

# TOXIC EFFECTS OF THREE SELECTED MALAYSIAN TIMBERS PLANT EXTRACTS AGAINST SUBTERRANEAN TERMITES

Roszaini Kadir<sup>1,\*</sup>

## ABSTRACT

The toxic effects of selected Malaysian timbers (*Madhuca utilis*, *Anisoptera laevis* and *Endospermum malaccense*) heartwood extracts were studied with the aim to determine and understanding the function of wood extracts as a natural protection against termite. The results show that no-choice experiments revealed toxic properties of all investigated extracts by the contact against *Coptotermes gestroi* and *Coptotermes curvignathus*. However, high termite mortality was only achieved with *Madhuca utilis* extracts and methanol solvents.

**Keywords:** *Madhuca utilis*, *Anisoptera laevis*, *Endospermum malaccense*, wood extractives, antitermitic activity, *Coptotermes gestroi*, *Coptotermes curvignathus*.

## INTRODUCTION

Extractives are low molecular weight compounds that can be extracted by polar or non-polar solvents and encompass complex, and had diverse physical properties (Fengel and Wegener 1989). Because of this, many different solvents and mixtures have been used for extraction. Solvents such as hexane and acetone/water mixtures have been used with some tropical timbers (Kilic and Niemz 2010); methanol and hexane with *Azadirachta excelsa* (Ahmad Said *et al.* 2006) and ethanol-benzene with *Shorea ovalis* and *Neobalanocarpus heimii* (Ahmad-Said and Mohd-Hamami 1982). In addition, structure, distribution and quantity of secondary metabolites are useful markers for chemotaxonomy (Banthorpe *et al.* 1972).

It is known that wood extracts are a major contributory factor in the natural durability of the wood (Scheffer and Cowling 1966, Hillis 1987). Many studies (Carter *et al.* 1975, Steller and Labosky 1982, Chang *et al.* 2001, Chang and Cheng 2002, Watanabe *et al.* 2005, Elango *et al.* 2012, Roszaini *et al.* 2014, Roszaini *et al.* 2015) show some promising result on wood extractive against termites. They found that bark and Heartwood extractives exhibited antitermitic activity in a certain percentage of concentrations. Meanwhile, Arango *et al.* (1992) reported that several advantages can be obtained from the application of wood extractives as wood preservatives. It is relatively safer than synthetic preservative, but still effective. It is Barnes (1992) also easier to detoxify and dispose off without adverse environmental effects because it's the organic based materials.

<sup>1</sup>Biocomposite and Wood Protection Programme, Forest Product Division, Forest Research Institute Malaysia (FRIM), Selangor, Malaysia.

\*Corresponding author: rosaini@frim.gov.my

Received: 20.12.2016 Accepted: 11.06.2017

In some instances, it is only present in small amounts (3 to 6% of oven-dry weight) (Rudman 1965, Mori *et al.* 1997, Reyes-Chilpa *et al.* 1998, Celimene *et al.* 1999, Windeisen *et al.* 2002, Haupt *et al.* 2003, Neya *et al.* 2004, Mburu *et al.* 2007). In other cases, Roszaini (2011) found in her study that this value can achieve up to 15% (of oven-dry weight) for heartwood and to 35% (of oven-dry weight) for bark of tropical timbers.

Phenolic compounds, terpenes, carbohydrates, long-chain fatty acids, waxes and other substances, including steryl esters and sterols are among the mainly chemical compounds in heartwood extractives (Fengel and Wegener 1989). Many single or groups of extraneous compounds are known to inhibit the activities of biological agents. For example, sesquiterpenes possess a wide spectrum of biological activity, playing a role in plant defense mechanisms against insects and fungi (Fraga 2003, Wu *et al.* 2005) and, pinosylvin and pinosylvin-monomethyl-ether have been found toxic to fungi (the *Sirex* fungus, presumably *Amylostereum* sp.) (Hillis and Inoue 1968).

Meanwhile, *Madhuca utilis* (Ridley) H.J. Lam ex K. Heyne known as bitis (local name) is one of the large trees which can achieve up to 50 m in height, 1 m in diameter and 2 m high of buttresses (Orwa *et al.* 2009). It belongs to the family of Sapotaceae and classified as heavy hardwood with a density of 820 - 1,120 kg/m<sup>3</sup> air dry (Lim *et al.* 1998).

*Anisoptera laevis* (Ridl) which is also known as merawan under Malaysian common name is an evergreen tree with a relatively small crown. The tree belongs to the family of Dipterocarpaceae and locally distributed in lowland primary forest of Peninsular Malaysia (Ken 2014). The timber is a medium hardwood with a density of 495–980 kg/m<sup>3</sup> air dry. Its wood is hard and heavy, and particularly used for bridge, rafters, joists, door and window frames, flooring, joinery, furniture manufacture, veneer and plywood manufacture (Wood identification 2010).

*Endospermum malaccense* Miq. (sesendok) is a timber belonging to the family of Euphorbiaceae. It can be found in lowland to low-Montane forest (up to 1000m altitude) and in all states of Peninsular Malaysia (except Perlis) (Mohd Shukari 1982). It's also one of the timber species that has been proposed for plantation in Peninsular Malaysia as an alternative timber species to rubberwood with an excellent working and nailing properties (Ahmad Zuhaidi *et al.* 2002, Khairul *et al.* 2010).

However, to the best of our knowledge, a study of the wood extracts of *M. utilis*, *A. laevis* and *E. malaccense* extracted with different solvent from Malaysia, or any other country, has not been reported to date. One study done by Roszaini *et al.* (2014) shows some promising as antitermitic of *M. utilis* when extract with toluene/EtOH but, they do not include other solvents in their study. In another study, methanol extraction of *E. malaccense* showed highest antifungal activity against a white-rot fungus, *Pycnoporus sanguineus*, at a minimum effective amount of 100 µg (Kawamura *et al.* 2011). No single study was done for *E. malaccense* and *A. laevis* wood extracts against termite. On the other hand, studies (Naczka and Shahidi 2004, Spigno *et al.* 2007, Kajdžanoska *et al.* 2011, Lolita *et al.* 2012) have shown that different solvent extracts different compounds. Based on their studies, it is very important to find the best solvents for extraction of these compounds from plants especially for tropical timbers.

The objective of this paper is to investigate the effects of different solvent extractions on some wood species with respect on the feeding behavior of the two Asian subterranean termites *Coptotermes gestroi* and *C. curvignathus*. Although *M. utilis*, *A. laevis* and *E. malaccense* have been reported in durable, moderate and non-durable class timbers respectively, its antitermitic activity has not been tested. So this would be the first study of the antitermitic activity of crude extract of different Malaysian wood species against the two aggressive Asian subterranean termites.

## MATERIALS AND METHODS

### Plant material

Heartwood of three Malaysian timbers: *Madhuca utilis* (Ridl.) H.J.Lam (bitis), *Anisoptera laevis* (Ridl) (merawan) and *Endospermum malaccense* Miq. (sesendok) were cut from felled trees stored in

the FRIM log yard.

### Termite

Two subterranean termites, *Coptotermes gestroi* Wasmann and *C. curvignathus* Holmgren (Isoptera: Rhinotermitidae), were collected from active field colonies at the Forest Research Institute Malaysia (FRIM) campus using a method described before (Roszaini *et al.* 2009).

### Wood block bioassay against subterranean termites

The un-extracted or had previously been extracted (extracted for 8 hours in an orbital shaker) wood blocks (25 mm x 25 mm x 6 mm) were subjected to no choice feeding tests according to ASTM D3345-08 (ASTM 1988) standard methods with slightly modified. Rubberwood (*Hevea brasiliensis*) were used as controls.

**Table 1.** Classification of natural durability of wood against termites (ASTM D3345, 1988).

Block aspect after test	Classifications
Sound, surface nibbles permitted	10
Light attack	9
Moderate attack, penetration	7
Heavy	4
Failure	0

Screw-top bottles of 8 cm in diameter by 13 cm high were filled with 200 g of sterilized sand and 30 ml distilled water. The bottles were left overnight to equilibrate to laboratory conditions before test initiation. One block of each timber species were placed on the surface of the damp sand and 400 termites (360 workers and 40 soldiers) were added to each bottle. All bottles were stored in an incubator maintained at  $22\pm 2^\circ\text{C}$  and  $65\pm 5\%$  relative humidity for 28 days. Within this period, if it was found that all termites appeared dead, the bottle would be taken out and the number of days until 100% mortality would be recorded. At the end of the fourth week the blocks were removed, cleaned, dried overnight and reweighed. The remaining live termites were weighed and recorded for each of the bottles. Then the wood blocks were classified according to the standard method used (Table 1).

### Extraction and isolation

All the heartwood timber species were ground to fine sawdust powder, passed through a 250 mesh sieve and dried at  $60^\circ\text{C}$  (to avoid the possibility of extracts degradation) before extraction. About 50 g of wood sawdust was extracted with four different solvents [absolute methanol (MeOH), absolute ethanol (EtOH), acetone and petroleum ether (PETETHER)] for 8 hours used an orbital shaker (Gallenkamp, UK). The extracts were concentrated under reduced pressure at  $45^\circ\text{C}$ , using a rotary evaporator (EYELA, SB-651, Rikakikai Co. Ltd. Tokyo, Japan) and stored in a refrigerator ( $-4^\circ\text{C}$ ), until used for analyses. Weight losses of samples were calculated from the oven dry weights at  $60^\circ\text{C}$  (48 hours) before and after the extraction. Retention of extractive material was calculated ( $\text{mg}/\text{m}^3$ ) as follows:

$$R = \frac{(M_1 - M_0) \times C}{V} \quad (1)$$

where,  $M_1$  is weight after treatment (g),  $M_0$  is a weight before treatment (g),  $C$  is concentration levels of solutions and  $V$  is volume of filter paper ( $m^3$ ). The extractive retentions ( $mg/m^3$ ) in treating filter paper as calculated by solution uptake are presented in Table 2.

**Table 2.** Mean extractive retentions ( $mg/m^3$ ) in treated filter paper as calculated by solution uptake.

Solvent	Concentrations	Species/ Retention ( $mg/m^3$ )		
		<i>M. utilis</i>	<i>A. laevis</i>	<i>E. malaccense</i>
Methanol	0,5	0,38 (0,25)	1,78 (0,26)	0,95 (0,25)
	1,0	1,21 (0,10)	2,80 (0,72)	2,19 (0,38)
	2,0	4,38 (1,06)	6,15 (2,49)	3,84 (0,38)
	3,0	8,23 (2,06)	6,26 (3,36)	7,41 (0,99)
	4,0	10,10 (2,12)	9,44 (1,37)	9,44 (1,01)
Ethanol	0,5	1,07 (0,14)	0,93 (0,17)	0,93 (0,26)
	1,0	2,52 (1,25)	1,92 (0,41)	1,87 (0,10)
	2,0	5,93 (0,87)	4,17 (1,48)	3,40 (0,50)
	3,0	7,41 (0,86)	5,27 (0,75)	7,08 (2,06)
	4,0	9,00 (2,66)	7,24 (0,66)	8,56 (0,66)
PETETHR	0,5	0,82 (0,36)	0,38 (0,10)	0,60 (0,41)
	1,0	2,03 (1,19)	0,99 (0,33)	0,99 (0,16)
	2,0	2,85 (0,95)	1,65 (0,00)	1,43 (0,83)
	3,0	4,61 (2,06)	2,30 (0,75)	1,81 (0,57)
	4,0	5,71 (3,04)	3,07 (0,38)	2,85 (0,38)
Acetone	0,5	1,10 (0,05)	1,06 (0,05)	0,96 (0,55)
	1,0	1,98 (0,33)	1,87 (0,41)	1,70 (0,25)
	2,0	3,51 (0,50)	2,41 (2,47)	2,83 (1,87)
	3,0	5,27 (0,29)	3,82 (0,29)	3,27 (1,87)
	4,0	7,24 (0,66)	6,36 (1,52)	5,93 (1,32)

Note: Mean of five replicates, numbers in parentheses are standard deviations.

### Antitermitic bioassay (Toxicity determination)

The bioassay method used by previous studies (Roszaini *et al.* 2013) with slightly modified was used to evaluate the antitermitic activity of wood extracts against *C. gestroi* and *C. curvignathus*.

Samples of 5,0 mg, 10 mg, 20 mg, 30 mg and 40 mg of wood extract from four different wood species were dissolved in 100  $\mu$ l of MeOH to obtain solutions (m/v) of 0,5%; 1,0%; 2,0%; 3% and 4%, respectively. Then 20  $\mu$ l of the solutions were applied to each 30 mg filter paper samples (Advantec, 8 mm diameter and 1,5 mm thickness) and dried in vacuum desiccators for 24 hours. The paper discs were weighed before and after drying. Untreated paper discs were used as a control. 20 active termite workers were introduced into each Petri dish (90 mm diameter and 16 mm height) which contained 3 g of sterile sand. A few drops of water were added periodically to the basal edge of each Petri dish. All the Petri dishes with covers were placed into an incubator (maintained in darkness) at  $22\pm 2^\circ\text{C}$  and  $65\pm 5\%$  RH and the mortality of the termites was counted and recorded every 24 hours for 10 days. Each test contained 5 replicates including the control. The consumption of the filter papers was calculated from the difference in dry weights before and after the exposure. A dose-mortality line was developed depends on the exposure time(s) and the lethal concentration ( $LC_{50}$ ) of wood extracts was determined using the probit method (Finney 1971).

### Statistical analysis

One way analysis of variance (ANOVA) was performed on all data to determine the significance of variation in extracting compounds and antitermitic between wood species as well as between samples using MINITAB 15 computer programme. The  $LC_{50}$  values were determined directly from probit

analysis or calculated by substituting 50% for “y” into the curve equation in the graph.

## RESULTS AND DISCUSSION

### Extractives yield

The quantities of extractive yield of three tropical timber species are presented in Table 3. Table 3 shows that MeOH yielded greater amounts of extractive than the other three solvents (EtOH, PETETHR and acetone) in all timber species. *M. utilis* were classified as durable timbers under Malaysian grading rules (Lim *et al.* 1998), yielded significantly more extractive (7,00%) than the moderately durable (*A. laevis*) (3,44%) and non-durable (*E. malaccense*) (0,72%) timbers, in MeOH use the shaker method. The same pattern also occurred when EtOH (5,21%; 2,98% and 0,28% respectively) and acetone (3,25%; 1,67% and 0,44% respectively) were used. However, *A. laevis* yielded more (1,29%) compared to *M. utilis* (0,13%) and *E. malaccense* (0,30) when PETETHR was used. As indicated by several authors (Chang *et al.* 2001, Syofuna *et al.* 2012, Ogunwusi *et al.* 2013), extracts which are low molecular weight compounds in the wood can be extracted by many solvents. However, they differ among timber species, between individual tree of the same species and solvents (Scheffer and Cowling 1966, Nascimento *et al.* 2013) due to genetic variation and environmental (Ericsson *et al.* 2001). Furthermore, solvent polarity plays a key role in determining the extract yields to be obtained (Bashash *et al.* 2012). On the other hand, shaker method is not a good method with respect to extraction efficiency for plant materials. As indicated by a few studies before (Park *et al.* 2001, Kothari *et al.* 2012), a heat-employing methods' (soxhlet) proved to be the best option for extraction any plant materials.

In another study, even though MeOH is indeed the most common and effective solvent, it has been reported is an environmental pollutant and more toxic than other alcohols (Kapasakalidi *et al.* 2006, Bridgers *et al.* 2010). Thus EtOH is preferred as solvent extraction (Delgado-Vargas and Paredes-Lopez 2002).

**Table 3.** Effect of different solvent extraction on extractive yields of three wood species.

Wood species	Extractive yields (%)			
	Methanol	Ethanol	Petroleum ether	Acetone
<i>M. utilis</i>	7,00 <sup>a</sup>	5,21 <sup>b</sup>	0,13 <sup>d</sup>	3,25 <sup>c</sup>
<i>A. laevis</i>	3,44 <sup>a</sup>	2,98 <sup>b</sup>	1,29 <sup>d</sup>	1,67 <sup>cd</sup>
<i>E. malaccense</i>	0,72 <sup>a</sup>	0,28 <sup>c</sup>	0,30 <sup>bc</sup>	0,44 <sup>b</sup>

Note: Means with the same letters are not significantly different at 95% confidence limit.

### Bioassay test against termites

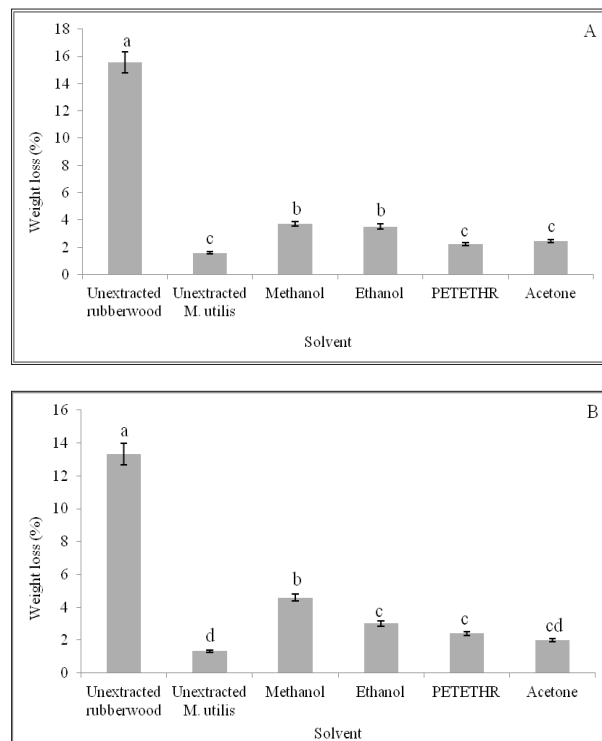
#### Termite mortality

Among the three timber species tested, *M. utilis* heartwood samples were very resistant to attack by both subterranean termite; *C. gestroi* and *C. curvignathus*. Daily assessment shows that majority of the termite in *M. utilis* test bottles died within 15 days compared to 18 days in *A. laevis* and more longer (26 days) in *E. malaccense* test bottles. Result from this study shows that all castes of termite used (workers and soldiers) either in *C. gestroi* or *C. curvignathus* completely died in all *M. utilis* extracts. *A. laevis* extracts using PETETHR showed 1,0% and 0,05% while *E. malaccense* extracts using MeOH showed 0,08% and 0,02% of workers surviving for *C. gestroi* and *C. curvignathus*, respectively. Surprisingly, *E. malaccense* EtOH extracts showed 1,22% of *C. gestroi* workers surviving at the end of the test. All termites also 100% died when tested with unextracted samples of *M. utilis* and *A. laevis* but showed minimal survival (0,01% against *C. gestroi* and 0,005% against *C. curvignathus*, respectively) in unextracted *E. malaccense* samples. Higher survival occurred in *brasiliensis* test bottles (2,1%

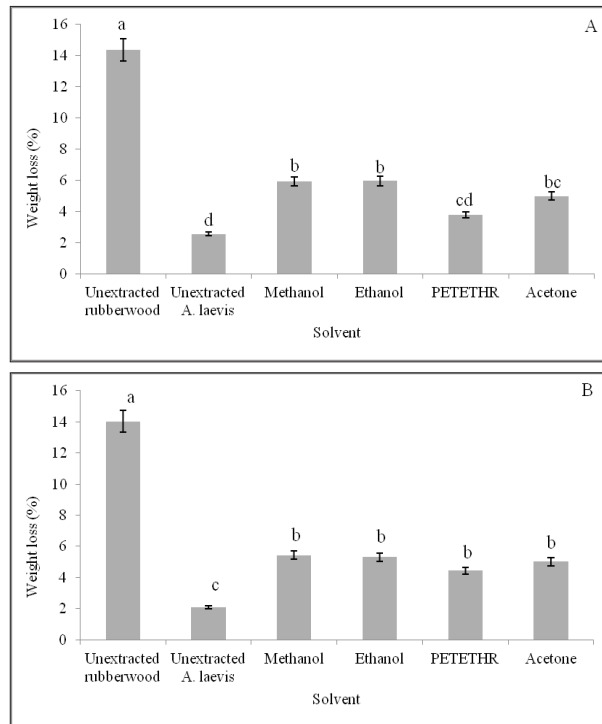
against *C. gestroi* and 2,8% against *C. curvignathus*). Even though the mortality percentages due to the used wood of extracts were not significantly different from control (*brasiliensis*), suggesting the toxic effect of these three timber species wood extracts against termites.

The results of termite mortality could be the reaction of termites to the toxic, anti-feeding and / or repellent effects (Yuan and Hu 2011). In all cases, higher termite mortality exists when exposed to un-extracted samples compared to extracted indicates the function of heartwood extractives as a natural wood preservative against termites (Syofuna *et al.* 2012, Tascioglu *et al.* 2012, Kirker *et al.* 2013). In other words, wood extracts are one of the factors that increase the termite mortality.

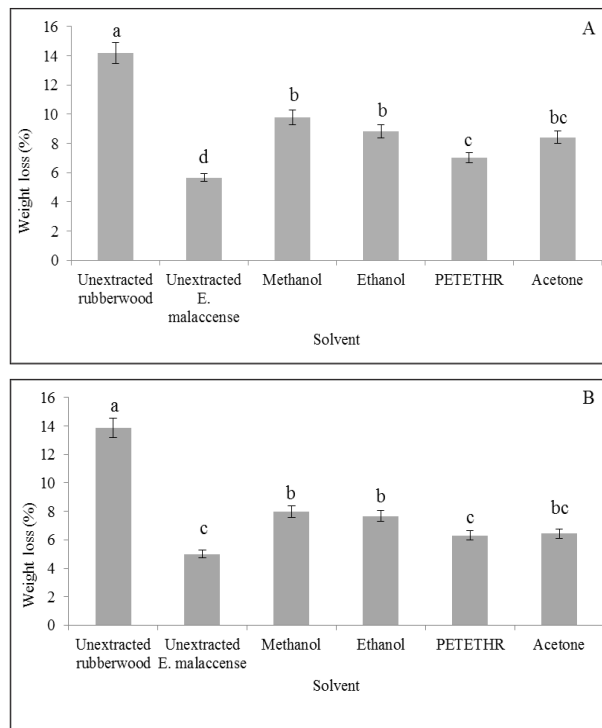
On the other hand, the results, evidently indicate that *M. utilis* heartwood extractives contain biologically active compounds that were potent to *C. gestroi* and *C. curvignathus*. MeOH apparently was a better solvent in extracting the toxic chemical compounds followed by EtOH, acetone and PETETHR. *M. utilis* extract completed the mortality of *C. gestroi* and *C. curvignathus* at the concentration of 4% compared to *A. laevis* and *E. malaccense* even though there was not much difference between *C. curvignathus* and *C. gestroi* mortality in every concentration. MeOH extracts that killed both termite species tested may have reacted and made a food substrate to be toxic to both termite species. Golpayegani *et al.* (2014) in their study on mulberry wood (*Morus alba*) extractives against *Reticulitermes flavipes* also found that MeOH is the second best solvent besides acetone that give a low termite survival. On the other hand, Syofuna *et al.* (2012) reported that different compounds obtained from different solvents will show a different effect towards termite resistance. In conclusion of Taylor *et al.* (2006) study, to understand the natural durability of wood against termites, we can't just focus on a single compound alone, but this resistance is a combination of several compounds that are present in the wood.



**Figure 1.** Weight loss of *M. utilis* extracted in selective solvents and exposed for 4 weeks to A: *C. gestroi* and B: *C. curvignathus* blocks that were subjected to various extraction procedures. Columns with the same letter are not significantly different at  $\alpha = 0,05$ .



**Figure 2.** Weight loss of *A. laevis* extracted in selective solvents and exposed for 4 weeks to A: *C. gestroi* and B: *C. curvignathus* of blocks that were subjected to various extraction procedures. Columns with the same letter are not significantly different at  $\alpha = 0,05$ .



**Figure 3.** Weight loss of *E. malaccensis* extracted in selective solvents and exposed for 4 weeks to A: *C. gestroi* and B: *C. curvignathus* of blocks that were subjected to various extraction procedures. Columns with the same letter are not significantly different at  $\alpha = 0,05$ .

## Weight loss

Figure 1, Figure 2 and Figure 3 reports the effects of the different extracts on the feeding behavior of two different subterranean termite species. The result of no-choice termite bioassays also shows that extracted blocks gave a higher wood consumption compared with un-extracted blocks in all wood species tested. Both termite species consumed more wood on un-extracted *E. malaccense* samples (5,66% against *C. gestroi* and 5,01% against *C. curvignathus*, respectively) than the other two timber species; *M. utilis* (1,58% against *C. gestroi* and 1,33% against *C. curvignathus*, respectively) and *A. laevis* (2,57% against *C. gestroi* and 2,09% against *C. curvignathus*, respectively). Indirectly, these results suggest that *M. utilis* heartwood is more resistant to both termites than the other two timber species. *E. malaccense* extracted blocks had the highest mass loss at all solvent used [MeOH – 9,78%, EtOH – 8,84% PETETHR – 7,01% and acetone – 8,41% against *C. gestroi* and MeOH – 8,00%, EtOH – 7,68% PETETHR – 6,31% and acetone – 6,44% against *C. curvignathus* (Figure 3)] whereas *M. utilis* extracted blocks had the lowest weight loss [MeOH – 3,71%, EtOH – 3,52% PETETHR – 2,22% and acetone – 2,44% against *C. gestroi* and MeOH – 4,59% EtOH – 3,01% PETETHR – 2,40% and acetone – 1,98% against *C. curvignathus* (Figure 1).

In all cases, a significant effect was observed on the weight loss of wood blocks against *C. gestroi*. All solvents (MeOH, EtOH, acetone and PETETHR) lead to similar trends on the two termites tested (except *M. utilis* against *C. gestroi*), probably indicating the presence of the same molecules. Both species of termites also show a similar trend in wood weight loss. However, the performance of wood durability for each timber species depends on the type of solvent used. As reported by González-Laredo *et al.* (2015), both quantity and particularly the quality of extractives have a key role, but their relative contribution varies considerably from substrate to substrate. On the other hand, studies have shown that extracts of wood is the important factor that determine the durability of wood. This agreed with the study done by Roszaini and Hale (2012) on twelve species of tropical timbers against *C. curvignathus* and *C. gestroi*. They found that timbers with high extractive content had high termite resistance and species with lower extractive content showed poor performance. In addition, Lapornik *et al.* (2005) reported that different solvent extracts different chemical compound. The differences also could be due to the properties of the phenolic components of the plants concerned.

## Antitermitic bioassay

The result of antitermitic activities of wood extract is depicted in Table 4, Table 5 and Table 6. The antitermite functions were dependent on the chemical composition of the wood extracts. Previous study indicates that *M. utilis* extracts under varied concentrations inhibit termite feeding. Similarly, *M. utilis* extracts showed the strongest anti-termite activities against *C. gestroi* and *C. curvignathus* (Roszaini *et al.* 2014). It is evident from an earlier study that constituents of wood extracts could affect their anti-termite activity; some influenced greater potency while some others lower, e. g. Monoterpene hydrocarbon possessed lower anti-termite activity as compared with oxygenated constituents (Watanabe *et al.* 2005, Roszaini *et al.* 2014).

Table 4, Table 5 and Table 6 indicated that heartwood extracts of *M. utilis* had more anti-termite activities against both subterranean termites; *C. gestroi* and *C. curvignathus* than *A. laevis* and *E. malaccensis*. The percentage of paper consumption was 1,01% (MeOH extracts), 1,37% (EtOH extracts), 1,92% (PETETHR extracts) and 1,68% (acetone extracts) at the concentration of 4% against *C. gestroi* while it was 1,15%; 2,24%; 2,11% and 1,72% respectively, for *A. laevis* and 1,66%; 2,34%; 2,38% and 2,27%; respectively, for *E. malaccensis*. The same trend (*M. utilis* extracts) also occurs on tests against *C. curvignathus*.

Table 4, Table 5 and Table 6 reveal that there was a significant increase in the number of termites in contact with the solvent control disc in comparison to the number of termites on the corresponding extract-treated disc ( $P < 0,05$ ; DF = 5) for all wood extracts tested. The current study demonstrated that all four concentrations of the heartwood extract from three different timber species were less preferred and avoided by the both subterranean termite, *C. gestroi* and *C. curvignathus*. Lower percentage of paper consumption was obtained at the highest concentration (4%) of every solvent extracts compared to 0,5% of the minimum concentration, respectively. This trend is the same for both termite species



tested. According to the statistical analyses, lower concentration levels (0,5%) of all timber extracts resulted in significant reductions in weight loss when compared to the untreated controls.

Extracts from all timber tested strongly inhibited termite feeding against *C. gestroi* and *C. curvignathus* although *E. malaccensis* heartwood extracts were much less than *M. utilis* and *A. laevis* extracts. *M. utilis* heartwood extracts with MeOH solvents is the most active against both termite species at any level of concentration. At 0,5% level of concentration of any solvent used, *M. utilis* extracts inhibited ~ 1,5-fold (against *C. gestroi*) and ~ 1,3-fold (against *C. curvignathus*) than *A. laevis* the heartwood extracts and ~ 2,0-fold and ~ 2,3-fold than *E. malaccensis*, respectively. At the highest level of concentration (4,0%) also in any solvent used, *M. utilis* extracts inhibited ~ 1,3-fold (against *C. gestroi*) and ~ 1,5-fold (against *C. curvignathus*) than *A. laevis* heartwood extracts and ~ 1,8-fold and ~ 2,0-fold than *E. malaccensis*, respectively. The strong feeding inhibition from *M. utilis* heartwood extractives could be due to the higher value of monoterpenes and sesquiterpenes groups where both are interfering with basic behavioural functions of insects (Werner and Illmann 1994, Roszaini *et al.* 2014). As indicated by other studies, the presence of flavonoids (Ohmura *et al.* 2000, Wang *et al.* 2004) and quinones (Nascimento *et al.* 2013) which possess natural repellent and toxic properties will also increase the durability of the timber against termites.

Findings suggested that all wood extracts may produce larvicidal effects (behaving like general toxicants) against both termites; *C. gestroi* and *C. curvignathus* but depends on the solvents used. Laboratory bioassay of *M. utilis* against both subterranean workers showed that the LC<sub>50</sub> value of *C. gestroi* was higher than *C. curvignathus* in all solvents used. Numerical LC<sub>50</sub> values differed based on solvent used (MeOH>EtOH>Acetone>PETETHR). The LC<sub>50</sub> of *M. utilis* heartwood MeOH extracts was 8,86% for *C. gestroi* and 8,51% for *C. curvignathus*, 9,17% and 8,98% for EtOH extracts 10,24% and 10,01% for PETETHR and 9,79% and 9,50% for acetone extracts, respectively (Table 4). Same trend also exists in *E. malaccensis* except with PETETHR solvents. The LC<sub>50</sub> for *E. malaccensis* was 10,35% for *C. gestroi* and 9,88% for *C. curvignathus* when using MeOH as a solvent 11,42% and 10,85% for EtOH, 11,14% and 11,66 for PETETHR and 13,31% and 12,67% for acetone, respectively (Table 6). Contrarily, with *M. utilis* and *E. malaccensis*, the LC<sub>50</sub> result of *A. laevis* heartwood extract against *C. curvignathus* was higher than *C. gestroi* (except when using MeOH solvents). The LC<sub>50</sub> values of MeOH solvents were 9,79% for *C. gestroi* and 9,15% for *C. curvignathus*, 10,34% and 11,98% for EtOH, 11,52% and 11,88% for PETETHR and 9,82% and 10,11% for acetone, respectively (Table 5). The lowest of LC<sub>50</sub> values of MeOH extracts followed by EtOH and acetone compared to PETETHR solvents could be to the phenolic content that they extracted. Phenolic content is one of the chemical constituents that influenced the rate of degradation. The higher the total phenolic content, the higher resistivity of the wood species. This means that only low concentrations necessary to turn off at least 50% of the number of termites (Shanbhag and Sundararaj 2013).

**Table 4.** Effect of *M. utilis* wood extracts on feeding and mortality of *C. gestroi* and *C. curvignathus*.

Treatment	Con. (%)	% paper consumption		% Feeding-Inhibition (FI%)		LC50 (%)	
		CG	CC	CG	CC	CG	CC
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Methanol		4,891 (0,66) <sup>b</sup>	4,282 (0,80) <sup>b</sup>				
	0,5	2,444 (0,38) <sup>c</sup>	2,533 (0,52) <sup>c</sup>	55,21 (2,39) <sup>d</sup>	59,88 (1,85) <sup>d</sup>	8,86 <sup>b</sup>	8,51 <sup>b</sup>
	1	1,992 (0,84) <sup>d</sup>	1,844 (0,22) <sup>c</sup>	68,44 (0,12) <sup>c</sup>	70,44 (0,88) <sup>c</sup>		
	2	1,787 (0,56) <sup>d</sup>	1,109 (0,19) <sup>d</sup>	76,94 (2,69) <sup>b</sup>	78,36 (0,11) <sup>b</sup>		
	3	1,554 (0,22) <sup>de</sup>	0,927 (0,22) <sup>d</sup>	79,52 (1,44) <sup>ab</sup>	85,64 (1,35) <sup>ab</sup>		
	4	1,012 (0,11) <sup>e</sup>	0,772 (0,45) <sup>d</sup>	82,38 (0,09) <sup>a</sup>	89,37 (1,35) <sup>a</sup>		
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Ethanol		5,173 (0,27) <sup>b</sup>	5,007 (0,51) <sup>b</sup>				
	0,5	3,267 (1,17) <sup>c</sup>	2,863 (1,43) <sup>c</sup>	50,44 (0,22) <sup>c</sup>	52,22 (1,22) <sup>c</sup>	9,17 <sup>b</sup>	8,98 <sup>b</sup>
	1	3,014 (0,66) <sup>c</sup>	2,222 (0,05) <sup>cd</sup>	55,38 (0,08) <sup>c</sup>	57,37 (0,36) <sup>c</sup>		
	2	2,447 (1,37) <sup>d</sup>	1,970 (1,11) <sup>d</sup>	62,10 (2,28) <sup>b</sup>	70,18 (0,64) <sup>b</sup>		
	3	1,633 (2,21) <sup>c</sup>	1,818 (0,44) <sup>de</sup>	69,99 (0,08) <sup>ab</sup>	74,49 (1,22) <sup>ab</sup>		
	4	1,379 (0,07) <sup>e</sup>	1,220 (1,52) <sup>c</sup>	76,43 (0,09) <sup>a</sup>	78,27 (1,35) <sup>a</sup>		
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Petroleum ether		5,487 (0,11) <sup>b</sup>	5,334 (1,24) <sup>b</sup>				
	0,5	4,111 (1,13) <sup>c</sup>	3,697 (0,07) <sup>c</sup>	46,62 (2,65) <sup>c</sup>	47,34 (0,08) <sup>c</sup>	10,24 <sup>a</sup>	10,01 <sup>a</sup>
	1	3,339 (0,59) <sup>d</sup>	3,018 (0,27) <sup>cd</sup>	50,11 (1,12) <sup>bc</sup>	50,98 (0,65) <sup>bc</sup>		
	2	2,445 (0,91) <sup>c</sup>	2,625 (0,18) <sup>de</sup>	55,33 (2,66) <sup>b</sup>	54,57 (0,22) <sup>b</sup>		
	3	2,008 (1,00) <sup>c</sup>	1,872 (0,66) <sup>c</sup>	68,21 (0,44) <sup>a</sup>	69,69 (2,64) <sup>a</sup>		
	4	1,927 (0,06) <sup>c</sup>	1,671 (0,83) <sup>c</sup>	70,58 (0,58) <sup>a</sup>	73,35 (3,22) <sup>a</sup>		
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Acetone		5,551 (0,11) <sup>b</sup>	5,221 (0,03) <sup>b</sup>				
	0,5	3,512 (1,11) <sup>c</sup>	3,421 (0,22) <sup>c</sup>	48,33 (1,66) <sup>c</sup>	49,11 (1,46) <sup>c</sup>	9,79 <sup>ab</sup>	9,50 <sup>a</sup>
	1	3,017 (1,09) <sup>cd</sup>	2,990 (0,33) <sup>cd</sup>	50,22 (0,88) <sup>c</sup>	51,52 (0,06) <sup>c</sup>		
	2	2,455 (0,77) <sup>d</sup>	2,510 (0,52) <sup>de</sup>	54,87 (0,08) <sup>c</sup>	58,88 (1,22) <sup>b</sup>		
	3	2,383 (0,06) <sup>d</sup>	2,077 (0,47) <sup>e</sup>	62,01 (1,35) <sup>b</sup>	63,31 (1,64) <sup>b</sup>		
	4	1,682 (0,05) <sup>c</sup>	1,456 (0,01) <sup>c</sup>	75,37 (0,98) <sup>a</sup>	77,51 (1,64) <sup>a</sup>		

CG = *C. gestroi*, CC = *C. curvignathus*. Con. = Concentration. Mean ( $\pm$  SD) of 5 replicates for each species. Percentage values followed by the same letter are not significantly different in the same group at the 0,05 level of probability. LC<sub>50</sub> = Lethal Concentration which causes a 50% reduction in feeding as compared to the non-treated control.

**Table 5.** Effect of *A. laevis* wood extracts on feeding and mortality of *C. gestroi* and *C. curvignathus*.

Treatment	Con. (%)	% paper consumption		% Feeding-Inhibition (FI%)		LC50 (%)	
		CG	CC	CG	CC	CG	CC
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Methanol		4891 (0,66) <sup>b</sup>	4,284 (0,80) <sup>b</sup>				
	0,5	4,050 (0,23) <sup>b</sup>	3,893 (0,59) <sup>bc</sup>	40,39 (2,56) <sup>d</sup>	45,33 (1,12) <sup>c</sup>	9,79 <sup>b</sup>	9,15 <sup>c</sup>
	1	3,344 (0,08) <sup>c</sup>	3,342 (1,26) <sup>c</sup>	45,22 (1,13) <sup>c</sup>	50,01 (2,69) <sup>b</sup>		
	2	2,593 (0,22) <sup>d</sup>	3,017 (0,85) <sup>c</sup>	50,01 (1,14) <sup>c</sup>	52,33 (1,16) <sup>b</sup>		
	3	1,875 (0,44) <sup>d</sup>	2,540 (2,36) <sup>d</sup>	57,35 (8,55) <sup>b</sup>	56,33 (2,25) <sup>ab</sup>		
	4	1,156 (0,22) <sup>c</sup>	1,245 (0,22) <sup>c</sup>	65,71 (3,69) <sup>a</sup>	60,38 (7,14) <sup>a</sup>		
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Ethanol		5,174 (0,27) <sup>b</sup>	5,000 (0,51) <sup>b</sup>				
	0,5	4,508 (0,11) <sup>b</sup>	4,144 (0,03) <sup>c</sup>	35,62 (1,12) <sup>c</sup>	40,61 (2,44) <sup>b</sup>	10,34 <sup>ab</sup>	11,98 <sup>a</sup>
	1	3,775 (0,67) <sup>c</sup>	3,69 (2,21) <sup>cd</sup>	48,33 (0,82) <sup>b</sup>	46,46 (0,97) <sup>b</sup>		
	2	2,924 (0,43) <sup>cd</sup>	3,110 (1,92) <sup>d</sup>	48,59 (0,07) <sup>b</sup>	52,38 (0,02) <sup>a</sup>		
	3	2,416 (0,52) <sup>d</sup>	2,598 (0,08) <sup>d</sup>	51,68 (0,65) <sup>b</sup>	56,66 (1,17) <sup>a</sup>		
	4	2,248 (0,09) <sup>d</sup>	1,875 (1,47) <sup>c</sup>	60,44 (2,87) <sup>a</sup>	58,53 (3,44) <sup>a</sup>		
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Petroleum ether		5,484 (0,11) <sup>b</sup>	5,332 (1,24) <sup>b</sup>				
	0,5	4,965 (2,25) <sup>b</sup>	4,627 (0,81) <sup>b</sup>	32,28 (3,34) <sup>d</sup>	35,51 (1,80) <sup>c</sup>	11,52 <sup>a</sup>	11,88 <sup>a</sup>
	1	4,036 (1,28) <sup>c</sup>	3,882 (0,65) <sup>c</sup>	38,80 (0,44) <sup>d</sup>	40,01 (1,64) <sup>bc</sup>		
	2	3,773 (0,67) <sup>c</sup>	3,267 (2,22) <sup>c</sup>	43,45 (0,65) <sup>c</sup>	42,57 (1,22) <sup>b</sup>		
	3	2,995 (0,09) <sup>cd</sup>	2,393 (0,98) <sup>cd</sup>	47,31 (2,29) <sup>b</sup>	48,88 (0,88) <sup>ab</sup>		
4	2,115 (0,88) <sup>d</sup>	1,821 (0,14) <sup>d</sup>	51,11 (3,12) <sup>a</sup>	52,21 (4,12) <sup>a</sup>			
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Acetone		5,551 (0,11) <sup>b</sup>	5,228 (0,03) <sup>b</sup>				
	0,5	4,330 (2,27) <sup>b</sup>	3,982 (0,18) <sup>b</sup>	39,92 (0,47) <sup>c</sup>	37,74 (0,87) <sup>c</sup>	9,82 <sup>b</sup>	10,11 <sup>b</sup>
	1	4,010 (0,12) <sup>c</sup>	3,332 (0,53) <sup>c</sup>	42,22 (1,88) <sup>bc</sup>	46,22 (1,62) <sup>b</sup>		
	2	3,427 (0,04) <sup>c</sup>	2,763 (0,64) <sup>c</sup>	46,36 (1,01) <sup>b</sup>	48,88 (1,25) <sup>b</sup>		
	3	2,186 (0,66) <sup>cd</sup>	2,344 (0,15) <sup>cd</sup>	48,00 (2,22) <sup>b</sup>	52,22 (1,11) <sup>ab</sup>		
4	1,722 (0,72) <sup>d</sup>	1,082 (0,22) <sup>d</sup>	56,81 (0,87) <sup>a</sup>	59,22 (3,39) <sup>a</sup>			

CG = *C. gestroi*, CC = *C. curvignathus*. Con. = Concentration. Mean ( $\pm$  SD) of 5 replicates for each species. Percentage values followed by the same letter are not significantly different in the same group at the 0,05 level of probability. LC<sub>50</sub> = Lethal Concentration which causes a 50% reduction in feeding as compared to the non-treated control.

**Table 6.** Effect of *E. malaccensis* wood extracts on feeding and mortality of *C. gestroi* and *C. curvignathus*.

Treatment	Con. (%)	% paper consumption		% Feeding-Inhibition (FI%)		LC50 (%)	
		CG	CC	CG	CC	CG	CC
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Methanol		4,891 (0,66) <sup>b</sup>	4,288 (0,80) <sup>b</sup>				
	0,5	4,390 (0,64) <sup>b</sup>	4,641 (0,59) <sup>b</sup>	28,56 (3,36) <sup>b</sup>	29,33 (3,38) <sup>b</sup>	10,35 <sup>b</sup>	9,88 <sup>b</sup>
	1	3,664 (0,14) <sup>b</sup>	4,017 (1,14) <sup>b</sup>	30,00 (2,33) <sup>b</sup>	32,45 (1,14) <sup>b</sup>		
	2	3,033 (0,64) <sup>bc</sup>	3,010 (1,11) <sup>bc</sup>	36,84 (0,02) <sup>ab</sup>	35,64 (7,25) <sup>ab</sup>		
	3	2,672 (0,65) <sup>bc</sup>	2,883 (0,99) <sup>bc</sup>	42,11 (5,52) <sup>a</sup>	43,29 (2,26) <sup>a</sup>		
	4	1,667 (0,25) <sup>c</sup>	2,089 (0,06) <sup>c</sup>	48,88 (0,08) <sup>a</sup>	45,31 (1,17) <sup>a</sup>		
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
Ethanol		5,170 (0,27) <sup>b</sup>	5,009 (0,51) <sup>b</sup>				
	0,5	4,502 (0,11) <sup>b</sup>	4,144 (0,03) <sup>b</sup>	25,17 (3,25) <sup>b</sup>	23,48 (2,82) <sup>b</sup>	11,42 <sup>b</sup>	10,85 <sup>b</sup>
	1	3,773 (0,67) <sup>b</sup>	3,680 (2,21) <sup>b</sup>	29,99 (1,42) <sup>b</sup>	27,55 (2,02) <sup>b</sup>		
	2	2,929 (0,43) <sup>bc</sup>	3,110 (1,92) <sup>bc</sup>	30,14 (0,56) <sup>ab</sup>	29,65 (0,64) <sup>ab</sup>		
	3	2,592 (0,08) <sup>bc</sup>	2,598 (0,08) <sup>bc</sup>	40,01 (0,08) <sup>a</sup>	30,63 (0,11) <sup>a</sup>		
	4	2,343 (1,47) <sup>c</sup>	2,016 (1,47) <sup>c</sup>	42,44 (1,22) <sup>a</sup>	41,77 (0,35) <sup>a</sup>		
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
		5,487 (0,11) <sup>b</sup>	5,330 (1,24) <sup>b</sup>				
	0,5	4,482 (0,12) <sup>b</sup>	4,732 (2,98) <sup>b</sup>	23,67 (1,28) <sup>b</sup>	24,99 (1,69) <sup>b</sup>	11,14 <sup>b</sup>	11,66 <sup>a</sup>
	1	3,471 (2,64) <sup>b</sup>	4,014 (3,56) <sup>b</sup>	27,27 (3,44) <sup>b</sup>	29,25 (2,78) <sup>b</sup>		
	2	3,013 (1,89) <sup>bc</sup>	3,472 (0,44) <sup>bc</sup>	31,02 (1,36) <sup>ab</sup>	31,04 (0,66) <sup>ab</sup>		
	3	2,668 (0,06) <sup>bc</sup>	3,111 (0,63) <sup>bc</sup>	35,64 (1,78) <sup>a</sup>	31,98 (0,08) <sup>a</sup>		
	4	2,381 (1,45) <sup>c</sup>	2,521 (1,17) <sup>c</sup>	38,20 (0,88) <sup>a</sup>	32,11 (1,22) <sup>a</sup>		
Control		6,382 (0,35) <sup>a</sup>	6,015 (0,46) <sup>a</sup>				
		5,555 (0,11) <sup>b</sup>	5,222 (0,03) <sup>b</sup>				
	0,5	4,423 (0,03) <sup>b</sup>	4,670 (0,11) <sup>b</sup>	28,44 (1,26) <sup>b</sup>	26,62 (0,66) <sup>b</sup>	13,31 <sup>a</sup>	12,67 <sup>a</sup>
	1	3,212 (1,38) <sup>b</sup>	3,880 (0,07) <sup>b</sup>	29,98 (3,24) <sup>b</sup>	29,65 (0,98) <sup>b</sup>		
	2	2,885 (2,20) <sup>bc</sup>	3,111 (1,25) <sup>bc</sup>	33,19 (2,64) <sup>ab</sup>	32,46 (0,44) <sup>ab</sup>		
	3	2,452 (1,21) <sup>bc</sup>	2,623 (1,48) <sup>bc</sup>	38,57 (0,02) <sup>a</sup>	37,23 (0,22) <sup>a</sup>		
	4	2,278 (0,08) <sup>c</sup>	2,484 (1,14) <sup>c</sup>	46,33 (0,84) <sup>a</sup>	40,04 (0,74) <sup>a</sup>		

CG = *C. gestroi*, CC = *C. curvignathus*. Con. = Concentration. Mean ( $\pm$  SD) of 5 replicates for each species. Percentage values followed by the same letter are not significantly different in the same group at the 0,05 level of probability. LC<sub>50</sub> = Lethal Concentration which causes a 50% reduction in feeding as compared to the non-treated control.

On the other hand, the LC<sub>50</sub> values which is an appropriate measure for determining the toxicity of a chemical has always been questioned before. However, it is a good basis for a preliminary assessment to determine the potential risk of a compound under conditions specified and also it gives an idea to generate on the order of magnitude of the lethal concentration (Duffus 1980).

## CONCLUSIONS

This study shows that the solvents influence the yield and wood extracts properties against subterranean termites; *C. curvignathus* and *C. gestroi*. MeOH solvent had higher extraction yields in every timber species tested. The MeOH extraction increases the anti-termite activity than EtOH, PETETHR and acetone extraction. A comparative study on field trials is recommended to ascertain the respective needed dose of the extracts. Studies should also be conducted to characterize the chemical compound that causes the durability of a timber against subterranean termites.

## ACKNOWLEDGEMENTS

The authors are extremely grateful to the staff of Wood Entomology Laboratory (Mrs Zaini Soit, Mrs. Zaitihaiza Khamaruddin and Mrs. Norziah Ishak) for helping in collecting termites and preparation of the wood extracts. The study was funded by FRIM Research Project grant (Grant No.

41310404005).

## REFERENCES

- Ahmad-Said, S.; Mohd-Hamami, S. 1982.** Responses to wood and wood extractives of *Neobalanocarpus heimii* and *Shorea ovalis* by the drywood termites, *Cryptotermes cynocephalus* (Isoptera: Kalotermitidae). *Pertanika* 6(3):28-31.
- Ahmad Said, S.; Maria, L.T.L.; Faujan, A.; Mohd Hamami, S. 2006.** Feeding response of subterranean termite, *Coptotermes curvignathus* (Isoptera: Rhinotermitidae) to *Azadirachta excelsa* (Meliaceae) extractives and its timber. *Sociobiology* 48(2):447-455.
- Ahmad Zuhaidi, Y.; Zakaria, I.; Rosdi, K. 2002.** Species for timber plantations, in: Krisnapillay B (Ed), *A Manual for Forest Plantation Establishment in Malaysia*. Malayan Forest Records No. 45. Forest Research Institute Malaysia, Kepong, pp. 13-23.
- Arango, A.R.; Green, F.I.; Hintz, K.; Lebow, P.K.; Miller, B.R. 1992.** Natural durability of tropical and native woods against termite damage by *Reticulitermes flavipes*. *International Biodeterioration and Biodegradation* 57:146-150.
- American Society for Testing and Materials. ASTM. 1988.** Standard test method of laboratory evaluation of wood and other cellulosic materials for resistance to termites (D3345-88). In: *ASTM Annual Book of Standards* Vol. 4.10 Wood West Conshohocken, PA, 1988; Vol. 4.10, pp. 430-432.
- Banthorpe, D.V.; Charlwood, B.V.; Francis, M.J.O. 1972.** The biosynthesis of monoterpenes. *Chemical Reviews* 72(2):115-155.
- Barnes, H.M. 1992.** Wood protecting chemicals from the 21<sup>st</sup> century. International Research Group on Wood Preservation. 24<sup>th</sup> Annual Conference Meeting at Orlando, Florida, USA, 16-20 May 1992. IRG/WP 93-30018. 29p.
- Bashash, M.; Bolandi, M.; Zamindar, N. 2012.** Phenolic content of selected sumac fruits from Iran with different solvent. *Journal of Chemical Health Risks* 2(4):17-20.
- Bridgers, E.N.; Chinn, M.S.; Truong, V.D. 2010.** Extraction of anthocyanins from industrial purple-fleshed sweetpotatoes and enzymatic hydrolysis of residues for fermentable sugars. *Industrial Crops and Products* 32:613-620.
- Carter, F.L.; Beal, H.R.; Bultman, D.J. 1975.** Extraction of antitermitic substances from 23 tropical hardwoods. *Wood Science* 8:406-410.
- Celimene, C.C.; Micales, J.A.; Ferge, L.; Young, R. 1999.** Efficacy of pinosylvins against white rot and brown rot fungi. *Holzforschung* 53:491-497.
- Chang, S.T.; Wang, J.H.; Wu, C.L.; Chen, P.K.; Kuo, Y.H. 2001.** Comparison of the antifungal activity of cadinane skeletal sesquiterpenoid from Taiwan (*Taiwania crypromerioides* Hayara) heartwood. *Holzforschung* 54(3): 241-245.
- Chang, S.T.; Cheng, S.S. 2002.** Antitermite activity of leaf essential oils and their constituents from *Cinnamomum osmophloeum*. *Journal of Agriculture and Food Chemistry* 50:1389-1392.
- Delgado-Vargas, F.; Paredes-Lopez, O. 2002.** *Natural colorants for wood and nutraceutical uses*. CRC Press: Boca Raton, FL, USA.
- Duffus, J.J. 1980.** *Environmental toxicology*. Edward Arnold Publishers Ltd, London.
- Elango, G.; Abdul Rahuman, A.; Kamaraj, C.; Bagavan, A.; Abduz Zahir, A.; Santhoshkumar, T.; Marimuthu, S.; Velayutham, K.; Jayaseelan, C.; Vishnu Kirthi, A.; Rajakumar, G. 2012.** Efficacy of medicinal plant extracts against formosan subterranean termite, *Coptotermes formosanus*. *Industrial Crops and Products* 36:524-530.

- Ericsson, T.; Fries, A.; Gref, R. 2001.** Genetic correlation of heartwood extractives in *Pinus sylvestris* progeny tests. *Forest Genetics* 8(1):73-79.
- Fengel, V.D.; Wegener, G. 1989.** *Wood – chemistry, ultrastructure and reactions.* Walter de Gruyter, Berlin. 613p.
- Finney, D.J. 1971.** *Probit analysis*, 3<sup>rd</sup> Edition, London: Cambridge University Press.
- Fraga, B.M. 2003.** Natural sesquiterpenoids. *Natural Product Reports* 20(4):392-413.
- Golpayegani, A.S., Thevenon, M.F. Gril, J., Masson, E., Pourtahmasi K. 2014.** Toxicity potential in the extraneous compounds of white mulberry wood (*Morus alba*). *Maderas. Ciencia y Tecnología* 16(2): 227-238.
- González-Laredo, R.F.; Rosales-Castro, M.; Rocha-Guzmán, N.E.; Gallegos-Infante, J.A.; Moreno-Jiménez, M.R.; Karchesy, J.J. 2015.** Wood preservation using natural products. *Madera y Bosques* 21(Núm. esp.):63-76.
- Haupt, M.; Leithoff, H.; Meier, D.; Puls, J.; Richter, H.G.; Faix, O. 2003.** Heartwood extractives and natural durability of plantation-grown teakwood (*Tectona grandis* L.) – A case study. *Holz Roh Werkst* 61:473-474.
- Hillis, W.E. 1987.** *Heartwood and tree exudates. Amount of extractives.* Springer, Berlin Heidelberg New York. 268p.
- Hillis, W.E.; Inoue, T. 1968.** The formation of polyphenols in trees-IV: The polyphenols formed in *Pinus radiata* after *Sirex* attack. *Phytochemistry* 7(1):13-22.
- Kajdžanoska, M.; Petreska, J.; Stefova, M. 2011.** Comparison of different extraction solvent mixtures for characterization of phenolic compounds in strawberries. *Journal of Agriculture and Food Chemistry* 59 (10): 5272-5278.
- Kapasakalidis, P.G.; Rastall, R.A.; Gordon, M.H. 2006.** Extraction of polyphenols from processed black currant (*Ribes nigrum* L.) residues. *Journal of Agriculture and Food Chemistry* 54:4016-4021.
- Kawamura, F.; Sitti Fatimah, M.R.; Othman, S.; Rokiah, H.; Ohara, S. 2011.** Antioxidant and antifungal activities of extracts from 15 selected hardwood species of Malaysian timber. *European Journal of Wood Products* 69:207-212.
- Ken, F. 2014.** Useful tropical plants database (2014). [online] <<http://tropical.theferns.info/viewtropical.php?id=Anisoptera+laevis>>. [consulted 8/9/2016].
- Khairul, M.; Mohd Noor, M.; Mohamad Omar, M.K.; Abdul Hamid, S.; Mohd Hafiz, M.; Khairul, A.; Izran, K. 2010.** Solid wood and veneer study of 12-year-old sesendok clone. *Journal of Modern Applied Science* 4:1844-1913.
- Kilic, A.; Niemz, P. 2010.** Extractives in some tropical woods. *European Journal of Wood Products* 70: 79-83.
- Kirker, G.T.; Blodgett, A.B.; Arango, R.A.; Lebow, P.K.; Clausen, C.A. 2013.** The role of extractives in naturally durable wood species. *International Biodeterioration and Biodegradation* 82:53-58.
- Kothari, V.; Gupta, A.; Naraniwal, M. 2012.** Comparative study of various methods for extraction of antioxidant and antibacterial compounds from plant seeds. *Journal of Natural Medicines* 12(2):162-173.
- Lapornik, B.; Prošek, M.; Wondra, A.G. 2005.** Comparison of extracts prepared from plant by-products using different solvents and extraction time. *Journal of Food Engineering* 71:214-222.
- Lim, S.C.; Gan, K.S.; Choo, K.T. 1998.** Timber Notes - Heavy Hardwoods (I). *Timber Technology*

*Bulletin* No. 8, ISSN: 139-258.

**Lolita, T.; Zanda, K.; Ruta, G. 2012.** Comparison of different solvents and extraction methods for isolation of phenolic compounds from horseradish roots (*Armoracia rusticana*). *World Academy of Science. Engineering and Technology* 6:1155-1160.

**Mburu, F.; Dumarcay, S.; Gérardin, P. 2007.** Evidence of fungicidal and termiticidal properties of *Prunus africana* heartwood extractives. *Holzforschung* 61:323-325.

**Mohd Shukari, M. 1982.** Malaysia Timber - Sesenduk. *Malayan Forest Service Trade Leaflets* No.66.

**Mori, M.; Aoyama, M.; Hokkaido, S. 1997.** Antifungal constituents in the bark of *Magnolia obovata*. *Holz Roh Werkstoff* 55:275-278.

**Nascimento, M.S.; Santana, A.L.B.D.; Maranhão, C.A.; Oliveira, L.S.; Bieber, L. 2013.** Chapter 13 phenolic extractives and natural resistance of wood. In: Biodegradation life of science. Chamy, R. and Rosenkranz, F. (eds). InTech, p 349–370. DOI:10.5772/56358.

**Werner, R.A.; Illmann, B.L. 1994.** The role of stilbene- like compounds in host tree resistance of Sitka spruce to the spruce beetle, *Dendroctonus rufipennis*. In: Proceeding, behaviour, population dynamics and control of forest insect conference, 6–11 February 1994, Mani, Hi. OARDC/Ohio State University, Wooster, OH.

**Nacz, M.; Shahidi, F. 2004.** Extraction and analysis of phenolics in food. *Journal of Chromatography A* 1054:95-111.

**Neya, B.; Hakkou, M.; Petrisans, M.; Gérardin, P. 2004.** On the durability of *Burkea africana* heartwood: evidence of biocidal and hydrophobic properties responsible for durability. *Annals of Forest Science* 61:277-282.

**Ogunwusi, A.A.; Onwuala, A.P.; Ogunsanwo, O.Y. 2013.** Comparative analysis of wood properties of *Azelia Africana* and *Anogeissus leiocarpus* growing in Nigeria. *Chemistry and Materials Research* 3(3):8-12.

**Ohmura, W.; Doi, S.; Aoyama, M.; Ohara, S. 2000.** Antifeedant activity of flavonoids and related compounds against the subterranean termite *Coptotermes formosanus* Shiraki. *Journal of Wood Science* 46:149-153.

**Orwa, C.; Mutua, A.; Kindt, R.; Jamnadass, R.; Simons, A. 2009.** Agroforestry Database: A tree reference and selection guide version 4.0. [online] <<http://www.worldagroforestry.org/af/treedb/>>. [consulted 6/6/2016].

**Park, C.E.; Baek, N.I.; Park, C.H. 2001.** Extraction of panaxynol and panaxyctol compounds from Korean ginseng. *Biotechnology and Bioprocess Engineering* 6:433-437.

**Reyes-Chilpa, R.; Gomez-Garibay, F.; Moreno-Tores, G.; Jimenez-Estrada, M.; Quiroz-Vasquez, R.I. 1998.** Flavanoids and isoflavanoids with antifungal properties from *Platymiscium yucatanum* heartwood. *Holzforschung* 52:459-462.

**Roszaini, K. 2011.** Wood extractives as natural preservatives against termites and fungi. PhD Thesis. University of Bangor.

**Roszaini, K.; Hale M.D. 2012.** Comparative termite resistance of 12 Malaysian timber species in laboratory tests. *Holzforschung* 66:127-130.

**Roszaini, K.; Rafeadah, R.; Mohd Dahlan, J. 2009.** Durability of Malaysian timbers against the Asian subterranean termite *Coptotermes gestroi* Wasmann. *Journal of Institute of Wood Science* 19:16-21.

**Roszaini, K.; Norazah, M.A.; Mailina, J; Zaini, S.; Mohammad Faridz, Z. 2013.** Toxicity and antitermite activity of the essential oils from *Cinnamomum camphora*, *Cymbopogon nardus*, *Melaleuca*

*cajuputi* and *Dipterocarpus* sp. Against *Coptotermes curvignathus*. *Wood Science and Technology* 47(6): 1273-1284.

**Roszaini, K.; Norazah, M.A.; Zaini, S.; Zaitihaiza, K. 2014.** Anti-termite potential of heartwood and bark extract and chemical compounds isolated from *Madhuca utilis* Ridl. H. J. Lam and *Neobalanocarpus heimi* King P. S. Ashton. *Holzforschung* 68(6):713-720.

**Roszaini, K.; Khairul, A.; Zaitihaiza, K.; Zaini, S. 2015.** Chemical compositions and termiticidal activities of the heartwood from *Calophyllum inophyllum* L. *Anais da Academia Brasileira de Ciências* 87(2):743-751.

**Rudman, P. 1965.** The cause of natural durability in timber. XVIII. Further notes on the fungi toxicity of wood extractives. *Holzforschung* 19:57-58.

**Scheffer, T.C.; Cowling, E.B. 1966.** Natural resistance of wood to microbial deterioration. *Annual Review of Phytopathology* 4:147-168.

**Shanbhag, R.R.; Sundararaj, R. 2013.** Physical and chemical properties of some imported woods and their degradation by termites. *Journal of Insect Science* 13:63.

**Spigno, G.; Tramelli, L.; De Faveri, D.M. 2007.** Effects of extraction time, temperature and solvent on concentration and antioxidant activity of grape marc phenolics. *Journal of Food Engineering* 81(1):200-208.

**Steller, S.D.; Labosky, P. 1982.** Antitermitic properties of cellulose pads treated with bark extractives. *Wood Fiber Science* 65(18):107-114.

**Syofuna, A.; Banana, A.Y.; Nakabonge, G. 2012.** Efficiency of natural wood extractives as wood preservatives against termite attack. *Maderas Ciencia y Tecnología* 14(2):155-163.

**Tascioglu, C.; Yalcin, M.; Troya, T.D.; Sivrikaya, H. 2012.** Termiticidal properties of some wood and bark extracts used as wood preservatives. *Bioresources* 7(3):2960-2969.

**Taylor, A.M.; Gartner, B.L.; Morrell, J.J. 2006.** Effects of heartwood extractive fractions of *Thuja plicata* and *Chamaecyparis nootkatensis* wood degradation by termites or fungi. *Journal of Wood Science* 52: 147-153.

**Wang, Q.A.; Zhou, B.; Shan, Y. 2004.** Progress on antioxidant activation and extracting technology of flavonoids. *Chemical Products and Technology* 11:29-33.

**Watanabe, Y.; Mihara, R.; Mitsunaga, T.; Yoshimura, T. 2005.** Termite repellent sesquiterpenoids from *Callitris glaucophylla* heartwood. *Forest Ecology and Management* 258:1918-1923.

**Werner, R.A.; Illmann, B.L. 1994.** The role of stilbene- like compounds in host tree resistance of Sitka spruce to the spruce beetle, *Dendroctonus rufipennis*. In: Proceeding, behaviour, population dynamics and control of forest insect conference, 6–11 February 1994, Mani, Hi. OARDC/Ohio State University, Wooster, OH.

**Windeisen, E.; Wegener, G.; Lesnino, G.; Schumacher, P. 2002.** Investigation of the correlation between extractives content and natural durability in 20 cultivated larch trees. *Holz Roh Werkstoff* 60:373-374.

**Wood Identification. 2010.** Properties and uses Merawan.[online]. <[https://info.frim.gov.my/woodid/Properties\\_detail.cfm?Name=Merawan](https://info.frim.gov.my/woodid/Properties_detail.cfm?Name=Merawan)>[consulted 5/10/2016].

**Wu, C.L.; Chien, S.C.; Wang, S.Y., Ku, Y.H.; Chang, S.T. 2005.** Structure-activity relationships of cadinane-type sesquiterpene derivatives against wood decay fungi. *Holzforschung* 59:620-627.

**Yuan, Z.; Hu, X.P. 2011.** Evaluation of differential antitermitic activities of *Lantana camara* oven-dried tissues against *Reticulitermes virginicus* (Isoptera: Rhinotermitidae). *Journal of the Indian Institute of Science* 18:671-681.