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COLOUR CHANGE AND EFFECTIVITY OF CHEMICALLY-SMOKED BASED PRESERVATIVES COMPOUNDS ON THREE FAST-GROWING TROPICAL TREE SPECIES WOOD

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Timber from plantation forests dominantly contains sapwood and a high percentage of juvenile wood susceptible to termite attack. The resistance of wood against termite attack was found to be enhanced by smoke treatment. The current study investigated the effectiveness of preservatives developed based on chemically-smoke compound on three tropical fast-growing tree species against termite attack. The preservatives formulations A, B, C and D were developed using different compositions of acidic, phenolic, benzene-derivative and alcoholic compound. The wood species selected were from gmelina (*Gmelina arborea*), jabon (*Anthocephalus cadamba*) and rubber wood (*Hevea brasiliensis*). The test was conducted in a laboratory according to the Indonesian standard SNI 7207-2014 using subterranean termite (*Coptotermes curvignathus*). The results showed that after the preservation process the wood colour which was previously light bright, red and yellow colour turned to darker shades. The untreated woods had poor resistant to subterranean termite attack with an average class of 4.5. In contrast, the preserved woods had moderate resistance with an average or enhanced class of 3.3 or 1.2, respectively. The formulations A, B, C and D were not significantly different with formulation D showed the best results in wood resistance. Therefore, these formulae could be incorporated with other types of chemicals similar to the compounds contained in the wood smoke to produce a more effective preservative for better enhancement of wood resistance.

Keywords: Colour change, fast-growing tropical wood, preservative based on smoke compounds, termite resistance

INTRODUCTION

In 2020, Indonesian log production reached 61 million m^3 with 60% of it were exploited from plantation forests aged less than 10 years old (BPS 2021). The timbers dominantly consisted of sapwood with a high percentage of juvenile wood. As a result, they had inferior physical-mechanical properties and were susceptible to attacks by biodeterioration organisms, specifically termites in the tropical area (Fajriani et al. 2013, Hadi et al. 2015).

Fast-growing tree species were primarily planted in the forests because they could be harvested in short rotation to achieve faster returns of investments, such as mangium (*Acacia mangium*), eucalypt (*Eucalyptus* sp.), sengon (*Falcataria moluccana*), jabon (*Anthocephalus cadamba*), gmelina (*Gmelina arborea*) and rubber wood (*Hevea brasiliensis*). Based on Martawijaya et al. (2014), these woods were not from the resistant class or were susceptible to be attacked by biodeterioration organisms. Therefore, preservatives treatments were recommended for the timber before being utilised for construction and furniture manufacturing purposes to achieve longer service life

The resistance of some tropical wood species to subterranean termite attack was successfully enhanced after smoke treatment. Previous research stated that smoke treatment on mindi (*Melia azedarach*) and sugi wood (*Cryptomeria* *japonica*) using mangium smoke for 12 hours or 15 days increased their resistance to the attack of termite (Hadi et al. 2010a & 2010b). The results matched the highest resistant class of subterranean and dry wood termites according to the Indonesian standard SNI 7207-2014 (SNI 2014) and with equal susceptibility to polystyrene-impregnated and borax preserved timber. Other study showed that the smoke of mangium could also be applied to sengon and pulai (*Alstonia* sp.) for three days to increase the resistance to the class of subterranean and dry wood termites and equal susceptibility with polystyrene-impregnated timber (Hadi et al. 2012).

In some further studies, Hadi et al. (2016a & 2016b) used mangium smoke to treat sengon, manii (*Maesopsis eminii*) and mangium glulams for 15 or 30 days. The glulam was constructed with the same species for all layers or with mangium for the face and back layers and a core of manii or sengon. Meanwhile, the untreated and imidacloprid-preserved woods were also prepared for comparison.

A study by Hadi et al. (2020a) pyrolyzed salam (*Syzygium polyanthum*) to produce charcoal and the byproduct smoke was used to treat mangium and sengon woods for 1, 2 and 3 weeks. The dominant chemical compounds of salam liquid smoke were acetic acid, phenol, ketone, benzene, aldehyde and other compounds. After treatment, there were differences in colour change ($\Delta E>12$) from untreated wood, and the colour change of mangium was smaller than sengon. Additionally, imidacloprid-preserved wood showed a significant colour change ($6<\Delta E<12$) compared to untreated timber. In terms of resistance to termite attack, the untreated mangium wood had moderate susceptibility to subterranean termite attack (resistance class III), while sengon was very poor (resistance class V). The smoke of salam wood could enhance wood resistance to termite attack, while 1 and 2 weeks for mangium and sengon, respectively which resulted in the wood becoming very resistant (resistance class I). These types of smoked wood were more resistant to subterranean termite attack than imidacloprid-preserved timber (average class II resistance).

Another study by Hadi et al. (2020b) found that the smoke of kesambi (*Schleichera oleosa*) wood dominantly consists of acetic acid, phenol, ketones, amines and benzene. After sengon, jabon, mangium and pine (*Pinus merkusii*) were treated with kesambi smoke, the wood colour turner to a darker shade, lighter yellow tone and increased redness. At the same time, a more extended treatment period produced a darker shade to the timber and higher susceptibility to termite attack. However, there was no significant difference for 1, 2 and 3 weeks. Nandika et al. (2020) also used kesambi smoke to enhance gewang (*Corypha utan*) wood resistance to dry-timber termite (*Cryptotemes cynocephalus*) and fungi (*Schizophyllum commune*) attack. A year later, Nandika et al. (2021) used the same smoke for densified gewang glulam to enhance resistance to dry-wood termite and fungi attacks.

The treatment of wood and glulam with smoke significantly enhanced their resistance to bio-deterioration attacks, but the process is time-consuming. In order to shorten preservation period, timber impregnation using liquid smoke (wood vinegar) was conducted (Arsyad et al. 2019, Firouzbehi et al. 2020). The wood vinegar contained some important compounds such as hydrocarbon, ketones, alcohols, esters, formaldehydes, phenols, organic acids and heterocyclic compounds (Haji 2013, Tascioglu et al. 2012, Kim et al. 2008). These compounds were found to have several properties such as antibacterial (Lee et al. 2010, Yang et al. 2016), antioxidant (Yang et al. 2016), antifungal (Okutucu et al. 2011, Islam et al. 2009) or anti-termite activities (Yatagai et al. 2002, Oramahi & Yoshimura 2013). However, due to the limited source, as well as variation in composition and concentration of the active compound, it is possible to develop synthetic wood preservatives based on chemically smoke compounds. Therefore, this study aims to develop wood preservatives based on chemically smoke compounds and evaluate their effectiveness in preserving wood against termite attacks.

MATERIALS AND METHODS

Wood and preservatives preparation

Logs of tropical fast-growing tree species, namely gmelina (*Gmelina arborea*), jabon (*Anthocephalus cadamba*) and rubber wood (*Hevea brasiliensis*) with a diameter of 20 cm were collected from Bogor area, Indonesia. The logs were processed into test specimens with dimensions of 2.5 cm × 2.5 cm × 0.5 cm (length × width × thickness) for the subterranean termite test in the laboratory.

The wood specimens were air-dried to a moisture content of approximately 12%.

Table 1 shows the timber preservatives prepared by assigning each smoke compound to obtain formulation A, B, C and D with 5% concentration (w/w) and ethanol as solvent.

The wood specimens were immersed in each formula, then vacuumed at 0.80 bars for 30 minutes and followed by pressure treatment at 9.80 bars for 30 minutes (Hadi et al. 2016c). Subsequently, the retentions of each wood species and the formulation were measured. The specimens were then air-dried to a moisture content of approximately 12% using a fan and followed by two weeks of conditioning in a room (25–27 °C, 70–80% of relative humidity). For comparison purposes, the untreated wood as control was prepared for each wood species and the density of the specimens was measured before the termite test was conducted. A total of six replications were performed for each wood species and formula.

Physical properties

The physical properties determined in the study included wood density, preservative retention in the wood and colour changes after the process. Furthermore, the basic density of wood species was determined by measuring the specimen volume at air-dry conditions and oven-dry weight. It is calculated using the following formula:

$$\text{Wood density (kg m}^{-3}\text{)} = \frac{\text{oven dry weight (kg)}}{\text{volume of wood at air-dry condition (m}^3\text{)}}$$

Retention is the amount of preservative mass in kg m^{-3}. It was calculated using the following formula:

$$\text{Retention (kg m}^{-3}\text{)} = \frac{\text{amount of entered preservative to the wood (kg)}}{\text{volume of wood the wood (m}^3\text{)}} \times \text{concentration of preservative}$$

The wood colour characteristics were determined using the CIELab method. The L* (lightness), a* (green-red) and b* (blue-yellow) values were measured. Subsequently, the process was measured through a photograph obtained from a scanner machine. The L*, a* and b* values were measured using a colour sampler in the Adobe Photoshop CS5 application. Finally, the colour change of specimens was calculated according to Hunter Lab (1996) and Hrcková et al. (2018).

Termite resistance

Figure 1 shows the schematic of each wood specimen tested for subterranean termite (*Coptotermes curvignathus*) attack according to Indonesian standard SNI 7207-2014 (SNI 2014).

The procedure was performed using a no-choice test similar to Roszaini et al. (2019). The specimen was placed inside a simple glass jar containing 200 g of sand with 7% moisture content. A total of 180 workers and 20 soldiers of subterranean *Coptotermes curvignathus* were inserted into the glass jar and maintained in a dark room at 28 °C and 80% relative humidity for four weeks. The standard moisture content of sand was maintained at all time and water was added when moisture content of the sand decreased to less than 2%. At the end of the test, degree of damage, termite mortality, termite feeding rate, wood weight percent loss, as well as resistance class of each wood species and treatment were determined (Hadi et al. 2021).

Table 1 The formula of wood preservatives based on smoke compounds

Compound	Formula in weight ratio			
	A	B	C	D
Acetic acid	5	4	3	2
Guaiacol	5	3	4	7
Benzofuran	0	2	2	0
Furfuryl alcohol	0	1	1	1

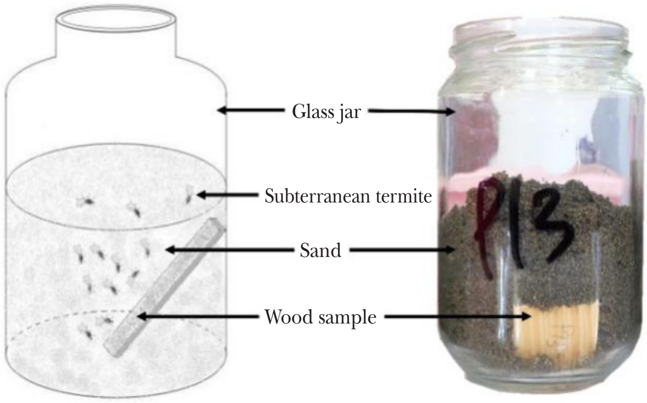

Figure 1 Termite test in laboratory (SNI 2014)

Data analysis

The data were analysed with a 3 × 5 completely randomized factorial design using two factors A and B, namely wood species and preservative formula. The first factor consisted of three levels, namely gmelina, jabon and rubber wood, while the second factor consisted of five levels, namely untreated wood (control) and formulations A, B, C and D. Duncan's multiple range tests were conducted when the main factor was significantly different at $p \leq 0.05$ and performed on the wood species due to the significant indifference of the interaction factor. Finally, the analysed data could be explained in the following linearly equation:

$$y_{ijk} = \mu + A_i + B_j + AB_{ij} + \varepsilon_{ijk}$$

where, y = Observation value of wood species (i), treatment (j) and replication (k). μ = general average, A= effect of wood species (i), B = effect of treatment (j), AB = interaction effect of wood species (i) and treatment (j) and ε = error effect of wood species (i), treatment (j), and replication (k).

RESULTS AND DISCUSSION

Physical properties and retention

Density

Table 2 shows the density, retention, colour characteristics in terms of L*, a* and b*, as well as colour change (ΔE) of each wood species and preservative formula. Tables 3 and 4 show the resume of variance and further multi-range analysis, respectively.

The untreated or controlled wood densities of gmelina, jabon and rubberwood were compared to Martawijaya et al. (2014) and MoEF (2020). Based on Table 3, timber species significantly affected wood density but not on the preservative formulation and the interaction of both factors. Table 4 shows gmelina wood had the highest density followed by rubberwood and jabon which showed no significant different. The preservative formulation did not affect the wood density because the retention average was from 30.4 to 34.3 kg m^{-3} or the mass increment was approximately 3%. Consequently, they were no difference from untreated wood. These amount were appropriate for wood preservation and in accordance with SNI 03-5010.1-1999 (SNI 1999), which required 8 to 14 kg m^{-3} retention.

Retention

Table 4 shows the wood species and preservative formulation had significant effect on retention, but not the interaction of the two factors. Gmelina and jabon, on the other hand, had the lowest and highest retention to the highest and lowest wood density, respectively. The wood density influenced the readiness of liquid to penetrate into the tissues. Furthermore, timber with lower density was easily penetrated by a chemical solution because of the large void space in its structure. A higher density wood resulted in a smaller void and thicker cell wall, which the wood be likely to have minor retention (Hadi et al. 2018). For the preservative formulation, the smallest and highest retention were found in A and B, respectively, while C and D were in between with no significant difference.

Table 2 The effect of different smoked compounds on each wood species' density, retention, and colour characteristics

Response	Wood sp.	Formulation					Average
		Control	A	B	C	D	
Density (kg m^{-3})	Gmelina	612 (64)	617 (52)	584 (34)	600 (8)	623 (72)	607 (50)
	Jabon	490 (30)	524 (34)	540 (31)	517 (43)	491 (37)	512 (38)
	Rubber	524 (84)	540 (76)	535 (77)	502 (60)	513 (64)	523 (69)
	Average	542 (79)	560 (68)	553 (54)	539 (60)	542 (82)	
Retention (kg m^{-3})	Gmelina	0	27.7 (0.8)	31.9 (1.2)	30.6 (1.1)	30.8 (1.2)	30.2 (1.9)
	Jabon	0	33.5 (0.7)	36.8 (2.5)	33.6 (1.8)	34.7 (2.1)	34.7 (2.2)
	Rubber	0	30.1 (1.5)	34.4 (1.4)	32.8 (0.7)	32.4 (1.6)	32.4 (2.0)
	Average	0	30.4 (2.7)	34.3 (2.7)	32.3 (1.8)	32.6 (2.3)	
L*	Gmelina	81.3 (1.0)	76.7 (2.1)	76.1 (1.3)	72.9 (1.9)	74.5 (1.8)	76.3 (3.4)
	Jabon	76.3 (4.8)	75.1 (2.7)	73.7 (5.3)	73.1 (0.9)	68.8 (2.3)	73.4 (2.7)
	Rubber	83.7 (1.3)	76.5 (3.9)	78.5 (4.7)	75.9 (4.1)	78.1 (0.5)	78.5 (4.0)
	Average	80.4 (4.1)	76.1 (2.8)	76.1 (4.3)	74.0 (2.8)	73.8 (4.3)	
a*	Gmelina	13.5 (0.7)	16.4 (0.5)	17.3 (2.4)	17.1 (0.6)	17.1 (1.5)	16.3 (1.9)
	Jabon	11.9 (2.2)	14.7 (1.2)	13.6 (2.0)	16.0 (1.4)	12.9 (1.6)	13.8 (1.7)
	Rubber	8.4 (3.5)	12.7 (2.5)	12.3 (3.1)	15.2 (3.7)	15.9 (0.6)	12.9 (3.4)
	Average	11.2 (3.1)	14.6 (2.1)	14.4 (3.2)	16.1 (2.2)	15.3 (2.2)	
b*	Gmelina	24.0 (0.9)	28.0 (0.8)	29.4 (1.8)	28.1 (1.6)	28.1 (1.3)	27.5 (2.2)
	Jabon	22.7 (1.2)	25.2 (1.4)	26.9 (1.2)	24.9 (1.0)	21.8 (1.2)	24.3 (2.2)
	Rubber	19.8 (4.8)	22.9 (5.0)	24.6 (2.7)	26.6 (2.8)	26.7 (1.4)	24.1 (3.2)
	Average	22.1 (3.2)	25.4 (3.5)	27.0 (2.7)	26.5 (2.2)	25.5 (3.0)	
ΔE	Gmelina	0	6.8 (1.8)	8.6 (3.2)	10.2 (1.8)	9.1 (2.3)	8.7 (2.4)
	Jabon	0	5.0 (0.6)	5.8 (1.7)	6.8 (2.8)	7.7 (3.8)	6.3 (2.3)
	Rubber	0	9.3 (2.8)	9.3 (3.2)	12.8 (4.4)	11.9 (5.6)	10.8 (3.6)
	Average	0	7.0 (2.6)	7.9 (3.0)	9.9 (3.8)	9.6 (4.2)	

Values in parentheses are standard deviations; L* = axis represents darkness to lightness, a* = axis represents the green–red opponent colors, b* axis represents the blue–yellow opponents, ΔE = colour change

Table 3 Variance analysis resume of physical properties

Response	Wood species (A)	Preservative formulation (B)	Interaction (AB)
Density	**	NS	NS
Retention	**	**	NS
L*	**	**	NS
a*	**	**	NS
b*	**	**	NS
ΔE	**	NS	NS

** = highly significant ($p \leq 0.01$), NS = not significant ($p > 5\%$); L* = axis represents darkness to lightness, a* = axis represents the green–red opponent colors, b* = axis represents the blue–yellow opponents, ΔE = colour change

Table 4 Multi-range test of physical properties

Parameter		Density (kg m^{-3})	Retention (kg m^{-3})	L*	a*	b*	ΔE
Wood sp.	Gmelina	607 b	30.2 a	76.3 b	16.3 b	27.5 b	8.7 b
	Jabon	512 a	34.7 c	73.4 a	13.8 a	24.3 a	6.3 a
	Rubber	523 a	32.4 b	78.5 c	12.9 a	24.1 a	10.8 c
Formulation	Control	542 a	-	80.4 b	11.2 a	22.1 a	
	A	560 a	30.4 a	76.1 a	14.6 b	25.4 b	7.0 a
	B	553 a	34.3 c	76.1 a	14.4 b	27.0 b	7.9 a
	C	539 a	32.3 b	74.0 a	16.1 b	26.5 b	9.9 a
	D	542 a	32.6 b	73.8 a	15.3 b	25.5 b	9.6 a

The same letters in a column of wood species or formula are not significantly different ($p \leq 0.05$)
The Post Hoc tests (Duncan) for the wood species and the formula were analysed separately because the interaction factor (between wood species and formula) was not significantly different
L* = axis represents darkness to lightness, a* = axis represents the green–red opponent colors, b* = axis represents the blue–yellow opponents, ΔE = colour change

Wood colour

Table 2 shows that the colour of the woods was light, bright, green, and yellow with L*, a*, and b* average value of 76.1 ± 3.7, 14.3 ± 2.6, and 25.3 ± 2.9, respectively. Table 3 shows that the wood species and preservation significantly affected the colour of wood, but not the interaction of the two factors. The multi-range test in Table 4 shows that the rubberwood colour was the brightest, followed by gmelina and jabon. Furthermore, gmelina had more red and yellow colours than jabon and rubberwood, which were not different. The colour difference of timber species was affected by its characteristics in terms of extractives, cellulose and lignin contents.

The preservation treatment affected the wood colour. The multi-range test in Table 4 shows that untreated wood differed from those preserved with the significantly indifferent A, B, C and D formulation. All preserved woods were darker (L* value was lower), redder (a* value was higher), and had a more yellow colour (b* value was higher) compared to the untreated wood. The colour difference between untreated and preserved wood species was indicated by a colour change value of 8.6 ± 3.5. The data analysed in Table 4 shows that the formulation A, B, C and D were not different from each other and had the same range of colour change values (6 to 12). The changes were classified according to distinct colour change (Hrčková et al. 2018).

Termite resistance

Table 5 shows the termite resistance of wood, including mortality, wood weight loss, timber resistant class, termite protection level and feeding rate. Tables 6 and 7 show the variance analysis resume and further multi-range test, respectively.

Termite mortality

Table 5 shows that the preservative formulation applied on the woods had 100% termite mortality while for untreated or control wood the average mortality was 7.1%. The low mortality value implied that the termites were suitable test species in terms of environment and feeding activities in a laboratory setting with light, temperature and relative humidity regulations. In addition, the 100% mortality on preserved wood implies that all preservative formulations effectively prevented termite attacks. The variance analysis in Table 6 shows that the wood species and the interaction between both factors did not affect termite mortality, in contrast to the preservative formula. The untreated woods belonged to the lowest class (V) or had very poor termite attack resistance (Martawijaya et al. 2014, Arinana et al. 2012). Furthermore, the untreated wood showed a low mortality value, implying that the termite could safely feed on the wood, unlike those preserved.

Table 5 The effect of different smoked compounds on the termite resistance of each wood species

Response	Wood sp.	Formulation					Average
		Control	A	B	C	D	
Mortality (%)	Gmelina	6.3 (1.2)	100 (0)	100 (0)	100 (0)	100 (0)	81.3 (38.1)
	Jabon	7.5 (1.4)	100 (0)	100 (0)	100 (0)	100 (0)	81.5 (37.6)
	Rubber	7.5 (0.9)	100 (0)	100 (0)	100 (0)	100 (0)	81.5 (37.6)
	Average	7.1 (1.3)	100 (0)	100 (0)	100 (0)	100 (0)	
Weight loss (%)	Gmelina	25.7 (3.3)	17.7 (3.9)	17.3 (4.5)	18.3 (3.9)	16.3 (3.6)	19.1 (5.0)
	Jabon	16.7 (2.6)	8.6 (2.7)	11.0 (2.9)	11.0 (1.4)	9.3 (3.0)	11.3 (3.7)
	Rubber	18.2 (6.1)	7.0 (3.9)	6.1 (4.0)	7.0 (2.0)	5.1 (5.8)	8.7 (6.5)
	Average	20.2 (5.7)	11.1 (5.9)	11.5 (5.9)	12.1 (5.4)	10.2 (6.2)	
Resistant class	Gmelina	5.0 (0.0)	4.5 (0.5)	4.3 (0.5)	4.5 (0.5)	4.5 (0.5)	4.6 (0.5)
	Jabon	4.2 (0.4)	2.7 (0.8)	3.3 (0.8)	3.7 (0.5)	3.2 (0.8)	3.4 (0.8)
	Rubber	4.3 (0.5)	2.2 (1.0)	2.0 (1.3)	2.3 (1.0)	2.0 (1.5)	2.6 (1.4)
	Average	4.5 (0.5)	3.1 (1.3)	3.2 (1.3)	3.5 (1.2)	3.2 (1.4)	
Protection level	Gmelina	3.2 (2.7)	6.3 (2.0)	6.7 (2.3)	6.3 (2.0)	6.8 (1.6)	5.9 (2.4)
	Jabon	3.3 (1.6)	6.8 (1.6)	6.5 (1.2)	6.0 (1.5)	6.8 (1.6)	5.9 (2.0)
	Rubber	3.3 (1.6)	7.3 (0.8)	8.3 (1.0)	7.7 (1.0)	8.3 (1.0)	7.0 (2.2)
	Average	3.3 (1.9)	6.8 (1.5)	7.2 (1.7)	6.7 (1.6)	7.3 (1.5)	
Feeding rate (μg d^{-1} $termite^{-1}$)	Gmelina	96 (11)	141 (41)	130 (45)	134 (30)	126 (36)	125 (36)
	Jabon	53 (9)	57 (16)	78 (26)	72 (9)	60 (19)	64 (19)
	Rubber	66 (35)	52 (34)	43 (34)	50 (40)	39 (47)	50 (37)
	Average	72 (28)	83 (52)	84 (50)	85 (46)	75 (51)	

Values in parentheses are standard deviations.

Table 6 Variance analysis resume of termite test

Response	Wood species (A)	Preservative Formula (B)	Interaction (AB)
Mortality	NS	**	NS
Weight loss	**	**	NS
Protection level	**	**	NS
Resistant class	**	**	NS
Feeding rate	**	NS	NS

** = highly significantly different ($p \leq 0.01$); NS = not significantly different ($p > 0.05$).

Table 7 Multi-range test of termite test

Parameter		Mortality	Weight loss	Resistant class	Protection level	Feeding rate
Wood sp.	Gmelina	81.3 a	19.1 c	4.6 c	5.9 a	125 b
	Jabon	81.5 a	11.3 b	3.4 b	5.9 a	64 a
	Rubber	81.5 a	8.7 a	2.6 a	7.0 b	50 a
Formula	Control	7.1 a	20.2 b	4.5 b	3.3 a	72 a
	A	100 b	11.1 a	3.1 a	6.8 b	83 a
	B	100 b	11.5 a	3.2 a	7.2 b	84 a
	C	100 b	12.1 a	3.5 a	6.7 b	85 a
	D	100 b	10.2 a	3.2 a	7.3 b	75 a

The same letters in a column of wood species or formula are not significantly different ($p \leq 0.05$)
The Post Hoc tests (Duncan) for the wood species and the Formula were analysed separately because the interaction factor (between wood species and formula) was not significantly different

As a comparison to the termite mortality test, a similar study used directly smoked liquid/wood vinegar with the addition of 8 and 10% animal adhesive impregnated into jabon wood (*Anthocephalus cadamba*) which resulted in only 62–66 % termite mortality (Arsyad et al. 2019). The lower anti-termite activity of the smoke liquid was used to compare the result when 5% of active chemicals were impregnated into the wood. However, another similar study used the smoke liquid from three kinds of bamboo impregnated into rubberwood. Due to high phenolic and acidic compounds in the smoke liquid from bamboo, the preserved wood presented termite mortality of above 85% (Arsyad et al. 2020).

Wood weight loss and resistance class

Table 6 shows that the average wood weight loss of untreated wood (20.2%) was much higher than the preserved type (11.2%). In other words, the wood weight loss of preserved wood was less than 45% compared to the untreated type. The phenomenon was in line with some previous studies stating that untreated wood had the highest percentage of weight loss and a poor repellency against termite attack (Hassan et al. 2018, Meckler et al. 2016). Tables 6 and 7 indicate that the preservative formula significantly affected the weight loss of wood. Furthermore, it showed similar result after the termite test. The preservative formulations B and D showed the lowest weight loss. It indicated that the preserved gmelina wood had the highest weight loss than the other samples. Even though gmelina had a higher density, its extractive and lignin contents had the lowest percentage, which also might influence the highest weight loss (Idris et al. 2008, Martawijaya et al. 2014). Therefore, it was suggested that both wood species and the preservative chemical compounds but not the interaction of the two factors had affected the wood weight loss.

The untreated woods of jabon, rubberwood, and gmelina belonged to the resistance classes 4.2, 4.3 and 5.0. They were classified as having poor to very poor resistance, since the woods were susceptible to termite attack. According to the analysis of variance, wood species and preservative formulation significantly affected wood weight loss. Even though the three timber species showed different values in wood weight loss, they were classified as susceptible to termite attack (Martawijaya et al. 2014).

The preserved woods had similar wood weight loss, and they were not significantly different. According to the resistant class, the untreated and preserved wood belonged to the 4.5 and 3.3 classes, respectively. It was shown that preservation had enhanced wood resistance by 1.2 class. In other words, the preservative effectively enhanced the wood's resistance to termite attack.

Protection level

Figure 2 shows the untreated and preserved rubber wood specimens after the test, while Table 5 shows the protection level of each wood species and the preservative formula. The resume of variance and further multi-range analysis are shown in Tables 6 and 7, respectively. The protection level of untreated and preserved wood reached 3.3 and 7.0, respectively.

The analysis of variance in Table 6 showed that wood species and preservative formula significantly affected protection level, but not the interaction of the two factors. Table 7 showed that rubberwood had the highest protection level. In contrast, the other two wood species were not significantly different. The untreated gmelina belonged to the resistant class of 5.0, while the other two belonged to 4.3 and was more susceptible to termite attack.

The untreated and preserved wood had a protection level of 3.3 and 7.0, respectively. The higher protection level value implies that the preservatives effectively increased wood resistance to termite attack. Among the formulations, preparation D presented the best results on protection level point of view, weight percent loss, and feeding rate.

Termite feeding rate

Table 5 shows the termite feeding rate of each wood species and their preservative formula. Tables 6 and 7 show the resume of variance and multi-range analysis. According to Table 6, wood species significantly affected the termite feeding rate, but not its preservation and interaction of the two. The termite feeding rate of untreated jabon reached 53 μg day^{-1} $termite^{-1}$. This value was similar to Hadi et al. (2020 & 2021), which

(a) Untreated rubber wood after the test.

(b) Preserved rubber wood with formula A after the test.

(c) Preserved rubber wood with formula B after the test.

(d) Preserved rubber wood with formula C after the test.

(e) Preserved rubber wood with formula A after the test.

Figure 2 Untreated and preserved rubber wood specimens after the test

reported that the termite feeding rate for the same wood species was 48 µg day^{-1} termite^{-1} and 50 µg day^{-1}termite^{-1}, respectively. On the other hand, Arinana et al. (2012) reported that the termite feeding rate of untreated rubber wood was 79 µg day^{-1} termite^{-1}. Thus, the results of the two untreated timber had similar feeding rates to previous studies.

Table 7 shows that gmelina wood had the highest feeding rate, while the two other species were not significantly different. The highest feeding rate of gmelina was in agreement with its wood weight loss, wood resistant class and termite protection level, while followed by jabon and rubber wood.

Preservation did not affect the termite feeding rate since untreated and preserved woods were not significantly different from each other. This was due to a large standard deviations of each treatment. However, the average feeding rate and standard deviation of untreated and preserved woods in this study were 72 ± 28 and 82 ± 49 µg day^{-1} termite^{-1}, respectively which implied that the variability in feeding characteristics was very high.

Untreated wood had the lowest feeding rate. These were on the contrary to wood weight loss, wood resistance class, and termite protection level, whereby the preserved wood had better results.

The feeding rate was calculated during the test by dividing the wood mass with living termites, and the average total termites was determined at the beginning and the end of the test. Figure 3 illustrates that through a linear curve (a) that represented number of dead termite along

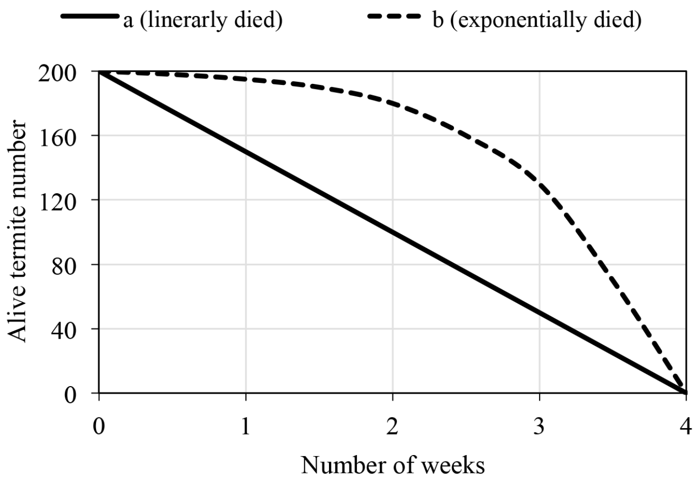

Figure 3 Alive termite number: (a) linearly died; (b) exponentially died

the test. In reality, the curve pattern could go downward or upward. The present work predicted with the exponential curve (b), where the number of living termites was higher at the first stage of the test and more dead termites at the end of the period. It suggested that the living termite was more significant in number during the test period (curve b) as compared to the calculation (curve a). The finding impliee that the feeding rate of preserved wood was more significant using curve (a) than the assumption model using curve (b). Therefore, it was recommended that the living termite to be counted daily during the test period.

CONCLUSIONS

The three tropical wood species were light density hardwoods with light brightness, red and yellow colours. In the experiment, woods preserved with formula A, B, C or D had a distinct colour change to darker, redder and more yellow. In the termite resistant test, untreated and preserved woods were more susceptible and moderately resistant to subterranean termite attack, respectively. All formulations A, B, C and D generated similar wood resistance. However, formulation D was considered to have the best resistant to termite attack, indicated by the lowest wood weight loss and feeding rate and the highest protection level. Therefore, in order to achieve more effective wood preservation, chemical compounds similar to the compounds contained in the wood smoke could be incorporated into the the preservative formulation to increase termite mortality.

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