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Biodeterioration Field Test and Mechanical Properties of *Maesopsis eminii* Wood Treated with Boron Preservative and Plant Oils

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Abstract: Boron preservatives have insecticidal and fungicidal effects. The leaching problem of boron preservative-treated wood can be overcome using oil treatment. This study evaluated the resistance in a biodeterioration field test and the mechanical properties of manii wood (*Maesopsis eminii* Engl.) treated with boric acid and plant oils. Manii wood samples were impregnated in two stages with boric acid and vegetable oils (neem, tamanu, and candlenut oils). The impregnation process was performed in a chamber at a pressure of 7 kg cm^{-2} for approximately 4 h. Next, the sample was heated at temperatures of 60 °C, 120 °C, and 180 °C. The biodeterioration field test was conducted in ground contact for 100 days. In addition, mechanical tests in terms of modulus of elasticity (MOE), modulus of rupture (MOR), and hardness were conducted using an Instron universal testing machine. The test results prove that the combination of boric acid preservation with neem, tamanu, or candlenut oil treatment increases the resistance of manii wood to subterranean termites, especially when the treatment is accompanied by heating at 120 °C. The combination treatment of boric acid and plant oils also increases the MOE, MOR, and hardness values of manii wood.

Keywords: durability; field test; impregnation; preservation; termites

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Citation: Priadi, T.; Badruzzaman, M.H.; Sofiaturizkiyah, N.; Hermawan, A.; Malik, J.; Hartono, R. Biodeterioration Field Test and Mechanical Properties of *Maesopsis eminii* Wood Treated with Boron Preservative and Plant Oils. *Forests* **2024**, *15*, 466. https://doi.org/10.3390/f15030466

Academic Editors: Xinzhou Wang and Jiangtao Shi

Received: 1 December 2023
Revised: 6 February 2024
Accepted: 21 February 2024
Published: 1 March 2024

1. Introduction

Fast-growing woods are increasingly being cultivated by communities and have great potential as a sustainable support for the wood industry. The rapid growth of trees supports forest cultivation with high productivity and is very profitable for society. Manii (*Maesopsis eminii* Engl.) is a fast-growing wood belonging to strength class III with a specific gravity of 0.45 g cm^{-3}; however, it is not durable (durability class III–V) [1]. The low durability of this wood means that it is easily attacked by destructive organisms [2]. Low durability and dimensional stability are serious problems in the use of fast-growing wood, especially for furniture and construction. Therefore, technology for improving wood quality is necessary to encourage the use of wood from fast-growing species, thereby enhancing its useful value.

Boron compounds such as borax ($Na_2B_4O_7$) and boric acid (H_3BO_3) have been widely used as wood preservatives because they are fungicidal and insecticidal [3,4]. Boron compounds are wood preservatives that are also fire retardants and are classified as environmentally friendly [5]. Boric acid is an insecticide that is readily soluble in water. When this compound is heated to temperatures exceeding 170 °C, it dehydrates to form HBO_2 or metabolic acid. Boric acid has a boiling point of approximately 300 °C and a melting point of 170 °C. Boric acid has a molecular weight of 61.83 g mol^{-1} and a density of 1.435 g cm^{-3} [6]. Boric acid preservation is scentless and does not change the wood color. However, the use of boron compounds in wood preservation is still restricted to interior use because they are easily washed off (leaching) when used in exterior functions that are frequently exposed to rainwater. This weakness of the boron compound preservative can be overcome by combining it with insecticidal plant oil and heating.

The substances collected from leaves, bark, stems, or fruit/seeds can be used as environmentally friendly wood preservatives. A lot of plants in Indonesia contain anti-fungal and anti-insect substances that have the potential to be used in wood protection, such as neem, candle nut, tamanu, etc. Neem, candlenut, and tamanu oils are extracted from fruit/seeds and have insecticidal properties [7,8]. Amalia and Pratiwi [9] reported that the extraction of neem seeds contains 30%–50% oil, which can be used in insect control. In addition, Chaerunisa and Pratiwi [10] revealed that oil from neem seeds has antibacterial properties. Tamanu oil is a natural pesticide that can be used to control pest attacks [11]. According to Musta et al. [12], tamanu oil is produced from the extraction of tamanu seeds with an oil content of 40%–73%. Moreover, Herman et al. [13] stated that candlenut oil is extracted from candlenut seeds with an oil content of 45%–50%. The candlenut oil contains α-oleo stearic acid, which is toxic to insects [13].

The combination of plant oil treatment with wood heating improves the physical properties and durability of wood [14]. Heating treatment to improve the properties of wood is performed at temperatures of 180–240 °C for 4–5 h [15]. Heat treatment is an environmentally friendly wood modification technique [16] that reduces water sorption and increases the dimensional stability of wood [17]. Heating to a temperature of 180 °C increases the resistance of wood to decay fungi [18,19].

Scientific information on the use of neem, tamanu, and candlenut oils in fast-growing wood quality improvement is still rarely found. The seed oils combined with boric acid were tested on a laboratory scale [20]. Thus, this study specifically aimed to evaluate the effectiveness of boric acid, neem, tamanu, and candlenut oils in field tests and on the mechanical properties of *Maesopsis eminii* wood. The success of this research would be very useful in the development of environmentally friendly wood preservation technology. In addition, the use of fast-growing wood would be more efficient because it could last longer with wider uses.

2. Materials and Methods

All research activities were performed at IPB University, namely, in the Sawmill and Woodworking Laboratory, Wood Drying and Preservation Laboratory, Wood Physics and Anatomy Laboratory, Termite Laboratory, and Mechanical Properties Laboratory.

The material used in this research was manii wood (*Maesopsis eminii* Engl.) from a tree with a diameter at a breast height of 30 cm, which was obtained from a community forest in Bogor, West Java. Manii wood logs were sawn into several boards with a thickness of 3 cm and dried in a drying kiln at 50 °C to a moisture content of 14%. The moisture content was checked with a moisture meter. Next, samples for the field test, modulus of elasticity (MOE), and modulus of rupture (MOR) were created in the same size, 20 mm × 20 mm × 300 mm, while the sample size for the hardness test was 30 mm × 30 mm × 60 mm. Boric acid (H_3BO_3) for analysis from Supelco® (CV Aneka Sarana Lab., Bogor, Indonesia) was dissolved in aquadest at a concentration of 5%. In addition, oils from neem (*Azadirachta indica*) and candlenut (*Aleurites moluccana*) seeds were obtained from South Sumatra, while tamanu (*Calophyllum inophyllum* L.) oil was obtained from Bali.

2.1. Impregnation and Heating

This research used three treatment combinations, namely boric acid (with and without boric acid), plant oils (neem, tamanu, candlenut, and without oil), and heating (60 °C, 120 °C, and 180 °C). The manii wood samples were impregnated with the 5% boric acid solution in a chamber at a pressure of 7 kg cm^{-2} for 4 h. The samples were weighed before (W0) and after the first impregnation (W1) to determine the retention (R) of the preservative using Equation (1) [21]. The wood test samples were dried again at 50 °C to a moisture content of 14%. Next, the wood samples were impregnated with plant oils (neem, candlenut, or tamanu) in a chamber under the same pressure and duration as the first impregnation. The samples were oven-dried again at 50 °C to a moisture content of 14%. The sample moisture content was checked with a moisture meter.

$$R = ((W1 - W0)/V) \times C \tag{1}$$

Here,

- R = preservative retention (kg m^{-3})
- W0 = weight of sample before impregnation (kg)
- W1 = weight of sample after impregnation (kg)
- V = volume of sample (m^3)
- C = boric acid concentration (%)

The samples were then heated in a Memmert oven at varying temperatures of 60 °C, 120 °C, or 180 °C for approximately 4 h at atmospheric pressure. Next, weighing was performed to determine the weight percent gain (WPG) of the samples using Equation (2) [22]. The test samples were conditioned at room temperature (28 °C) to test their resistance to biodeterioration and their mechanical properties. Each test was replicated five times.

$$WPG = ((ODW1 - ODW0)/WD0) \times 100 \tag{2}$$

Here,

- WPG = weight percent gain (%)
- ODW0 = weight of dry sample before oil impregnation (g)
- ODW1 = weight of dry sample after oil impregnation (g)

2.2. Ground-Contact Biodeterioration Field Test

The biodeterioration field test in ground contact used the ASTM D 1758-02 [23] method with modifications to the size of the wood samples, which was 2 cm × 2 cm × 30 cm. The test used 5 replications of samples. The samples were dried at 60 °C to a constant weight then the oven-dried weight (ODW2) of the samples was determined. Next, ¾ of the test sample length was vertically buried in the soil. The sample distance between rows was 60 cm, while the distance between columns was 30 cm. The distribution of test sample positions was performed randomly. The biodeterioration field test was conducted for 100 days.

After the field test, the samples were cleaned from the soil and dried in an oven at a temperature of 103 ± 2 °C until constant weight (ODW3). The weight loss and degree of damage were computed using Equations (3) and (4), respectively. Next, the degree of damage was classified based on the wood resistance classification shown in Table 1.

$$WL = ((ODW2 - ODW3)/ODW2) \times 100. \tag{3}$$

Here,

- WL = weight loss of the sample (%)
- BK01 = oven dry weight of the sample before the test (g)
- BK02 = oven dry weight of the sample after the test (g)

$$D = (B/T) \times 100. \tag{4}$$

Here,

- D = degree of damage (%)
- T = sample thickness (mm)
- B = depth of damage (mm)

Table 1. Classification of wood resistance of subterranean termites.

Grade No	Description
10	No attack, 1 to 2 small nibbles permitted
9	Nibbles to < 3% cross-section
8	Penetration 3% to < 10% of cross-section
7	Penetration 10% to < 30% cross-section
6	Penetration 30% to < 50% cross-section
4	Penetration 50% to < 75% cross-section
0	Failure

Adapted with permission from ASTM D 1758-02 [23] Standard Test Method of Evaluating Wood Preservatives by Field Tests with Stakes, copyright ASTM International.

2.3. Mechanical Properties Test

The modulus of elasticity (MOE) and modulus of rupture (MOR) tests referred to the BS: 373: 1957 [24] standard using an Instron universal testing machine (UTM) with a capacity of 5 kN. MOE and MOR bending tests were conducted by applying a load in the middle of the test sample in the tangential plane with a span distance of 28 cm and a loading speed of 6.6 mm min^{-1}. The MOE and MOR values were calculated as described in the standard.

Hardness testing was performed using an Instron UTM by pressing the wood surface with a half steel ball with a diameter of 11.3 mm (pressing area 1 cm^2). The loading speed was 6.35 mm min^{-1} so half of the steel ball was completely immersed in the wood. Then, the hardness value was calculated as described in the standard.

Descriptive data processing using Microsoft Excel application. The analysis of the effect of treatment variations on biodeterioration test variables and mechanical properties used a completely randomized factorial design in the SPPS program [25]. If the analysis of variance (ANOVA) showed a significant effect at a 95% confidence interval, then the Duncan test was applied.

3. Results and Discussion

3.1. Assessment of Impregnation

The boric acid retention in manii wood was 14.77 kg m^{-3}, which meets the Indonesian National Standard for interior and exterior uses (8.2 kg m^{-3} and 11.3 kg m^{-3}, respectively) [26]. The high retention value in this study was related to the specific gravity of manii wood, which was low at 0.42 [27]. This indicated that many cavities supported the permeability of the wood and facilitated the entry of preservatives.

After the second impregnation with plant oil, the WPG of candlenut oil was higher than that of the other two oils (Figure 1). This is related to oil viscosity. The lower the viscosity of the oil, the easier it is for the oil to penetrate the wood [28]. Based on the viscosity value, candlenut oil has the lowest value (14.5 mm^2 s^{-1}) [29], whereas the values of tamanu and neem oils are 69 [30] and 29.5 mm^2 s^{-1} [31], respectively. The WPG value was also influenced by the heating treatment; the higher the heating temperature, the lower the WPG value. This was due to the partial evaporation of the oil at higher heating temperatures. The features of treated manii woods are shown in Figure 2.

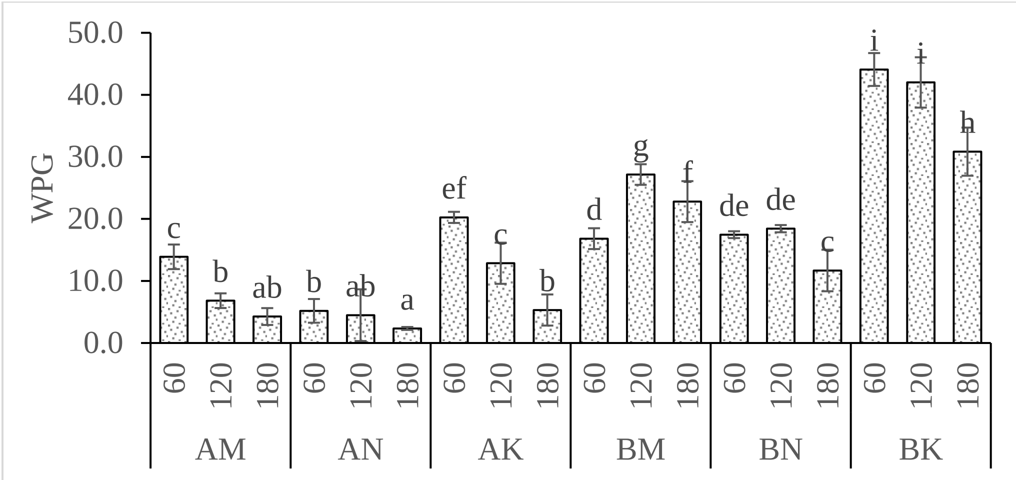


Figure 1. WPG of neem (M), tamanu (N), and candlenut (K) oils on manii woods treated without boric acid (A), with boric acid (B), and heated at 60 °C, 120 °C, and 180 °C. The same letters (a, b, c, etc.) indicate that the values are not significantly different in Duncan's test.

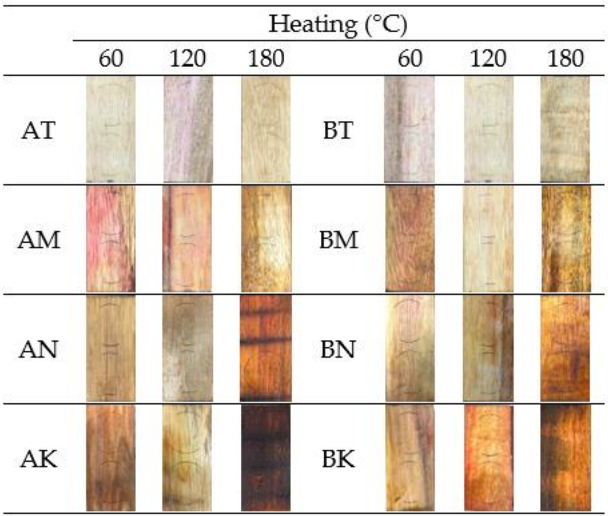


Figure 2. The feature of manii woods that were treated with boric acid (B), without boric acid (A), with tamanu oil (N), neem oil (M), candlenut oil (K), without plant oil (T), and heated at 60 °C, 120 °C, or 180 °C.

3.2. Ground-Contact Biodeterioration Field Test

The ground-contact field test of wood resistance to biodeterioration is critical because it determines the service life of wood as a building component. This test is significantly influenced by environmental conditions, location, and weather, such that termite and fungal attacks on wood can be faster than on wood in buildings. The average rainfall in Bogor from March to May 2023 was 404.7 mm/month with a relative humidity of 86.3% and a temperature of 21.9 °C [32]. Ground contact wood is easily attacked by subterranean termites, which are the most wood-destroying agents because they have large colonies in the ground. According to Nandika et al. [33], subterranean termites, particularly *Coptotermes curvignathus*, are the most vicious building pests.

Visual grading of the wood after the field test revealed that boric acid preservation (BT60) improved the resistance of manii wood in the biodeterioration test compared with the control (AT60) (Figures 3 and 4). This was due to the fungicidal and insecticidal properties of boric acid [3]. Boric acid reacts as a stomach poison for subterranean and dry wood termites through the feeding process, disrupting the physiological processes of cells and causing termite fatality [34].

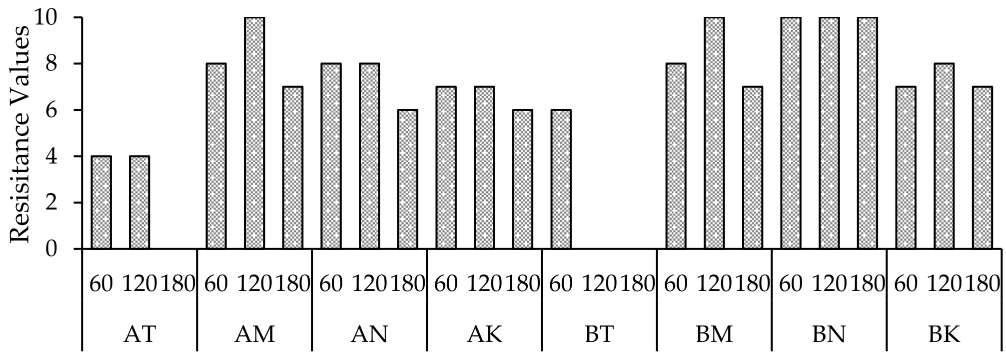


Figure 3. The resistance value in the field tests of manii woods treated with boric acid (B), without boric acid (A), with tamanu oil (N), neem oil (M), candlenut oil (K), without plant oil (T), and heating (60 °C, 120 °C, or 180 °C).

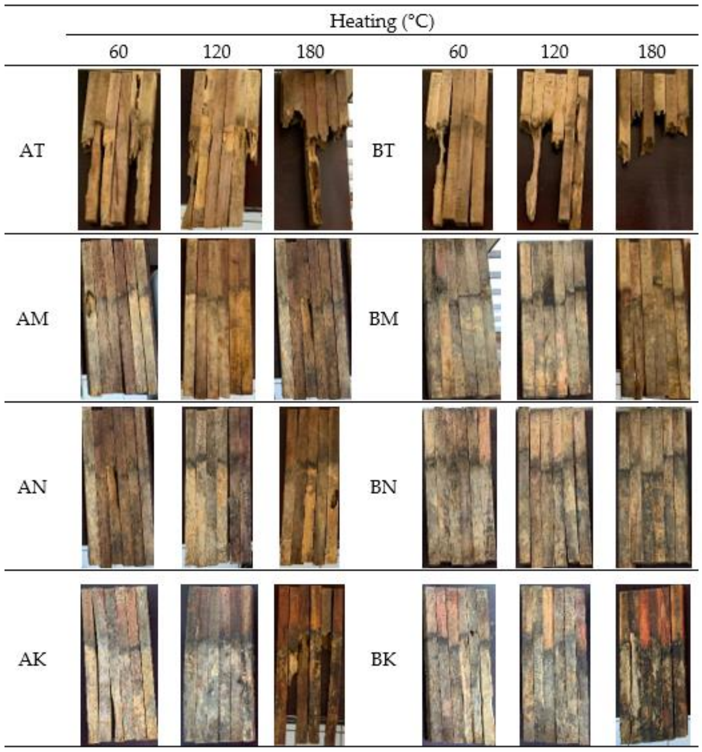


Figure 4. The conditions after the field test of treated manii woods with boric acid (B), without boric acid (A), with tamanu oil (N), neem oil (M), candlenut oil (K), without plant oil (T), and heating (60 °C, 120 °C, or 180 °C).

Treatment with the three plant oils (neem, tamanu, or candlenut) also significantly increased the resistance value of manii wood. According to Amalia and Pratiwi [9], neem plant extract contains the active ingredient triterpene or limonoid. Limonoids have insecticidal activity. Candlenut oil contains triglyceride compounds, such as palmitic acid, oleic acid, and linoleic acid, which have great potential as pesticides [35]. Candlenut oil also contains antifeedant compounds such as flavonoids, triterpenoids, and phenolics, which can be used to control pests [36].

The wood weight loss in the field tests (Figure 5) strongly supports the value of wood resistance based on visual grading. Loss of weight indicates damage to manii wood caused mainly by subterranean termite attacks. ANOVA at a 95% confidence interval revealed the interaction effect of plant oil and heat treatment on the weight loss of manii wood in the field test. Boric acid treatment alone (BT60) reduced the wood weight loss to 18.6%.

In other words, there was a reduction in wood weight loss due to biodeterioration (35%), which was lower than that of the control test sample (AT60) (28.5%), even though this was not statistically significant. The three plant oil treatments, neem (AM60), tamanu (AN60), and candlenut (AK60), significantly reduced the weight loss of manii wood in the biodeterioration field test compared with the control (AT60), with the values of wood weight loss being only 3.8%, 5.1%, and 4.3%, respectively. The oil treatment also caused significantly less weight loss than boric acid preservation (BT60) (22.6%). The combined treatment of boric acid with the three plant oils resulted in significantly less weight loss of manii wood than the boric acid treatment alone (BT60). The weight loss values due to biodeterioration in manii wood treated with a combination of boric acid with neem oil (BM60), tamanu oil (BN60), or candlenut oil (BK60) were 1%, 1%, and 3%, respectively.

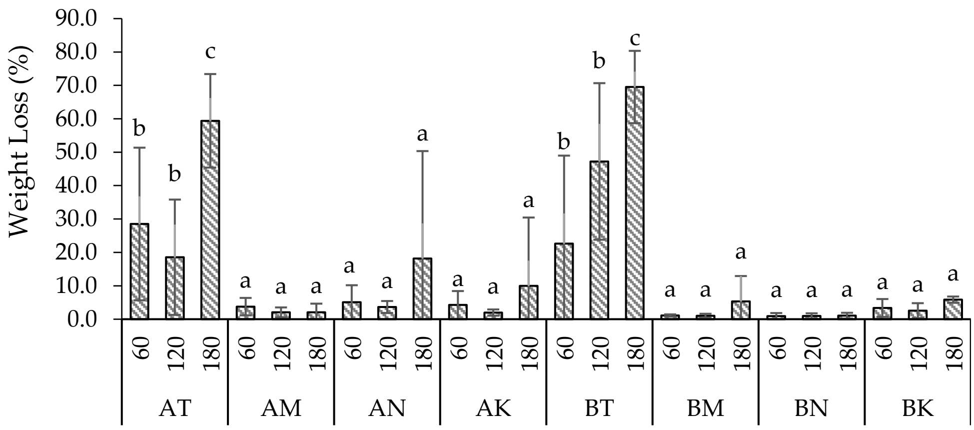
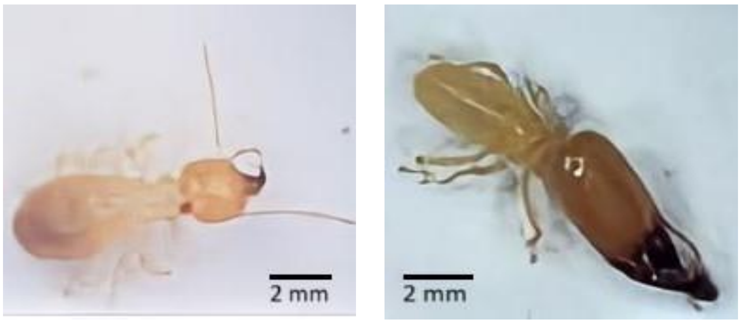


Figure 5. The weight loss in the field test of manii woods without boric acid (A), with boric acid (B), with tamanu oil (N), neem oil (M), candlenut oil (K), without plant oil (T), and heating (60 °C, 120 °C, or 180 °C). The same letters (a, b, c, etc.) indicate that the weight loss values are not significantly different in Duncan's test.

In this study, it was proven that the 120 °C heating treatment (AT120) decreased the weight loss of manii wood due to biodeterioration by 36% compared to the control (AT60), even though the difference was not statistically significant. However, when 120 °C heating was combined with neem oil treatment (AM120), the resistance value increased compared with the neem oil treatment with 60 °C heating (AM60). Similarly, the combined treatment of boric acid with neem oil or candlenut oil followed by heating at 120 °C (BM120 and BK120), was demonstrated to be more resistant to biodeterioration than the respective treatment combinations accompanied by heating at 60 °C (BM60 and BK60). In other words, boric acid preservation combined with plant oil treatment (neem, tamanu, or candlenut) and heating at 120 °C (BM120, BN120, and BK120) produced a better protection value for manii wood than boric acid treatment alone (BT60).

Based on the identification results using the determination key, Nandika et al. [33], the types of subterranean termites found on the tested woods were *Microtermes* sp. and *Capritermes* sp. (Figure 6). Based on the report by Arinana et al. [37], subterranean termites in the field test location, Arboretum at the Faculty of Forestry and Environment IPB, included *Capritermes* sp., *Schedorhinotermes* sp., *Microtermes* sp., and *Macrotermes* sp. The subterranean termite group found in this study belongs to the Termitidae family.



(**a**) (**b**)

Figure 6. Termites attacking wood samples in the field test: (**a**) *Microtermes* sp. and (**b**) *Capritermes* sp.

3.3. Mechanical Properties

Mechanical testing revealed that the MOE of manii wood exhibited varying changes according to the treatment. The ANOVA analysis showed that the boric acid treatment had a substantial influence on the MOE value of manii wood at a 95% confidence interval. Preservation with 5% boric acid increased the MOE of manii wood, by approximately 7%. The heat treatment up to 180 °C did not cause a significant change in MOE compared with that of the control manii wood, whose value was 4792 kg cm^{-2} (Figure 7). This was different from the report by Percin et al. [4], who reported that the MOE and MOR values of oak wood (*Quercus petraea* Liebl.) significantly decreased when heated at 190 °C, and slightly decreased in the boric acid treatment. The temperature was higher than that used in this study. At a temperature of 190 °C, it was thought that more chemical components of wood were degraded, especially hemicellulose.

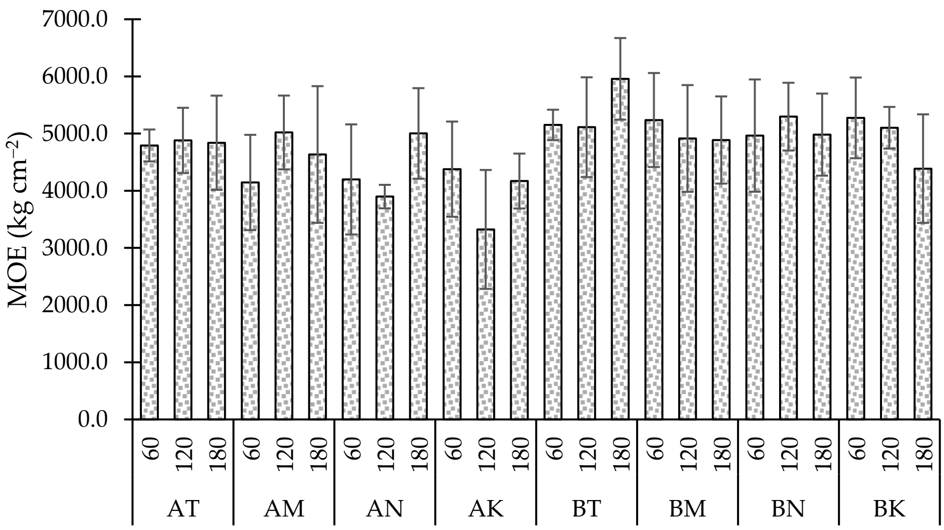


Figure 7. MOE of manii woods treated with boric acid (B), without boric acid (A), with tamanu oil (N), neem oil (M), candlenut oil (K), without plant oil (T), and heating (60 °C, 120 °C, 180 °C).

The combination of 5% boric acid preservation with plant oil treatment also generally increased the MOE value of manii wood, albeit not significantly, by up to 10%. However, the combination of boric acid, plant oil, and heat treatment at 180 °C reduced the MOE value of manii wood.

The MOR test resulted in changes that varied according to the treatment. The ANOVA results showed that the heating temperature significantly affected the MOR value of manii wood at a 95% confidence interval. Heating treatment at 180 °C significantly reduced the MOR of manii wood, mainly when combined with boric acid or plant oil treatments (Figure 8). This result supported the report by Yang and Liu [38] that the MOR of *Pterocarpus* *macrocarpus* Kurz wood decreased after 180 °C heat treatment due to chemical degradation in wood. However, the MOR of heated manii wood at 120 °C (AT120) slightly increased. This supported the research of Aydin [39] that the MOR of Taurus cedar steadily increased in heating at 80 and 120 °C for up to 8 h. It could be caused by the crystallization of amorphous cellulose.

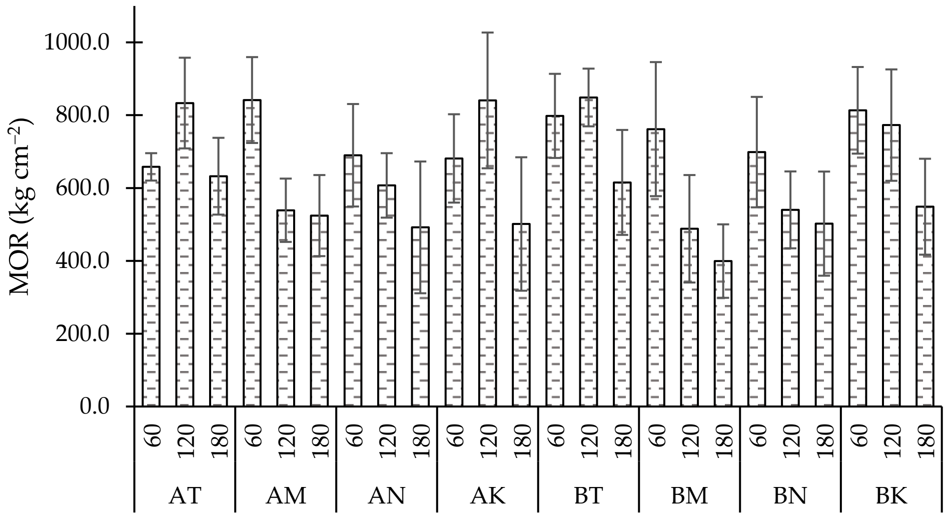


Figure 8. MOR values of manii woods treated with boric acid (B), without boric acid (A), with tamanu oil (N), neem oil (M), candlenut oil (K), without plant oil (T), and heating (60 °C, 120 °C, and 180 °C).

Preservation with 5% boric acid (BT60) increased the MOR value of manii wood by approximately 21%. This result was different from those of Simsek et al. [40], who revealed that boric acid preservation reduced the MOR of Oriental beech (*Fagus orientalis* L.) and Scots pine (*Pinus sylvestris* L.) wood. Neem oil treatment (AM60) significantly increased the MOR of manii wood by 28% compared with that of the control (AT60). In addition, the combination of boric acid treatment with plant oils (BM60, BN60, and BK60) produced higher MOR values than the control manii wood (AT60).

Boric acid (BT60) treatment slightly increased the hardness of manii wood by approximately 9% even though this was not statistically significant. Meanwhile, plant oil treatment significantly increased the hardness of manii wood, especially candlenut oil (AK60), by up to 31% compared with the control (AT60) (Figure 9). In general, the combined treatment of plant oil and heat treatment caused higher hardness of manii wood compared to the combined treatment of boric acid, plant oils, and heat treatment, which contained less plant oil in the wood due to the presence of boric acid. Oil heating can increase wood crystallinity which affects wood hardness. This was in line with the report of Suri et al. [41] that oil heat treatment at 180 °C for up to 3 h increased the hardness of *Pinus koraiensis* wood. Heating at 120 °C (AT120) slightly increased the hardness of manii wood, by approximately 10%, but this was not statistically significant. This result supported the report by Durmaz et al. [42] that the compression strength of Scots pine slightly increased when heated at 120 °C for up to 6 h, but it decreased when heated at 210 °C for 4 and 6 h. Heating at 180 °C in this study reduced the hardness value of manii wood, mainly when combined with boric acid and plant oils.

The combined treatment with boric acid and tamanu oil (BN60) resulted in a significantly higher value of manii wood hardness of approximately 38% compared to the control manii wood hardness (AT60). Likewise, heating at 120 °C combined with boric acid treatment and all plant oils (BM120, BN120, and BK120) produced hardness values that were significantly higher, up to 28% compared to the hardness of the control wood.

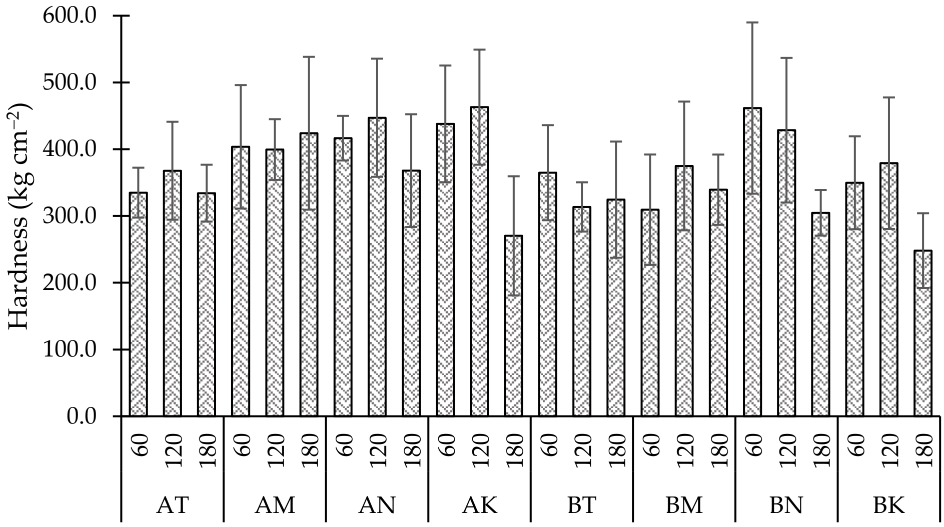


Figure 9. Hardness values of manii woods treated with boric acid (B), without boric acid (A), with tamanu oil (N), neem oil (M), candlenut oil (K), without plant oil (T), and heating (60 °C, 120 °C, and 180 °C).

4. Conclusions

Boric acid and heat treatment up to 180 °C could not protect manii wood from termites in the field test, except in combination with oil treatment. Plant oil treatment (neem, tamanu, and kemiri) increased wood resistance to subterranean termites in the biodeterioration field tests, especially in combination with boric acid and heating at 120 °C. Plant oil treatments decreased the MOE values unless combined with boric acid treatment, which increased the MOE of manii wood. The MOR and hardness of manii wood increased after plant oil treatment either with or without a combination with boric acid. The combination of boric acid, tamanu oil, and heating at 60 °C resulted in more improvement compared to other treatments in terms of termite resistance and mechanical properties of *Maesopsis eminii* wood. Field testing over a longer time (multi-years) is necessary to ensure the resistance of the wood to degrading organisms as well as to check the leaching possibility of preservatives during wood contact with the soil.

Author Contributions: Conceptualization, T.P.; data curation, T.P.; formal analysis, N.S.; funding acquisition, N.S.; investigation, M.H.B.; methodology, T.P.; project administration, N.S.; resources, M.H.B.; supervision, R.H. and A.H.; validation, T.P.; visualization, T.P.; writing—original draft, M.H.B.; writing—review and editing, J.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research and APC were funded by the Directorate General of Higher Education, Research and Technology, Ministry of Education, Culture, Research and Technology (DITJEN DIKTIRISTEK), grant number 001/E5/PG.02.00.PL/2023.

Data Availability Statement: Research data are provided at https://ipb.link/penelitian-1 (accessed on 16 November 2023).

Acknowledgments: This research was endorsed administratively and supervised by the Institute for Research and Community Services (LPPM), IPB University.

Conflicts of Interest: The authors declare no conflict of interest.

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