The Resistance of Heat-Modified Fast Growing Woods Against Decay Fungi

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Abstract. Fast growing woods from plantations forest generally have low quality and require improvement to resist degrading organisms. This study aimed to evaluate the resistance of heat-modified sengon, jabon, mangium, and short rotation teak woods against decay fungi. Heat treatment was applied at two different temperatures (150 °C and 180 °C) and for three different times (0, 2, and 6 hours). The decay resistance test used white rot (Schizophyllum commune Fr) and brown rot (Tyromyces palustris) fungibased on modified SNI 01-7207-2014 standard. The chemical analysis of heat-modified wood used Gas Chromatography-Mass Spectrometry. The results showed that the white rot fungal resistance was significantly affected by the interaction of wood species, temperature and period of heating, while the brown rot fungal resistance was significantly affected by the interaction of wood species and heating temperature. Heating at 180 °C for 6 hours increased the fungal resistance of sengon, jabon, and mangium woods. However, the fungal resistance of teak wood improved by heating at 150 °C for 6 hours. The durability improvement of the heat-modified woods were suspected due to the appearance or increase of antifungal substances such as benzoic acid, sinapaldehyde, vanillin and 2-methylantraquinone.

1. Introduction
The woods supply from plantation/ community forests are expected to overcome the increasing demand of wood mainly by industries. Many woods from community forests that are classified as fast growing species and have low quality, especially in terms of strength, durability, and dimensional stability. Therefore, the use of fast growing woods requires special treatment to fulfill the quality specifications. Indonesia is a tropical country that has high risk of biodeterioration in building wood components, including damage by decay fungi. According to Priadi, decay fungi generally attack wooden components that are exposed to wetting, such as by direct or indirect rainwater [1].

Heat treatment is one of the most widely developed wood modification technologies to improve wood quality. Heat treatment of mahogany at 90, 120, and 150 °C improved dimensional stability and reduced hygroscopicity of wood, but made darker wood color and reduced its mechanical properties [2]. Heat treatment at temperatures of 120, 150, and 180 °C decreased strength, caused discoloration, and decreased the density of sengon, jabon, and mangium woods [3, 4]. Heat treatment increased the resistance of spruce, pine, fir, and poplar woods against decay fungi, while the increase in termite resistance was not significant [5]. Heat treatment is easy to do, relatively affordable and environmentally friendly, thus avoiding the use of chemicals to preserve wood [6].
The objective of this study was to evaluate the effect of heat treatment on the resistance of sengon (Falcataria molucccana Miq.), jabon (Neolamarckia cadamba Roxb.), mangium (Acacia mangium Willd.), and teak (Tectona grandis Lf.) woods against white rot fungus (Schizophyllum commune. Fr.) and brown rot fungus (Tyromyces palustris).

2. Methods
Most of this research was conducted in several laboratories in the Division of Wood Quality Improvement Technology, Department of Forest Products, Faculty of Forestry and Environment, IPB University. The wood chemical analysis with the Gas Chromatography-Mass Spectrometry (GC-MS) was carried out at the Center of Forensic Laboratory (Puslabfor), the National Police Headquarters, East Jakarta. The wood materials were sengon (Falcataria molucccana Miq.), jabon (Neolamarckia cadamba Roxb.), mangium (Acacia mangium Willd.), and short rotation teak (Tectona grandis L.f.). The woods were obtained from around Bogor and Banten. The diameter of sengon, mangium teak and jabon logs were 40 cm, 22 cm, 40 cm and 33 cm, respectively.

The logs of teak, mangium, jabon, and sengon were sawn into a number of boards measuring 130 cm × 30 cm × 3 cm and dried in an experimental kiln at 40 °C to 10% moisture content. All the boards were mostly sapwood and cut into a sample size of 5 cm × 2.5 cm × 1.3 cm (L × T × R) for the tests of wood density and the resistance against decay fungi.

The heat treatment was carried out in an experimental kiln with an air circulation from a 1.5 kilowatt internal fan at a temperatures of 150 °C and 180 °C. The time to reach the targeted temperatures were about 6 hours. The heating time used 0 hour (as a control), 2 hours, and 6 hours. Then, the heat treated woods were conditioned at room temperature (28 °C) until the next testing process.

The density of wood samples were determined before and after heat treatments. The density was calculated based on the dimensions and weight of the woods under air dry condition. The wood density and its change due to heat treatment was calculated using equation (1) and (2) respectively.

$$\rho = \frac{B}{V}$$  \hspace{1cm}(1)

$$\Delta \rho = \left( \frac{\rho_1 - \rho_0}{\rho_0} \right) \times 100$$  \hspace{1cm}(2)

where: \(\rho\) = wood density (g cm\(^{-3}\)), \(B\) = the weight of wood (gram), \(V\) = the volume of wood (cm\(^3\)), \(\Delta \rho\) = the change of wood density (%), \(\rho_0\) = wood density before treatment (g cm\(^3\)), \(\rho_1\) = wood density after treatment (g cm\(^3\)).

Wood powder sample (40-60 mesh) as much as ±5 g for chemical analyses were prepared from the tested density samples represented the control and heated treatments. Wood powder (100 mg) was extracted with 1 ml of 10 ppm methanol at 45 °C for 2 hours. Chemical substance analysis was carried out using GC Agilent Technologies 7890A and MS Agilent Technologies 5975C with four main components, namely oven, front inlet, column, and detector. The sample was injected into the oven with a temperature of 290 °C and then forwarded to the front inlet (GC) split mode with an initial temperature of 290 °C, a pressure of 13.887 psi, and a flow rate of 33.7 ml minute\(^{-1}\), for two minutes. The GC system was connected to a Mass Spectrometry (MS) equipped with a fused capillary silica column of 30 mm × 0.25 mm × 0.25 m (length × diameter × film). The components were separated using helium as carrier gas at a constant flow of 1 ml min\(^{-1}\) and flowed into the detector. The difference in mass and conductivity were then defined as the mass spectrum. The interpretation of the GCMS mass spectrum was compared with the component spectra stored in the W10N14.L and wiley7n1 databases. The test results were then analyzed using GCMS Data Analysis software.

The wood resistance against decay fungi was tested based on modified SNI 01-7207-2014 [7]. The wood samples were 5 cm × 2.5 cm × 1.3 cm (W × H × R). White rot fungus (Schizophyllum commune Fr) and brown rot fungus (Tyromyces palustris) were prepared on Potato Dextrose Agar (PDA) media.
The composition to produce 1 liter PDA media consisted of 200 g of potato wedges, 20 g of agar, 20 g of dextrose, and 250 mg of the antibiotic chloramphenicol. The PDA media was sterilized in an autoclave at a temperature of 121 °C and a pressure of 1.02 atm for 20 minutes. The inoculation of the test fungi was carried out aseptically in laminar air flow follow. Then the incubation was held at room temperature (28 °C) until the surface of the PDA media covered with fungal mycelium (±14 days).

The wood samples were oven dried at 103±2 °C to obtain a constant weight (W1). The wood samples were exposed to the test fungal culture at room temperature (28 °C). After 12 weeks of fungal exposure, the wood samples were removed from the fungal culture, and cleaned from the mycelium. Furthermore, the wood samples were oven dried at 103±2 °C to a constant weight and weight (W2). The weight loss of wood due to fungal attack was calculated using Equation 3.

\[ WL = \frac{(W1-W2)}{W1} \times 100 \]  

where: WL = wood weight loss (%), W1 = dry weight of wood before test (g), W2 = dry weight of wood after test (g).

Data analyses used Microsoft Excel 2013 and SPSS Statistics 17.0 applications. The effects of wood species, temperature and time of heating on wood density and resistance against decay fungi used a Factorial Completely Randomized Design with three factors [8]. Factor A was 4 four wood species (sengon, jabon, mangium, and teak), factor B was 2 heating temperatures (150 °C and 180 °C), and factor C was 3 heating time (0, 2, and 6 hours). Then the Duncan test was performed when the analysis of variance (ANOVA) showed a significant effect at 95% confidence interval.

3. Results and Discussion

3.1. Wood density

The results showed that teak wood had the highest density of 0.76±0.06 g cm\(^{-3}\), followed by the lower density of mangium, sengon and jabon with the values of 0.64±0.05 g cm\(^{-3}\), 0.35±0.02 g cm\(^{-3}\), and 0.28±0.02 g cm\(^{-3}\) respectively. Heat treatment generally reduced the density of the four wood species, especially at 180 °C (figure 1). The decrease in wood density occurred due to a decrease in the equilibrium moisture content of the wood, the evaporation of wood extractive substances, and the degradation of wood components, especially hemicellulose [9, 10].

The increase of heating time from 2 to 6 hours generally caused the decrease in wood density. This study was in accordance with Guller and Karlinasari et al that the value of wood density decreased with the increase of temperature and time of heating [11, 3].

The analysis of variance (ANAVA) at a 95% confidence interval, showed that the interaction between wood species and heating temperature significantly affected the density change of wood. Based on the following Duncan test, the density decrease of heated jabon and mangium woods at 180 °C was significantly higher than that of the heated woods at 150 °C. The highest density decrease occurred in mangium wood, while the least density change occurred in jabon wood. This indicated the volume shrinkage of mangium wood was higher than that of the other tested woods. Idris et al stated that mangium wood has a shrinkage value from wet to oven dry of 2.68% and 7.4% in radial and tangential directions respectively [12].
3.2. Chemical analyses
The chemical analysis using GCMS (table 1) showed the appearance and increase of some antifungal compounds in the heated four woods species. Esteves et al reported that heat treatment caused the formation of new extractable compounds that occur due to hemicellulose degradation [13]. Some extractives disappeared from the wood, such as glycerol, oleic acid, linoleic acid, and b-sitosterol. The new compounds formed in heated *Eucalyptus globulus* wood were monosaccharides, hemicellulose dehydration products, and lignin derivative compounds such as syringaldehyde, syringic acid, and sinapaldehyde. According to Candelier et al the decrease in extractive content can be caused by the evaporation of low molecular weight compounds produced during heat treatment [14].

![Figure 1. The density change (Δρ) of woods due to heat treatments.](image_url)

| Wood | Sample | Substance                  | R Time$^a$ | Area (%) |
|------|--------|----------------------------|------------|----------|
|      |        |                            | 0  | 6       | 0  | 6       |
| Sengon | I     | Sinapaldehyde              | 21.668  |         | 14.290 |         |
|        | II    | Sinapaldehyde              | 21.591  |         | 9.640   |         |
| Jabon | I     | Benzoic acid               | 6.776   |         | 11.190  |         |
|        |       | Vanilin                    | 11.948  |         | 15.540  |         |
|        |       | Sinapaldehyde              | 21.693  |         | 21.430  |         |
|        | II    | Benzoic acid               | 6.631   |         | 12.850  |         |
|        |       | Vanilin                    | 11.862  |         | 14.880  |         |
|        |       | Sinapaldehyde              | 21.633  |         | 20.620  |         |
| Mangium | I    | Vanilin                    | 11.939  |         | 15.760  |         |
|        |       | Sinapaldehyde              | 21.659  |         | 21.668  | 44.760  |
|        |       | 2-Methylnaphthraquinone    | 23.412  |         | 23.412  | 11.740  |
|        | II    | Vanilin                    | 11.896  |         | 11.871  | 10.080  |
|        |       | Sinapaldehyde              | 21.591  |         | 21.591  | 24.930  |
| Teak  | I     | 2-Methylnaphthraquinone    | 23.420  |         | 23.514  | 12.770  |
|        | II    | Sinapaldehyde              | 21.772  |         | 21.772  | 1.470   |
|        |       | 2-Methylnaphthraquinone    | 23.610  |         | 23.610  | 24.200  |

$^a$R Time= Retention Time
Synapaldehyde appeared in the heated sengon, jabon, mangium and teak, while vanillin was found in heated jabon and mangium woods. The presence of sinapaldehyde and vanillin could affect the durability of the heated woods compared to the unheated ones. Benzoic acid only appeared in heated jabon wood. The proportion of tectoquinone (2-methylantraquinone) in teak wood increased after heat treatment. The percentage increase of compound in heated wood could be caused by the degradation of other components in the wood. According to Xue et al furfuraldehyde is a hemicellulose decomposition product whose concentration increased rapidly with increasing heating temperature of poplar wood [15].

Some substances in the tested woods decreased and increased after heat treatment. The content of vanillin in mangium wood increased after heat treatment. Syringaldehyde and vanillin are phenolic compounds belonging to the aldehyde group. This is in line with Xue et al that increasing temperature up to 180 °C increased aldehyde production [15]. In addition, Bourgois et al stated that the chemical changes in heated wood was affected by the heating time and temperature [16].

3.3. The resistance against white rot fungi
Wood decay can be indicated by the weight loss of wood. The higher wood weight loss, the lower resistance of wood against fungus. This research showed that heat treatment reduced the weight loss of some woods due to white rot fungus (S. commune) attack (figure 2). The weight loss of heated sengon and teak woods at 150 °C and heated sengon and jabon wood at 180 °C were less than that of unheated woods (controls). This fact was supported by the chemical analysis (table 1), which found some substances in the heated wood that can protect against decay fungi. For example, the proportion of tectoquinone (2-methylantraquinone) in teak increased after heat treatment.

![Figure 2](image_url)

**Figure 2.** The weight loss of woods due to white rot fungus (S. commune).

The analysis of variance (ANAVA) at 95% confidence interval showed that the interaction between wood species, temperature, and heating time had a significant effect on the wood weight loss by white rot fungal attack. Duncan's further test showed that the weight loss of mangium wood was not significantly different from that of teak wood, but the both values were significantly lower than that of sengon and jabon woods. The weight loss difference between those woods was related to the differences in the types and quantities of antifungal substances in the wood samples (table 1).

The Duncan's test results also showed that the weight loss values of heated sengon and jabon woods at 180 °C for 6 hours were significantly less than that of the unheated samples as can be seen in figure 2. Based on the results of chemical analysis using GCMS, synapaldehyde content appeared in the heated sengon and jabon woods. The content of benzoic acid was also found in heated jabon wood. According to Munib, benzoic acid can inhibit the growth of microorganisms [17]. Kamden et al also stated that chemical components in wood can be toxic to decay fungi and prevent its growth [18].
The wood weight loss could be affected by the toxicity and quantity of substances in wood and the capability of fungi. This research showed that the presence of tectoquinone caused better resistance of teak wood than sengon and jabon woods. Heat treatment could affect the extractive compounds in teak and mangium woods and affect differently to the attack of fungi. However, the heat treatment at 180 °C did not increase the resistance of mangium and teak woods against S. commune fungi.

3.4. The resistance against brown rot fungi

Weight loss occurred in all woods fed to brown rot fungi (T. palustris). The weight loss of teak wood was the lowest. Mangium wood was also had lower weight loss than that of sengon and jabon woods (figure 3). Teak wood contained tectoquinone (2-methylantraquinone). Haupt et al stated that tectoquinone was identified as a fungal growth inhibitor compound [19].

![Figure 3. The weight loss of woods due to brown rot fungus (T. palustris).](image)

This research showed that heat treatment reduced the weight loss of some wood samples, which indicated better wood resistance against brown rot fungus (T. palustris). Heated jabon and mangium woods at 150 °C and 180 °C had lower weight loss than the control samples. This is presumably due to the changes in hemicellulose during heat treatment. As stated by Boonstra et al that changes in wood (especially hemicellulose) during heat treatment can increase the resistance against brown rot fungus C. puteana [10]. In addition, according to Esteves and Pereira, hemicellulose is the most susceptible wood components to heat degradation [5]. Weiland and Guyonnet reported that heat treatment on pine and beech woods caused the transformation of hemicellulose from hydrophilic and easily digestible to hydrophobic [20].

The analysis of variance at the 95% confidence interval showed that there was a significant effect of interaction between wood species and heating temperature on wood weight loss by brown rot fungus. The Duncan's test resulted that heating at 180 °C resulted in lower weight loss values of jabon and mangium woods than that of the control samples. In addition, the weight loss of heated jabon wood at 180 °C was significantly lower than that of heated jabon wood at 150 °C. The resistance improvement of heated jabon and mangium woods against brown rot fungus was also in accordance with Boonstra et al that heat treatment at 180 °C for 6 hours increased wood durability against decay fungi [10]. This improvement in fungal resistance was supported by the chemical analysis. Heated jabon contained some antifungal substance such as benzoic acid, vanillin, and sinapaldehyde, while heated mangium wood contained vanillin, sinapaldehyde, and 2-methylantraquinone (table 1). Sinapaldehyde is a group of aldehydes that act as antifungals [21]. Vanillin is known as a compound that can prevent or slow down the growth of fungi [22].
Based on figures 2 and 3, it can be seen that the value of wood weight loss due to brown rot fungus (*T. palustris*) attack was higher than that due to white rot fungus (*S. commune*) attack. According to Highley and Illman, brown rot fungus is one of very destructive organisms on wood [23]. In some previous research were also reported that wood decay by *T. palustris* was higher than that by *S. commune* [24, 25]. Green and Highley stated that white rot fungi reduced the degree of polymerization (DP) of holocellulose gradually during the decay process, while brown rot fungi was able to rapidly depolymerize holocellulose [26]. In addition, brown rot fungi decreased wood strength faster than white rot fungi which indicated a higher degree of holocellulose depolymerization by brown rot fungi.

4. Conclusion
The weight loss of wood by white rot fungus (*S. commune*) was significantly affected by the interaction of wood species, temperature and heating time, while the weight loss of wood by brown rot fungus (*T. palustris*) was significantly affected by the interaction of wood species and heating temperature. Heated sengon and jabon woods at 180 °C for 6 hours were significantly more resistant against white rot fungus attack compared to the control and other treatments. Heated jabon and mangium woods at 180 °C for 6 hours were also significantly more resistant against brown rot fungus attack than the control and other treatments. The heat treatment of 150 °C for 6 hours slightly increased the resistance of teak wood from white rot fungi and brown rot fungi. The best heat treatment for sengon, jabon and mangium wood was heating at 180 °C for 6 hours, while for teak was heating at 150 °C for 6 hours.

The resistance increase of heated wood against decay fungi was thought to be related with the appearance or increase of some antifungal substances such as benzoic acid, sinapaldehyde, vanillin, and tectoquinone (2-methylantraquinone).

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