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The Color Changes in and Termite and Fungal Resistance of Modified *Maesopsis eminii* Engl. Wood with Boric Acid and Seed Oil

Trisna Priadi *, Junah Kistia, Indah Putri Khanifah and Tina Agustin

Department of Forest Products, IPB University, Bogor 16680, Indonesia
* Correspondence: trisnapr@apps.ipb.ac.id

Abstract: Manii (*Maesopsis minii*) is a fast-growing wood that is mainly produced for light construction and woodworking. The wood has low durability properties and requires improvements in quality. This research aims to evaluate the combination effect of boric acid, seed oil, and heating on the color of manii wood and its resistance against subterranean termites and decay fungi. The wood samples were modified by combining boric acid, neem oil, tamanu oil, and candlenut oil and heating at 70 °C and 140 °C for 4 h. The color change in the wood was evaluated using the CIELab method, while the resistance against subterranean termites (*Coptotermes curvignathus*) and decay fungi (*Schizophyllum commune*) was tested according to the SNI 7207-2014 standard. The results show that a significant color change occurred after the oil treatments. *L* and *b* values generally decreased, while the *a* values usually slightly increased after treatment. Boric acid significantly increased the resistance of manii wood against tested termites and fungi. The seed oils also improved wood resistance against termites, while the wood resistance against fungi significantly improved from the combination of boric acid and seed oil treatment. The lowest weight loss in termite and fungal tests occurred with the combination of boric acid and candlenut oil with heating at 140 °C.

Keywords: boron preservative; decay fungi; fast-growing wood; seed oil; termites; wood color

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1. Introduction

Manii wood (*Maesopsis eminii* Engl.) is a fast-growing species planted in many community forests in West Java [1]. Manii wood is mainly used for construction and wood working. Its texture is coarse with interlocked grains that produce a clear figure on board surfaces [2]. This fast-growing wood has a high productivity rate with an air-dry density of 0.39 g.cm^3 [3], specific gravity of 0.42, and a strength class of III, but its durability is low (durability class V) [4]. Thus, the wood is easily attacked by degrading organisms when it is used. This is a critical problem of fast-growing wood in structural utilization.

The preservation of fast-growing woods, especially with environmentally friendly techniques, is becoming more important. Boron compounds are well-known preservatives that can control fungal attacks [5] and insects [6]. However, boron preservatives are easily leached by water. Therefore, this preservative cannot be optimally used for exterior functions [7]. To solve this leaching problem, boron preservatives need to be combined with other materials or treatments. Combining boron preservatives with oil could reduce preservative leaching by water [8] and significantly improve decay resistance [9]. Plant oil treatment increases the hydrophobicity of wood [10] and reduces the wettability of the wood's surface [11].

The combination of boron with natural preservatives might increase the effectiveness of the wood's protection from destructive organisms. Natural preservatives extracted from plants have a pesticide effect, but are safe for humans and the environment. Some potential natural preservatives that have anti-termite effects are tamanu (*Calophyllum inophyllum*) [12], *Azadirachta indica* [13], and *candlenut* (*Aleurites moluccana* (L.) Willd) oils [14]. Heat treatment is an environmentally friendly method for protecting wood against various decay fungi [15]. Heat treatment at 200 °C significantly decreases equilibrium moisture content and density, and significantly improves the water-reabsorbing capacity and dimensional stability of poplar (*Populous sp.*) wood, while the darkening effect on wood can produce more desirable, highly aesthetic color tones and achieve color uniformity [16]. Heating the spruce wood at or above 200 °C resulted in greater resistance against brown-rot fungus *Serpula lacrymans* than white-rot fungus *Trametes versicolor* [17]. However, heat treatments did not protect wood in a field test against subterranean termites. The combination of thermal (180 and 200 °C) and organosilane treatments significantly improved the durability of pine wood against *Coniophora puteana* as well as against the micro-fungi [18]. Combining heat treatment at 200 °C with 75% neem and 25% sesame oil significantly reduced subterranean termite attacks [19]. The combination of boric acid and chitosan treatments followed by heating at 140 °C considerably improved the resistance of *Maesopsiss eminii* wood against white-rot fungi (*Schizophyllum commune*), dry-wood termites (*Cryptotermes cynocephalus*), and subterranean termites (*Coptotermes curvignathus*) [20]. Linseed oil treatment resulted in the best improvement in wood resistance against *Odontotermes obesus* termites, followed by neem, jatropha, jojoba, and eucalyptus oils [21]. Oil heating can also improve wood's dimensional stability and increase its resistance to fungi and termites [22].

The study of the synergetic effects of natural oils in efforts to improve boron preservatives would be developed as an eco-friendly preservation technique. Therefore, this study aims to evaluate the combination effect of boric acid, seed oil, and heating on the color of manii wood (*M. eminii*) and its resistance to subterranean termites and decay fungi.

2. Materials and Methods

Manii logs (*M. eminii*), including those made of heartwood and sapwood, with an average diameter of 38 cm obtained from a sawmill industry in Bogor were sawn into several 3 cm-thick boards. The boards were dried at 50 °C in an experimental kiln with a capacity of 1 m^3 to a moisture content of ±14%. Some test samples were then produced in various sizes according to Table 1.

Table 1. The size of the test samples.

No	Tests	Sample Size
1	Color evaluation	1 cm × 5 cm × 10 cm
2	Resistance test against subterranean termites	2.5 cm × 2.5 cm × 0.5 cm
3	Resistance test against decay fungi	5 cm × 2.5 cm × 1.5 cm

The impregnation of boric acid or seed oil was conducted in a preservation tank at a pressure of 7 $kg.cm^{-2}$ for 4 h. The combination of wood treatments is described in Table 2. All tests were conducted in 5 replications. The impregnants in this research were 5% boric acid, neem oil (*Azadirachta indica*), tamanu oil (*Calophyllum inophylum* L.), and candlenut oil (*Aleurites moluccana*). The following heat treatment was conducted in a laboratory heating oven, "Memmert," at 70 °C or 140 °C under atmospheric pressure for 4 h.

The retention of boric acid was calculated after the first impregnation with Equation (1). After the oil impregnation, the weight percent gain (WPG) value was determined by Equation (2).

Table 2. Treatment combinations used with manii wood.

No	Kode	Impregnants				Heating	
		Boric Acid 5%	**Neem Oil**	**Tamanu Oil**	**Candlenut Oil**	**70 °C**	**140 °C**
1	AT70	−	−	−	−	+	−
2	AT140	−	−	−	−	−	+
3	AM70	−	+	−	−	+	−
4	AM140	−	+	−	−	−	+
5	AN70	−	−	+	−	+	−
6	AN140	−	−	+	−	−	+
7	AK70	−	−	−	+	+	−
8	AK140	−	−	−	+	−	+
9	BT70	+	−	−	−	+	−
10	BT140	+	−	−	−	−	+
11	BM70	+	+	−	−	+	−
12	BM140	+	+	−	−	−	+
13	BN70	+	−	+	−	+	−
14	BN140	+	−	+	−	−	+
15	BK70	+	−	−	+	+	−
16	BK140	+	−	−	+	−	+

Notes: A = without boric acid; T = without oil; M = neem oil; N = tamanu oil; K = candlenut oil; B = boric acid; 70 = heating at 70 °C; 140 = heating at 140 °C; positive (+) = applied; negative (−) = not applied.

$$R = \frac{Wt - Wo}{V} \times C \quad (1)$$

$$WPG = \frac{Wh - Wb}{Wb} \times 100 \quad (2)$$

Here,
Wo = sample weight before boric acid impregnation (kg);
Wt = sample weight after boric acid impregnation (kg);
V = sample volume (m^3);
C = preservative concentration (%);
WPG = weight percent gain (%);
Wh = sample weight before oil treatment (g);
Wb = sample weight after oil and heat treatments (g).

The color of the wood was evaluated before and after treatments using a CanoScan 4400F scanner. The wood image was analyzed using the CIELab method that determined *L*a*b* values at three different points on the sample's surface using Adobe Photoshop CS3 application. Parameter *L** indicated light (+) or dark (−), *a** indicated reddish (+) or greenish (−), and *b** indicated yellowish (+) or bluish (−) [23] colors. The changes in *L**, *a**, and *b**, (*ΔL*, *Δa*, and *Δb*, respectively) were calculated using Equations (3)–(5). The color change (*ΔE*) was then calculated using Equation (6).

$$\Delta L = L_1 - L_0 \quad (3)$$

$$\Delta a = a_1 - a_0 \quad (4)$$

$$\Delta b = b_1 - b_0 \quad (5)$$

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2} \quad (6)$$

Here, L_1, a_1, and b_1 are the values of *L**, *a**, and *b**, respectively, after wood treatments, while L_0, a_0, and b_0 are the values before the treatments [24]. The color change (*ΔE*) was classified according to Table 3.

Table 3. Classification of color change (ΔE).

Color Change	Description
($0 < \Delta E \leq 0.5$)	Negligible
($0.5 < \Delta E \leq 1.5$)	Slightly perceivable
($1.5 < \Delta E \leq 3.0$)	Noticeable
($3.0 < \Delta E \leq 6.0$)	Appreciable
($6.0 < \Delta E \leq 12$)	Very appreciable

Source: Cui et al. [25].

The resistance test against subterranean termites and decay fungi was evaluated based on the modified SNI 7207:2014 standard [26]. Prior to testing, the wood samples were oven-dried at 70 °C to a constant weight.

The non-choice testing method against subterranean termites involved a wood sample that was placed in a test bottle, leaning on its wall. Moisturized sand (±200 g) at a moisture content of 5% below its water holding capacity was added to the bottle. Then, 200 healthy and active subterranean termites (*Coptotermes curvignathus* Holmgren) were placed into each bottle and covered with fine, perforated plastic. The wood's exposure to termites was performed in a dark room at ±28 °C. After 4 weeks of exposure, the samples were removed from the bottle, cleaned of sand, and oven-dried at 70 °C to a constant weight. The wood's weight loss was calculated using Equation (7). The wood's resistance against subterranean termites was classified based on Table 4.

Table 4. The resistance class of wood against subterranean termites.

Class	Description	Weight Loss (%)
I	Very resistant	<3.5
II	Resistant	3.5–7.4
III	Moderate resistant	7.5–10.8
IV	Low resistance	10.9–18.9
V	Vulnerable	>18.9

Source: SNI 7207-2014 [26].

$$WL = \frac{W0 - W1}{W0} \times 100 \quad (7)$$

Here,
WL = weight loss (%);
$W0$ = dry weight of the sample before the test (g);
$W1$ = dry weight of the sample after the test (g).

The wood resistance test against decay fungi used *Schizophyllum commune* on PDA (*potato dextrose agar*) media. After 12 weeks of the decay test at room temperature (±28 °C), the sample was cleaned from mycelium and oven-dried at 70 °C to a constant weight. The weight loss of the wood was calculated using Equation (7). The wood's resistance against the decay fungi was classified based on Table 5.

Table 5. Wood's resistance against decay fungi.

Class	Description	Weight Loss (%)
I	Very resistant	<0.5
II	Resistant	0.5–4.9
III	Moderate resistant	5.0–9.9
IV	Low resistance	10.0–30.0
V	Vulnerable	>30.0

Source: SNI 7207-2014 [26].

The effect of boric acid, seed oil, and heating on the color change on and resistance of manii wood against subterranean termites and decay fungi was statistically analyzed using a factorial, completely randomized design. Factor A had 2 levels (boric acid and no boric acid). Factor B had 4 levels (neem oil, tamanu oil, candlenut oil, and no oil). Factor C had 2 levels (70 and 140 °C). The Duncan test was then performed if the results of the analysis of variance (ANOVA) had a significant effect at a 95% confidence interval.

3. Results and Discussion

Manii (*M. eminii* Engl.) wood has a color that combines white sapwood and yellowish heartwood when freshly cut, and turns golden brown or dark brown when dry and exposed to the environment [2]. The texture of the wood is moderately coarse and even, with interlocked grains that produce a clear figure on quarter-sawn surfaces. Figure 1 shows that without oil and boric acid treatments, manii wood has different colors in the 70 °C and 140 °C heat treatments: slightly darker at 140 °C (AT140) than at 70 °C (AT70). This supports the previous report [27] that heat treatment reduces the lightness (*L*) of oak, birch, and pine woods.

Figure 1. The appearance of manii wood after heating at 70 or 140 °C, and treatments with boric acid (B), without boric acid (A), with neem oil (M), with tamanu oil (N), with candlenut oil (K), and without oil (T).

Boric acid treatment (BT70 and BT140) led to a brighter wood than treatments without boric acid (AT70 and AT140). However, in previous research, borate preservation darkened Scots pine and Oriental beech woods [28]. In general, all oil treatments (neem, tamanu, and candlenut) significantly changed the wood's appearance compared to treatments without oil. This is supported by the fact that the *L* values, in Figure 2, in all oil-treated woods, were less than 42 (darker), while untreated-oil woods showed *L* values of more than 56 (brighter). This is in accordance with Dubey et al. [29], who showed that oil heating resulted in a more uniform and darker color of *Pinus radiata* wood. Comparing oil treatments, tamanu oil showed a lower *L* value (darker) than neem and candlenut oils. Heating at 140 °C slightly increased the *a* and *b* values of manii wood, which became more reddish and yellowish. Similarly, boric acid treatment also caused a slight increase in the *a* and *b* values. On the other hand, oil treatments mostly resulted in increased *a* values but reduced *b* values, which represents more reddish and less yellowish hues than in treatments without oil. Figure 1 shows that all treated manii wood samples still had clear, attractive, natural features, although in different colors.

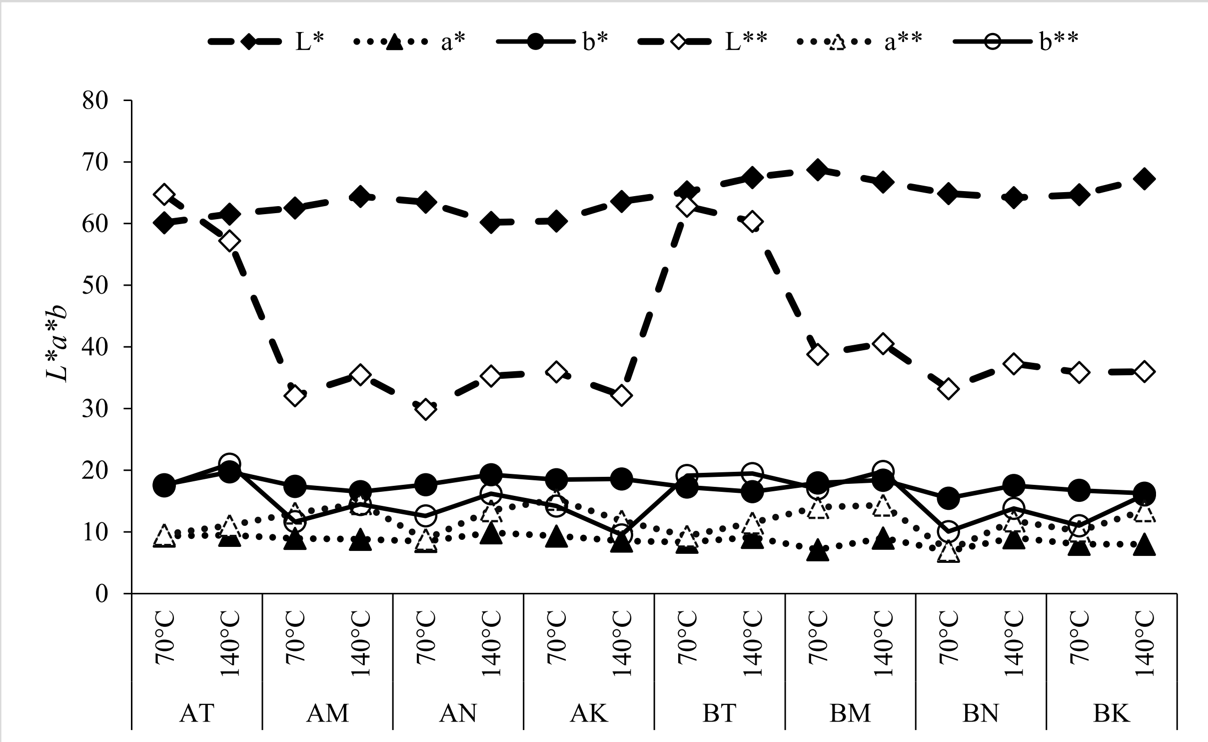

Figure 2. The *L*a*b* values of manii wood after heating at 70 or 140 °C, and treatments with boric acid (B), without boric acid (A), with neem oil (M), with tamanu oil (N), with candlenut oil (K), and without oil (T).

Figure 3 shows that the greatest color change (*ΔE*) occurred in the treatment with tamanu oil and 70 °C heating (AN70). All oil treatments caused significant color changes (*ΔE* greater than 25), five times higher than those of treatments without oil (AT70). As a comparison, the color changes (*ΔE*) in oil-heated Korean pine wood at 200 °C and 180 °C were about 30.0 and 18.4, respectively [30]. According to Cui et al. [25], a color change (*ΔE*) of more than six was categorized as very appreciable, which occurred in all treatments in this experiment. Heating at 140 °C caused a greater color change than heating at 70 °C, except in neem and tamanu oil treatments, which reduced the color change. The analysis of variance revealed the interaction effect of oil treatment and heating temperature on the color change (*ΔE*) in manii wood (Table 6). Furthermore, the Duncan test (Table 7) showed that, in the tamanu oil treatment, heating at 140 °C led to a color that was significantly different from that caused by heating at 70 °C, while in the neem and candlenut oil treatments, the color differences were not significant. Tamanu oil with 140 °C heating caused a 24% less color change compared with 70 °C heating.

Table 6. Compilation of analyses of variance (ANOVA).

Treatments	*ΔE*	Subterranean Termites	Decay Fungi
Boric acid (B)	0.791 ns	0.002 **	0.000 **
Oil (O)	0.000 **	0.02 *	0.002 **
Temperature (T)	0.867 ns	0.479 ns	0.000 **
B*O	0.875 ns	0.001 **	0.000 **
B*T	0.926 ns	0.733 ns	0.099 ns
O*T	0.003 **	0.839 ns	0.096 ns
B*O*T	0.675 ns	0.899 ns	0.749 ns

Notes: * = the effect is significant; ** = the effect is very significant; ns = the effect is not significant at 95% confidence interval.

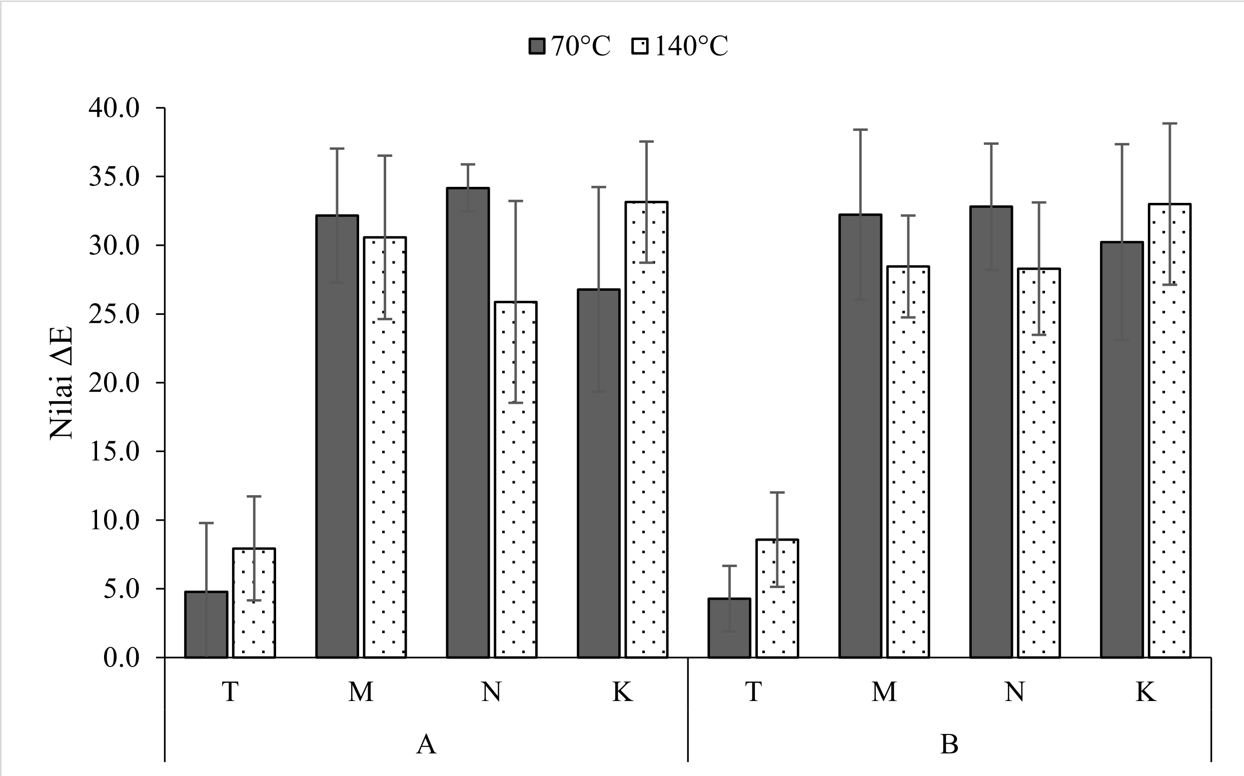

Figure 3. Color change (*ΔE*) in treated manii wood with heating at 70 or 140 °C and with boric acid (B), without boric acid (A), with neem oil (M), with tamanu oil (N), with candlenut oil (K), and without oil (T).

Table 7. The Duncan test for color change (*ΔE*).

Oil*Heating	*ΔE*
T 70	4.5210 a
T 140	8.2550 a
N 140	27.0820 b
K 70	28.5020 bc
M 140	29.5170 bcd
M 70	32.1890 cd
K 140	33.0650 cd
N 70	33.4860 d

Notes: Groups with the same letters indicate no statistical difference ($p < 0.05$) between the treatments according to Duncan's multiple range test.

The resistance test against subterranean termites (*C. curvignathus*) revealed that all treated manii woods lost less weight than the control sample (AT70) (Figure 4). The control sample showed an 11.54% weight loss due to subterranean termites. Based on the SNI 7207-2014 standard, this untreated manii was classified as Resistance Class IV (low resistance). Its deviation standard was high because the sample came from heartwood and sapwood manii woods. In general, heartwood contains more extractives than sapwood, which affects the wood's durability against biodeterioration agents. França et al. [31] similarly reported that heartwoods, compared to sapwood, of *Khaya ivorensis* and *K. senegalensis* were more resistant to decay fungi and subterranean termites.

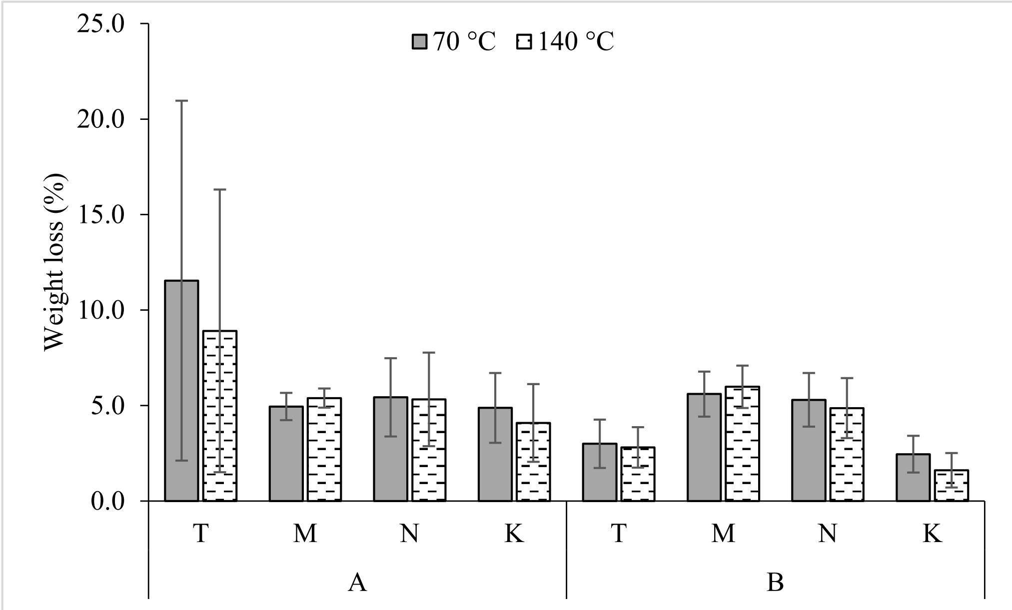

Figure 4. Weight loss of manii wood in the subterranean termite test after heating at 70 or 140 °C and treatments with boric acid (B), without boric acid (A), with neem oil (M), with tamanu oil (N), with candlenut oil (K), and without oil (T).

Boric acid significantly reduced the weight loss of manii wood, such that it was very resistant (Resistance Class I) against subterranean termites. The analysis of variance revealed that boric acid and oil treatments had a significant interaction effect at a 95% confidence interval on weight loss in the subterranean termite test (Table 6). Furthermore, the Duncan test revealed that boric acid treatment (BT) had a significantly lower weight loss than the untreated wood (AT) (Table 8). Boric acid is a well-known chemical insecticide [32] and has been mainly used for interior functions.

Table 8. Duncan test of weight loss due to subterranean termites.

Boric Acid*Oil	Weight Loss
BK	2.03 a
BT	2.90 ab
AK	4.48 ab
BN	5.08 b
AM	5.17 b
AN	5.38 b
BM	5.79 b
AT	10.22 c

Notes: Groups with the same letters indicate no statistical difference ($p < 0.05$) between the treatments according to Duncan's multiple range test.

Treatments with neem, tamanu, and candlenut oils (AM, AN, and AK, respectively) caused significantly less weight loss than treatments without oil (AT). All oil treatments increased the resistance against subterranean termites to Class II. These seed oils contained some substances that had biological activities and could be used for wood protection. Tamanu oil contains flavonoids, alkaloids, and saponins [33]. Neem oil contains tannins, flavonoids, alkaloids, steroids, saponins, and triterpenoids [34]. Candlenut oil contains saponins, alkaloids, phenolics, glycosides, flavonoids, and triterpenoids [35]. Flavonoids have antifungal and termiticidal effects [36]. Alkaloids have strong anti-termite and repellant activities against subterranean termites *Odontotermes obesus* [37]. Saponins exhibit notable insecticidal effects against *Rhyzopertha dominica* and *Tribolium castaneum* [38].

Combining neem or tamanu oils with boric acid could not cause greater resistance against subterranean termites than boric acid treatment (BT70). On the other hand, the combination of boric acid and candlenut oil with heating at 140 °C (BK140) caused less weight loss than boric acid treatment (BT70). BK140 had the least weight loss in this experiment. Heating at 140 °C reduced weight loss in the AT treatment (without boric acid and oils) and in the candlenut oil treatment (AK and BK). Compared to the control, heating at 140 °C increased the resistance class from IV (low resistance) to III (moderate resistance). A previous study showed that the effect of heat treatment on the resistance against termites varied between wood species and treatments. Heat treatment at 180 °C did not improve the resistance of spruce and Scots pine woods against termites. However, the termite resistance of Scot pine increased after heating at 210 °C [39].

Figure 5 shows the weight loss of wood in the resistance test against decay fungi (*S. commune*). Untreated manii wood showed an 11.3% weight loss that was classified as a low-resistance class (class IV) according to the SNI 7207-2014 standard. Therefore, preservation was strongly recommended for the use of manii wood, mainly for structural function. This decay test showed that the weight loss of manii wood decreased by 17% following boric acid treatment, which indicated an increase in the wood's resistance against decay fungi to Class III. Moreover, the combination of boric acid and all seed oils caused the wood's weight loss to range from 8.1% to 5.8%, which indicated a synergetic effect between boric acid and seed oil. The analysis of variance (ANOVA) (Table 6) showed that boric acid and oil had a significant interaction effect on the weight loss of manii wood. A single treatment of neem, tamanu, or candlenut oils did not produce a substantial effect on the weight loss of manii wood. However, when the seed oils were combined with boric acid, the weight loss of the manii wood was significantly less than that under treatment with boric acid alone. As revealed in the Duncan test (Table 9), boric acid–neem oil (BM), boric acid–tamanu oil (BN), and boric acid–candlenut oil (BK) treatments had significantly less weight loss than the treatment with boric acid alone (BT). Boric acid–candlenut oil treatments (BK) caused the least weight loss of manii wood in this research, which was 37% less than the BT treatment and 45% lower than the untreated sample (AT).

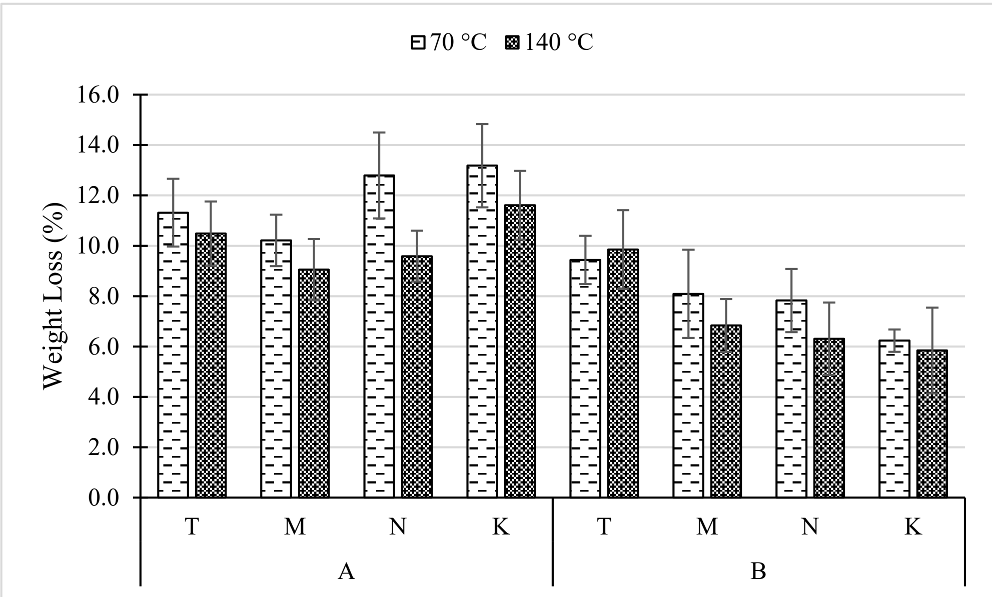

Figure 5. Weight loss of manii wood in the decay test after heating at 70 or 140 °C and treatments with boric acid (B), without boric acid (A), with neem oil (M), with tamanu oil (N), with candlenut oil (K), and without oil (T).

Table 9. Duncan test of weight loss due to decay fungi.

Boric Acid*Oil	Weight Loss
BK	6.04 a
BN	7.07 ab
BM	7.46 b
AM	9.63 c
BT	9.64 c
AT	10.90 cd
AN	11.19 de
AK	12.39 e

Notes: Groups with the same letters indicate no statistical difference ($p < 0.05$) between the treatments according to Duncan's multiple range test.

Tamanu oil contains saponins that have anti-fungal effects [40]. Neem oil effectively inhibits the growth of *Trichophyton mentagrophytes* [41]. The anti-fungal substances in neem oil are tannins and triterpenoid. Tannins are efficacious in suppressing brown-rot fungi [42], while triterpenoid can degrade cell organelles and inhibit the growth of pathogenic fungi [43]. Candlenut oil has flavonoids that can inhibit cell division, disrupt mitotic function, and inhibit fungal growth [44].

A statistical analysis also revealed that heating at 140 °C resulted in significantly fewer fungal attacks, as indicated by the lower weight loss of manii wood than that of heating at 70 °C. In a previous study, heat treatment at 210 °C increased the resistance against various fungi of Scots pine (*Pinus sylvestris*) and spruce (*Picea orientalis*) [39]. The changes in the wood's chemical composition due to heating can affect the resistance against decay fungi; hemicellulose content markedly decreases as temperature and heating duration increases [15].

4. Conclusions

The effect of combining boric acid, neem oil, tamanu oil, and candlenut oil and of heating (at 70 and 140 °C) showed some improvement in wood's resistance against subterranean termites and decay fungi. Oil treatment and heating at 140 °C produced darker and more even colors in the manii wood, while the wood's features were still clearly observable. L and b values generally decreased, while a values slightly increased after treatment. Boric acid increased the resistance of the manii wood against tested termites and decay fungi, while the seed oil treatments improved the resistance against termites. The combination of boric acid and seed oil significantly improved the wood's resistance against decay fungi. Heating at 140 °C also resulted in wood that was more resistant against decay fungi. The lowest weight loss in the termite and fungal tests occurred with the combination of boric acid and candlenut oil and with heating at 140 °C.

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