# THE FIRE RESISTANCE AND FIELD TEST OF TREATED *Maesopsis eminii* WOOD WITH BORON PRESERVATIVE, VEGETABLE OILS, AND HEATING

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THE FIRE RESISTANCE AND FIELD TEST OF TREATED *Maesopsis eminii* WOOD WITH BORON PRESERVATIVE, VEGETABLE OILS, AND HEATING. Boric acid can be combined with vegetable oil treatment to enhance wood preservation. This research aimed to evaluate the fire resistance and above-ground field test of treated manii (*Maesopsis eminii* Engl.) wood with boric acid, vegetable oils, and heating. Manii wood samples were impregnated sequentially with boric acid solution and vegetable oils (neem, tamanu, and candlenut) in a tank at a pressure of 7 kg $cm^{-2}$ for 4 hours at room temperature, ±26 ºC. The subsequent heat treatment was at 60ºC, 120ºC, and 180ºC under atmospheric pressure for 4 hours. The fire resistance was evaluated based on sample weight loss after burning with a heating torch at 180°C ± 5°C for 4 minutes. The above-ground field test of woods was conducted on a shelf with a slope of 45º for 90 days. The results revealed that the combination of boric acid and vegetable oils treatment had better fire resistance than boric acid treatment and the control of manii wood. In the above-ground field test, the combination of boric acid and vegetable oils treatment also resulted in less weight loss due to weathering and fungal attacks. Moreover, the moisture content change was less than that of the boric acid treatment and the control samples. However, oil treatment caused a higher color change than the control samples during the field test.

Keywords: Color, fast-growing wood, heating, modification, moisture content, weight loss

*KETAHANAN API DAN UJI LAPANG KAYU MAESOPSIS EMINII YANG DIBERI PERLAKUAN PENGAWET BORON, MINYAK NABATI, DAN PEMANASAN. Asam borat dapat dikombinasikan dengan perlakuan minyak nabati untuk meningkatkan efektivitas pengawetan kayu. Penelitian ini bertujuan untuk mengevaluasi ketahanan api dan uji lapang tanpa menyentuh tanah dari kayu manii (*Maesopsis eminii* Engl.) yang diberi perlakuan dengan asam borat, minyak nabati dan pemanasan. Kayu manii diimpregnasi dengan larutan asam borat dan minyak nabati (mimba, nyamplung, dan kemiri) dalam tangki pada tekanan 7 kg $cm^{-2}$, masing-masing selama 4 jam pada suhu kamar, ±26ºC. Selanjutnya perlakuan panas dilakukan pada suhu 60ºC, 120ºC dan 180ºC pada tekanan ruang selama 4 jam. Ketahanan api dievaluasi berdasarkan penurunan berat kayu setelah pembakaran pada suhu 180°C ± 5°C selama 4 menit. Uji lapangan kayu tanpa menyentuh tanah dilakukan pada rak dengan kemiringan 45º selama 90 hari. Hasil penelitian menunjukkan bahwa kombinasi perlakuan asam borat dan minyak nabati menghasilkan ketahanan api yang lebih baik daripada perlakuan asam borat saja dan kontrol kayu manii. Hasil uji lapang tanpa menyentuh tanah membuktikkan bahwa kombinasi perlakuan asam borat dan minyak nabati nyata menurunkan kehilangan berat akibat serangan jamur dan perubahan kadar air kesetimba dibanding perlakuan asam borat saja maupun kontrol. Namun, perlakuan minyak nabati menyebabkan perubahan warna yang lebih besar dibandingkan dengan kontrol selama uji lapang tersebut.*

*Kata kunci: Kadar air, kayu cepat tumbuh, kehilangan berat, modifikasi, pemanasan, warna*

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## I. INTRODUCTION

Fast-growing trees are planted in many community forests as the materials for furniture, building components, and other purposes. Fast-growing plantation forests have high productivity and short harvest periods. However, fast-growing woods generally have low quality (Arsyad, 2022) and need quality improvement technology. Manii wood (*Maesopsis eminii*) is one of the fast-growing species that has durability class IV (not durable) (Febrianto et al., 2013), and a density of 0.56 ± 0.27 g $cm^{-3}$ (Epila et al., 2017). Manii wood can be used for stairs, furniture, plywood, decorative veneer, general molding, parquet flooring, carpentry wood, poles, pulp and paper products, etc. (Zahidah & Zairul, 2018). A proper quality improvement technique is very important to increase the service life and uses of manii wood. Therefore wood as a renewable material can be used widely indoors and outdoors.

The function of wood in buildings may deteriorate when exposed to the environment and weather conditions(Kubovski et al. 2018). High rainfall and humidity in Indonesia support and accelerate the biodeterioration of wood products. For example, Bogor City's average rainfall and relative humidity were 3510.0 mm and 90.8% respectively (BPS, 2022). Another challenge in building materials is that wood is combustible (Popescu & Pfriem, 2020). The ignition temperature of a wood is 200−210°C (Liu, Pang, Lv, Wang, & Wang, 2021). So, wood's function in buildings needs fire protection (Ohashi, Igarashi & Nagaoka, 2018) to increase the safety and convenience of living (Östman et al. 2001). Generally, wood contains 50% carbon, 6% hydrogen, and 44% oxygen which makes it flammable (Dayadi, 2021).

Preservation is a well-known technique to prevent biodeterioration in wood and increase the service life of wood products. Preservation in a pressurized tank would give better retention and penetration of preservatives in wood (Teng et al., 2018). Pressurized preservation has become a commercial method in wood industries to produce high-quality, durable wood products. Boron compounds such as boric acid ($H_3BO_3$) are commonly used as wood preservatives, which have fungicidal and insecticidal effects (Percin, Sofuoglu & Uzun, 2015). Preservation with boric acid does not cause unwanted odor and discoloration on wood. Besides, boron preservatives can be obtained at an affordable price. However, boron preservation must be combined with some other treatments to resist leaching (Istriana & Priadi, 2021). Combining boron compound and methyl methacrylate significantly improved the dimensional stability and the resistance of wood against decay fungi and termites (Priadi et al. 2020). Combining boron preservative with oil treatment successfully reduced preservative leaching (Tomak, 2022). Oil treatment reduced water absorption in wood (Can & Sivrikaya, 2019) and caused a hydrophobic effect on wood (Tchebe et al. 2020).

Some vegetable oils in Indonesia have been used traditionally for pest control, medicine, and many other purposes. Neem oil, candlenut oil, and tamanu oil are extracted from the fruits or seeds. Neem oil has active ingredients nimbi and nimbidin, which have antiviral, bactericidal, and fungicidal activities (Gadira, Wirianata & Kristalisasi, 2018), while tamanu oil also has insecticidal effect (Showler, 2017). Saponins, phenolics, alkaloids, glycosides, triterpenoids, and flavonoids found in candlenut oil have the ability to stop the growth of fungi (Soeshanty & Samsudin, 2014). The termite attack resistance of wood increased after the treatments of neem (Fatima, Ahmed & Hassan, 2021), tamanu (Adegoke, Ajala & Alamu, 2015), and candlenut oils (Ayouaz, Fibri, Arab, Mouhoubi, & Madani, 2023).

A lot of studies have been done on wood modification to improve wood quality (Ormondroyd, Spear, & Curling, 2015). Wood modification can improve the quality of fast-growing woods. One of the eco-friendly wood modifications is heat treatment (Candelier, Hannouz & Elaieb, 2015). Heat treatment affects wood's chemical components (hemicellulose, lignin, and cellulose) and changes the hydrophobic properties of wood (Wu, Deng, Li, Xi, Tian, Yu, & Zhang, 2021).

Scientific information regarding the combination of boric acid with vegetable oil to improve wood quality is still limited. Therefore, this study aimed to assess how boric acid, vegetable oil, and heat treatments affected the manii wood's ability to withstand fire and fungal biodeterioration in the field.

## II. MATERIALS AND METHODS

### A. Location and Materials

This research was done at some laboratories in the Faculty of Forestry and Environment, IPB University. Wood sample preparation was conducted at the workshop. The impregnation process was done at the Laboratory of Drying and Preservation. The heat treatment and burning test were conducted at the Laboratory of Physical Properties, while the fungal resistance evaluation was at the open field test site (Figure 1) of the Wood Quality Improvement Division, Faculty of Forestry and Environment, IPB University.

Two manii (*Maesopsis eminii* Engl.) logs with a diameter of ± 30 cm were bought from a sawmill in Bogor. The logs were sawn into boards with 30 mm thickness. The boards were kiln-dried at a temperature of 50°C to get ±14% moisture content (MC). Then the test samples were made in the size of 2 cm × 2 cm × 2 cm (burn test) and 15 cm × 7.5 cm × 2 cm (above-ground biodeterioration test). In addition, pro-analysis boric acid ($H_3BO_3$) was produced by Supelco, Denmark, which was then dissolved in aquadest at 5% concentration. Three vegetable oils, namely neem (*Azadirachta indica*), tamanu (*Calophyllum inophylum* L), and candlenut (*Aleurites moluccana*) oils were purely produced through cold press from the seeds. Tamanu and candlenut oils were provided by Sahabat Atsiri Nusantara, Jakarta, while neem oil was provided by Indoneem from Bali.

### B. Sampling Techniques

#### 1. Impregnation and Heating

Wood impregnation with 5% boric acid solution (Perçin et al., 2015) was conducted in a tank at a pressure of 7 kg $cm^{-2}$ for about 4 hours. The samples were weighed before (B0) and after the impregnation (B1) to determine the retention (R) of the preservative according to Equation 1. After oven-drying at 50°C to 14% MC, the same pressure and time as the initial impregnation were used to impregnate the samples with vegetable oils (tamanu, candlenut, or neem) in the tank. Then, the samples were

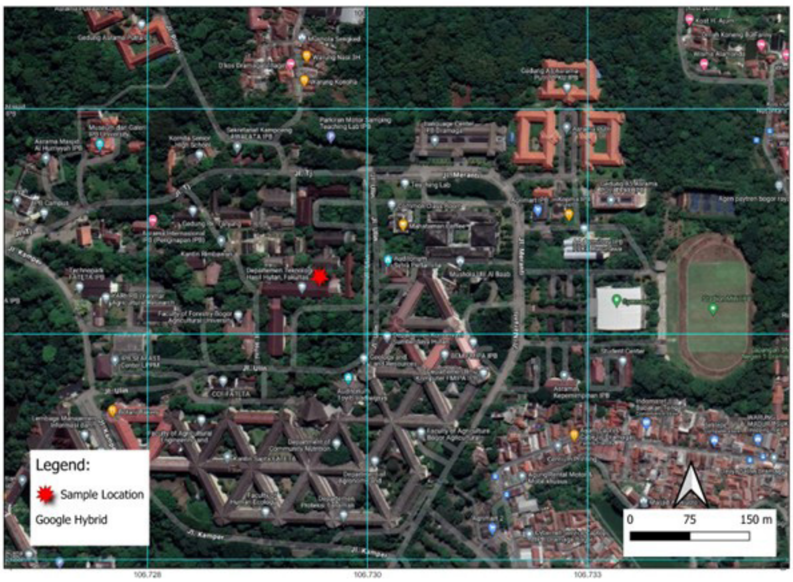


Figure 1. Location of field test at Faculty of Forestry and Environment, IPB University, West Java, Indonesia

redried at 50 °C to 14% MC.

R = (W1-W0): V × C ........................................(1)

Where:,
R = preservative retention (kg $m^{-3}$)
W0 = sample weight before impregnation (kg)
W1 = sample weight after impregnation (kg)
V = sample volume ($m^3$)
C = preservative concentration (%)

Heat treatment of wood samples after the impregnation used a Memmert heating oven at various temperatures (60, 120, and 180)°C for 4 hours under atmospheric pressure. The 15 cm × 7.5 cm × 2 cm samples were weighed to determine weight percent gain (WPG) with Equation 2. The entire treatment is shown in Table 1.

WPG = (W2-W1): W1×100 ..............................(2)

Where:
WPG = the weight percent gain of the sample (%)
W2 = sample dry weight after oil impregnation (g)
W1 = sample dry weight before oil impregnation (g)

## 2. Fire Resistance Test

The wood samples were burned with a heating torch at 180 ± 5°C for 4 minutes (Figure 2). The temperature of the sample was monitored with an infrared thermometer according to the research of Yulianto, Hadikusumo, & Listyanto (2009). The samples were weighed before (Wi) and after (Wb) the test to determine the weight loss with Equation 3.

WL=(Wi-Wt): Wi×100 ......................................(3)

Where:
WL = weight loss (%)
Wi = sample weight before test (g)
Wt = sample weight after test (g)

## 3. Above-Ground Field Test

Wood samples were placed on a shelf facing east at a 45° angle to be exposed to the environment (Figure 3) considering the research by Kim, Kim & Lee (2016). The exposure was carried out for 90 days. The dry weight of the sample was determined before and after exposure to calculate the weight loss

Table 1. Treatment combinations on manii wood without boric acid (A), with boric acid (B), without oil (T), neem oil (M), tamanu oil (N), candlenut oil (K), and heating temperatures (60°C, 120°C, 180°C)

| | A | | | | B | | | |
|---|---|---|---|---|---|---|---|---|
| | T | M | N | K | T | M | N | K |
| 60°C | AT60 (control) | AM60 | AN60 | AK60 | BT60 | BM60 | BN60 | BK60 |
| 120°C | AT120 | AM120 | AN120 | AK120 | BT120 | BM120 | BN120 | BK120 |
| 180°C | AT180 | AM180 | AN180 | AK180 | BT180 | BM180 | BN180 | BK180 |

Figure 2. Heating torch (a) and burning test of a wood sample using a heating torch (b)

of samples. Besides that, the moisture content changes of woods were measured with a digital moisture meter, inGCO HETWM01. The weight loss and moisture content change of wood were calculated with Equations 3 and 4. The color change of wood was scanned using a CHN Spec CS-10 colorimeter, which showed the color values of L, a, and b. The color scanning was conducted before and after the exposure on two of the same areas of the samples (Figure 4). In the CIELab method, the L-value represents the brightness parameter which has a value of 0 to 100 (black to white). Green to red is indicated by the a-value, whereas blue to yellow is shown by the b-value (Bora, 2017). The color change (ΔE) was calculated by Equation 5.

$$\Delta MC = (MCt - MCi) : MCi \times 100 \quad \text{.................(4)}$$

Where:
ΔMC = the change of moisture content (%)
MCi = moisture content before test (g)
MCt = moisture content after the test (g)

$$\Delta E = \sqrt{[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]} \quad \text{.....................(5)}$$

Where:
ΔE = the color change of the sample
ΔL = the change in brightness
Δa = the change of red or green color
Δb = the change of yellow or blue color

Figure 3. Above-ground field test of manii woods

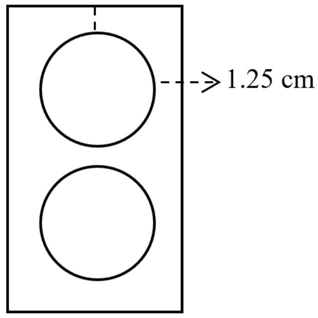


Figure 4. Schematic of the color test area

## C. Data Analysis

The obtained data of preservative retention and oil weight percent gain were analyzed descriptively using Microsoft Excel software. The SPSS software was also used to evaluate the effect of treatments on wood resistance using 2 × 4 × 3 factorial experiments in a completely randomized design (Paiman, 2015). The factors consist of two preservation (boric acid and without boric acid), four vegetable oil treatments (neem, candlenut, tamanu, and without vegetable oil), and three heating temperatures (60°C, 120°C, and 180°C). These 24-treatment combinations were replicated five times. Analysis of Variance (ANOVA) was conducted. When the ANOVA resulted in a significant effect, then Duncan's Multiple Range Test (DMRT) was used to determine the magnitude of the difference.

# III. RESULTS AND DISCUSSION

## A. Evaluation of Impregnation

Retention is an important indicator in the preservation process. The retention of boric acid preservative in manii wood was 14.77 kg $m^{-3}$, which met the standard of SNI 01-5010.1-1999 (Indonesia National Standard) which is 8.2 kg $m^{-3}$ for interior and 11.3 kg $m^{-3}$ for exterior usage (BSN, 1999). The retention in wood preservation can be influenced by several factors such as wood moisture content, wood anatomy, wood density, and the properties of preservatives (Syahrial, Sribudianti & Somadona, 2022). Boric acid retention in manii wood was quite high because manii wood has a medium-specific gravity (0.42) (Muslich & Rulliaty, 2016), thus having a lot of cavities in the wood that supports its permeability.

The weight percent gain value (WPG) of manii wood (Figure 5) treated with boric acid and candlenut oil (BK) was higher than the other treatments. This could be influenced by the lower viscosity of candlenut oil (7.7 cP) (Hidayah, Riyanta, & Mahardika, 2022)) than that of tamanu oil (54 cP) (Christina, Sungadi, Hindarso, & Kurniawan, 2017).) and neem oil (29.5 cP) (Yusriah, Hambali & Dadang, 2017).

Heat treatment at higher temperatures produced lower WPG values. This was presumably due to the evaporation of some oils and some degradation of the chemical components of wood cell walls, particularly hemicellulose at higher heating temperatures. This study supports the results reported by Kia et al. (2020) that the WPG of poplar wood (*Populus deltoids*) heat treated with rapeseed oil decreased by increasing the temperature from 180°C to 220°C. The result of the analysis of variance (ANOVA) revealed that the interaction of boric acid, oil, and heat treatments significantly affected the WPG of oils at the 95% confidence interval. Based on the Duncan test, the treatment combination of boric acid and vegetable oil caused a higher WPG than that of oil treatment without boric acid. In addition, the combination treatment of boric acid with candlenut oil and heating at 60°C (BK60) gave a significantly higher WPG value than other oil treatments. This is because of the lower viscosity of candlenut oil and lower heating temperature in this treatment.

## B. Burning Test

Increasing the fire resistance of wood can reduce the fire risk of building (Sulistyo et al., 2020). Figure 6 shows that the lowest weight loss in the burning test (20.67%) occurred when boric acid was combined with candlenut oil and heated at 60°C (BK60). The treated wood's fire resistance increases with decreasing weight loss burning intensity. The combination of vegetable oil, heat treatments, and boric acid preservative significantly impacted the burning intensity and weight loss of manii wood, according to the ANOVA at the 95% confidence interval. The Duncan analysis showed that combining boric acid preservative with oil treatment significantly reduced the weight loss compared to the control (AT60) and only boric acid treatment (BT60).

The decrease in weight loss was affected by the presence of oil, mainly candlenut oil in manii wood. The more the candlenut oil in wood, the lower the weight loss of manii wood. The vegetable oil in the wood tended to inhibit ignition and the spread of flame on the wood.

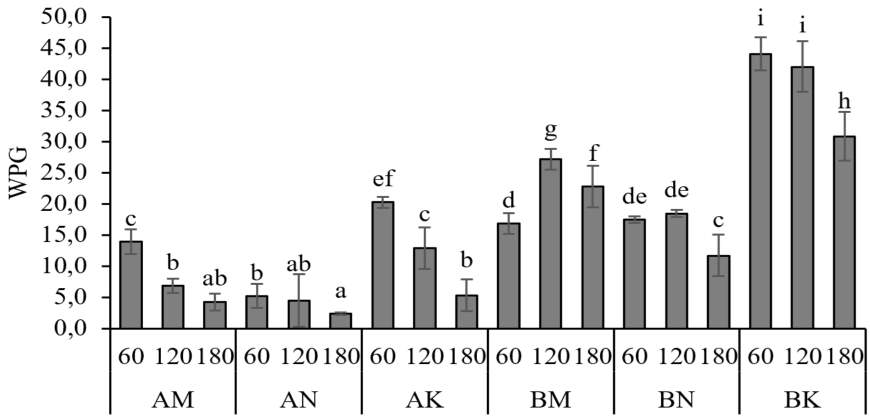


Figure 5. Weight percent gain (WPG) of neem (M), tamanu (N), and candlenut (K) oils on manii wood treated without boric acid (A), with boric acid (B), and heating temperatures (60°C, 120°C, 180°C). The same letters (a, b, c, etc.) indicate the values were not significantly different in Duncan's test

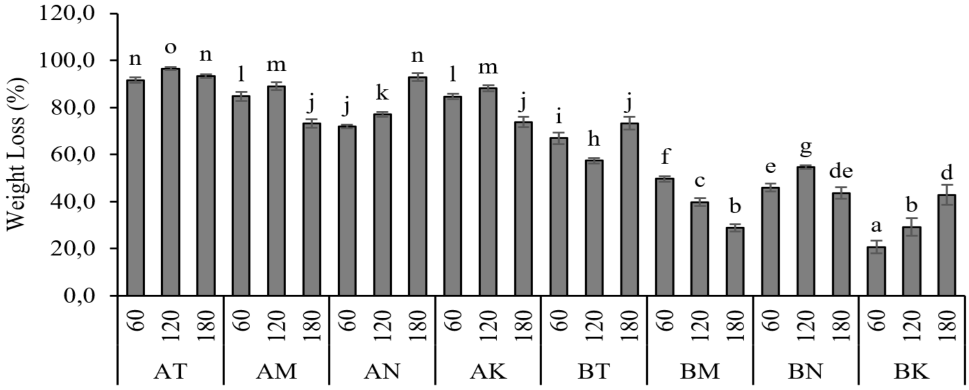


Figure 6. Weight loss in the burning test of manii wood treated without boric acid (A), with boric acid preservative (B), without vegetable oil (T), with neem oil (M), tamanu oil (N), candlenut oil (K), and heating temperatures (60°C, 120°C, 180°C). Values that are not substantially different in Duncan's test are shown by the same letters (a, b, c, etc.)

The existence of vegetable oil in the pores and cavities of manii wood reduced the availability of oxygen in the wood, which inhibited the flame (Mensah, Jiang, Renner, & Xu, 2023). The provision of boric acid had a significant effect in reducing the intensity of combustion of wood. This supported the research of Lin et al. (2019) that boric acid compounds reduced the weight loss of pine wood. Boron compounds inhibited the combustion of wood by breaking reactions with oxygen (Dayadi, 2021). The boron component formed a glassy coating on the wood which reduced the spread of burning (Can, Grzeskowiak & Özlüsoylu, 2018). The higher temperature of heating caused a higher weight loss compared to that of 60°C heating. This is supported by Rabe, Klack, Bahr, & Schartel (2020) that heat treatment can degrade hemicellulose and polymers in wood and make wood cannot withstand burning.

### C. Above-Ground Field Test

The weight loss of all tested manii wood decreased after 90 days of exposure (Figure 7). This was caused by wood degradation due to fungal attacks and weather factors such as rainfall and sun radiation, so the weight of the wood becomes lighter. The wood samples in the test were exposed to the weather, often experiencing wetting by rainwater and heating by sunlight. The wetting of rainwater increased the water content of the wood, thus supporting the germination of fungal spores that stick to the wood. Heating by sunlight caused the photodegradation of wood followed by microchecks so that the fungal hyphae penetrated through the pores, cavities, and microchecks which support the wood degradation process. Enzymatic reactions by decay fungi degraded wood cell wall components, especially hemicellulose, and cellulose, so the wood loses weight. According to data from BMKG (2023), Bogor Regency experienced 404.7 mm of rainfall per month from March to May, with average temperatures of 21.9°C and humidity of 86.3%. Reinprecht et al. (2018) report that all tested tropical woods underwent changes throughout the weathering test, including longitudinal macro-checks, a drop in cellulose crystallinity, a decrease in guaiacyl lignin that was faster than syringyl lignin, and photo-oxidized and washed-out cell walls.

The ANOVA at the 95% confidence interval revealed that the interaction of boric acid preservative, vegetable oil, and heat treatments significantly affected the manii wood weight loss in the above-ground field test. The following Duncan analyses showed that the oil treatment caused a significantly smaller weight loss than

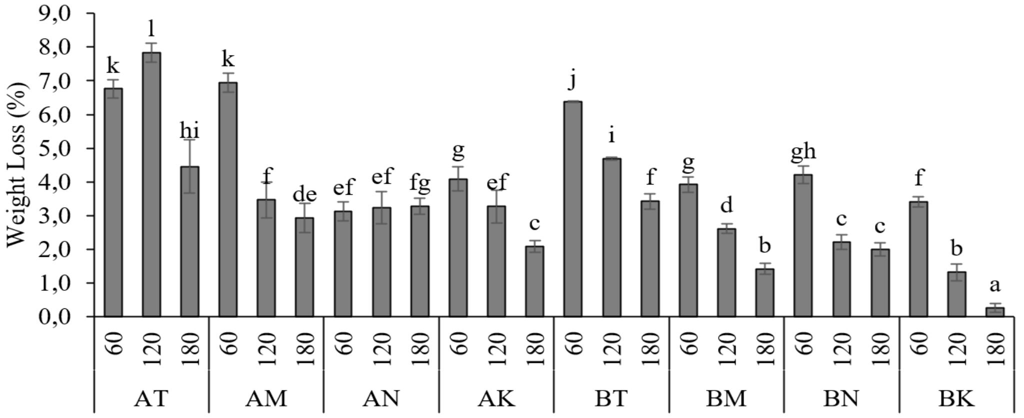


Figure 7. The weight loss in the above-ground field test of manii wood treated without boric acid (A), with boric acid (B), without vegetable oil (T), with tamanu oil (N), neem oil (M), candlenut oil (K), and heating temperatures (60°C, 120°C, 180°C). The same letters (a, b, c, etc.) indicate values that are not significantly different in Duncan's test

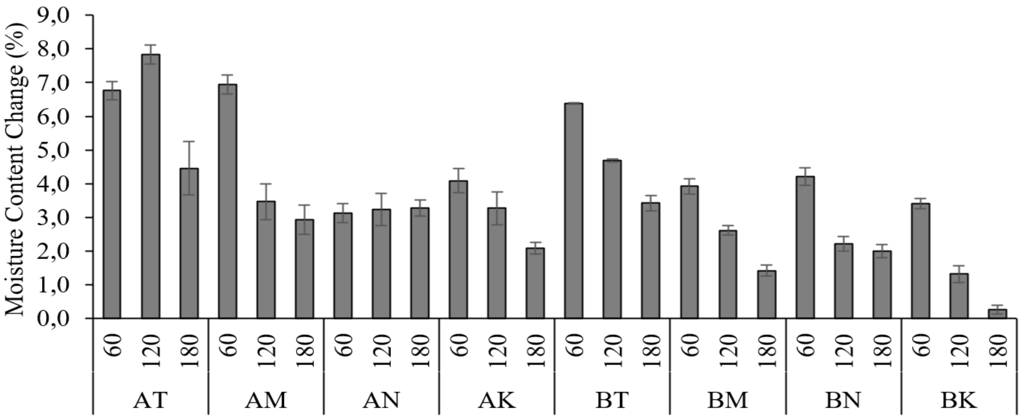


Figure 8. The moisture content change in the above-ground field test of manii wood treated without boric acid (A), with boric acid (B), without vegetable oil (T), with neem oil (M), tamanu oil (N), oil candlenut (K), and heating temperatures (60°C, 120°C, 180°C)

the control sample (AT60) and boric acid treatment alone (BT60). Boric acid treatment without oil also significantly reduced the value of weight loss compared to the control (AT60). The combination of boric acid preservative with candlenut oil treatment resulted in a significantly lower weight loss than the other treatments, especially those that were heated at 120°C and 180°C. This was due to more hazelnut oil entering the wood than other plant oils and less preservatives leaching during the field test. In addition, the higher heating temperature caused changes in cell wall chemistry, mainly hemicellulose as reported by Liang & Wang (2017) that hemicellulose was more sensitive to temperature than other cell wall components. Heating at 180°C caused β-glucosidic bonds and side chains in hemicelluloses to be cleaved.

Natural exposure changed the moisture content of manii wood (Figure 8). The oil-treated wood had less moisture changes than those without oil treatment, especially those that were heated at 120°C and 180°C. This is related to the hydrophobic properties of oil or water-repellent (Subagyo & Muliadi, 2017). This reduction of wood moisture absorption is useful in outdoor uses so that wood will be more stable and can be more resistant to fungal attacks. This follows the reports by Pelaez-Samaniego et al. (2013) that thermal modification reduced water absorption and thickness swelling due to the removal of hemicelluloses. Thermal treatment also improved the resistance to decay. Shukla (2019) also revealed that heat treatment enhanced dimensional stability and biological durability against fungi of short-rotation *Acacia auriculiformis* wood.

In the above-ground natural exposure, the color analyses showed that most wood samples' L-value decreased, indicating becoming darker (Figure 9). Wood color is an important parameter affecting consumer interest (Conroy, Morrell, & Knowles, 2019). Hidayat et al. (2017) stated that many consumers prefer dark-colored woods to bright-colored ones. Wood without oil had an increased a-value (redder) and a decreased b-value (less yellow). Oil-treated wood experienced various changes in both a-value and b-value. According to Turkoglu, Baysal, and Toker (2015), the change in the a-value was caused by the change of extractive content in the wood, while the lignin degradation mostly caused the change in the b-value.

The color change (ΔE) of manii wood following natural exposure was significantly impacted by the combination of oil and heat treatments, according to the analysis of variance at a 95% confidence interval (Figure 10). The Duncan test resulted in that wood treated with neem and tamanu oil experienced a significantly

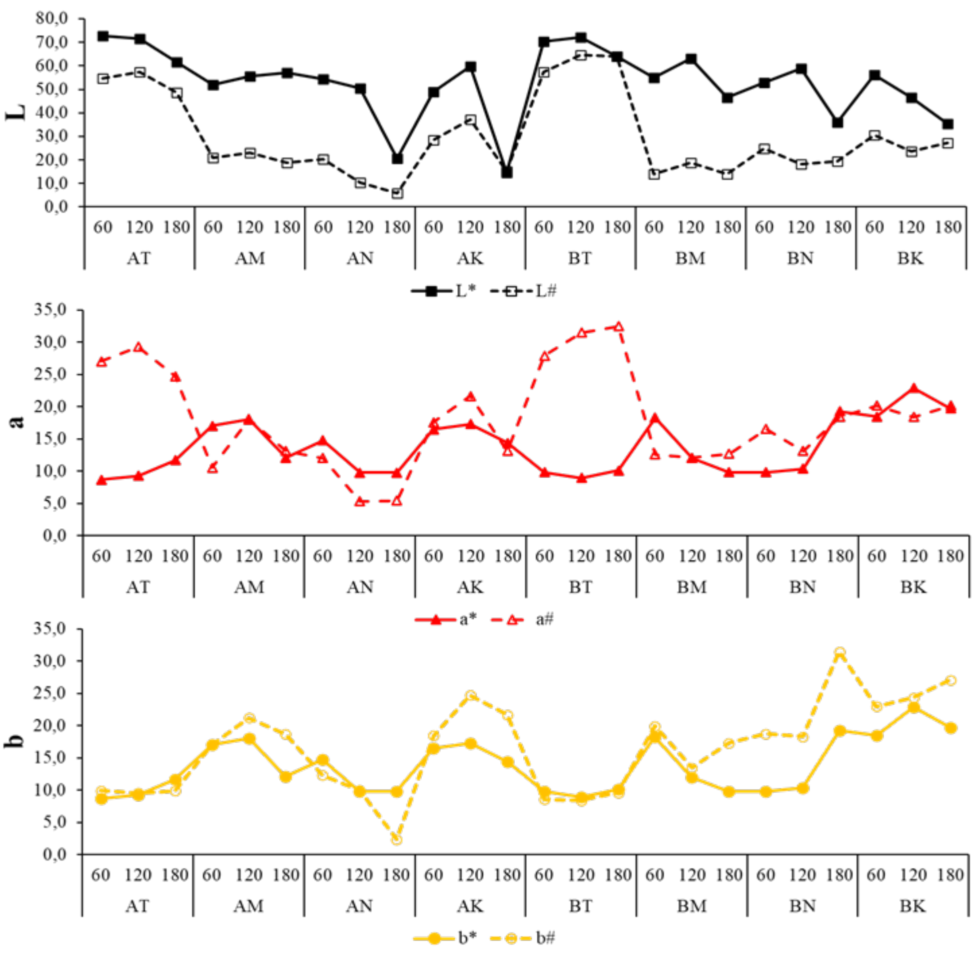


Figure 9. The L, a, and b values in above-ground field test on manii wood treated without boric acid (A), with boric acid preservative (B), without vegetable oil (T), with tamanu oil (N), neem oil (M), candlenut oil (K), and heating temperatures (60°C, 120°C, 180°C) before (*) and after (#) natural exposure

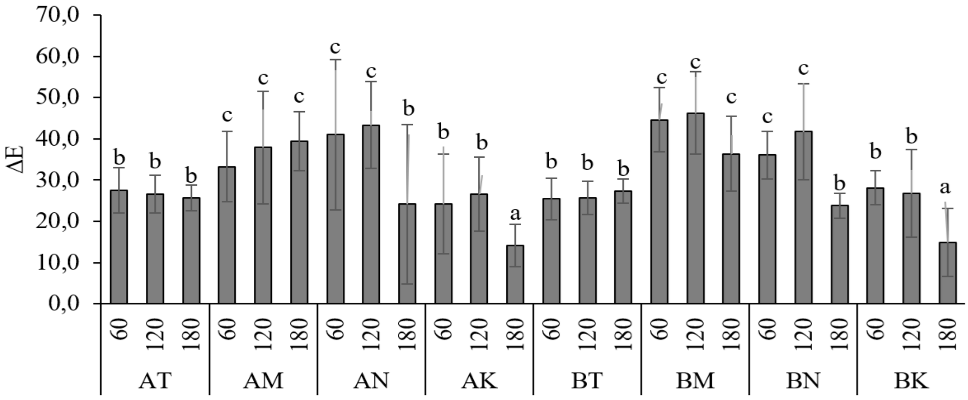


Figure 10. The Color change (ΔE) in the above-ground field test of manii wood treated without boric acid (A), with boric acid (B), without vegetable oil (T), with tamanu oil (N), neem oil (M), hazelnut oil (K), and heating temperatures (60°C, 120°C, 180°C). The same letters (a, b, c, etc.) indicate values that are not significantly different in Duncan's test

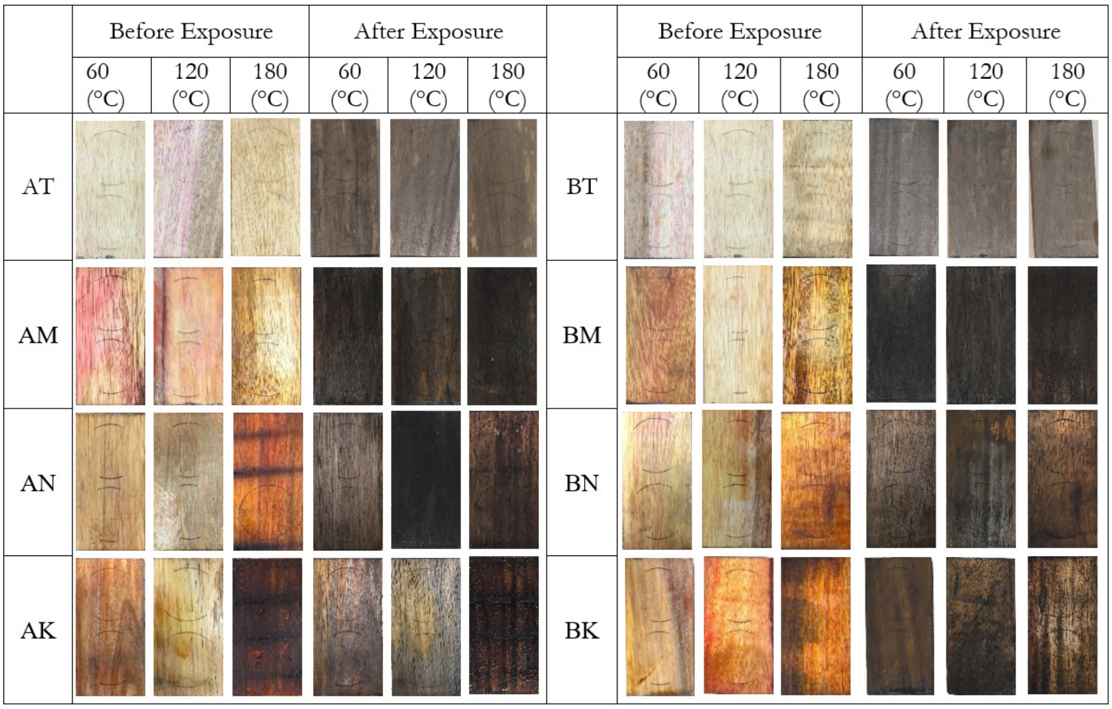


Figure 11. The Color changes in the above-ground field test of manii wood treated without boric acid (A), with boric acid (B), without vegetable oil (T), with tamanu oil (N), neem oil (M), candlenut oil (K), and heating temperatures (60°C, 120°C, 180°C)

higher discoloration than the control. Wood treated with candlenut oil had a smaller color change after exposure than the other oil treatments, even less than the control wood. This was because the treatment of candlenut oil and heating produced a darker wood color than the other treatments. Wood color changes occur when exposed to weather, temperature and humidity changes, and repeated wetting of rain, dew, and sunlight (Krisdianto, Satiti & Supriadi, 2018). The features of manii wood before and after natural exposure are shown in Figure 11.

## IV. CONCLUSION

Boric acid treatment improved the fire resistance of Maesopsis eminii wood, especially when combined with candlenut oil. Wood treated with vegetable oils (neem, tamanu, and candlenut) was more resistant to biodeterioration when exposed to above-ground natural conditions. All the tested woods experienced a darker discoloration in the natural exposure. The combination treatment of boric acid with candlenut oil and heating at 120°C gave better resistance of manii wood against fire and biodeterioration than the other treatments. **Therefore, this treatment is prospective for improving non-durable wood for outdoor use**.

## ACKNOWLEDGEMENT

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