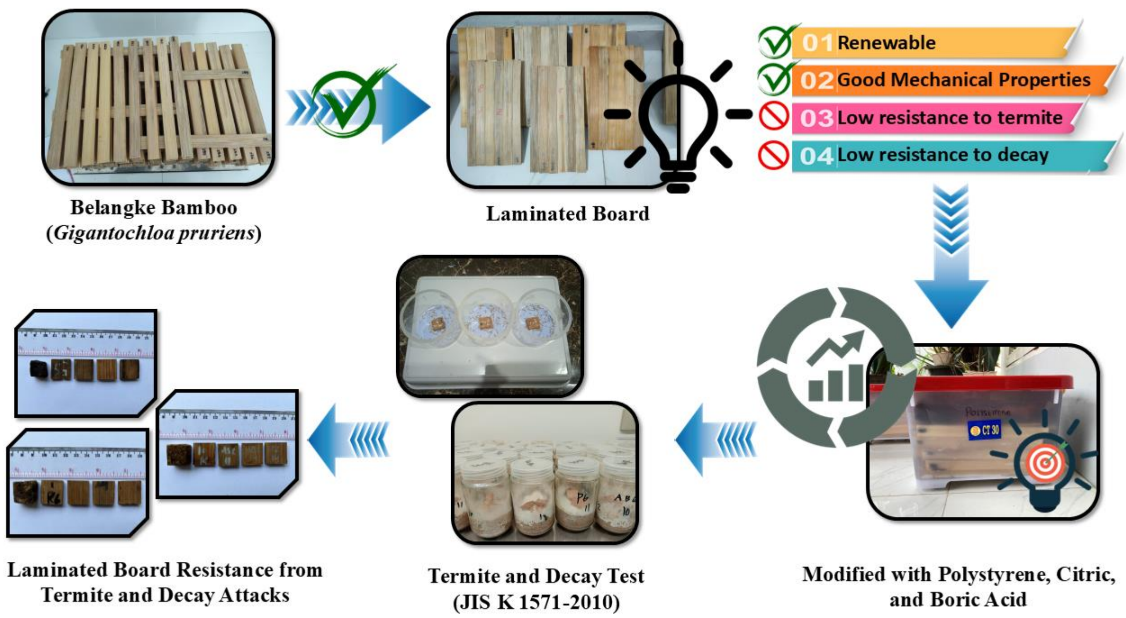
GRAPHICAL ABSTRACT



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Polystyrene, citric, and boric acid are capable of enhancing the quality of bamboo as a raw material for laminated board (LB). Although the characteristics of the modified LB has met the JAS 234 (2003) standard, the resistance against termite and decay attacks was still unknown. In this work, a 6-h immersion time was used to immerse bamboo lamina in polystyrene, citric, and boric acid. Laminated board comprising 3 layers of 30 cm x 15 cm x 1.5 cm (length x width x thickness) were constructed using 280 g/m^2 isocyanate adhesive from bamboo lamina using double-spread adhesive method. This was followed by resistance testing against termite wood and decay caused by *T. versicolor* and *F. palustris* using the JIS K 1571 (2010) standard. Parameters calculated after testing for termite included weight loss and mortality, while weight loss was determined after evaluating the decay using JIS standard. The results showed that modification with polystyrene, citric, and boric acid slightly increased the resistance of LB from belangke bamboo against termite and decay attacks. In comparison, samples modified with polystyrene had lower weight loss than others, which showed high resistance to attacks. This showed that modification with polystyrene could be recommended to improve the quality of LB from belangke bamboo.

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Keywords: Bamboo; Belangke bamboo; Laminate board; Modifications; Termite resistance; Decay resistance

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INTRODUCTION

Bamboo is the most-produced non-timber forest product in Indonesia (Wardana *et al.* 2022). The Central Bureau of Statistics (2020) estimated that the country produced about 25,900 tons of bamboo. This forest product is a non-timber material with significant basic qualities, short rotation cycles, fast-growing species (3 to 5 years), and high productivity, reaching 20 to 40 tons/ha/year (Artiningsih 2012; Febrianto *et al.* 2015;

Siswanto *et al.* 2022). In recent years, the demand for bamboo has increased due to a decrease in the quantity and quality of raw wood products (Febrianto *et al.* 2015). The widespread application as a building material compared to wood is attributed to high modulus elasticity (Sinarta *et al.* 2020; Yadav and Mathur 2021; Andriani and Putra 2022).

Among several species, belangke bamboo (*Gigantochloa pruriens*) is a potential building material. It is a native species of North Sumatra, which has expanded to the districts of Karo and Gayo (Iswanto *et al.* 2022). According to the previous study, belangke bamboo was found to have a density of 580 to 610 kg/m^3 and high strength (Iswanto *et al.* 2020). Furthermore, belangke bamboo is superior to others due to longer fibers (Darwis *et al.* 2020), showing potential for application in the development of composite board (Belatrix *et al.* 2022; Hartono *et al.* 2022; Iswanto *et al.* 2022).

Particleboard and laminated board (LB) are composite boards made from bamboo. According to Iswanto *et al.* (2022), belangke bamboo particleboard has excellent mechanical qualities, with the ability to improve quality of wood particleboard when applied as a surface coating (Savov *et al.* 2023). A previous study reported that lamina bamboo had a modulus of rupture and elasticity ranging from 60 to 68 MPa and 73 to 83 MPa, respectively (Nurmalasari and Goestav 2020). This showed that the mechanical qualities of the raw bamboo used in LB were good (Hartono *et al.* 2022; Wulandari *et al.* 2022). Despite the significant potential, the disadvantages of using bamboo as a raw material for LB included high susceptibility to attack by harmful organisms, showing the need for modification (Iswanto and Togatorop 2019; Mahawan Sumawa *et al.* 2019).

In this context, polystyrene, citric, and boric acid modification has been shown to be effective in enhancing the quality of bamboo as a raw material for LB. Compared to LB modified with citric and boric acid, modification using polystyrene has a higher modulus of rupture, elasticity, density, and shear strength, alongside less delamination (Hartono *et al.* 2024). LB modified with a 6-h immersion in polystyrene met JAS 234 (2003) standards regarding density, moisture content (MC), delamination, modulus of rupture, and elasticity (Hartono *et al.* 2024). Despite the significant results, the resistance of LB against termite and decay attacks remains unknown. Therefore, this study aimed to determine the resistance of bamboo LB modified with polystyrene, citric, and boric acid against termite and decay attacks.

EXPERIMENTAL

Raw Material Preparation

Concentrations of 20% citric acid and 5% boric acid were dissolved in water (Basri *et al.* 2022; Priadi *et al.* 2022). Subsequently, the catalyst potassium peroxy-disulfate was combined with 100% polystyrene at a ratio of 1:0.01 v/v (Hadi *et al.* 2021a). Belangke bamboo base was divided into lamina pieces of 30 cm x 2 cm x 0.5 cm (length x width x thickness). This was followed by drying lamina in an oven set at 60 °C for 24 h, or until MC dropped to 10%. For 6 h, bamboo lamina was immersed in several solutions, covered in aluminum foil (polymerization process), and dried for 24 h at 60 °C (Hadi *et al.* 2021a, 2022).

Manufacturing of Laminated Board (LB)

The double adhesive spread method and isocyanate adhesive with a spread level of 280 g/m^2 was used to construct the bamboo lamina into three layers of LB, each measuring

30 cm x 15 cm x 1.5 cm (length x width x thickness) (Hartono *et al.* 2024; Komariah *et al.* 2015; Hadi *et al.* 2022). The isocyanates to hardener ratio used to prepare the isocyanate adhesives was 85:15 (w/w%). LB was cold pressed for 24 h with clamps on all sides and conditioned for 10 days at room temperature, with the steps shown in Fig. 1.

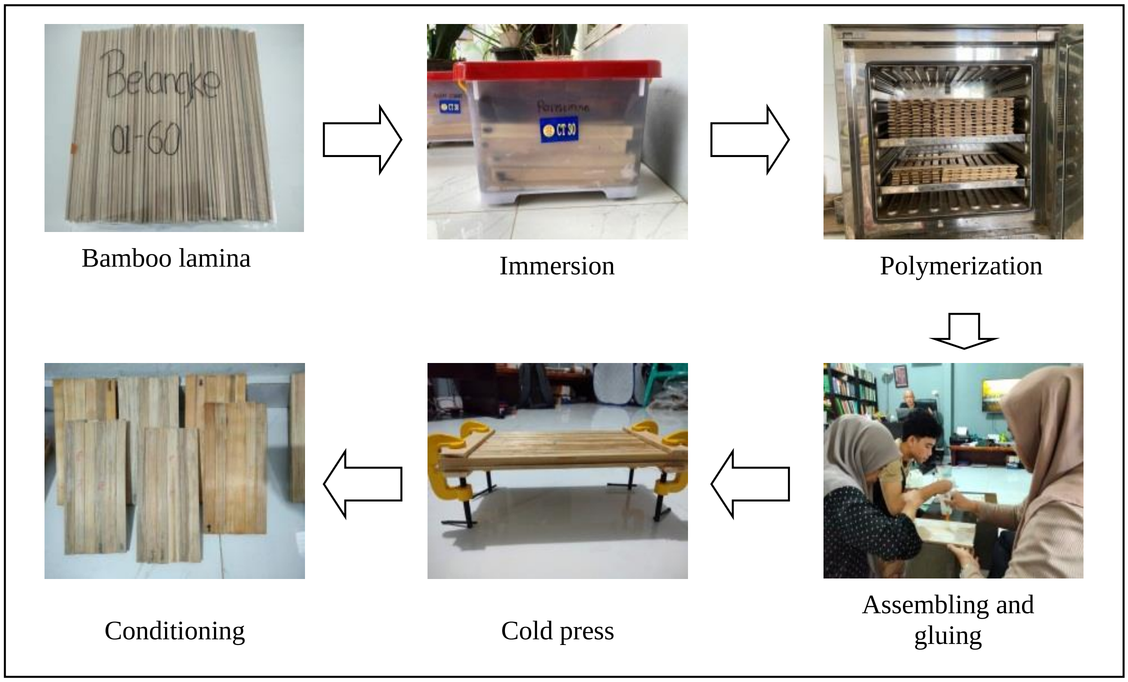

Fig. 1. Manufacturing of laminated board (LB)

Physical Properties Test

MC and density were measured following JAS 234 (2003).

Termite Test

Testing for termite resistance in LB was performed following the JIS K 1571 (2010) standard, as shown in Fig. 2. Parameters calculated after testing for termite with JIS standards consist of weight loss and mortality. Using a plaster bottom (5 mm high), sample blocks (20 x 20 x 10 mm^3) were placed in an acrylic cylinder (65 mm in diameter and 60 mm in height). From a laboratory colony at the National Research and Innovation Agency, 150 laborers and 15 soldiers of *Coptotermes gestroi* were acquired and fed on the sample blocks. During this process, 3 weeks were spent keeping the testing containers dark, between 25 and 30 °C, as well as 80% and 90% relative humidity. For every type of board, 3 replicates were examined, and test samples were cleaned after termite examination and baked for 48 h at 60 °C. Weight loss (WL) and mortality of samples after being fed to termite was calculated based on the following Eqs. 1 and 2,

$$\text{WL (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

$$\text{Mortality (\%)} = \frac{D}{n} \times 100 \quad (2)$$

where W_2 is the mass following testing (g), W_1 is the mass before testing (g), D is the number of dead laborers termite (per piece), and n is the number of laborers termite in the test (150).

Fig. 2. Termite test on LB

Decay (*Trametes versicolor and Fomitopsis palustris*) Test

Based on JIS K 1571 (2010) standards, LB was evaluated against wood-rot decay (*T. versicolor* and *F. palustris*), as shown in Fig. 3. An infection was created in a 100-mL aliquot of liquid medium containing 0.3% peptone, 1.5% malt extract, and 4% glucose using a stock culture of *F. palustris* or *T. versicolor*. The inoculated liquid medium was incubated for 10 days at 26 °C using a shaker set to 120 rpm. A 250 g medium of sea sand was soaked with 80 to 85 mL of a nutrition solution containing 1.5% malt extract, 0.3% peptone, and 4% glucose for *T. versicolor* in a glass container. For *F. palustris*, approximately half of each component was used for analysis. The jars were inoculated with these liquid fungal stock cultures using 3 to 5 mL. Specimens were layered on top of the growing mycelium after spreading to cover the medium in the glass jars.

The 20 × 20 × 5 mm^3 wood blocks from *Hevea brasiliensis* were used as the control. The parameter found was WL% following 48 h of the sample being in an oven at 60 °C after the decay was assessed using JIS K 1571 (2010) standards. Before testing, the mass of LB was obtained through weighing (W_1). The sample was placed in a tightly closed test container to prevent contamination from other decaying objects, and the medium was covered with rotting decay. After 12 weeks, the sample was cleaned and air-dried in an oven at 60 °C for 48 h (W_2). A total of 3 replicates were examined for every board and the value of weight loss (WL) was calculated using the formula below,

$$\text{WL}\ (\%) = \frac{W_1 - W_2}{W_1} \times 100 \qquad (3)$$

where W_2 is the mass following testing (g) and W_1 is the mass before testing (g).

Fig. 3. Decay test on LB

Data Analysis

The type of solution (polystyrene, boric, and citric acids) was one of the variables included in the non-factorial completely randomized design (CRD) method. Analysis of variance (ANOVA) was used for statistical analysis (IBM SPSS Statistics 23, Armonk, NY, USA). The result was considered to have a substantial impact when the significance value of ANOVA was less than 0.05. Therefore, Duncan Multiple Range Test (DMRT) was conducted at a 95% confidence interval.

RESULTS AND DISCUSSION

Compared to LB modified with citric acid (7.00%) and boric acid (3.00%), polystyrene (7.67%) samples had a higher weight percent gain (WPG), as shown in Table 1. LB with polystyrene immersion experienced an increase in weight due to the ability of the cell walls in the bamboo to bind water. Nurhanifah *et al.* (2020) reported that polystyrene impregnation affected WPG of glulam. According to Hadi *et al.* (2021), the impregnation caused the lamina to have a certain amount of polymer loading and weight percent gain. The density increment of polystyrene glulam reached 10.7% compared with untreated glulam. Polystyrene would penetrate the empty pores and polymerize in the anatomical structure of the wood (Hadi *et al.* 2021).

Table 1. Weight Percent Gain, Density, and MC of LB

Characteristic	Control	Untreated	Citric acid	Boric acid	Polystyrene
Weight percent gain (%)	-	-	7.00 (1.00) b	3.00 (1.00) a	7.67 (0.58) b
Density (g/cm^3)	0.52 (0.08) a	0.84 (0.03) b	0.79 (0.04) b	0.82 (0.04) b	0.80 (0.03) b
MC (%)	5.56 (1.60) a	12.48 (0.98) b	10.44 (1.34) b	10.65 (1.09) b	10.65 (1.09) b

Note: The same letters in a column mean that those conditions did not result in significant differences ($p \leq 0.05$), Values in parentheses are standard deviations.

Regarding bamboo strips treated with a 5% boric acid solution, *Gigantochloa levis* had WPG value of 3.6%, *Dendrocalamus asper* was 1.47%, while *Bambusa vulgaris* and *Gigantochloa scortechinii* had 2.9% and 2.0%, respectively (Yusof *et al.* 2023). Each layer of WPG bamboo was subjected to the deposition of boric acid in the cell wall and lumen (Colakoglu *et al.* 2003). Wood modified with citric acid had a WPG of 7% (Feng *et al.* 2014), while those with 20% and 40% produced 25% and 28% WPG, respectively (Basri *et al.* 2022). The results showed that wood modified with citric acid could have higher WPG values and more termite resistance (Treu *et al.* 2020). Table 1 shows that the average density of LB ranged from 0.79 to 0.84, and MC from 10.44 to 12.48%. LB modified with polystyrene, boric, and citric acids had a smaller MC than the untreated LB ($p < 0.05$).

Termite mortality in LB ranged from 16.89% to 100%, as shown in Fig. 4. The mortality of LB modified with polystyrene, boric, and citric acids was higher than control and untreated, showing that termite used was healthy. Figure 4 shows termite WL after a 3-week exposure, which varied between 5.8% and 28.3%. After modification, the results showed that WL was reduced compared to the control wood, indicating the healthy condition of termites. Compared to the untreated, the modified LB had a lower WL by termite ($p < 0.05$) due to the influence of MC. As shown in Table 1, MC of LB modified was lower than untreated samples, which increased the resistance to termite attacks (Hadi *et al.* 2021b). The data analysis also showed that termite WL was significantly influenced by the type of solution used. In comparison, LB treated with boric acid showed lower activity against attacks than polystyrene and citric acid, as presented in Fig. 5.

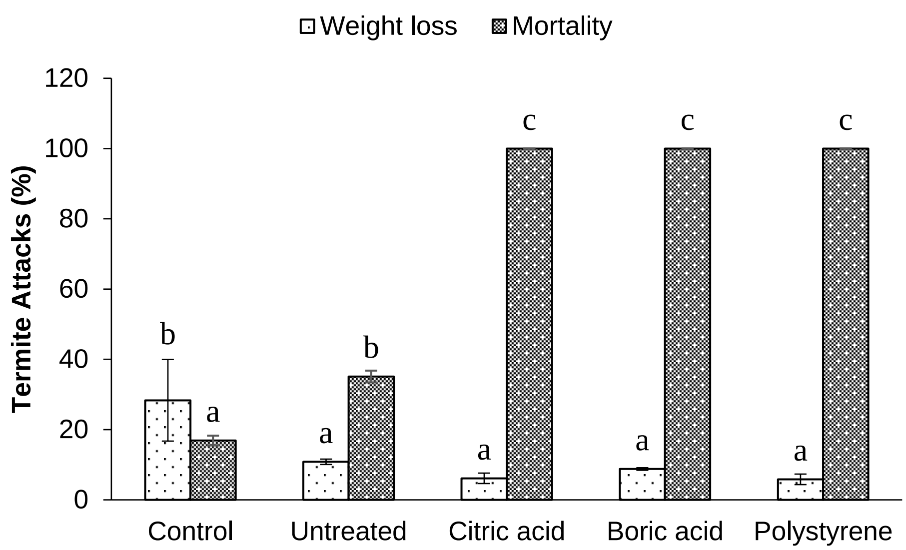

Fig. 4. Weight loss and mortality of LB after exposure to termite

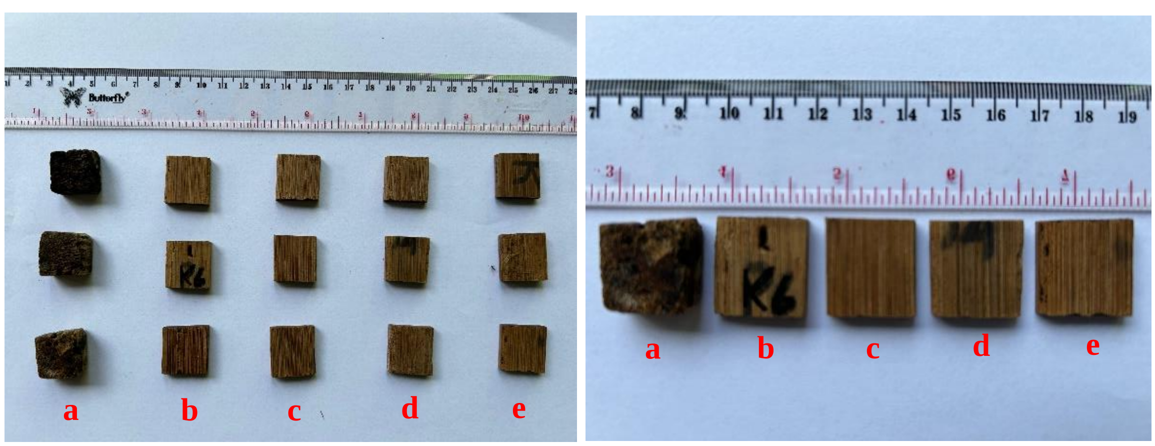

Fig. 5. LB after testing with termite: (a) control, (b) untreated, (c) modified with citric acid, (d) modified with boric acid, and (e) modified with polystyrene

Figure 6 shows WL of LB ranging from 12.3 to 43.8% after 12 weeks of decay by *T. versicolor* and *F. palustris*. In this study, WL of LB treated with polystyrene, boric, and citric acids was lower compared to the control and untreated ($p < 0.05$). Similarly, this phenomenon was impacted by MC, as strand bamboo was the least resistant to attacks by subterranean termite and decay (Iswanto *et al.* 2017). High-starch bamboo was also less resistant to termite than wood (De Melo *et al.* 2015; Maulana *et al.* 2022), as shown in Figs. 7 and 8.

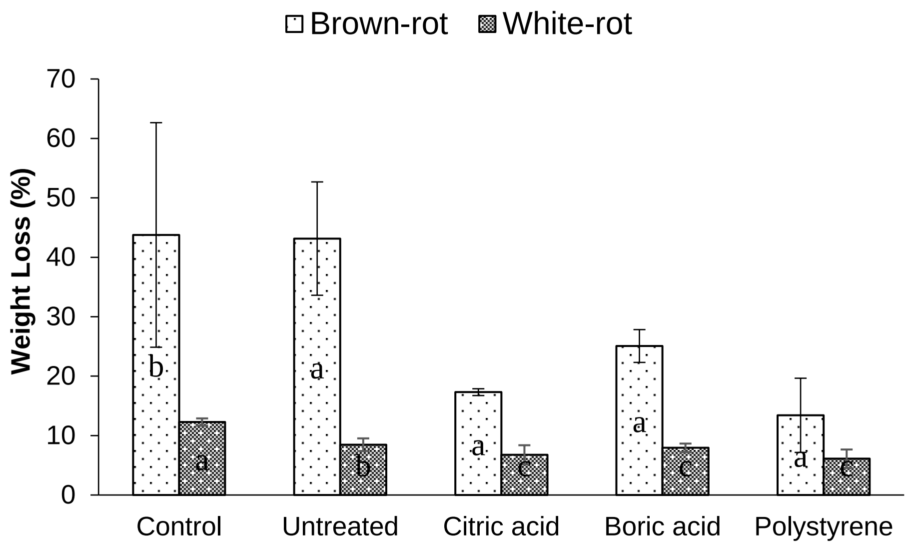

Fig. 6. Weight loss of LB after exposure to decay brown rot and white rot

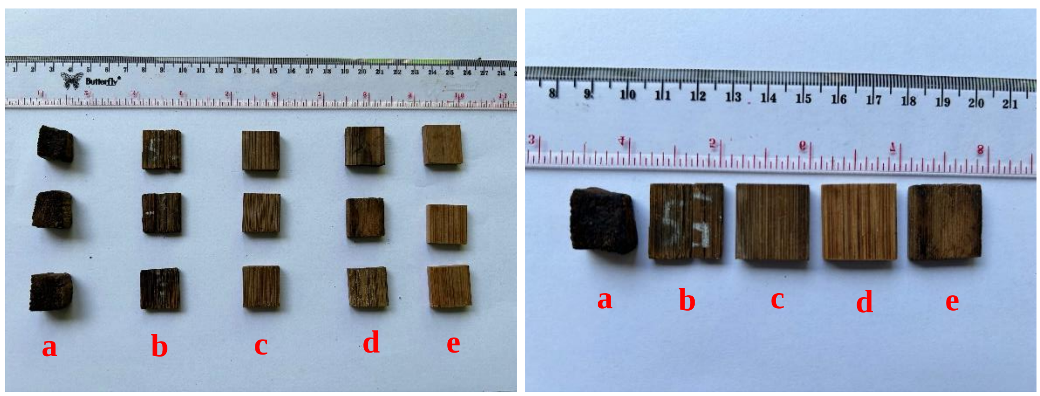

Fig. 7. LB after testing with brown rot: (a) control, (b) untreated, (c) modified with citric acid, (d) modified with boric acid, and (e) modified with polystyrene

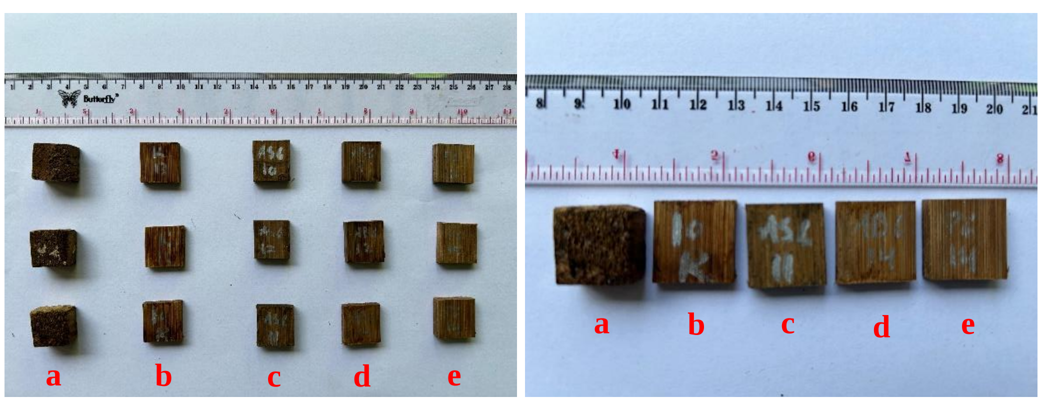

Fig. 8. LB after testing with white rot: (a) control, (b) untreated, (c) modified with citric acid, (d) modified with boric acid, and (e) modified with polystyrene

The effect of citric acid on termite and decay attacks had been explored in various contexts, showing potential benefits in enhancing resistance. Citric acid was found to alter surface morphology in treated materials, leading to reduced debris and bacterial presence, which could contribute to decay resistance (Tanaka *et al.* 1989). In periodontal studies, the application led to a demineralized zone that exposed collagen fibrils, potentially enhancing the material's structural integrity against decay (Garrett *et al.* 1978). Additionally, the role of citric acid in altering material properties could indirectly impact termite behavior. The degradation of termiticides was influenced by the chemical environment, which could be modified by citric acid (Saran and Kamble 2008). This interaction with other compounds potentially enhanced the effectiveness of existing termite treatments.

Boric acid is recognized for its effectiveness as a wood preservative against termite and decay attacks. These unique properties allow enhancement of wood durability while being environmentally friendly. Boric acid also interacts with wood components, forming complexes that reduce leaching and enhance preservative action. The mechanism of interaction allows boron to remain active against pests and reduce environmental impact (Pizzi and Baecker 1996). The combination of boric acid with proteins, such as albumin, leads to a durable, non-toxic wood preservative that significantly retards leaching (Thevenon *et al.* 1998). Treated wood shows resistance to decay fungi and termite, with studies reporting effectiveness after multiple weathering cycles (Yalinkilic *et al.* 1998). Boric acid's antifungal properties are complemented by insecticidal effects, making it a broad-spectrum preservative (Thevenon *et al.* 1998).

The effect of polystyrene on termite and decay attacks is multifaceted, including both degradation processes and interaction with biological agents. Previous studies had shown that polystyrene was relatively resistant to decay, although degradation could be influenced by environmental factors and biological activity. Polystyrene experiences thermal degradation, mainly through pyrolysis, which produces volatile compounds such as styrene. This process is temperature-dependent, as higher temperatures lead to increased styrene emissions (Gurman *et al.* 1987). Accelerated weathering studies show that polystyrene degrades in two stages, namely initial photooxidation followed by microcrack formation, enhancing fragmentation into microplastics (Strohriegl *et al.* 2021). Although polystyrene is not a natural food source for termites, the presence in the environment can affect termite behavior. The degradation products are also capable of altering the habitat, potentially attracting or repelling termites (Braun-Lüllemann *et al.* 1997). Studies on the degradation of styrene by fungi suggest that biological agents can metabolize styrene, showing potential for biological control in polystyrene-rich environments (Braun-Lüllemann *et al.* 1997).

CONCLUSIONS

In conclusion, this study successfully investigated the resistance of laminated board (LB) modified with polystyrene, citric, and boric acid against termite and decay attacks. The results obtained were as follows:

1. LB modified with polystyrene, citric, boric and acids had a higher mortality and lower weight loss (WL) than untreated and control samples at termite attacks.
2. The modification of LB using polystyrene citric, and boric acid had lower weight loss than untreated and control at brown-rot and white-rot decay attacks.
3. The samples modified with polystyrene, citric, and boric acid slightly increased the resistance of LB from belangke bamboo against termite and decay attacks.

4. LB modified with polystyrene had lower WL than other samples, indicating that the samples were more resistant to termite and decay attacks.
5. Based on the results, LB modified with polystyrene was recommended to improve the quality of LB from belangke bamboo.

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REFERENCES CITED

Andriani, C., and Putra, H. A. (2022). "Sifat mekanik bambu sebagai bahan konstruksi [Physical and mechanical properties of bamboo as a construction material]," *Tekstur (Jurnal Arsitektur)* 7(2), 22-31.

Artiningsih, N. K. A. (2012). "Pemanfaatan bambu pada konstruksi bangunan berdampak positif bagi lingkungan [The use of bamboo in building construction has a positive impact for the environment]," *Metana* 8(1), 1-9.

Basri, E., Hanifah, N., Martha, R., Rahayu, I. S., Mubarok, M., Darmawan, W., and Gérardin, P. (2022). "Effect of citric acid and benzophenone tetracarboxyclic acid treatments on stability, durability, and surface characteristic of short rotation teak," *Forests* 13(11), article 1938. DOI: 10.3390/f13111938

Belatrix, N. N., Arnandha, Y., and Firmansyah, D. (2022). "Analisis sifat mekanik lentur papan laminasi kombinasi bambu petung dan bambu ater [Analysis of the flexible mechanical properties of laminated boards combined with petung bamboo and ater bamboo]," *Inersia*, 18(1), 54-61. DOI: 10.21831/inersia.v18i1.48260

Braun-Lüllemann, A., Majcherczyk, A., and Hüttermann, A. (1997). "Degradation of styrene by white-rot fungi," *Applied Microbiology and Biotechnology* 47(2), 150-155. DOI: 10.1007/s002530050904

Central Bureau of Statistics (2020). *Statistik Produksi Kehutanan [Statistics of Forestry Production]*, Direktorat Statistik Peternakan, Perikanan, dan Kehutanan [Directorate of Livestock, Fisheries, and Forestry Statistics], Central Bureau of Statistics, Jakarta, Indonesia.

Colakoglu, G., Colak, S., Aydin, I., Yildiz, U. C., and Yildiz, S. (2003). "Effect of boric acid treatment on mechanical properties of laminated beech veneer lumber," *Silva Fennica* 37(4), article 488. DOI: 10.14214/sf.488

Darwis, A., Iswanto, A. H., Jeon, W. S., Kim, N. H., Wirjosentono, B., Susilowati, A., and Hartono, R. (2020). "Variation of quantitative anatomical characteristics in the culm of belangke bamboo (*Gigantochloa pruriens*)," *BioResources* 15(3), 6617-6626. DOI: 10.15376/biores.15.3.6617-6626

De Melo, R. R., Stangerlin, D. M., Santana, R. R. C., and Pedrosa, T. D. (2015). "Decay and termite resistance of particleboard manufactured from wood, bamboo and rice husk," *Maderas: Ciencia y Tecnologia* 17(1), 55-62. DOI: 10.4067/S0718-221X2015005000006

Febrianto, F., Jang, J. H., Lee, S. H., Santosa, I. A., Hidayat, W., Kwon, J. H., and Kim, N. H. (2015). "Effect of bamboo species and resin content on properties of oriented strand board prepared from steam-treated bamboo strands," *BioResources* 10(2), 2642-2655. DOI: 10.15376/biores.10.2.2642-2655

Feng, X., Xiao, Z., Sui, S., Wang, Q., and Xie, Y. (2014). "Esterification of wood with citric acid: The catalytic effects of sodium hypophosphite (SHP)," *Holzforschung* 68(4), 427-433. DOI: 10.1515/hf-2013-0122

Garrett, J. S., Crigger, M., and Egelberg, J. (1978). "Effects of citric acid on diseased root surfaces," *Journal of Periodontal Research* 13(2), 155-163. DOI: 10.1111/j.1600-0765.1978.tb00164.x

Gurman, J. L., Baier, L., and Levin, B. C. (1987). "Polystyrenes: A review of the literature on the products of thermal decomposition and toxicity," *Fire and Materials* 11(3), 109-130. DOI: 10.1002/fam.810110302

Hadi, Y. S., Hermawan, D., Abdillah, I. B., Mubarok, M., Arsyad, W. O. M., and Pari, R. (2022). "Polystyrene-impregnated glulam resistance to subterranean termite attacks in a laboratory test," *Polymers* 14(19), article 4003. DOI: 10.3390/polym14194003

Hadi, Y. S., Hermawan, D., Sulastiningsih, I. M., Basri, E., Pari, G., Pari, R., and Abdillah, I. B. (2021a). "Color change and physical-mechanical properties of polystyrene-impregnated glulam from three tropical fast-growing wood species," *Forests* 12(10), article 1420. DOI: 10.3390/f12101420

Hadi, Y. S., Mulyosari, D., Herliyana, E. N., Pari, G., Arsyad, W. O. M., Abdillah, I. B., and Gérardin, P. (2021b). "Furfurylation of wood from fast-growing tropical species to enhance their resistance to subterranean termite," *European Journal of Wood and Wood Products* 79(4), 1007-1015. DOI: 10.1007/s00107-021-01676-4

Hartono, R., Iswanto, A. H., Priadi, T., Herawati, E., Farizky, F., Sutiawan, J., and Sumardi, I. (2022). "Physical, chemical, and mechanical properties of six bamboo from sumatera island indonesia and its potential applications for composite materials," *Polymers* 14(22), article 4868. DOI: 10.3390/polym14224868

Hartono, R., Muliani, P. F., Sutiawan, J., Amanda, P., Sumardi, I., and Rofii, M. N. (2024). "Properties of laminated board from Belangke bamboo (Gigantochloa pruriens) modified with citric acid, boric acid, and polystyrene," *Wood Material Science and Engineering* 2024, 1-8. DOI: 10.1080/17480272.2024.2320735

Iswanto, A. H., and Togatorop, R. M. M. (2019). "Effect of particle immersing in various concentrations of acetic acid to enhance the sandwich particleboard (SPb)," *KnE Engineering* 1(2), 20-29. DOI: 10.18502/keg.v1i2.4428

Iswanto, A. H., Aritonang, W., Azhar, I., Supriyanto, and Fatriasari, W. (2017). "The physical, mechanical and durability properties of sorghum bagasse particleboard by layering surface treatment," *Journal of the Indian Academy of Wood Science* 14(1), 1-8. DOI: 10.1007/s13196-016-0181-7

Iswanto, A. H., Hakim, A. R., Azhar, I., Wirjosentono, B., and Prabuningrum, D. S. (2020). "The physical, mechanical, and sound absorption properties of sandwich particleboard (SPb)," *Journal of the Korean Wood Science and Technology* 48(1), 32-40. DOI: 10.5658/WOOD.2020.48.1.32

Iswanto, A. H., Madyaratri, E. W., Hutabarat, N. S., Zunaedi, E. R., Darwis, A., Hidayat, W., Susilowati, A., Adi, D. S., Lubis, M. A. R., Sucipto, T., *et al.* (2022). "Chemical, physical, and mechanical properties of belangke bamboo (*Gigantochloa pruriens*) and its application as a reinforcing material in particleboard manufacturing," *Polymers* 14(15), article 3111. DOI: 10.3390/polym14153111

JAS 234 (2003). "Glued laminated timber," Japan Agricultural Standard, Tokyo, Japan.

JIS K 1571 (2010). "Test methods for determining the effectiveness of wood preservatives and their performance requirements," Japanese Standards Association, Tokyo, Japan.

Komariah, R. N., Hadi, Y. S., Massijaya, M. Y., and Suryana, J. (2015). "Physical-mechanical properties of glued laminated timber made from tropical small-diameter logs grown in Indonesia," *Journal of the Korean Wood Science and Technology* 43(2), 156-167. DOI: 10.5658/WOOD.2015.43.2.156

Mahawan Sumawa, I. W. A., Awaluddin, A., and Irawati, I. S. (2019). "Pengaruh bahan pengawet boraks dan ekstrak tembakau terhadap perilaku rekatan bambu laminasi perekat polymer isocyanate [Effect of borax and tobacco extract preservation on bonding behavior of laminated bamboo using polymer isocyanate]," *Jurnal Permukiman* 14(2), 104-111. DOI: 10.31815/jp.2019.14.104-111

Maulana, M. I., Jeon, W. S., Purusatama, B. D., Kim, J. H., Prasetia, D., Yang, G. U., Savero, A. M., Nawawi, D. S., Nikmatin, S., Sari, R. K., *et al.* (2022). "Anatomical characteristics for identification and quality indices of four promising commercial bamboo species in Java, Indonesia," *BioResources* 17(1), 1442-1453. DOI: 10.15376/biores.17.1.1442-1453

Nurhanifah, Hermawan, D., Hadi, Y. S., Arsyad, W. O. M., and Abdillah, I. B. (2020). "Shear strength and subterranean termite resistance of polystyrene impregnated sengon (*Falcataria moluccana*) glulam," *IOP Conference Series: Materials Science and Engineering* 935, article ID 012052. DOI: 10.1088/1757-899X/935/1/012052

Nurmalasari, I., and Goestav, B. (2020). "Klasifikasi Balok Laminasi Bambu (Studi Kasus Pabrik Laminasi Bambu PT. Indonesia Hiju Papan Cisolok Jawab Barat) [Classification of bamboo laminated beams (Case study of bamboo lamination factory PT. Indonesia Hiju Papan Cisolok West Java]," *Jurnal Student Teknik Sipil Edisi* 2(3), 183-191.

Pizzi, A., and Baecker, A. (1996). "A new boron fixation mechanism for environment friendly wood preservatives," *Holzforschung* 50(6), 507-510. DOI: 10.1515/hfsg.1996.50.6.507

Priadi, T., Kistia, J., Khanifah, I. P., and Agustin, T. (2022). "The color changes in and termite and fungal resistance of modified *Maesopsis eminii* Engl. wood with boric acid and seed oil," *Forests* 13(12), article 1998. DOI: 10.3390/f13121998

Saran, R. K., and Kamble, S. T. (2008). "Concentration-dependent degradation of three termiticides in soil under laboratory conditions and their bioavailability to eastern subterranean termites (Isoptera: Rhinotermitidae)," *Journal of Economic Entomology* 101(4), 1373-1383. DOI: 10.1603/0022-0493(2008)101[1373:CDOTTI]2.0.CO;2

Savov, V., Antov, P., Zhou, Y., and Bekhta, P. (2023). "Eco-friendly wood composites: Design, characterization and applications," *Polymers* 15(4), article 892. DOI: 10.3390/polym15040892

Sinarta, I. N., Damara Putra, I. N., and Yasa Bagiarta, I. K. (2020). "Analisa kekuatan struktur bambu pada pembangunan entry building green school ubud [Analysis of the strength of bamboo structures in the construction of the Ubud green school entry building]," *UKaRsT* 4(1), 39-53. DOI: 10.30737/ukarst.v4i1.661

Strohriegl, P., Senker, J., Meides, N., Menzel, T., Poetzschner, B., Löder, M. G. J., Mansfeld, U., and Altstaedt, V. (2021). "Reconstructing the environmental degradation of polystyrene by accelerated weathering," *Environmental Science and Technology* 55(12), 7930-7938. DOI: 10.1021/acs.est.0c07718

Tanaka, K., O'Leary, T. J., and Kafrawy, A. H. (1989). "The effect of citric acid on retained plaque and calculus," *Journal of Periodontology* 60(2), 81-83. DOI: 10.1902/jop.1989.60.2.81

Thevenon, M. F., Pizzi, A., and Haluk, J. P. (1998). "Protein borates as non-toxic, long-term, wide-spectrum, ground-contact wood preservatives," *Holzforschung* 52(3), 81-83. DOI: 10.1515/hfsg.1998.52.3.241

Treu, A., Nunes, L., and Larnøy, E. (2020). "Macrobiological degradation of esterified wood with sorbitol and citric acid," *Forests* 11(7), article 776. DOI: 10.3390/F11070776

Wardana, S., BauToknok, and Rukmi. (2022). "Keanekaragaman jenis-jenis bambu (*Bambusa* spp.) di desa lempe kecamatan dampal selatan kabupaten toli-toli [Diversity of bamboo types (*Bambusa* spp.) in Lempe village Dampal Selatan Toli-Toli district]," *Jurnal Ilmiah kehutanan* 10(2), 87-91.

Wulandari, F., Habibie, and Ningsih, R. V. (2022). "Karateristik sifat fisika dan mekanika papan laminasi bambu petung (*Dendrocalamus asper*. Backer) dengan susunan bilah ke arah tebal [The effect of strip arrangement on physical and mechanical properties petung bamboo laminated board (*Dendrocalamus asper Backer*)]," *Jurnal Hutan Tropika* 17(2), 207-214.

Yadav, M., and Mathur, A. (2021). "Bamboo as a sustainable material in the construction industry: An overview," in: *Materials Today: Proceedings* 43(5), 2872-2876. DOI: 10.1016/j.matpr.2021.01.125

Yalinkilic, M. K., Tsunoda, K., Takahashi, M., Gezer, E. D., Dwianto, W., and Nemoto, H. (1998). "Enhancement of biological and physical properties of wood by boric acid-vinyl monomer combination treatment," *Holzforschung* 52(6), 667-672. DOI: 10.1515/hfsg.1998.52.6.667

Yusof, N. M., Hua, L. S., Tahir, P. M., James, R. M. S., Al-Edrus, S. S. O., Dahali, R., Roseley, A. S. M., Fatriasari, W., Kristak, L., Lubis, M. A. R., *et al.* (2023). "Effects of boric acid pretreatment on the properties of four selected Malaysian bamboo strips," *Forests* 14(2), article 196. DOI: 10.3390/f14020196

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