The Blue Stain Attack and Its Effect on The Mechanical Properties of Five Light-Colour Woods

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Abstract. The processing of light-color wood often has problems due to blue stain, which can reduce the quality and economic value of the wood. This research aimed to evaluate the intensity of blue stain attack on five light-color woods and the effect on their mechanical properties. Pine, rubber, jabon, sengon, and gmelina logs with an average diameter of 30 cm were turned into 3 cm thickness disc samples for staining fungal test; 2 cm × 2 cm × 30 cm and 3 cm × 3 cm × 6 cm samples for bending and hardness tests respectively. All the samples were exposed to the environment above ground on a rack for six weeks. The results showed that the highest intensity of blue stain attack was found in pine wood (84%), followed by rubber wood (80%), jabon wood (65%), sengon wood (36%), and gmelina wood (27%). The mechanical properties (modulus of elasticity, modulus of rupture, and hardness) of all wood-attacked blue stains did not significantly differ from their control samples.

1 Introduction

Processing of light-color wood as a raw material for making furniture has a problem because it is easily attacked by blue stains [1]. Wood staining is generally caused by fungi from the Ascomycetes or Deuteromycetes class. In tropical areas such as Indonesia, the staining fungus species *Lasiodiplodia theobromae*, which belongs to the class Deuteromycetes, was found attacking tropical wood species, such as pine wood [2, 3]. Recently, the fungi *Aspergillus chevalieri* and *Paecilomyces maximus* or *P. formosus* have been identified that attacked rubber wood more severely than other fungi [4]. Indonesia is a country with a tropical climate which has high rainfall and warm weather, which support the growth of fungi. The average rainfall, air temperature, and humidity are 2500 mm year^{-1}, 27 ºC, and 86% respectively [5]. These environmental conditions support the growth of the blue stain, with the optimum temperature for the growth of the blue stain ranging from 22-30 ºC.

Previous research has shown that wood attacked by blue stain will be more susceptible to decay fungi [6]. Fungi prefer acidic wood. The white decaying fungus *Schizophyllum commune* grows optimally in the pH range of 5 to 6 [7]. Therefore, wood that has been attacked by blue stain will be easier to be attacked by decaying fungi due to the acidic nature of the wood. In addition, wood attacked by blue stain has certainly experienced a decrease in quality. Although a blue stain attack does not degrade wood structure, this attack will make it easier for other destructive organisms, such as decay fungi, to attack the wood.

The mechanism of blue stain attack on wood can be caused by spores carried by rainwater, wind, or insect activity. Spores that have attached to the wood grow into hyphae, then enter the wood through the voids, intercellular channels, pits and continue to spread to the surrounding cells [3].

Several types of wood, such as rubber, pine, jabon, sengon, and gmelina are in great demand by wood craftsmen. Besides having bright colors and distinctive patterns, these woods are easy to process. However, jabon, rubber, pine, sengon, and gmeliana are classified as durability class IV-V. Wood with durability class IV-V is susceptible to attack by wood destroying organisms, including wood staining fungi. Wood with high permeability, such as pine wood, is more susceptible to fungi attack because it allows the fungi to grow well [8]. Rubber wood is very susceptible to staining fungal attacks even shortly after logging.

Blue stain attack is indicated by the appearance of dark blue stains on the wood surface [9]. This blue stain attack is visible clearly, especially on light-color wood surfaces. This of course will significantly reduce the quality of wood and become a considerable loss. Discoloration due to fungal attacks is quite a serious problem for using wood as a raw material for furniture, especially if it wants to display the natural colors and patterns of wood. The economic losses caused by fungal attacks in the United States and Finland each year reach 150 and 570 billion rupiahs [10, 3]. Meanwhile, losses caused by blue stain attacks on rubber wood in Indonesia reach 220 billion rupiahs annually [11, 4]. The large number of losses caused by this fungal attack will have a negative impact on the development of the timber industry in Indonesia.

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Scientific information regarding the attack of staining fungi on wood in Indonesia and their control is still limited. In this regard, the study aimed to evaluate the intensity of blue stain attack on five species of light-color woods and its effect on mechanical properties.

2 Materials and methods

2.1 Materials

The wood materials used in this research were pine (*Pinus Merkusii*), rubber (*Hevea brasiliensis*), jabon (*Anthocephalus cadamba*), sengon (*Falcataria moluccana*), and gmelina (*Gmelina arborea*) with the average diameter of 30 cm, which were obtained from the Ciampea, Bogor, West Java. Some disc-shaped samples with a thickness of 3 cm were made to evaluate the intensity of fungal attack on wood. The size of the modulus of elasticity (MOE) and modulus of rupture (MOR) samples were 2 cm × 2 cm × 30 cm, while the hardness test sample was 2 cm × 2 cm × 6 cm. Each test sample was replicated five times.

The instruments used in this research include callipers, digital scales, an oven, a scanner, transparent acrylic with a millimetre block scale, a Chun Yen Universal Testing Machine (UTM), a thermometer, and a hygrometer.

2.2 Methods

2.2.1 Natural exposure

Natural exposure was conducted in the open space of the physical properties laboratory, faculty of forestry and environment, Bogor Agricultural Institute. The test samples were placed on exposure racks without touching the ground. Temperature and humidity were measured periodically with a thermometer and hygrometer. Natural exposure continued until week six. During the exposure, the sample was also scanned using a scanner.

2.2.2 Blue stain attack intensity

The surface area of wood attacked by the blue stain was measured using transparent acrylic outlined according to the size of millimeter paper. The intensity of blue stain attacks was calculated using Formula 1. Measurement of blue stain attack intensity was carried out periodically in weeks 1, 2, 3, 4, 5, and 6 after natural exposure. In addition, visual observations were also made of the color of the stain and the type of attack found on the wood parts.

$$I = \frac{area\ of\ wood\ attacked\ by\ blue\ stain}{wood\ surface\ area} \times 100 \qquad (1)$$

Explanation :
I : Blue stain attack intensity (%)

2.2.3 Mechanical testing

Mechanical testing was carried out on the control and naturally exposed samples using a Chun Yen Universal Testing Machine (UTM). The control and exposed samples were previously fan-dried at room temperature to a moisture content of ±12%. The bending and hardness tests of the wood refer to the standard BS 373 : 1957. Calculating of the modulus of elasticity (MOE), modulus of rupture (MOR), and hardness used formulas 2, 3, and 4.

$$MOE = \frac{P'\ L^3}{4\ \Delta'\ b\ h^3} \qquad (2)$$

$$MOR = \frac{3\ P\ L}{2\ b\ h^2} \qquad (3)$$

Explanation :
MOE : *modulus of elasticity* (kgf cm^{-2})
MOR : *modulus of rupture* (kgf cm^{-2})
P' : load at below proportional limit (kg)
P : maximum load (kg)
L : span (cm)
Δ' : deflection at below proportional limit (cm)
b : wide (cm)
h : thick (cm)

$$K = \frac{P}{A} \qquad (4)$$

Explanation :
K : hardnees (kg cm^{-2})
P : maximum load (kg)
A : peasure area (cm^2)

2.2.4 Statistical analysis

The obtained data were analyzed using a one-factor complete randomized design (CRD) with five replications. When the analysis of variance (ANOVA) at 95% confidence interval showed a significant effect, further tests were carried out using Duncan's analysis. The data were analyzed using IBM Statistical Product Service Solution (SPSS).

3 Result and discussion

3.1 The intensity of blue stain attack

The observations showed that all wood species had been attacked by staining fungi since the first week of exposure. The blue stain attack on wood was characterized by the presence of round spots or blue-black stripes. The blue stain attack on wood samples is shown in Fig. 1. The color changes were caused by the hyphal pigments of the blue stain that are bluish or blackish [12]. Some types of blue stains, such as *Lasiodiplodia theobromae* produce dark melanin pigments. Melanin pigments produced by staining fungi to increase the survival of these fungi [3].

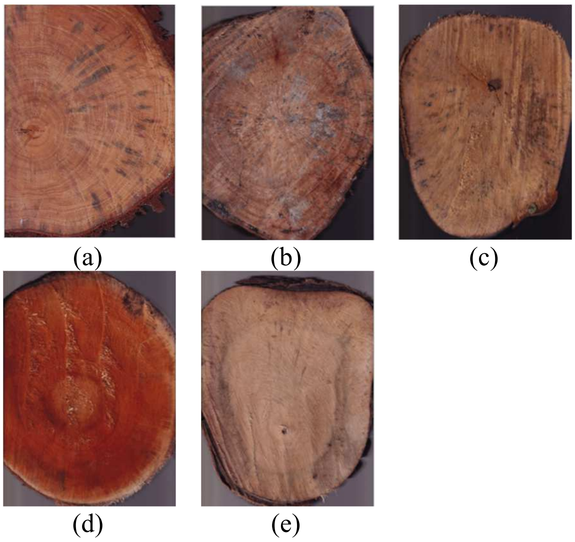

Fig. 1. The first week of blue stain attack on pine (a), rubber (b), jabon (c), sengon (d), and gmelina (e) woods.

Blue stain attack starts from the sapwood towards the heartwood. In the first week, pine, rubber, and jabon were already attacked by blue stains on the sapwood and heartwood. While in sengon and gmelina, the heartwood was not attacked by blue stain until the sixth week (Fig. 2). This is because sapwood has cells that are still alive and have higher moisture content than heartwood [13]. The high moisture content of wood is comfortable for the fungal growth. Besides that, sapwood contains living cells and food storage such as starch [13]. The growth of blue stain is highly dependent on the availability of water and nutrients in the wood. Wood must contain enough food storage, free water, and oxygen for mycelium growth [3].

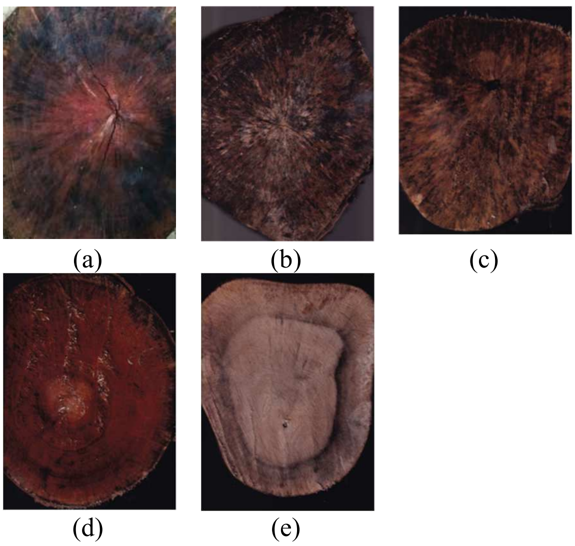

Fig. 2. The sixth week of blue stain attack on pine (a), rubber (b), jabon (c), sengon (d), and gmelina (e) woods.

The intensity of fungal attack on five wood species during the six weeks of exposure is shown in Fig. 3. The highest percentage of blue stain attack was shown in pine wood, followed by rubber, jabon, sengon, and gmelina woods. Based on the ANOVA test, in the sixth week, the type of wood had a significant effect on the intensity of fungal attack at the 95% confidence interval. Duncan's further test revealed that the intensity of fungal attacks on rubber and pine was significantly higher than on the other woods (three times higher than that on gmelina wood). Similarly, the intensity of the fungal attack on jabon was significantly higher, reaching twice the attack on gmelina. In comparison, the intensity of fungal attack on sengon was approximately the same as gmelina. The differences in the intensity of fungal attack on each type of wood could be caused by starch content, extractives, porosity, and the durability of wood.

There are many factors that can affect blue stain attack on wood. These factors can come from within the wood (substrate) and factors from the surrounding environment. The availability of nutrients, water, oxygen, and pH in the wood (substrate) greatly affects the ability of the fungus to grow on the substrate [14]. However, under certain conditions, such as too high water content, fungi cannot grow due to insufficient oxygen in the substrate. Environmental conditions also contribute to the fungal growth. Temperature, light, and air humidity are other factors that also need to be considered for the growth and development of fungi. But in this case, the optimal temperature for the growth of blue stain ranges from 22 - 30 ^{o}C [3].

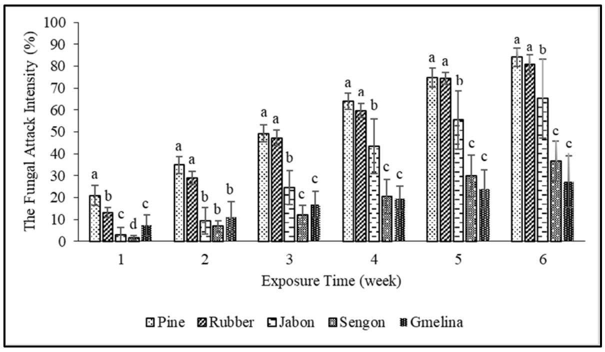

Fig. 3. Staining fungal attack intensity on pine, rubber, jabon, sengon, and gmelina woods during six weeks of above-ground natural exposure. Different letters (a, b, and c) mean significantly different values (α=0,05).

Jabon, sengon, and gmelina woods were relatively less susceptible to blue stain attack than the other wood species. This was evidenced by the percentage of blue stain attack area on these three types of wood ranging from 1% to 7% in the first week of observation. The highest attack intensity of blue stain in the sixth week was in pine wood, reaching 84%, followed by rubber wood 80%, jabon 65%, sengon 36%, and gmelina 27%. These results showed consistency from the beginning to the end of the observation that pine has the highest attack intensity by blue stain. Starch and simple sugars are nutrient sources for the blue stain to grow and develop. In several studies, it was reported that pine and rubber have high starch content, especially in the sapwood. Kasim [15] reported higher starch content in pine and rubber than in sengon and gmelina. Starch is an important energy reserve for plants, which is stored in the parenchyma cells [19]. Jabon and gmelina wood have high extractive content, making them less susceptible to fungal stain attacks [15].

3.2 Mechanical properties

The mechanical testing of control and exposed samples are shown in Fig. 4, 5, and 6. The highest modulus of elasticity (MOE) was in pine wood (139514 kgf cm^{-2}), while the lowest was in jabon wood (5868 kgf cm^{-2}). The results of statistical analysis showed that the attack of blue stain fungi on naturally exposed wood did not have a significant effect on the MOE of wood at the 95% confidence interval. The figure shows that in pine wood and the other four woods, there were no significant differences in MOE values between the natural-exposed samples that were attacked by fungi and the control samples without blue stain attack.

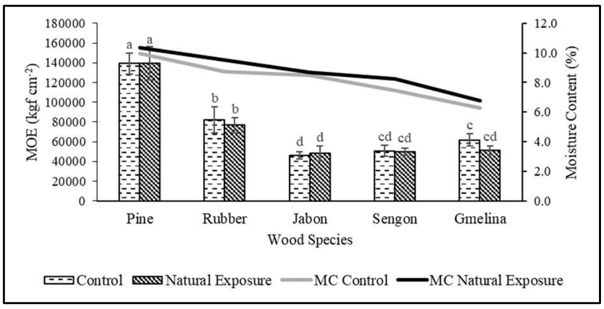

Fig. 4. MOE of pine, rubber, jabon, sengon, and gmelina woods after natural exposure. Different letters (a, b, c, and d) mean significantly different values (α=0,05).

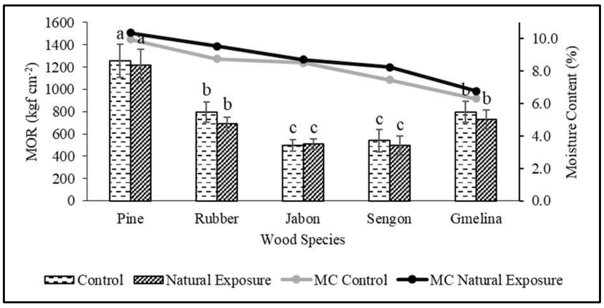

Fig. 5. MOR of pine, rubber, jabon, sengon, and gmelina woods after natural exposure. Different letters (a, b, and c) mean significantly different values (α=0,05).

The MOR values did not show any significant difference between the samples after natural exposure and the control samples. The highest MOR was in pine wood (1255 kgf cm^{-2}), while the lowest MOR was in sengon (496 kgf cm^{-2}). Based on the ANOVA test results, the type of wood had a real influence on both MOE and MOR values, while the blue stain attack on natural exposure for six weeks did not have a significant influence on the MOE and MOR values.

Blue stain attack on wood only occupies the lumen cell [16]. Blue stain cannot degrade wood cell walls, so the strength of wood attacked by blue stain does not decrease. The condition of the wood cell wall contributes to the strength properties of wood [17].

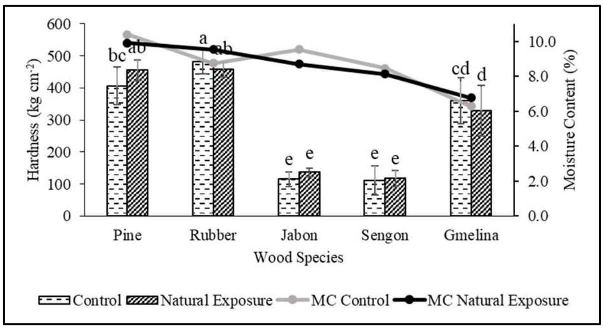

Fig. 6. Hardness of pine, rubber, jabon, sengon, and gmelin woods after natural exposure. Different letters (a, b, and c) mean significantly different values (α=0,05).

As in the MOE and MOR tests, blue stain attack in natural exposure to wood did not have a significant effect on wood hardness. This can be seen from the hardness values of the samples after natural exposure and the control samples that were not significantly different. In accordance with the ANOVA test, only the type of wood had a significant effect on the hardness value at the 95% confidence interval.

In pine and jabon, wood hardness showed an increase after natural exposure, although the increase was not significant. This might be due to differences in the moisture content of the wood. Changes in wood permeability can occur in wood attacked by blue stain during natural exposure, which can affect wood moisture content. Moisture content is one of the factors that affect the mechanical properties of wood [18].

4 Conclusion

The highest intensity of blue stain attack was found on pine (84%), followed by rubber (80%), jabon (65%), sengon (36%), and gmelina (27%). Blue stain attacked from the first week of exposure on all the tested woods. Pine, rubber, and jabon have been attacked by blue stains on both sapwood and heartwood since the first week of exposure. The heartwood of sengon and gmelina was not attacked by blue stain even until the sixth week of exposure. The blue stain attack started from the sapwood towards the heartwood, especially on the ray cells. Six weeks of blue stain attack did not significantly affect the MOE, MOR, and hardness values of the five tested wood species.

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