The Resistance of Modified Manii Wood with Boric acid and Chitosan/Glycerol and Heating Against Fungi and Termites

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Abstract. Manii wood (Maesopsis eminii Engl.) is a fast grown species that has low durability (class IV) and requires preservation. Boric acid is generally used in wood preservation. However, its application needs to be combined with other treatments to prevent from leaching. This study aimed to evaluate the resistance of manii wood after double impregnation of boric acid and chitosan or glycerol and heat treatment. Heating temperatures were 70°C and 140°C. The durability test was carried out against white rot fungus (Schizophyllum commune), dry wood termites (Cryptotermes cynocephalus), subterranean termites (Coptotermes curvignathus) according to SNI 7207-2014 standard, and field test based on ASTM D 1758-08 standard. The retention of boric acid in manii wood was 15.2 ± 1.0 kg m⁻³. The interaction of boric acid and chitosan/ glycerol impregnations and heat treatment significantly affected the wood resistance against decay fungi and termites. Impregnation of boric acid and glycerol by heating at 140°C increased the resistance of wood against dry wood and subterranean termites. Double impregnation of boric acid and chitosan followed by heating at 140°C was the best treatment in this research that improved significantly the resistance of manii wood against white rot fungi, dry wood termites and subterranean termites.

1. Introduction
The need of wood is increasing along with population growth, especially high quality wood that is easy to process, and resistant to attacks by degrading organisms. Most of commercial timber (80-85%) on the market has low durability, especially fast grown woods from plantation and community forests. Low durability woods are was easily attacked by degrading organisms [1]. According to Jasni among 4000 of wood species in Indonesia about 15% are high durability wood (I and II) while the remaining 85% are undurable wood including class III-IV and V [2].

Manii wood (Maesopsis eminii Engl.) is one of the fast grown species and can be used as building material. Manii wood has almost white sapwood and a yellowish-brown gold heartwood, has a rather rough wood texture and crossed fibers [3]. Manii wood is widely available in the market, but its durability is low hence its service life is short [4]. The resistance of manii wood against Schizophyllum commune belongs to the durability class IV [5]. Therefore, preservation is very important to a longer service life. In addition, other alternatives to improve low durability is by wood modifications.

Wood modification is a promising method for improving the quality of fast grown species. The wood modification by furfuryl alcohol impregnation can improve the dimensional stability of wood [6]. Impregnation with boron and MMA improved the dimensional stability and durability of wood [7]. Wood modifications generally aims to reduce the various weaknesses of low-quality wood. The modifications used in this study were impregnation and heat-treatment. Impregnation method is a
technique of wood modification by using pressure that facilitates a solution penetration into the wood and produces better retention and penetration [8]. Chemicals penetrate into the vessel, lumen, or wood cell wall. The chemical impregnation fills the cell walls and forms bonds [7].

This study applied double impregnation with boric acid and chitosan or glycerol. Boric acid (H₃BO₃) is a widely used boron-based preservative [9]. Boric acid is odorless, does not change wood color, has fungicide and insecticide effect [10]. However, boron preservative is leachable by water [11]. Tomak et al. revealed that boron compounds were leached from the wood in 14 days of test so that the durability of wood was almost the same as the control [12].

Chitosan has the potential as an environmentally friendly wood preservative, abundant, cheap, antibacterial, and antifungi Zivonic et al. [13]. Some researchers have tested the antifungal properties of chitosan. Chitosan inhibited the growth of Penicillium digitatum [14]. Salman showed that 2% chitosan treatment inhibited the highest growth of Aspergillus foetidus [15]. According to Oldertroen et al. the existence of chitosan in wood can inhibit the growth of staining fungus, and stable in wood [16]. Glycerol can be used as preservatives, solvents, and plasticizers [17]. Glycerol can increase the calorific value of wood [18]. In addition, Dauvergne et al. said that the combination of boron and glycerol can reduce the growth of Portia placenta in pine wood [19].

Heat modification can increase the biological resistance of wood against fungal attacks, decrease hemicellulose, reduce hygroscopic properties, and increase dimensional stability [20]. Wood heat-treatment temperatures are generally above 100°C, or between 150-230°C [21]. Heat-treatment improved wood quality with decreasing hygroscopic properties of wood, improved stability, and increased wood durability [22]. Heating is one of wood modification techniques that is environmentally friendly [23]. It can improve wood dimensional stability and resistance against wood degrading organisms [24,25].

2. Materials and Methods
2.1. Materials preparation
Manii wood (Maesopsis eminii Engl.) were cut from a tree that had height of 15 meters and a diameter of 50 cm in the arboretum of the Faculty of Forestry and Environment, IPB University. Manii log’s were cut using circular table saw to be some board’s with a thickness of 6 cm. The boards were dried in an experimental kiln at 50°C to gain moisture content of 14%. The sample size for the test of white-rot fungus (Schizopyllum commune), dry wood termites (Cryptotermes cyanocephalus), subterranean termites (Coptotermes curvignathus), and field test were 5 cm × 2.5 cm × 1.5 cm, 2.5 cm × 2.5 cm × 0.5 cm, 2.5 cm × 2.5 cm × 5 cm and 2 cm × 2 cm × 37 cm, respectively. Each test used five replications. Boric acid, chitosan, and glycerol were used as impregnation materials. Boric acid solutions were made at 5% concentration for impregnation I and chitosan 2% or glycerol 10% for impregnation II.

2.2. Impregnation process and heat treatment
The sample tests were dried in the oven at a temperature of 40°C until 9% moisture content (MC). The impregnation treatments were in two stages then followed by heat treatments at temperatures 70°C or 140°C for 4 hours, as described in Table 1. Impregnation of boric acid was conducted in a pressurized tank at 7 kg cm⁻² for 4 hours. Subsequently, the samples were drained and weighted to calculate the retention of boric acid. After that, the impregnation of chitosan was carried out in a pressurized tank at 6 kg cm⁻² for 2 hours Casado-sanz et al. while glycerol impregnation at 7 kg.cm⁻² for 4 hours [26,19]. Heat treatments were conducted after impregnation II at temperatures of 70°C or 140°C for 4 hours in a heating oven. Before and after the impregnation II, the sample were oven-dried at 103±2°C to calculate the value of weight percent gain (WPG).
Table 1. Combination of boric acid treatments with chitosan or glycerol and heating

| Code   | Impregnant I | Impregnant II | Heating (4 hours) |
|--------|--------------|---------------|-------------------|
|        | Boric acid 5%| Chitosan 2%    | Glycerol 10%      | 70 °C | 140 °C |
| NT70   | -            | -             | -                 | √     | -     |
| NT140  | -            | -             | -                 | √     | -     |
| NC70   | -            | √             | -                 | √     | -     |
| NC140  | -            | √             | -                 | -     | √     |
| NG70   | -            | -             | √                 | √     | -     |
| NG140  | -            | -             | √                 | -     | √     |
| BT70   | √            | -             | -                 | -     | √     |
| BT140  | √            | -             | -                 | -     | √     |
| BC70   | √            | √             | -                 | -     | -     |
| BC140  | √            | √             | -                 | -     | -     |
| BG70   | √            | -             | √                 | √     | -     |
| BG140  | √            | -             | √                 | -     | √     |

Remarks: NT70 (Non-Treatment 70°C); NT140 (Non-Treatment 140°C); NC70 (Non-Boron Chitosan 70°C); NC140 (Non-Boron Chitosan 140°C); NG70 (Non-Boron Glycerol 70°C); NG140 (Non-Boron Glycerol 140°C); BT70 (Boron Treatment 70°C); BT140 (Boron Treatment 140°C); BC70 (Boron-Chitosan 70°C); BC140 (Boron-Chitosan 140°C); BG70 (Boron-Glycerol 70°C); BG140 (Boron-Glycerol 140°C)

2.3. White-rot fungal resistance testing
Sample tests were dried at 70°C to 9% MC and weighed (W0). Then, the sample test were wetted using aquades for 1 minute, then plastic wrapped, and put in the microwave for sterilization in 1 minute. Furthermore, the sample test was inserted into a petri dish PDA culture with mycelium of white-rot fungus (Schizophyllum commune). The inoculation was performed aseptically in laminar air flow. Incubation was carried out for 12 weeks at temperature of ±25°C. The test sample was removed and cleaned from attached mycelium, then ovened at 103±2°C to a constant weight and weighed (Wk1). Furthermore, of the initial dry weight (Wk0) and weight loss (WL) were calculated by the equation (1) and (2):

\[
W_{\text{k0}} = \frac{W_{0}}{\frac{W_{0} + W_{1}}{2}} \times 100 \tag{1}
\]

\[
WL (%) = \frac{W_{\text{k0}} - W_{\text{k1}}}{W_{\text{k0}}} \times 100 \tag{2}
\]

2.4. Dry Wood Termites Resistance Testing
Sample tests were oven dried at 70°C to 9% MC and weighed (W0). Paralon tubes were wet sterilized using autoclaves at a temperature of ± 121°C for 15 minutes the tube end was glued on a wood surface. After that, 50 dry wood termites (Cryptotermes cynocephalus) were put in each paralon tube. Then the test was kept in a dark room for 12 weeks and observed every month. The samples were cleaned and dried in the oven at 103±2°C and weighed (Wk1). Furthermore, the initial dry weight (Wk0) and weight loss (WL) of the samples were calculated by equation (1) and (2).

2.5. Subterranean termites resistance testing
Wood samples of 2.5 × 2.5 × 0.5 cm were oven dried at 70°C to ±9% MC and weighed (W0). The test sample was put into a glass jar by standing at the base, and 200 grams of moist sand having 9% below water holding capacity were added. Furthermore, 200 workers of subterranean termites (Coptotermes curvignathus) were placed. The experimental unit was stored in a dark room. After 4 weeks, the test sample was removed from the glass jar and cleaned from the sand. The wood samples were dried in an oven at 103±2°C and weighed (Wk1). Furthermore, the initial dry weight (Wk0) and weight loss (WL) of the samples were calculated by the equation (1) and (2).
2.6. In Ground Field Test of Biodeterioration

Wood samples of 2 cm × 2 cm × 37 cm were dried at 70°C, weighed (W0) and dimensionally measured. Sengon (Falcataria moluccana) wood was used as comparative samples having durrability class IV. Furthermore, the sample tests were buried randomly with a depth of 2/3 of the sample height in the soil at the Arboretum Faculty of Forestry and Environment IPB University with a distance between woods 30 cm × 60 cm. After three months of exposure period, the samples were cleaned and visually evaluated. The test samples were dried in an oven at 103±2ºC and weighed (Wk1). Initial dry weight (Wk0) and weight loss were calculated using equation (1). The percentage of cross-sectional damage determines the wood biodeterioration grading system due to subterranean termite attacks [27] in table 2.

| Resistance levels | Attacks condition                        |
|-------------------|------------------------------------------|
| 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 reaches 10 to 30% of cross-section |
| 6                 | Penetration reaches 30 to 50% of cross-section |
| 4                 | Penetration reaches 50 to 75% of cross-section |
| 0                 | Failure                                   |

2.7. Data analysis

The effect impregnation of boric acid, chitosan or glycerol and heating treatments on the resistance of manii wood were statistically analyzed using a factorial completely randomized design (2 × 3 ×2). The experimental design included three variable factors of treatment with five replications. The factors were preservative (no preservative, boric acid), impregnant (chitosan, glycerol, or without glycerol chitosan), and heating temperatures (70°C and 140°C). Analysis of variance was followed by Duncan test when there was a significant effect at the 95% confidence interval. The data were processed using Microsoft Excel 2013 and IBM SPSS Statistic 26.0

3. Results and Discussion

3.1. Evaluation of impregnation process

Retention is a success parameter of a preservation process. Boron preservative retention is required at 8.2 kg m⁻³ for under-roof uses and 11.3 kg m⁻³ for off-roof uses [28]. The results showed that the retention of boric acid in manii wood was 15.2 ± 1.0 kg m⁻³. The retention value of this study was lower than Mursyidah [24] that was 30 kg m⁻³ in manii wood at 10 kg cm⁻² for 6 hours [25]. A high retention related to its molecular weight. According to Yaras the molecular weight and density of boric acid were 61.83 g mol⁻¹ and 1.44, respectively [29]. Manii wood was easily treated boric acid preservative. According to Krisdianto et al. manii wood belongs to treatability class I [5].

Weight percent gain (WPG) is a percentage of additional weight of wood due to impregnation compared to the initial weight of wood. The results showed that WPG of glycerol was higher than that of chitosan in manii wood (figure 1).
Figure 1. The value of WPG chitosan (C) or glycerol (G) in *Maesopsis eminii* previously impregnated with boric acid (B) and without boric acid (N).

The analysis of variance and Duncan test at the 95% confidence interval showed that the interaction of boric acid impregnation and heat treatment had a significant effect on WPG of chitosan/ glycerol in manii wood. Based on Duncan test, WPG of glycerol was significantly higher than that of chitosan. In addition, the WPG of glycerol in wood previously treated with boric acid (BG70) was significantly lower than that untreated one (NG70), while WPG of chitosan in wood contained boric acid (BC) was no different from that without boric acid (NC). Boron treated wood had significantly lower WPG of glycerol/ chitosan than untreated wood. Heated wood at 140°C had lower WPG of glycerol and chitosan than heated wood at 70°C. The WPG of glycerol higher than chitosan, which could be caused by the lower viscosity of glycerol than chitosan. According to Pagliaro and Rossi chitosan has a melting point of 264°C and a boiling point of 118°C, while glycerol has a melting point of 20°C and a boiling point of 290°C [30].

3.2. The resistance against white-rot fungi

Wood resistance against white-rot fungi was analyzed based on weight loss value. Weight loss of wood indicated damage to the cell walls of both hemicellulose, cellulose, and lignin components due to the attack of white-rot fungi [31]. The results (figure 2) showed that boric acid impregnation as well as heating 140°C generally increased the resistance of manii wood against white-rot fungi. Based on SNI 7207: 2014, heated boric acid treatment at 140°C (BT140) and heated boric acid and chitosan treatment at 140°C (BC140) increased the durability class III of control (NT70) to a durability class II in the test of decay resistance against white-rot fungi.
The weight loss of *Maesopsis eminii* Engl in a test of resistance to white-rot fungi after treatment with and without boric acid (B &N), with and without chitosan/ glycerol (C, G, T), and heating (70°C and 140°C).

The results (figure 2) showed that the weight loss of treated manii wood were lower than that of control wood (NT70) which was 3.96%. The lowest weight loss value was 140°C at 0.48%. The analysis of variance at the 95% confidence interval showed that the interaction of impregnation treatment of boric acid, chitosan/ glycerol, and heating exerted a very significant effect (p<0.01) on the weight loss value of manii wood in the resistance test against white-rot fungi. The Duncan test showed that heated boric acid at 70°C treatment (BT70) resulted in significant lower weight loss than control (NT70). This suggests that boric acid was able to withstand the attack of white-rot fungi. Temiz *et al.* showed that boric acid reduce weight loss (1-2%) on *Pine sylvestris* when exposed to decay *Postia placenta* [9].

Dywnda and Zainul stated that boric acid can be used as an antiseptic, insecticide, pH buffer, or neutron absorbent [32]. The Duncan test also showed that the weight loss of wood treated by boric acid, chitosan and heating at 140°C (BC140) was significant lower than control (NT70) and boric acid treatment (BT70). According to Gorgij *et al.* chitosan 2% has good performance in inhibiting the growth of fungi [33]. Salman also stated that treatment of a 2% chitosan concentration in PDA media showed the smallest diameter growth in the *Aspergillus foetidus* [15]. The mechanism of action of chitosan in inhibiting the growth of microbes in the presence of interactions between the positive charge on chitosan molecules and the negative charge on microbial cell membranes leads to the release of protein elements and other elements of microbial intracellular constituents [34]. According to Sedjati chitosan has a positively charged amino group that can bind negative charge from other compounds that are different from other neutrally charged polysaccharides [35].

Heating 140°C also increased the protection of boric acid against white-rot fungi as evidenced by lower weight loss in wood treated with boric acid and heating at 140°C (BT140) than wood treated with boric acid and heating 70°C (BT70). This is supported the research of Calonego *et al.* that heat treatment at 140°C on *Eucalyptus grandis* wood reduced weight loss by 34.32% in resistance test against *Picolnourus sanguineus* [36]. Weiland and Guyonnet revealed that the heat treatment on pine and beech woods caused the transformation of hemicellulose from hydrophilic and easily digestible into hydrophobic [37].

### 3.3. The resistance against dry wood termites

In this test, weight loss of wood indicates a termite attack in wood. The higher weight loss value, the less resistant wood of wood against dry wood termites [38]. The results (figure 3) showed that each treatment of boric acid, chitosan or glycerol, and heating in general increased wood resistance against dry wood termite attacks. This was indicated by a decrease in the weight loss value of tested wood. figure 3 showed the treated wood with boric acid and glycerol (BG) was more resistant against attacks...
of dry wood termites with lower weight loss value than control (NT70). Based on SNI 7207-2014, the treatment of boric acid, chitosan and heating at 140°C (BC140) as well as the treatment of boric acid, glycerol and heating at 140°C (BG140) in the resistance test against dry wood termites.

Figure 3. The weight loss of Maesopsis eminii in a test of resistance to dry wood termites after treatment with and without boric acid (B &N), with and without chitosan/ glycerol (C, G, N), and heating (70°C and 140°C).

The analysis of variance at the 95% confidence interval proved that the interaction between boric acid, chitosan/ glycerol and heating temperature had a very significant effect (p<0.01) on the weight loss value of manii wood in the resistance test against dry wood termites. Furthermore, Duncan test showed that the weight loss value of wood treated with boric acid and heating at 140°C (BT140) was significant lower than that of control (NT70). This revealed that boric acid has insecticidal properties against dry wood termites. Boron compounds such as borax (Na₂B₄O₇) and boric acid (H₃BO₃) are used as insecticidal preservatives [39]. The double impregnation of boric acid and chitosan or glycerol and heating at 140°C (BC140 or BG140) resulted in a significant lower weight loss than the control (NT70). Chitosan is a polysaccharides that can serve a barrier to the entry of protozoa. Batista et al. states that Eucalyptus grandis wood treated with 140°C heat has low resistance to Cryptotermes sp. attacks compared to controls weight loss value of less than 1 % [40].

3.4. The resistance against subterranean termites in laboratory scale
The results (figure 4) showed that in general the impregnation of boric acid, chitosan, glycerol or heating 140 °C is able to reduce the weight loss of wood against the attack of subterranean termites. Based on SNI 7207:2014, wood impregnation with boric acid and chitosan or glycerol as well as heating of 140 °C (BG140 and BC140) resulted in an increase in the class of durable IV on control (NT70) to durable class II in resistance test to subterranean termites.
Figure 4. The value of weight loss of *Maesopsis eminii* Engl. in a test of resistance to subterranean termites after treatment with and without boric acid (B & N), with and without chitosan/ glycerol (C, G, T), and heating (70°C and 140 °C).

The analysis of variance at 95% confidence level proved that the treatment interaction of boric acid treatment, chitosan/ glycerol and heating temperature had a significant effect (p<0.05) on the weight loss value in the manii wood resistance test against subterranean termites. Duncan test showed that the treatment of boric acid (B70), boric acid and glycerol (BG70) or boric acid-chitosan (BC70) produced a significantly lower value of control (NT70). According to Ahmed et al. the weight loss value of wood preserved with boric acid is lower than the control in testing against termite attack *Coptotermes acinaciformis*; boric acid also has effectiveness as a slow-working toxicity and low toxicity that it can disturb the colony of subterranean termites *Odontotermes* sp. [41,42]. According to Hayashi boric acid can stick stably to the wood due to the high adhesion of chitosan on the wood so as to with against of subterranean termites [43]. The chitosan treatment (NC70) also increases the resistance of lower weight loss from control (NT70).

The heating treatment 140°C (NT140) also showed a significant lower weight loss value than control at 70°C (NT70). This is due to changes in the chemical composition of wood as heating temperatures increase from 140, 180, 200, and 220°C for 2, 4, and 6 hours [44]. In addition, the double impregnation of boric acid and chitosan acid by heating 140°C (BC140) resulted in significant lower weight loss than the control and treatment of boric acid (BT70) as well as the lowest value in the manii wood resistance test of subterranean termite attacks.

3.5. Field test

The field test based on ASTM D 1758-02 is one of the methods that describes the actual condition, strongly influenced by the environment, place and weather so that termites or fungus can attack the tested wood. The durability of manii wood after the field test was reviewed based on weight loss value and visual evaluation. Based on visual evaluation (figure 5) shows the treated of chitosan or glycerol with heating 140°C in general increased the resistance value of wood. The best resistance against subterranean termites was obtained in the treated wood with boric acid and chitosan impregnation followed by heating at 140°C (BC140).
Figure 5. The visual evaluation (a) and value of weight loss (b) of *Maesopsis eminii* Engl. in a test of resistance to subterranean termites after treatment with and without boric acid (B &N), with and without chitosan/ glycerol (C, G, T), and heating (70°C and 140°C).

The analysis of variance at 95% confidence level proved that the interaction between boric acid treatment, chitosan/ glycerol and heating temperature had a significant effect (p<0.05) on the weight loss of manii wood in field test. Duncan test revealed that the treatment of boric acid (B140) and boric acid-chitosan (BC140) with a heating of 140°C resulted in a significant lower weight loss than the control sample (NT70). Because boric acid is fungicide and insecticide [45] and chitosan has bioactive properties. The heating treatment at 140°C in boric acid-chitosan treatment (BC140) also showed a significant lower value compared to boric acid-chitosan treatment with heating at 70°C (BC70) and boric acid treatment with heating 70 °C (BT70). Heat treatments causes significant degradation of amorp polysaccharides components so that a decrease in nutrient content can lead to increased wood resistance [46].

The results of termite identification based on key determination by Nandika *et al.* showed that the types of termites that attack wood in field tests for three months (figure 6) were *Microtermes* sp., *Macrotermes* sp., and *Capritermes* sp [47]. Arinana *et al.* found four species of subterranean termites that attack wood samples at the Arboretum Faculty of Forestry IPB, among them are *Schedorhinotermes* sp., *Microtermes* sp., *Capritermes* sp., and *Macrotermes* sp [48]. The types of subterranean termites from the family Termitidae which is also against termites commonly found in the tropics [47]. *Capritermes* sp. is not found in residential areas, while *Microtermes* sp. is the most dominant species of subterranean termites attacking wood. Natawiria states that *Macrotermes* sp. can live in hard, wet, and moist soils [48]. According to Sulistyawati *et al.* *Macrotermes gilvus* Hagen. was found in the Arboretum of the Faculty of Forestry and Environment of IPB University [50].

Figure 6. Subterranean termite that attacked the *Maesopsis eminii*, under 20x magnification: (a) *Capritermes* sp., (b) *Microtermes* sp., and (c) *Macrotermes* sp.

4. Conclusion
The interaction of boric acid, chitosan/ glycerol and heat treatments had a very significant effect (p<0.01) on the resistance of manii wood against white-rot fungi and dry wood termites, as well as had a significant effect (p<0.05) on the resistance against subterranean termite attacks in laboratory and field test. Glycerol or chitosan treatment resulted in a significant lower weight loss than controls in wood
resistance tests against white-rot fungi, dry wood termites, and subterranean termites. The heat treatment 140°C caused significant lower weight loss than heating at 70°C in each wood resistance test against white-rot fungi, dry wood termites, subterranean termites, and field test.

The recommended treatment for modifying manii wood is the double impregnation of boric acid and chitosan accompanied by a heating at 140°C which is generally best at improving the resistance of manii wood from all the destroying organisms.

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References
[1] Yunasfi 2008 Fungi at Eucalyptus urophylla S.T. Blake in Log Yard (TPK) PT. Toba Pulp Lestari, Tbk. Kabupaten Toba Samosir North Sumatera. Sumatera, Jurnal Hutan dan Masyarakat. 3 (1): 1-110
[2] Jasni 2016 Keawetan alami 57 jenis kayu Indonesia dengan pengujian di bawah naungan Jurnal Penelitian Hasil Hutan 34(3): 179-188
[3] Samssoedin I, Sukiman H, Wardani M, NM Heriyanto 2016 Keawetan alami 57 jenis kayu Indonesia dengan pengujian di bawah naungan Jurnal Penelitian Hasil Hutan 34(3): 179-188
[4] Nurmeryteni I 2007 Uji kubur kayu afrika (Maesopsis eminii Engl.) yang diawetkan dengan bahan pengawet impralit CKB Skripsi (Bogor: Institut Pertanian Bogor)
[5] Krisdianto, Barly, Abdurrohim S, and Mandang YI 2013 Atlas Kayu Indonesia Jilid IV. Bogor: Pusat Penelitian dan Pengembangan Keteknikan Kehutanan Dan Pengolahan Hasil Hutan
[6] Esteves B, Nunies L, and Pereira H 2011 Properties of Furfurilated Wood (Pinus pinaster) Eur, Journal Wood Prod, 69(4), 521-525
[7] Priadi T, Orfian G, Cahyono T, Iswanto AH 2020 Dimensional stability, color change, and durability of boron-MMA treated red jabon (Antocephalus macrophyllus) Wood J Korean Wood Sci Technol 48(3): 315-325
[8] Barly, Martawijaya 2000 Keterawetan 95 jenis kayu terhadap impregnasi dengan bahan pengawet impralit CKB Buletin Penelitian Hasil Hutan 18(2): 69-78
[9] Temiz A, Alfreedsen G, Eikenes M, Terziev N 2008 Decay resistance of wood treated with boric acid and tall oil derivatives. Bioresource Technology 9(9): 2102-2106
[10] Percin O, Sofuoglu SD, Uzun O 2015 Effect on boron impregnation and heat treatment on mechanical properties of oak (Quercus petraea Liebl.) wood BioResource. 10(3): 3963-3978
[11] Baysal E, Yalinklic MK 2005 A new boron impregnation technique of wood by vapor boron acid to reduce leaching boron from wood Wood Science and Technology 39(3): 187-198
[12] Tomak ED, Viitanen H, Yildiz UC, Hughes M 2011 The combined effects of boron and oil heat treatment on the properties of beech and Scots pine wood Part 2: Water absorption, compression strength, color changes, and decay resistance J Mater Sci. 46: 608 – 615
[13] Zivonic S, Davis RH, Golden DA 2015 Chitosan as an Antimicrobial in Food Products. Handbook of Natural Antimicrobials for Food Safety and Quality (Cambridge: Woodhead Publishing
[14] Waeawthongrak W, Pismchpen S, Leelasuphakul W 2015 Effect of Bacillus subtilis and chitosan application on green mold (Penicilium digitatum Sacc.) decay in citrus fruit Posthary Bio Technol 99 49
[15] Salman A 2020 Karakterisasi cendawan pewarna pada kayu karet (Hevea brasiliensis Muel.) dan responnya terhadap aplikasi kitosan Thesis (Bogor: Institut Pertanian Bogor)
[16] Oldetroen K, H-Kittikun A, Aam BB, Larnoy E 2016a Resistance of rubber wood (Hevea brasiliensis) treated with chitosan or silane against surface molds J Wood Prod 75 112
[17] Permata 2020 Pemanfaatan maltosa dan gliserol sebagai sumber poliol dalam pembuatan perekat poliuretan Jurnal Sainitika 15 8

[18] Pratama AP, Yenie E, Edward YS 2020 Pemanfaatan tandan kosong sawit dan lumpur IPAL produksi minyak sawit sebagai bahan baku pembuatan briket dengan crude gliserol sebagai perekat JOM TEKNIK 7 5

[19] Dauvergne ET, Soulounganga P, Gerardin P, Loubinoux B 2000 Glycerol/ glyoxal a new boron fixation system for wood preservation and dimensional stabilization Holzforschung 54 126

[20] Ma’aruf SD, Bakri S, Hidayat W 2020 Pengaruh oil heat treatment terhadap perubahan warna dan stabilitas dimensi kayu cepat tumbuh Seminar Nasional (Lampung: Universitas Negeri Lampung)

[21] Coto Z, Wahyudi I, Hadiyanne A 2015 Meningkatkan Kualitas Kayu Melalui Peningkatan Sifat Fisik untuk Kayu yang Tumbuh Cepat dan Berdiameter Kecil. (Bogor: IPB Press)

[22] Gustina 2016 Sifat fisis, sifat mekanis dan keawetan kayu ganitri (Elaeocarpus sphaericus) setelah perlakuan pemanasan Skripsi (Bogor: Institut Pertanian Bogor)

[23] Ates S, Akylidz MH, dan Ozdemir H 2009 Effect of heat treatment on calabrian pine (Pinus brutia Ten.) wood BioResources 4 1043

[24] Todorovic N, Popovic Z, Milic G, dan Popadic R 2012 Estimation of heat treated beechwood properties by color change. BioResources 7(1): 799-815

[25] Mursyidah I 2018 Sifat fisis dan keawetan kayu manii termodifikasi impregnasi senyawa boron dan pemanasan Skripsi (Bogor: Institut Pertanian Bogor)

[26] Casado-sanz MM, Silva-castro I, Herrero L, Ramos P, Martin-gil J, and Rello L 2019 White-rot fungi control on Populus spp. wood by pressure treatments with silver nanoparticles, chitosan oligomers and propolis Forest 10: 1-10

[27] [ASTM] American Society for Testing and Materials 2006 Standard Test Method of Evaluating Wood Preservatives by Field Test with Stakes American Society for Testing and Materials United States: ASTM D 1758-06

[28] [SNI] Standar Nasional Indonesia 2014 Uji Ketahanan Kayu terhadap Organisme Perusak Kayu SNI 7207:2014 Jakarta: Badan Standarisasi Nasional

[29] Yaras A 2017 Assesment of the effect of borac and boric acid additives in cutting fluids on milling of AISI O2 using MQL system Int J Adv Manuf Techn. 95 2013

[30] Pagliaro M, Rossi M 2008 The Future of Glycerol: New Uses of a Versatile Raw Material. RSC Green Chemistry Book Series (London: RSC Publishing)

[31] Antai SP, Crawford DL 1982 Degradation of extractive-free lignocelluloses by coriolus versicolor and poria placenta J of App Microbio Biotech 14 168

[32] Dwynda I, Zainul R 2018 Boric Acid (H3BO3): Recognize the molecular interactions in solutions J.Europe 1 69

[33] Gorjig R, Tarmian A, Karimi AN 2014 Effect of chitosan on the mold resistance of wood and its surface properties. Int J of Ligno Prod 1 49

[34] Gaol ML, Oemry S, Pangestiningsih Y 2015 Uji suspensi kitosan untuk mengendalikan rayap Coptotermes curvignathus pada tanaman karet di lapangan Jurnal Online Agroekoteaknologi 2 678

[35] Sedjati S 2006 Pengaruh Konsentrasi Kitosan Terhadap Mutu Ikan Teri (Stolephorus heterolobus) Asin Kering Selama Penyimpanan Suhu Kamar Thesis (Semarang: Universitas Diponegoro)

[36] Calonego FW, Severo ET, Furtado EL 2010 Decay resistance of thermally-modified Eucalyptus grandis wood at 140, 160, 180, 200 and 220 C Bioresource Technology 101 9394

[37] Weiland JJ, Guyonnet R 2003 Study of chemical modifications and fungi degradation of thermally modified wood using DRIFT spectroscopy J Holz Als Roh-Und Werkstoff 61 220

[38] Suprapti S, Djarwanto 2012 Ketahanan enam jenis kayu terhadap jamur pelapuk Jurnal Penelitian Hasil Hutan 30 235
[39] Kartal SN, Hwang WJ, Imamura Y 2007 Water absorption of boron-treated and heat-modified wood J Wood Sci 53 457
[40] Batista DC, Nisgoski S, Oliveira S, Graciela, Paes JB 2016 Resistance of thermally modified Eucalyptus grandis W. Hill ex maiden wood to deterioration by dry-wood termites (Cryptotermes sp.) Ciência Florestal. 26 678
[41] Ahmed BM, French JRJ, Vinden P 2004 Evaluation of borate formulations as wood preservatives to control subterranean termites in Australia Holzforschung 58 454
[42] Farid A, Zaman M, Saeed M, Khan M, Shah T 2015 Evaluation of boric acid as a slow-acting toxicant against subterranean termites (Heterotermes and Odontotermes) Journal of Entomology and Zoology Studies 3 216
[43] Hayashi M 2002 Antimicrobial agent composition. (Japan: JP2002154906A)
[44] JECFA 2013 Glycerol. Evaluations of the Joint FAO/WHO Expert Committee on Food Additives
[45] Yalcin M, Sahin HI 2015 Changes in chemical structure and decay resistance of heat-tread narrow-leaved ash wood Maderas: Ciencia Y Technologia. 2 446.
[46] Esteves B, Pereira H 2009 Wood modification by heat treatment: review Bioresource 4 404
[47] Nandika D, Rismayadi Y, Diba F 2015 Rayap: Biologi dan Pengendaliannya Edisi ke-2 (Surakarta: Muhammadiyah University Press)
[48] Arinana, Fannani AR, Nandika D, Haneda NF 2020 Field test on the palatability of the subterranean termites to pine wood with various treatments. Biodiversitas 21 5771
[49] Natawiria DJ 1979 Timbulnya serangan rayap Coptotermes travian Hav. Dan Coptotermes curvignatus Holmgren pada tanaman kehutanan Indonesia (Jakarta: Lembaga Penelitian Hutan)
[50] Sulistyawati I, Suhasman, dan Hadi YS 2010 Effect of weight loss attacked by subterranean termite on mechanical properties of mangium wood (Singapore: Seventh Conference of the Pacific Rim Termite Research Group)