EFFECT OF DRYING OF DIFFERENT LIGHT HARDWOOD TROPICAL TIMBER SPECIES ON DURABILITY AGAINST *COPTOTERMES CURVIGNATHUS* HOLMGREN UNDER LABORATORY AND FIELD TESTS

*K. Roszaini**

Senior Research Officer
E-mail: roszaini@frim.gov.my

A. H. Muhammad Al Amin

Research Officer
Forest Research Institute Malaysia (FRIM), Kepong, Kuala Lumpur, Malaysia
E-mail: muhammadalamin@frim.gov.my

(Received 1 November 2023)

Abstract. The effects of drying temperature and duration on the durability of *Lagerstroemia* sp. and *Cinnamomum* sp. against subterranean termites, *Coptotermes curvignathus*, were evaluated in no-choice and choice laboratory tests as well as in the aboveground test. Samples measuring 25 mm × 25 mm × 6 mm and 100 mm × 40 mm × 20 mm were dried in an oven at three different temperatures: 60°C, 80°C, and 100°C for two different time periods: 10 and 15 d. In comparison between the control sample and the treated sample, the control sample showed the highest MC, the lowest visual rating, the lowest termite mortality, and the highest weight loss. For the treated samples, the results show that the samples for both wood species have a low resistance limit to termites at low temperatures and a short-drying time. The weight loss is also high for samples with high MC. The mortality rate of termites was also high in samples dried at high temperatures over a long period of time compared with samples dried at low temperatures for a short period of time. The visual rating results also showed the same trend as the weight loss results. The results for these three categories are identical for the no-choice, choice, and aboveground tests. The analysis demonstrates that the high material resistance of tropical wood species is mostly dependent on the temperature and length of time spent in the kiln.

Keywords: *Lagerstroemia* sp., *Cinnamomum* sp., drying, durability, *Coptotermes curvignathus.*

INTRODUCTION

When we deal with wood, we cannot escape the attack of pests, especially termites, as the humid temperatures in Malaysia strongly favor the activity of these pests. The presence of cellulose, the main food source in wood, is a center of attraction for termites. This can only be avoided if the wood used is properly treated. It is estimated that the damage caused by these pests in Malaysia amounts to RM 400 million per year (Anon 2021) and is estimated at over USD 40 billion for all places where termites are found (Subekti et al 2015).

Drying is one of the ways or alternative methods to improve the durability of wood against insects, decay, and other pests without using preservatives. It can be considered as a biocide-free alternative to improve the performance of wood species with low natural durability. The drying process can be seen as a hygrothermal wood treatment (Sehlstedt-Persson and Wamming 2010). In this process, some of the water is removed from the wood, which leads to a reduction in MC. This water removal process is necessary for further utilization of wood. Generally, temperature, time, species, and process precision all affect durability. As the temperature and treatment duration increased, density, swelling, and surface roughness decreased (Korkut et al 2008).

High MC is one of the factors that favor attacks on wood by biological agents, especially termites and fungi (Sajap et al 2008). The significance of moisture for termite survival has already been

* Corresponding author

extensively discussed in previous studies (Oberst et al 2019). For example, the *Coptotermes acinaciformis* is a species of termite that prefers moist wood over dry wood and changes its MC depending on local conditions (McManamy et al 2008). *Reticulitermes flavipes* cannot maintain an infestation of wood without soil contact at an MC <24% as it requires a constant water supply. They require at least 30% wood moisture to survive for 6 mos.

Drying has been shown to have an impact on the durability of wood species. Fatima et al (2015) examined the resistance of three wood species drying at various drying temperatures and drying times against termites. The authors found that the wood-drying process had an effect on the durability of the wood. They also found that wood drying at a temperature (100°C) for 15 d has a higher durability than other combinations. Aihetasham et al (2012) examined the feeding of microcerotermes championsi on eight commercial wood species (*Cedrus deodara*, *Acacia arabica*, *Tectona grandis*, *Mangifera indica*, *Morus alba*, *Azadirachta indica*, *Ficus religiosa*, and *Melia azedarach*) drying at different temperatures. The study found that wood weight loss (WL) increased as the drying temperature increased, but did not have an effect on MC. Doi et al (2005) reported that the wood of Japanese larch (*Larix leptolepis*) dried at high temperatures (120-130°C) was susceptible to infestation by decay fungus and termite. In their study on heartwood samples of *Cryptomeria japonica* dried at high temperatures, Kano et al (2004) found that chemical compounds, such as sequirin C and agatharesinol, were vaporized, which caused the wood to be less resistant to subterranean termites (*Reticulitermes speratus*). In another study, pine (*Pinus sylvestris*) was significantly attacked when thermally modified at a temperature of 210°C for 15 min (Shi et al 2007). This means that drying wood at high temperatures is not suitable, as it alters the chemical components of the wood.

The leaves, roots, and bark of this species, *Lagerstroemia* sp., are traditionally used in medicine, especially for diabetes and to reduce body weight. Locally known as Bungur, it is a lesser-known timber species of the Lythraceae family originating in the Indo-Malayan region (including Indochina), extending into Indonesia and the Philippines, and often cultivated as an ornamental. Six new monomeric and dimeric ellagitannins, three new ellagitannins, 3-*O*-methylprotocatechuic acid, caffeic acid, *p*-coumaric acid, kaempferol, quercetin, and isoquercitrin are among the chemical compounds extracted from the leaves (using aqueous acetone) that have antioxidant, antibacterial, antiviral, antinociceptive, antidiarrheal, antiinflammatory, cytotoxic, antidiabetic, antifibrotic, and antiobesity effects (Chan et al 2014).

Cinnamomum sp. is an aromatic tree that belongs to the Lauraceae family. It is mainly distributed in Asia, China, and Australia (Jayaprakasha and Rao 2011) and is widely known as a culinary herb and traditionally used in medicine (Yanakiev 2020). It grows mainly in the tropical and subtropical regions of Southeast Asia, Australia, and America (North, Central, and South). With more than 500 compounds found in this plant, it has the potential for immunomodulatory, antiinflammatory, antitumor, antimicrobial, antioxidant, antifungal, antitermitic, insecticidal, and anticancer activities (Chang and Cheng 2002; Cheng et al 2009; Mdoe et al 2014; Wu et al 2020).

The wood of *Lagerstroemia* sp. is moderately durable, whereas *Cinnamomum* sp. is not durable when exposed to the weather or in contact with the soil (Wong 1982). A study by Febrianto et al (2015) on *Lagerstroemia* sp. wood grown in West Java, Indonesia, found that the sapwood of *Lagerstroemia* sp. is classified as resistant (natural durability class II) to *Coptotermes curvignathus* according to SNI 01-7207 (2006). *Cinnamomum* sp. only shows a WL of 0.98% when exposed to *C. curvignathus,* which classifies as very resistant according to EN 118 (2013) and Kadir et al (2017).

This study aims to find out if and how drying processes affect the durability of *Lagerstroemia* sp. and *Cinnamomum* sp. These two species were chosen to find alternatives to wood species that are commonly used, especially less well-known

species that are still not used commercially. Indirectly, it can also diversify the final product from wood. The focus was to assess how different drying times and temperatures affect termite feeding and mortality of subterranean termites, *C. curvignathus*, in the laboratory and aboveground tests.

MATERIALS AND METHODS

Raw Materials

Two Malaysian tropical timber species, *Lagerstroemia* sp. and *Cinnamomum* sp., were sampled from the Forest Research Institute Malaysia (FRIM) timber yard. Both species grow naturally on the FRIM site and were identified by FRIM's anatomist, Dr. Nordahlia Abdullah Siam. *Lagerstroemia* sp. was about 30 yr old and had a diameter of 62.3 cm, whereas *Cinnamomum* sp. was about 28 yr old and had a diameter of 49.5 cm. Only one tree was used for each species.

Each log is split into 50 mm × 100 mm × 200 mm-sized pieces of wood using a rip saw machine and labeled between sapwood and heartwood. The wood blocks, measuring 25 mm × 25 mm × 6 mm (laboratory) and 100 mm × 40 mm × 20 mm (aboveground), were cut from the heartwood of the basal part of each tree species. The difference between sapwood and heartwood is identified by color.

The wood blocks were then oven-dried according to six different drying sequences for each species and weighed after (initial weight). All samples were conditioned for 2 wk before testing began. For these tests, five (no-choice in the laboratory) and 10 (choice in the laboratory and aboveground) replicates were used for each drying series, resulting in a total of 350 samples. The samples for the laboratory and aboveground tests came from the same trees.

Moisture Content Determination

The MC of both wood species was measured in the oven-dried state immediately after treatment but before the termite test was carried out. The MC of the control sample (without drying treatment) was also measured before the termite test was carried out. To determine the MC, a total of five replicates (25 mm × 25 mm × 6 mm) were cut from the basal parts of each wood species. Before oven drying, each replicate was first weighed (W_i) and then dried at 103 ± 2°C until it reached a constant weight (W_o). The MC was calculated based on Eq (1)

$$\text{Moisture content } (\%) = \frac{Wi - Wo}{Wo} \times 100\% \quad (1)$$

Termites

Subterranean termites, *C. curvignathus* Holmgren, were collected by breaking and carefully tapping infested rubber trees (*Hevea brasiliensis*) at the Forest Research Institute Malaysia (FRIM) and placing them in plastic trays with moist paper toweling. Termite species were identified using the key from Tho (1992). The stock of termites was brought back to the laboratory on the same day the test began.

Termite Test

Laboratory tests (no-choice and choice tests). The samples were subjected to a termite bioassay according to the FRIM in-house (IHM/WEL/4 2014) no-choice and choice (the termites are given two things to eat, control vs heat-treated of the same species) test procedure.

Each 8 cm × 13 cm screw-cap bottle was filled with 200 g of sterilized sand (test medium) and 30 mL of distilled water. The bottle is left overnight to equilibrate the moisture in the sand after being moistened with distilled water before testing begins. The test block (one block for the no-choice test and two blocks for the choice test) was placed at the bottom of the bottle. Then, 400 healthy termites in their natural ratio (360 workers and 40 soldiers) were added to each bottle. All bottles were kept in an incubator at 22 ± 2°C and 65 ± 5% RH for 28 d. If all termites are found dead (no tunneling activities) during this test period, the test bottle is removed, and the number of days until 100% death is recorded. At the end

of the 28 d, the blocks were removed, cleaned, dried overnight (103 ± 2°C), and weighed again (final weight). The remaining live termites were counted and recorded for each of the bottles. The termite mortality is calculated based on Eq (2)

$$\text{Termite mortality } (\%) = \frac{\text{initial number of termite used} - \text{number alive at the end of test}}{\text{initial umber of termite used}} \times 100 \quad (2)$$

Each test sample (either choice samples or no-choice tests) was scored according to the standard method [IHM/WEL/4 (2014)]: 0 = failure (almost complete loss of strength); 4 = very heavy infestation, 50-75% of the cross-sectional area affected; 6 = heavy infestation, 30-50% of the cross-sectional area affected; 7 = moderate/heavy infestation, penetration, 10-30% of the cross-sectional area affected; 8 = moderate infestation, 3-10% of the cross-sectional area affected; 9 = light infestation up to 3% of the cross-sectional area affected; 9.5 = traces, nibbling on the surface allowed, and 10 = sound. The WL is calculated based on Eq (3)

$$\text{Weight loss } (\%) = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100 \quad (3)$$

Aboveground test. The aboveground test was carried out on the basis of FRIM's in-house method (IHM/WEL/1 2004). The field test sites are located on cleared areas in the FRIM substation in Mata Ayer, Perlis. The soil is lateritic, with a pH between 4.97 and 5.25 (Md Noor 2003) and an average annual precipitation of 112.76 mm (Anon 2022). The area is overgrown with grass, weeds, shrubs, and pines and is infested with Asian subterranean termites, *C. curvignathus*, and *Coptotermes gestroi*. Certain parts of the area are also heavily infested with *Macrotermes* spp. and *Globitermes* spp.

The wood blocks for the aboveground test were oven-dried according to six different drying sequences for each species and weighed (initial weight). All samples were conditioned for 2 wk before the test began. Nine drums were placed in the area on February 20, 2022. A layer of highly susceptible woody substrate, *H. brasiliensis*, was placed close to the ends at the bottom of the drums. Then a square section of galvanized welded mesh (25 mm square opening) was placed on the top of the wood substrate. The test specimens covered with *H. brasiliensis* were placed on the galvanized welded mesh. The specimens were randomly arranged to avoid mutual contact. All specimens were left for 16 wk without disturbing them. The same control sample (not oven-dried) as in the no-choice and choice tests was used as a control sample. At the end of the 16 wk, the test samples were removed, cleaned, dried overnight (103 ± 2°C), and weighed again (final weight). Each test sample was assigned a classification according to the standard method [IHM/WEL/1 (2004)]: 0 = intact; 1 = traces of infestation, surface nibbling allowed; 2 = light and superficial infestation, up to 3% of the cross-sectional area affected; 3 = moderate/severe infestation, penetration, 4-40% of the cross-sectional area affected; 4 = severe/very severe infestation, 41-70% of the cross-sectional area affected; and 5 = failure (almost complete loss of strength). The WL is calculated based on Eq 3.

Statistical Analysis

Variations in WL, degree of infestation, and termite mortality with different drying methods of wood were compared and analyzed by analysis of variance (ANOVA, one-way) using Microsoft Excel 2003 to determine which groups differed significantly at the 5% significance level (α) when ANOVA indicated a significant difference between temperature and drying time and also between percentage WL and visual assessment in samples of both wood species. The assumptions of normality of the data were tested on the raw data using the Shapiro–Wilk test. The threshold for significance was set at $\alpha = 0.05$. If the assumptions were met, a one-way ANOVA was performed using PROC GLM, followed by a comparison of means using the Duncan multiple range test. If the assumptions were not met, a logarithmic transformation was used to normalize the data.

RESULTS AND DISCUSSIONS

Laboratory Test

No-choice. Table 1 shows the results of the no-choice test for two different types of wood drying at different temperatures, and drying times. The wood dried by different methods degraded the termites according to WL and visual assessment, with the degree of degradation varying according to temperature and drying time. The temperature and wood moisture played a significant and complementary role in the wood consumption of *C. curvignathus*.

It was found that the sample of *Cinnamomum* sp. dried at 80°C for 10 d was more susceptible to termites with a higher WL of 4.4% than the samples dried at 100°C for 15 d, which had the lowest WL of 0.5%. For *Lagerstroemia* sp., the most susceptible samples (WL of 4.1%) were found at 60°C for a 10-d drying period, and the least susceptible (2.0%) were found in samples dried at 100°C for 15 d. This shows that the resistance of both species of wood to termite attack increases with increasing intensity of the drying temperature and longer drying. Higher and lower WLs of *Cinnamomum* sp. occurred in test samples with high (19.1%) and low (13.2%) MC, respectively. The same trend was observed for the test samples of *Lagerstroemia* sp. Higher WL was observed in the high MC sample (17.1%), and lower WL was observed in the low MC sample (13.3%) (Table 1). ANOVA analysis also showed significant WL (except for a few cases) when the samples of the two wood species were dried at different temperatures and drying times in the no-choice test (temperature [df = 6; $F = 11.5294$, $p = 0.0037$ for *Cinnamomum* sp. and df = 6; $F = 14.458$, $p = 0.00194$ for *Lagerstroemia* sp., respectively] and drying time [df = 6; $F = 9.3637$, $p = 0.00748$ for *Cinnamomum* sp. and df = 6; $F = 6.5374$, $p = 0.00358712$ for *Lagerstroemia* sp.]).

The test results show that samples with a high MC (dried at 60°C for 10 and 15 d) show a higher WL. There is a reason for this when the wood MC is high, there is a lot of free water in the cell cavities, which contributes to the wood becoming softer. When the wood is dried, the OH group in the wood decreases due to the amount of water that has leaked out. This leads to a lack of OH groups that attract water and, therefore, a lower MC in the wood. The wood is less sensitive to changes in humidity, which further increases its stability and durability (Leggate et al 2020). Therefore, temperature plays an important role and is also complementary to WL at all moisture

Table 1. The average percentage of weight loss, termite mortality and MC, and visual rating of dried woods against *C. curvignathus* in no-choice laboratory tests.

	Treatments					
Wood species	Temperature (°C)	Days	Wood weight loss (%)	Visual rating	Termite mortality (%)	Moisture content (%)
Cinnamomum sp.	Control	Control	6.4 (0.26)a	6.0 (1.20)d	44.3 (5.36)d	46.3 (2.12)a
	60	10	4.0 (0.97)bc	6.4 (1.11)d	75.1 (8.67)c	15.0 (1.47)c
	60	15	3.5 (1.07)c	7.0 (0.00)c	76.2 (1.11)c	14.6 (1.17)c
	80	10	4.4 (0.83)b	7.0 (1.00)c	86.9 (2.56)b	19.1 (0.94)b
	80	15	3.0 (1.44)d	7.4 (0.95)c	89.3 (2.58)b	15.0 (3.09)c
	100	10	1.7 (1.28)d	8.2 (1.64)b	100 (0.00)a	12.7 (0.68)d
	100	15	0.5 (0.41)e	8.6 (1.22)a	100 (0.09)a	13.2 (0.47)d
Lagerstroemia sp.	Control	Control	5.5 (0.08)a	6.0 (1.00)d	36.5 (2.22)d	40.1 (1.87)a
	60	10	4.1 (1.31)b	6.2 (1.67)d	71.2 (2.68)c	17.1 (0.86)b
	60	15	3.2 (1.29)c	7.0 (0.00)c	76.2 (1.33)c	16.0 (2.34)c
	80	10	3.5 (0.41)c	6.4 (0.45)d	76.5 (1.22)c	16.9 (1.11)c
	80	15	3.0 (1.65)c	7.0 (0.00)c	80.0 (0.00)c	13.6 (0.66)d
	100	10	2.3 (1.69)d	7.8 (0.00)b	92.5 (1.78)b	13.5 (1.18)d
	100	15	2.0 (0.99)d	8.5 (1.34)a	100 (0.000)a	13.3 (1.00)d

Mean (±SD) of five replicates for each timber species. Percentage values followed by the same letter (vertical) are not significantly different in the same group at the 0.05 level of probability.

levels. This is confirmed by Gautam and Henderson (2011), where the highest percentage of WL by *Coptotermes formosanus* occurred in wood blocks with high MC (125-150%) compared with low MC (22-24%). In other studies, Sponsler and Appel (1990) reported that termite nesting materials and wood with an MC >16% have air spaces that are saturated with moisture and thus ensure the survival of termites, although the permeability of their cuticle is the main process of drying out water from their body.

The mortality of *C. curvignathus* in both wood species samples treated at high temperatures (100°C) for a longer period (10 and 15 d) was significantly higher than at low temperatures (60°C) and shorter duration (10 d) (Table 1). Termite mortality increased with increasing drying temperatures and longer drying durations. The lowest mortality (36.5%) was observed in the control treatment of *Lagerstroemia* sp. after 28 d, and the highest mortality rate (100%) was observed in samples of treated *Lagerstroemia* sp. dried at 100°C for 15 d and samples of *Cinnamomum* sp. dried at 100°C for 10 and 15 d. The increase in temperature showed a significant difference (df = 6; $F = 9.99521$, $p = 0.01953$ for *Cinnamomum* sp. and df = 6; $F = 5.5896$, $p = 0.05596$ for *Lagerstroemia* sp., respectively) in termite mortality, except when the temperature was increased from 60 to 80°C for the species *Cinnamomum* sp.

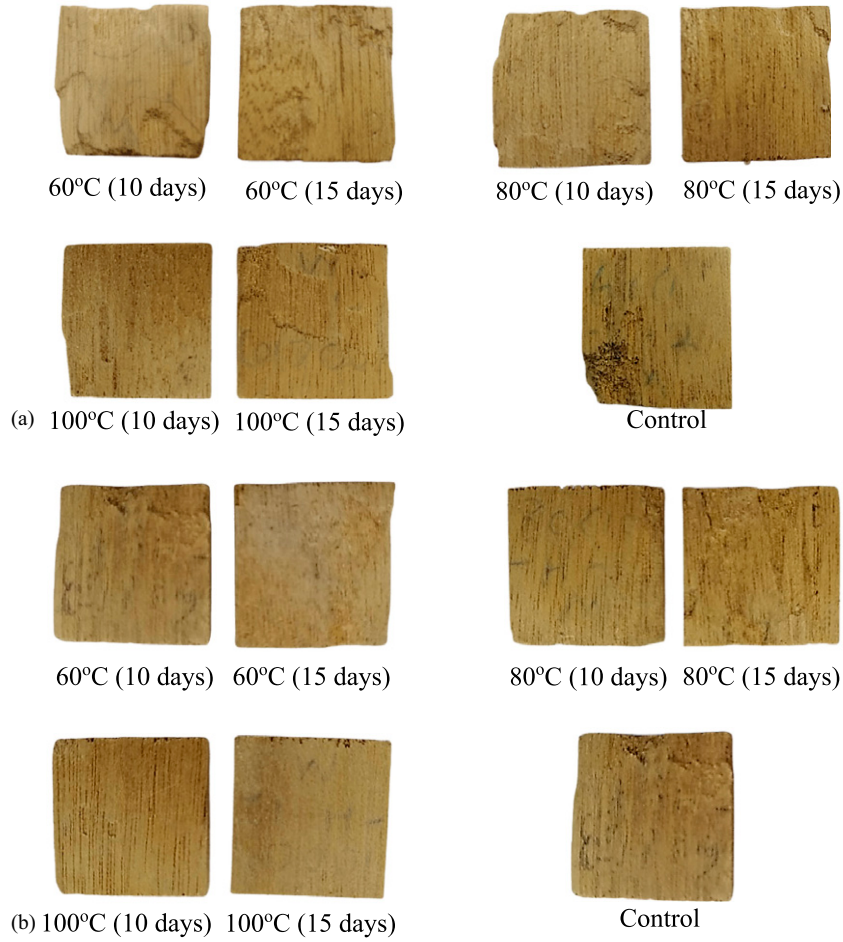

Figure 1. A representative sample of *Cinnamomum* sp. after 28 d exposure to *C. curvignathus* in (a) no-choice and (b) choice tests.

Increasing the drying time (10-15 d) also showed no significant difference (df = 6; $F = 3.144497$, $p = 0.126549$ for *Cinnamomum* sp. and df = 6; $F = 1.957738$, $p = 0.180843$ for *Lagerstroemia* sp., respectively) in termite mortality, except for the samples of *Cinnamomum* sp. dried at a temperature of 100°C.

The results of the visual assessment of the no-choice test show that both samples of *Cinnamomum* sp. and *Lagerstroemia* sp. had higher visual ratings (8.6 and 8.5, respectively) when dried at higher temperatures (100°C) and the longest drying time (15 d), which were rated as slightly to moderately impaired (3-10% of cross-sectional area impaired) (Table 1). The lowest visual score (6.4 for *Cinnamomum* sp. and 6.2 for *Lagerstroemia* sp.) was observed when treated at 60°C and dried for 10 d (Fig 1). Both wood species control samples had a visual rating of 6.0. Significant differences (df = 6; $F = 14.8256$, $p = 0.00846$ for *Cinnamomum* sp. and df = 6; $F = 5.12517$, $p = 0.064205$ for *Lagerstroemia* sp., respectively) in the visual ratings in the no-choice test were observed between the samples of the two wood species, with few exceptions. The results of the visual ratings for the choice test also showed the same trend as for the no-choice test. The highest score (9.6 for *Cinnamomum* sp. and 8.5 for *Lagerstroemia* sp.) was obtained for a 15-d treatment at 100°C and the lowest (8.5 for *Cinnamomum* sp. and 6.9 for *Lagerstroemia* sp.) for a 10-d drying at 60°C.

The ANOVA analysis showed that there was no significant difference (df = 6; $F = 0.09756$, $p = 0.76535$ for *Cinnamomum* sp. and df = 6; $F = 0.094847$, $p = 0.768515$ for *Lagerstroemia* sp., respectively) in visual assessment between the samples of *Cinnamomum* sp. treated with different drying methods, except for the treatment at 100°C and the drying duration of 15 d. Significant differences (df = 6; $F = 28.5935$, $p = 0.0043$ for *Cinnamomum* sp. and df = 6; $F = 23.5739$, $p = 0.00284$ for *Lagerstroemia* sp., respectively) in visual assessment occurred only in some samples of *Lagerstroemia* sp. In general, visual assessment scores for *Cinnamomum* sp. increased from heavy infestation to light infestation in the no-choice test and from moderate infestation to allowed traces and superficial nibbles in the choice test. In *Lagerstroemia* sp., however, the visual rating increased from heavy infestation to moderate infestation.

Choice test. In the choice test, temperature and drying time also had significant effects on the

Table 2. The average percentage of weight loss, termite mortality and MC, and visual rating of dried woods against *C. curvignathus* in choice laboratory tests.

	Treatments					
Wood species	Temperature (°C)	Days	Wood weight loss (%)	Visual rating	Termite mortality (%)	Moisture content (%)
Cinnamomum sp.	Control	Control	6.4 (1.11)a	8.0 (0.00) c	42.6 (6.35)d	44.2 (2.38)a
	60	10	4.1 (1.86)b	8.5 (0.98)b	74.7 (1.46)c	15.0 (0.74)c
	60	15	4.6 (0.52)b	8.8 (1.11)b	79.8 (2.26)c	16.5 (2.53)b
	80	10	4.0 (0.99)b	8.8 (0.64)b	88.2 (1.00)b	14.8 (1.64)c
	80	15	3.6 (0.16)c	9.0 (0.00)b	89.5 (0.98)b	13.5 (0.87)d
	100	10	1.2 (1.64)d	9.2 (2.44)b	98.5 (1.00)a	12.9 (0.66)e
	100	15	0.5 (0.41)c	9.6 (1.84)a	100 (0.00)a	12.1 (0.53)e
Lagerstroemia sp.	Control	Control	6.0 (0.74)a	6.5 (1.00)c	30.1 (3.37)e	39.9 (1.88)a
	60	10	4.9 (1.26)b	6.9 (1.46)c	70.2 (1.48)d	16.5 (1.11)b
	60	15	4.0 (1.34)c	7.0 (0.00)c	74.5 (2.24)cd	15.4 (0.68)c
	80	10	4.7 (1.72)b	6.4 (1.32)d	77.8 (1.88)bc	16.3 (2.12)b
	80	15	4.5 (0.47)bc	7.0 (0.00)c	81.2 (1.08)b	13.7 (1.00)d
	100	10	4.2 (1.90)c	8.2 (1.22)b	92.2 (1.00)a	13.8 (0.98)d
	100	15	2.6 (1.38)d	8.5 (1.00)a	98.9 (0.560)a	13.5 (0.66)d

Mean (±SD) of ten replicates for each timber species. Percentage values followed by the same letter (vertical) are not significantly different in the same group at the 0.05 level of probability.

percentage WL of the test blocks of both wood species. As in the no-choice test, the WL of the wood blocks infested with *C. curvignathus* differed significantly difference with increasing temperature (df = 6; F = 14.5185214, p = 0.0776713 for *Cinnamomum* sp. and df = 6; F = 11.23461, p = 0.084267 for *Lagerstroemia* sp.) and drying time (df = 6; F = 44.286825, p = 0.005564 for *Cinnamomum* sp. and df = 6; F = 39.758081, p = 0.007422 for *Lagerstroemia* sp.). The highest percentage WLs were 4.6% (*Cinnamomum* sp. dried at 60°C in the 15-d dry period) and 4.9% (*Lagerstroemia* sp. dried at 60°C in the 10-d dry period) (Table 2). The lowest (less susceptible) were 0.5% (*Cinnamomum* sp.) and 2.6% (*Lagerstroemia* sp.). Both samples were dried at 100°C in a 15-d drying period (Fig 2). *Coptotermes curvignathus* consumed more *Cinnamomum* sp. (6.4%) compared with *Lagerstroemia* sp. (6.0%) for control samples. The highest and lowest WL values for both wood species occurred in samples with high (16.5% for *Cinnamomum* sp. and 16.5% for *Lagerstroemia* sp.) and low MC (12.1% for *Cinnamomum* sp. and 13.5% for *Lagerstroemia* sp.).

As with the no-choice test, the *Lagerstroemia* sp. sample is more likely to be eaten by termites due to the higher percentage of WL compared with

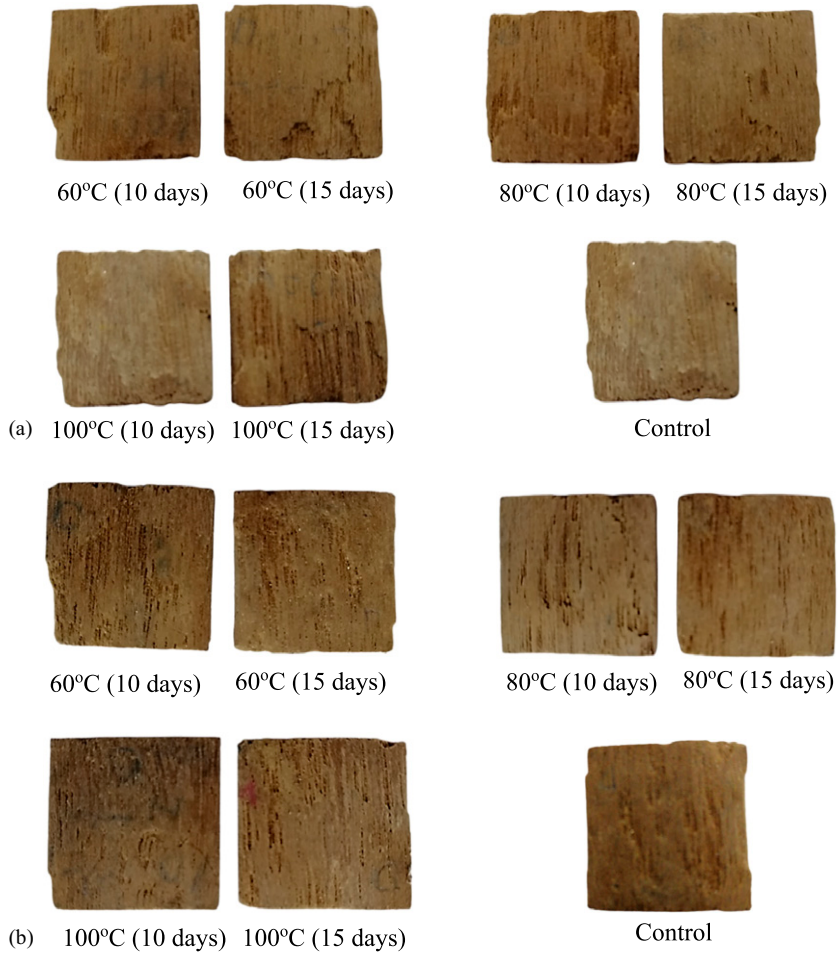

Figure 2. A representative sample of *Lagerstroemia* sp. after 28 d exposure to *C. curvignathus* in (a) no-choice and (b) choice tests.

Cinnamomum sp. Weekly monitoring revealed that the termites in the samples from the *Cinnamomum* sp. test bottle died earlier (only 2-3 wk of life) than the termites in the *Lagerstroemia* sp. test bottle (4 wk). For both wood species (*Cinnamomum* sp. and *Lagerstroemia* sp.), a significant (df = 6; F = 7.700679, p = 0.0032209 for *Cinnamomum* sp. and df = 6; F = 6.642439, p = 0.041922 for *Lagerstroemia* sp.) reduction in WL was observed at the highest temperature (100°C) and the longest drying time (15 d) compared with the lowest temperature (60°C) and the shortest drying time (10 d).

The mortality of *C. curvignath*us in wood samples treated at high temperature (100°C) for a longer period (15 d) was significantly higher (df = 6; F = 27.60096, p = 0.001913 for *Cinnamomum* sp. and df = 6; F = 23.00843, p = 0.003011 for *Lagerstroemia* sp.) than at low temperature (60°C) and shorter duration (10 d). Termite mortality increased with increasing drying temperatures and longer drying durations. The lowest mortality (30.1%) was observed in the control treatment of *Cinnamomum* sp. after 28 d in the choice test, and the highest mortality rate (100%) was observed in samples of *Cinnamomum* sp. dried at 100°C for 15 d. The increase in temperature showed a significant difference (df = 6; F = 268431, p = 0.0048 for *Cinnamomum* sp. and df = 6; F = 22.0723, p = 0.00333 for *Lagerstroemia* sp., respectively) in termite mortality. Increasing the drying time (10-15 d) also showed no significant difference (df = 6; F = 2.888526, p = 0.108567 for *Cinnamomum* sp. and df = 6; F = 0.033058, p = 0.858009 for *Lagerstroemia* sp., respectively) in termite mortality, except for the samples of *Cinnamomum* sp. dried at a temperature of 100°C. The high mortality of termites at high temperatures can be caused by a lack of moisture. Termites, especially subterranean termites, need moisture to continue living. Actually, subterranean termites cannot survive without moisture (Ferreira et al 2019). Temperature is the most important abiotic factor that affects the ability of termites to survive because it can cause movement, reduce survival, and cause rapid knockdown and death (Appel et al 1983; Quarcoo et al 2019).

In terms of visual rating, *Cinnamomum* sp. has a higher value (8.0-9.6) than *Lagerstroemia* sp. (6.4-8.5). Both control samples showed the lowest visual rating value (8.0 for *Cinnamomum* sp. and 6.5 for *Lagerstroemia* sp.) compared with the treated samples for the same species. There is no significant difference (df = 6; F = 0.615384615,

Table 3. The average percentage of weight loss and MC, and visual rating of dried woods against *C. curvignathus* in aboveground tests.

	Treatments				
Wood species	Temperature (°C)	Days	Wood weight loss (%)	Visual rating	Moisture content (%)
Cinnamomum sp	Control	Control	7.9 (1.22)a	3.6 (1.42)a	39.9 (3.41)a
	60	10	5.5 (0.68)b	3.4 (1.00)ab	20.1 (1.12)b
	60	15	5.7 (0.02)b	3.5 (0.98)a	20.5 (0.66)b
	80	10	5.1 (1.11)b	3.1 (0.07)b	16.3 (0.88)c
	80	15	4.8 (2.54)bc	2.8 (0.56)b	15.9 (2.12)c
	100	10	4.3 (1.11)c	2.3 (0.44)c	13.9 (1.00)d
	100	15	3.6 (0.98)d	2.0 (1.22)c	14.0 (1.43)d
Lagerstroemia sp.	Control	Control	12.1 (1.22)a	4.3 (2.22)a	42.1 (1.22)a
	60	10	10.0 (1.0)b	4.0 (1.11)a	21.7 (1.86)b
	60	15	9.9 (0.87)bc	3.8 (0.98)ab	19.6 (2.10)b
	80	10	8.8 (0.06)c	3.8 (0.012)ab	17.0 (1.46)c
	80	15	8.6 (1.11)c	3.6 (0.09)b	16.3 (2.22)c
	100	10	7.2 (2.74)d	2.8 (1.32)c	13.5 (0.48)d
	100	15	6.5 (2.22)c	2.5 (1.00)c	14.4 (0.56)d

Mean (±SD) of 10 replicates for each timber species. Percentage values followed by the same letter (vertical) are not significantly different in the same group at the 0.05 level of probability.

$p = 0.45537$ for *Cinnamomum* sp. and df = 6; $F = 0.285714286$, $p = 0.60751$ for *Lagerstroemia* sp., respectively) shown by ANOVA for the extension of drying time at the same temperature, but it is different when the temperature is increased, except for treatment with a temperature of 100°C for both drying times (10 and 15 d). A different situation occurred in samples of *Lagerstroemia* sp. Significant differences (df = 6; $F = 7.1227283$, $p = 0.0370837$ for *Cinnamomum* sp. and df = 6; $F = 5.6443$, $p = 0.05508$ for *Lagerstroemia* sp., respectively) occurred in samples treated at the same temperature but at different drying times. This situation is the exception for samples treated at 60°C for both drying times. However, all the treatments given to both species of wood improve the visual quality of the treated wood.

Aboveground test. The results of the aboveground test show that the percentage WL of *Cinnamomum* sp. is lower than that of *Lagerstroemia* sp. (Table 3). However, after 16 wk of exposure, both species showed the same trend in percentage WL (wood consumption) and also in visual assessment. The percentage WL decreased (from 5.5 to 3.6% for *Cinnamomum* sp. and from 10.0 to 6.5% for *Lagerstroemi*a sp.) when the temperature (from 60 to 100°C) and drying time (from 10 to 15 d)

Figure 3. A representative sample of *Cinnamomum* sp. after 16 wk exposure to *C. curvignathus* in the aboveground test.

were increased, although there were no significant differences in a few cases. The percentage WL for both wood species parallels the MC of the wood samples. The WL decreases as the MC decreases. There were signs of infestation in all test boxes, confirming that termites were present and widespread in each test box. A significant (df = 6; F = 10.28571429, p = 0.01248 for *Cinnamomum* sp. and df = 6; F = 010, p = 0.01335 for *Lagerstroemia* sp., respectively) reduction in WL was observed in both wood species (*Cinnamomum* sp. and *Lagerstroemia* sp.) at the highest temperature (100°C) and at the longest drying time (15 d) compared with the control treatment. Temperature is another important factor for the feeding and survival of subterranean termites (Nakayama et al 2005; Gautam and Henderson 2011; Aihetasham and Iqbal 2012).

The visual ratings of the two wood species samples ranged from 2.0 (light and superficial infestation, up to 3% of the cross-sectional area infested) to 4.3 (heavy or very heavy infestation, 41-70% of the cross-sectional area infested) for the percentage area of termite infestation on the wood surface. The control sample was the most severely

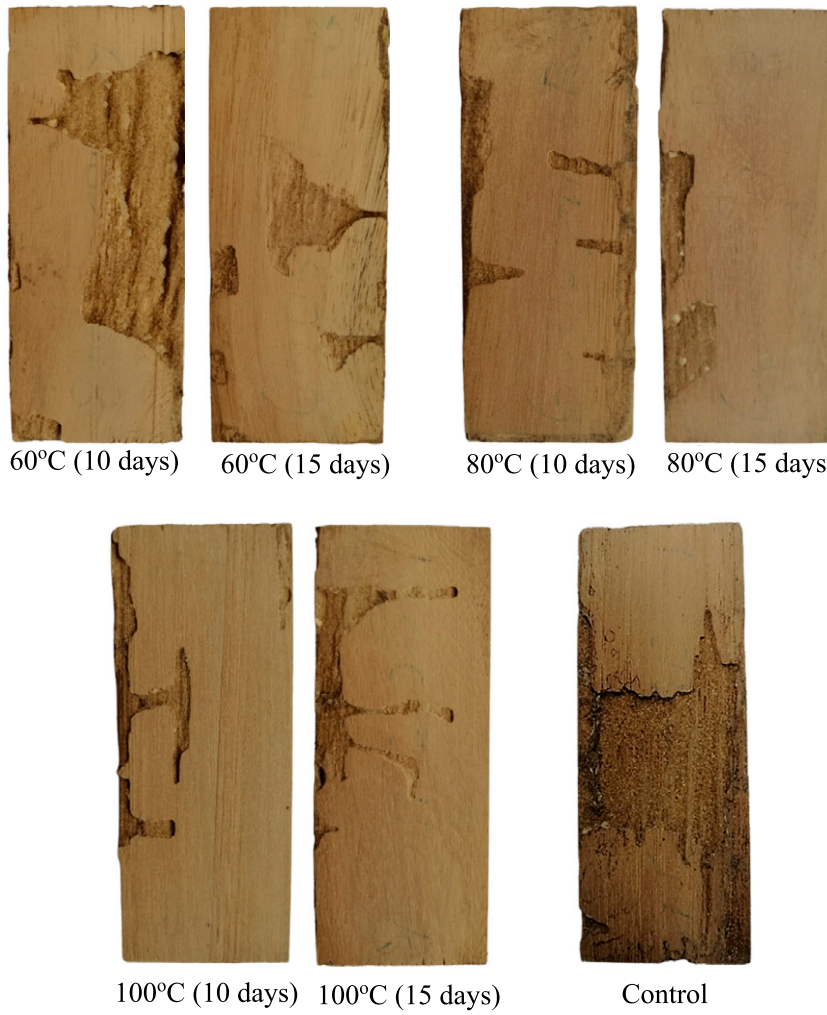

Figure 4. A representative sample of *Lagerstroemia* sp. after 16 wk exposure to *C. curvignathus* in the aboveground test.

damaged, with an average rating of 3.6 (*Cinnamomum* sp.) and 4.3 (*Lagerstroemia* sp.). In general, a higher temperature and a longer drying time reduced termite infestation on the wood samples for both species studied. The visual observations support the WL results (Figs 3 and 4).

The difference in WL caused by termite attacks on wood species can be caused by the fact that certain wood species have characteristics that make them palatable to termites and depend on the chemical, physical, and biological properties of the wood (Supriana 1988). *Cinnamon* groups consist of a variety of resinous compounds, including cinnamaldehyde, cinnamic acid, and numerous essential oils. Essential oils are among the substances that protect the wood from pest attacks (Senanayake et al 1978; Franzios et al 1997; Kadir et al 2013; Rao and Gan 2014), but not all extracts are toxic against destructive factors (Sjöstrom 1993; Wistara et al 2002).

CONCLUSIONS

The drying method of two different Malaysian woods was tested to determine whether the drying process affected the durability of the wood against subterranean termites. The drying temperature and drying time affect the WL and visual evaluation of the two tested wood species. In general, the higher the drying temperature and the longer the drying time, the lower the WL and the higher the visual evaluation value. There were no significant differences in terms of WL percentage or visual rating on samples from both wood species.

ACKNOWLEDGMENTS

The author would like to thank the staff of the Wood Entomology Laboratory (Mrs. Norziah Ishak and Mr. Nooranizam Ahmad) for their invaluable technical assistance on this research project. This research did not receive specific grants from public, commercial, or nonprofit funding agencies.

REFERENCES

Aihetasham A, Iqbal S (2012) Feeding preferences of *Microcerotermes championi* (Synder) for different wooden blocks dried at different temperatures under forced and choice feeding conditions in laboratory and field. Pakistan J Zool 44(4):1137-1144. https://zsp.com.pk/pdf44/1137-1144%20_34_%20PJZ-605-11A%20final%20checking%201-8-12.pdf

Anon (2021) A guide to termite infestations in Malaysia. https://www.freemalaysiatoday.com/category/leisure/property/2021/10/02/a-guide-to-termite-infestations-in-malaysia/. Accessed on 13 May 2022.

Anon (2022) Climate change knowledge portal: Malaysia. https://climateknowledgeportal.worldbank.org/country/malaysia/climate-data-historical Accessed on 10 August 2022.

Appel AG, Reierson DA, Rust MK (1983) Comparative water relations and temperature sensitivity of cockroaches. Comp Biochem Physiol 74(2):357-361.

Chan EWC, Tan LN, Wong SK (2014) Phytochemistry and pharmacology of *Lagerstroemia speciosa*: A natural remedy for diabetes. Int J Herb Med 2(2):100-105.

Chang ST, Cheng SS (2002) Antitermitic activity of leaf essential oils and components from *Cinnamomum osmophleum*. J Agric Food Chem 50(6):1389-1392.

Cheng S, Liu J, Huang C, Hsui Y, Chen W, Chang S (2009) Insecticidal activities of leaf essential oils from *Cinnamomum osmophloeum* against three mosquito species. Bioresour Technol 100(1):457-464.

Doi S, Aoyama M, Yamauchi S, Kurimoto Y (2005) Changes of decay and termite durabilities of Japanese larch (*Larix leptolepis*) wood due to high-temperature kiln drying processes. J Wood Sci 51(5):526-530.

EN 118 (2013) Wood preservatives. Determination of preventive action against *Reticulitermes* species (European termites) (laboratory method). USDA Forest Service. Washington DC. 24 pp.

Fatima R, Ahmed S, Arshad M, Sahi ST (2015) Effect of seasoning of different woods on resistance against *Odontotermes obesus* (Ramb.) under laboratory and field choice and no-choice tests. Bioresource 10(4):6363-6377.

Febrianto F, Pranata AZ, Septiana D, Arinana A, Gumilang A, Hidayat W, Jang J-H, Lee S-H, Hwang W-J, Kim N-H (2015) Termite resistance of the less known tropical woods species grown in West Java. Indonesia. J Korean Wood Sci Technol 43(2):248-257.

Franzios G, Mirotsou M, Hatziapostolou E, Kral J, Scouras ZG, Mavragani-Tsipidou P (1997) Insecticidal and genotoxic activities of mint essential oils. J Agric Food Chem 45(7):2690-2694.

Gautam BK, Henderson G (2011) Relative humidity preference and survival of starved Formosan subterranean termites (Isoptera: Rhinotermitidae) at various temperature and relative humidity conditions. Environ Entomol 40(5):1232-1238.

IHM/WEL/1 (2004) Working procedure (PK) A1: FRIM test protocol for wood entomology: Test method for determining the relative protective effectiveness of a wood preservative above ground contact. Forest Research Institute Malaysia, Kepong, Selangor.

IHM/WEL/4 (2014) Working procedure (PK) A4: FRIM test protocol for wood entomology: Standard test method for laboratory evaluation of wood and other cellulosic materials for resistance to subterranean termites based on ASTM D3345–17 and AWPA E1–17. Forest Research Institute Malaysia, Kepong, Selangor.

Jayaprakasha GK, Rao LJM (2011) Chemistry. biogenesis and biological activities of *Cinnamomum zeylanicum*. Crit Rev Food Sci Nutr 51(6):547-562.

Kadir R, Mohd Ali NA, Jamil M, Soit Z, Zolfatah MF (2013) Toxicity and anti-termite activity of the essential oils from *Cinnamomum caphora, Cymbopogon nardus*, *Melaleuca cajuptui* and *Dipterocarpus* sp. against *Coptotermes curvignathus*. Wood Sci Technol 47:1273-1284. http://doi.org/10.1007/s00226-013-0576-1.

Kadir R, Salmiah U, Rahim S, Shahlinney L, Nor Azried AR, Baharudin K, Mohd Adawi TO, Ps K, Hamidah A (2017) Qualitative and quantitative determination of resistance of twenty-two Malaysian commercial timbers through subterranean termite feeding behavior. FREIJ 1(2):52-60.

Kano H, Shibutani S, Hayashi K, Lijima Y, Doi S (2004) Effect of high-temperature drying processes on termite resistance of Sugi (*Cryptomeria japonica*) heartwood. Mokuzai Gakkaishi 50(2):91-98 (In Japanese).

Korkut DS, Korkut S, Bekar I, Budakçi M, Dilik T, Çakicier N (2008) The effects of heat treatment on the physical properties and surface roughness of Turkish hazel (*Corylus colurna* L.) wood. Int J Mol Sci 9(9): 1772-1783.

Leggate W, Kumar C, McGavin RL, Faircloth A, Knackstedt M (2020) The effects of drying method on the wood permeability, wettability, treatability, and gluability of southern pine from Australia. BioRes 16(1): 698-720.

McManamy K, Koehler PG, Branscome DD, Pereira RM (2008) Wood moisture content affects the survival of eastern subterranean termites (Isoptera: Rhinotermitidae) under saturated relative humidity conditions. Sociobiology 52(1):145-156.

Mdoe FP, Cheng SS, Msangi S, Nkwengulila G, Chang ST, Kweka EJ (2014) Activity of *Cinnamomum osmophloeum* leaf essential oil against *Anopheles gambiae* s. s. Parasit Vectors 7(209):1-6.

Md Noor H (2003) Growth of teak (*Tectona grandis*) on lateritic soil at Mata Ayer Forest Reserve, Perlis. J Trop for Sci 15(1):190-198.

Nakayama T, Yoshimura T, Imamura Y (2005) Feeding activities of *Coptotermes formosanus* Shiraki and *speratus* (Kolbe) as affected by moisture content of wood. J Wood Sci 51(1):60-65.

Oberst S, Lenz M, Lai JCS, Evans TA (2019) Termites manipulate moisture content of wood to maximize foraging resources. Biol Lett 15(7):20190365.

Quarcoo FY, Hu XP, Appel AG (2019) Temperature-mediated variations in behavior and mortality caused by non-repellent insecticides in subterranean termites (Blattodea: Rhinotermitidae). Insects 10(2):37-51.

Rao PV, Gan SH (2014) Cinnamon: A multifaceted medicinal plant. Evid Based Complement Alternat Med 2014:642942.

Sajap AS, Kulis J, Loong CY (2008) Effect of moisture and relative humidity on survival and feeding activity of the Asian subterranean termite, *Coptotermes gestroi* (Isoptera: Rhinotermitidae). Sociobiology 52(3):579-587.

Sehlstedt-Persson M, Wamming T (2010) Wood drying process: Impact on Scots pine lumber durability. J Wood Sci 56(1):25-32.

Senanayake UM, Lee TH, Wills RBH (1978) Volatile constituents of cinnamon (*Cinnamomum zeylanicum*) oils. J Agric Food Chem 26(4):822-824.

Shi JL, Kocaefe D, Amburgey T, Zhang J (2007) A comparative study on brown-rot fungus decay and subterranean termite resistance of thermally-modified and ACQ-C-treated wood. Holz Roh Werkst 65(5):353-358.

Sjöstrom E (1993) Wood chemistry: Fundamentals and applications, 2nd edition. Academic Press, Inc., San Diego, CA.

SNI 01-7207 (2006) Uji ketahanan kayu dan produk kayu terhadap organisme perusak kayu. Badan Standarisasi Nasional, Jakarta, Indonesia (In Indonesian).

Sponsler RC, Appel AG (1990) Aspects of the water relations of the Formosan and eastern subterranean termites (Isoptera: Rhinotermitidae). Environ Entomol 19(1):15-20.

Subekti N, Yoshimura T, Rokhman F, Mastur Z (2015) Potential for subterranean termite attack against five bamboo species in correlation with chemical components. Procedia Environ Sci 28:783-788.

Supriana N (1988) Studies of natural durability of tropical timbers to termite attack. Int Biodeter 24(4-5):337-341. http://doi.org/10.1016/0265-3036(88)90019-X.

Tho YP (1992) Termites of Peninsular Malaysia. Edited by Kirton LG. Malayan Forest Record No. 36. Forest Research Institute Malaysia, Kuala Lumpur. 224 pp.

Wistara INJ, Rachmansyah R, Denes F, Young RA (2002) Ketahanan 10 jenis kayu tropis. J Teknol Hasil Hutan 15(2):48-56 (In Indonesian).

Wong TM (1982) A dictionary of Malaysian timbers. Revised by Lim SC, Chung RCK. Malayan Forest Record No. 30. Forest Research Institute Malaysia, Kuala Lumpur. 201 pp.

Wu M, Ni L, Lu H, Xu H, Zou S, Zou X (2020) Terpenoids and their biological activities from *Cinnamomum*: A review. J Chem 2020(5097542):1-14.

Yanakiev S (2020) Effects of Cinnamon (*Cinnamomum* spp.) in dentistry: A review. Molecules 25(18). http://doi.org/10.3390/molecules25184184.