Color changes and smoke penetration of jabon (Anthrocephalus cadamba) and tusam (Pinus merkusii) woods after smoke treatment

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Abstract. Wood color is one of the physical properties that influence aesthetic values. Color has an important place regarding to human’s style. Color can be the preferential factors prior to people when making a decision to purchase wood products. The aim of the research was to evaluate the impact of smokes period (one-, two-, and three-week) on the color change and smoke penetration of tusam (Pinus merkusii) and jabon (Anthrocephalus cadamba) woods. The smoke was generated from pyrolysis of salam (Syzygium polyanthum) wood. Color evaluation was done with CIEL*a*b* method. The assessment of smoke penetration was done with visual identification using ImageJ application. The results demonstrated that smoke treatment resulted in the color change of the wood. Smoke treatment caused value of L* (lightness), a* (red-green), and b* (yellow-blue) of wood treated were decreasing from original wood. The wood was darker with longer period of smoke. Appearance of smoked wood was different totally from original color of wood. In visual identification showed that smoke was penetrated less than 1 mm of each wood. It was found that all smoke periods can be applied for natural coloring for smoky color type.

1. Introduction
Tusam (Pinus merkusii) and jabon (Anthrocephalus cadamba) woods are fast-growing wood species that commonly planted in Indonesia [1]. Wood from plantation forest is needed to be preserved for a longer service life. One of the ecofriendly process is by smoking. Smoked wood has been carried out by Hadi et al. [2,3,4]. Wood smoking treatment has proven increased wood resistance [5,6]. However, from [7] reported that smoking treatment can cause discoloration on wood. Wood color is important for aesthetic value of a wood product.

Wood products in general have two color characteristics, namely brightness and darkness properties. Color in wood is natural, but wood color can be changed with several treatments such as heat treatment and chemical modification [8]. Color can be the first parameter of consumer decisions when bought a wood product. Each region has different characteristics for determining color [9]. Consequently, wood color is one defining factor in marketing.

Research on color changes of wood due to smoking and smoke penetration in fast-growing wood species is limitedly worked out. Therefore, the purposes of this study was to identify the effect of smoking on color changes and penetration of smoke on jabon and tusam woods.
2. Materials and Methods

2.1. Material
Salam (*Syzygium polyanthum*) wood was pyrolized to produce charcoal. Jabon and tusam specimens were exposed to the smoke released for a period of 1, 2, or 3 weeks. All wood samples were 0.5 cm by 2.5 cm in cross section and 2.5 cm in the longitudinal direction. Untreated specimens were also prepared for comparison purposes. All wood samples were collected from Bogor, West Java, Indonesia.

2.2. Wood color and smoke penetration determination
The wood color and smoke penetration were determined via a photo of a wood sample with visual identification using *ImageJ* application. The wood color was determined using CIELab method [10]. The values of L* (black-white), a* (red-green), and b* (blue-yellow) were determined. For each sample were taken at four points for measurements and the values were averaged. The color change (ΔE) was calculated regarding to CIELab [11]. Color change can be classified into six classes [12]. For smoke penetration determination, the wood samples were cut. Ten points were taken on the cutting samples for measurements and the values were then averaged.

3. Results and discussion

3.1. Wood color
The most important parameter which considered in basic wood color parameter on many application is lightness (L*). As the longer period of smoking, the L* values gradually decreased in both wood species, which was confirmed that smoke can makes wood color more dark. Based on Table 1, it can be seen that the two wood species had almost the same values. The changes value of L* was large with 1 week smoked. Whereas, smoking for 2 weeks and 3 weeks had similar value of lightness. Dark color is one factor that attracted consumer interest in wood products [9]. In addition, further data [8] showed that consumer interest in wood products with lightness score was ranged from 50-60. The value of a* (red-green) coordinates showed small changes or not visible. The change was smaller than the change in lightness. Both wood species has the same trend of changes. The longer period of smoke decreased a* value.

### Table 1. Average values L*, a*, b*, and color changes parameters

| Wood species | Treatments | L*      | a*      | b*      | ΔE      |
|--------------|------------|---------|---------|---------|---------|
| Tusam        | Untreated  | 68.13±5.50 | 9.44±1.51 | 32.19±2.56 | na.     |
|              | Smoke 1 W  | 34.75±1.37 | 6.63±1.05 | 17.19±1.94 | 37.16±3.75a |
|              | Smoke 2 W  | 29.63±1.36 | 3.81±1.25 | 9.75±1.74 | 45.46±3.13b |
|              | Smoke 3 W  | 27.88±1.83 | 2.75±0.54 | 8.75±1.32 | 47.38±5.20b |
| Jabon        | Untreated  | 78.19±0.77 | 4.13±0.43 | 23.75±2.05 | na.     |
|              | Smoke 1 W  | 35.25±1.36 | 5.50±0.87 | 20.00±1.02 | 43.32±0.86b |
|              | Smoke 2 W  | 27.44±0.59 | 3.69±0.80 | 11.31±1.64 | 52.37±1.13c |
|              | Smoke 3 W  | 25.38±1.80 | 2.44±0.31 | 8.88±1.38 | 55.00±2.01c |

Remarks: na is not available; Values followed by the same letter within the column are not statistically different regarding to Duncan’s multi range test.

According to [8], consumer interest for wood working in the value of a* is about 5-8. The value of b* (yellow-blue) coordinates were decreased by smoking. It was occurred in both wood species and have the same trend. With one-week period of smoke showed the biggest change in value b*. But, if
the period of smoking were longer, the value of \( b^* \) becomes smaller. The best value of yellow-blue coordinate for consumer interest ranged from 20-24 [8].

### Table 2. Analysis of variance results for \( L^* \), \( a^* \), \( b^* \), and \( \Delta E \)

| Parameter        | Color changes (\( \Delta E \)) |
|------------------|--------------------------------|
| Wood Species     | **                             |
| Treatments       | **                             |
| Interaction      | *                              |

Remarks: * Significantly different at \( p =< 5\% \); * Highly significantly different at \( p =< 1\% \).

The color changes (\( \Delta E \)) of both wood have the same trend and even similar. Table 1 showed the longer period of smoke made the value \( \Delta E \) will greater. Based on value [12] about classified color change both wood species and all treatment had different color. That phenomena can be seen in Fig 1. However, these results are different from [7], that smoke process does not provide color changes because the smoke period is relatively faster. The results of statistical analysis show that there is a real interaction. In addition, wood with smoke duration of 2 weeks and 3 weeks produces the same color change. As shown in Figure 1 color changes among wood species were different each other.

The color change of wood due to smoke were influenced by various factors such as smoke density, temperature, and moisture content. If the level of smoke density, temperature, and moisture content is high, then the color changes will be accelerated [13]. In addition, the discoloration of wood is caused by phenolic group which react simultaneously with carbonyl groups and the process occurred through hydrogen bonds of hydroxyl group [14]. It will allow the new formation of hydrogen bonds between smoke and wood [14]. Therefore, the longer smoke process causes the accumulation of phenol and the carbonyl group to react, hence causing the wood to be darken.

### Figure 1. The color of wood specimen before and after smoke process

3.2. Smoke penetration

A high value of penetration indicated a better produced product, because the deeper preservative that enters the wood tissues. The penetration value of smoke was showed in Table 3. The smoke penetration value is smaller than boron penetration in cold-immersed condition on mangium wood, which is 28 mm [15]. Descriptively, jabon wood that smoked for 1 week showed the smallest value of smoke penetration than the tusam wood. Based on the average value and standard deviation, it can be seen that jabon and tusam wood almost have equal penetration values. Variation different value of smoke penetration were affected by different types of wood species and anatomical size cells of wood. Tusam wood belongs to conifer or softwood but jabon wood belong to hardwood. Further data [16], cell sizes of tusam and jabon wood in term of length were 5,457 \( \mu \text{m} \) and 1,979 \( \mu \text{m} \), respectively, for diameter were 49 \( \mu \text{m} \) and 54 \( \mu \text{m} \), respectively, for wall thickness were 4 \( \mu \text{m} \) and 3.2 \( \mu \text{m} \), respectively.
and for lumen diameter 41 \(\mu m\) and 47.6 \(\mu m\), respectively. Although, the biggest lumen diameter belongs to jabon wood, but softwood has simple anatomical cells than hardwood [17].

Table 3. Depth penetration of smoke on tusam and jabon wood

| Wood species | Smoke penetration (mm) |
|--------------|------------------------|
|              | Smoke 1 Week | Smoke 2 Weeks | Smoke 3 Weeks |
| Tusam        | 0.51±0.12 | 0.70±0.16 | 0.74±0.13 |
| Jabon        | 0.36±0.09 | 0.60±0.13 | 0.69±0.08 |

Figure 2. Smoke penetration of smoked wood

Conclusions
1. Untreated wood has different color from the smoked wood.
2. The longer period of smoking will decrease values of \(L^*, a^*\) and \(b^*\), causing wood color become darker than the untreated wood and affecting deeper smoke penetration.
3. Smoking period of two- and three-week application had similar wood color and smoke penetration on jabon and tusam wood.

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**Acknowledgements**

The authors gratefully acknowledge financial support from Competency Research Grant, Ministry of Research, Technology and Higher Education of the Republic of Indonesia. The authors also thank to IPB University for supporting research facilities.