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Section 1 Biology

Effects of teak, Tectona grandis Linn, heartwood extractives against Heterotermes indicola (Isoptera: Rhinotermitidae)

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ABSTRACT

Heartwood extractives from *Tectona grandis* were investigated for antitermitic activities against *Heterotermes indicola* in laboratory experiments. Extractives were removed from wood shavings by soxhlet extraction using an ethanol: toluene (2:1) solvent system. Termite feeding and mortality followed a concentration dependent response. The highest termite mortality occurred at an extractive concentration of 10 mg/ml. The calculated LC50 based on the concentration dependant response was 3.2 mg/ml. Extractives showed high repellency and antifeedant activity against *H. indicola*. Tests in which extractives were used to vacuum-pressure treat southern pine and cottonwood, showed that *T. grandis* extractives imparted resistance to these non-durable species. At the highest concentration of extractives tested, complete mortality was observed after termites were exposed to extractive-treated southern pine and cottonwood. Compared to solvent controls, minimum weight losses of 3.6 and 3.5% were observed for extractive-treated southern pine and cottonwood, respectively, at the 10mg/ml concentration after 28 days of exposure. Termites exposed to a subset of extractive treated then leached southern pine and cottonwood showed high mortality. These results suggest that *T. grandis* extractives have antitermitic properties and may be potentially useful in the development of environmentally friendly wood preservative.

Keywords: *Tectona grandis*, Preservative, lower termite, extractive transfer, *Heterotermes indicola*

1. INTRODUCTION

Species of *Heterotermes* (Rhinotermitidae) commonly infest structures and account for significant damage attributed to wood in service in regions where they occur. *Heterotermes* belongs to the same family as the more well-known subterranean termites, *Reticulitermes* and *Coptotermes*, but have not been reported on as extensively. *Heterotermes* primarily occur in the warm Neotropics including the southwestern United States, the Indian subcontinent, Australia and the Arabian Peninsula. *Heterotermes indicola* (Wasmann) is one of the most economically important and destructive subterranean termite pest species in Pakistan. It has become a major structural pest of wood in service in this country and has been ranked as the most destructive termite species in the city of Lahore (Dugal *et al.* 2015). It has also been reported to attack paper, clothes and other cellulosic materials. This species is considered to be particularly tenacious
since it remains active throughout the year (Dugal et al. 2015, Misbah ul haq et al. 2015, Hassan et al. 2017). Earlier studies showed that H. indicola attacks a wide range of wood species including Eriobotrya japonica (Thunb.) Lindl, Acacia spp., Populus euramericana Guinier, Melia azedarach L., Mangifera indica L., Putranjiva roxburghii Wall, Moringa oleifera Lam., Heterophragma adenophyllum (Wall. ex G.Don) and several other woods. Dalbergia sissoo Roxb, Pinus roxburghii Sarg., Syzygium cumini (L.), Cedrus deodara (Roxb.) G. Don were found to be resistant against this species in field and laboratory tests (Dugal et al. 2015, Hassan et al. 2016, Afzal et al. 2017).

Tectona grandis Linn (Teak) is a tropical hardwood species belonging to the Verbenaceae family and is highly valued due its natural durability, texture, and aesthetic properties (Krishnapillay 2000, Khera & Bhargava 2013). It is one of the most important plantation species in tropical forestry and is native to Thailand, Indonesia, India and Myanmar (Bhat et al. 2005). Teak is well-known for its natural resistance to native and non-native termites. In preference tests, it has been shown to be less favoured by species of Coptotermes, Globitermes, Microceratotermes, Macrotermes, and Reticulitermes (Ngee et al. 2004, Thulasidas and Bhat 2007, Lukmandaru and Takahashi 2008). Termite resistance of T. grandis to Heterotermes indicola, however, has not been previously studied.

Studies using other subterranean termite species have shown that resistance is due to the presence of certain bioactive compounds in teak heartwood (Lukmandaru and Takahashi 2009, Dungani et al. 2012). These bioactive compounds have been identified as anthroquinones and tectoquinones (Haluk et al. 2001, Mankowski et al. 2016, Ismayati et al. 2016). Several other phytochemical compounds; saponins, steroids, alkaloids, flavonoids, methyl-anthra-1,4-quinone, tecomaquinone, methylquinizarin, tectoquinol, dehydroxy-α-lapachone have also been separated and identified from the heartwood and leaves of the teak plant (Khan and Mlungwana 1999, Ohmura et al. 2000, Gupta and Singh 2004, Lacret et al. 2012). Previous studies also showed that vacuum-pressure treating non-durable wood species with the heartwood extractives of durable wood species can increase the durability of the non-durable wood (Adegeye et al. 2009, Kirker et al. 2015). The need for further investigation into this concept of transferable durability using natural compounds is of interest in the development of more environmentally friendly wood preservative systems (Asamoah et al. 2011a). The teak heartwood used in this study was characterized in a previous study and found to contain Squalene, 2-methyl-9, 10-Anthracenedione, 1-Methyl-3, 4-dihydroisoquinoline, are known to have strong antifungal and antitermitic activities (Mankowski et al. 2016). Chemicals present in the extractives that effect and eliminate symbionts from the termite gut have been explored previously in this species (Hassan et al. 2017). However, no studies exist which examine the resistance of T. grandis and the toxicity of its extractives against H. indicola. In the current study, we report the repellent and antifeedant activity along with toxicity of heartwood extractives of T. grandis against feeding by this termite in choice and no-choice feeding tests. The potential of heartwood extractives as a wood preservative for non-durable wood species was also examined.

2. EXPERIMENTAL METHODS

2.1 Wood Samples and Extraction. Heartwood of marine grade Tectona grandis was acquired from a supplier in the United States (McIlvain, Pittsburgh, PA). For extractive removal, wood
was converted into wood shavings using a planer. After air drying to ~10-12% MC in the laboratory, shavings (12 g) were soxhlet extracted using 300 ml of an ethanol: toluene (2:1) solvent mixture according to ASTM D1105-96 "Standard Test Method for Preparation of Extractive-Free Wood", with minor modifications (ASTM 2014, Hassan et al. 2017). The solvent containing the extractives was placed in a tared round bottom flask, and evaporated to dryness at reduced pressure using a rotary evaporator. The dried residue was re-weighed and then redissolved with solvent (ethanol: toluene) for a final concentration of 100.0 mg/ml (w/v) based on the dry weight of the residue.

2.2 Preparation of Extractive-Free Wood. ASTM Standard (D1105-96) was followed to prepare extractive free blocks of *T. grandis*, with some modifications. *Tectona grandis* was cut into 19×19×19 mm blocks in Mississippi (USA) with an electric saw. Conditioned blocks (33°C, 62±3% RH) were numbered and weighed prior to being placed in soxhlets and extracted for six hours using the ethanol: toluene (2:1) mixture. Blocks were then washed with ethanol to remove excess toluene and secondarily extracted for six hours in ethanol (95%) alone. Ethanol-extracted blocks were air dried overnight and then boiled for six hours in 3.0 litres of distilled water with water changes every hour.

2.3 Filter Paper Bioassay. Oven dried (60°C) Whatman No. 1 filter paper (42.5 mm diameter) was weighed and treated with five different concentrations (1.25, 2.5, 5.0, 7.5, and 10.0 mg/ml) of heartwood extractives. Concentrations were prepared from stock solution using ethanol-toluene as a solvent. Each filter paper was then treated with 200 µl of each solution concentration. Treatments were done in replicates of three along with a control treatment which was treated with ethanol: toluene alone. After treatment, filter papers were oven dried at 60°C for 12 hours and weight gain after treatment was calculated. A total of 50 termites (*H. indicola*) were released into jars containing 20 grams of sand, 3.6 ml water and treated filter papers, and maintained in an incubator at 27°C and 75% RH for fifteen days. At the end of the test, termite mortality was calculated by counting the number of live termites. Filter papers were cleaned, oven dried at 60°C for 12 hours, and weight loss was calculated. A vacuum desiccator was used to equilibrate the weight of filter paper after drying. Image J software (Developed by Wayne Rasband, Bethesda, Maryland) was used to calculate the area of filter paper consumed by the termites.

2.4 Repellency and Antifeedant Bioassays. We followed the method outlined by Kadir et al. (2014) to test for repellency. Whatman No.1 filter paper (9 cm in diameter) was sliced into two equal halves; one-half was treated with 1 ml of each concentration of extract and the second half was treated with solvent only (Fig.1). For the control treatment, one paper half was treated with solvent and other half with water. After drying under a fume hood, both halves (treated and control) were re-joined using adhesive tape that was placed on the underside of the two filter paper halves. The re-joined filter paper was then placed in a 9.1 cm diameter Petri plate and 50 active termites were released in the centre of the plate. Assessment of repellency was performed after 1, 2, 3, 4 and 12 h by counting a number of termites on treated and untreated filter paper. Percent repellency and antifeedancy were calculated using the method described by Hassan et al. 2016.
2.5 Choice and No-Choice Test of Extractive-Free Wood. Extracted and un-extracted *T. grandis* heartwood blocks were exposed to termites in choice and no-choice feeding tests according to the AWPA E-1 test (AWPA 2015). Screw top jars were filled with 150 grams sand along with 27 ml distilled water and held for two hours to equilibrate. For the no-choice test, extracted and un-extracted blocks were conditioned (33°C, 62±3% RH), weighed and placed on a small square of foil on top of the damp sand with one block in each jar. For the choice test, each jar contained one extracted and one un-extracted block. Each experiment used five replications. A total of 400 termites (396 workers and 4 soldiers) were released into each jar, which were kept in an incubator at 27°C/75±2% relative humidity for 28 days. After 28 days, the number of live termites was counted. Blocks were brushed to remove sand, conditioned for one week, and re-weighed to determine weight loss.

2.6 Termite Bioassay of Southern Pine and Cottonwood Treated With Extractives. Weighed and conditioned (33°C, 62 ± 3% RH) southern pine (SP) and cottonwood (CW) sapwood blocks (19×19×19 mm) were pressure treated with different concentrations (2.5, 5 and 10 mg/ml) of teak extractives. For controls, blocks were treated with solvent only (ethanol-toluene) or water. Blocks were pressure treated by placing five blocks in a 300 ml beaker containing the treatment solution in a vacuum-pressure chamber. Blocks were held under vacuum for 30 min and after that pressure was applied at 260 kPa (40 psi) for 60 minutes. After pressure treatment, blocks were blotted dry using paper towels, weighed, and re-conditioned at 33°C and 62±3% RH. The termite bioassay was conducted according to AWPA E1 with modifications as described in section 2.5.

2.7 Leach Resistance of Extractive Treated Southern Pine and Cottonwood Against Termites. In order to determine leaching of extractives from treated blocks, we followed the AWPA E11 standard with modifications. After conditioning, five blocks were submerged in 300 ml of deionized water (pH 7) in a 500 ml vessel and were subjected to vacuum to soak the blocks. The vessel was subject to mild agitation with water changes after 6, 24 and 48 hours then every 48 hours thereafter. The leaching process was continued for 14 days. No-choice tests against *H. indicola* were run according to the AWPA E1 standard. Wood weight loss and termite mortality was recorded after exposure to termites after 28 days. The bioassay method was the same as described in section 2.5.
2.8 Statistical Analysis. Probit analysis (Finney 1971) was used to calculate the lethal concentration (LC$_{50}$) of the extractives using the Polo-PC software. All other data was analysed using a one-way analysis of variance (ANOVA) to determine if there was any significant variation between treatments. A Student's t-test was used to separate mean termite mortality and weight loss of leached and un-leached wood blocks using MINITAB 17. All means were separated at the 5% significance level using the Tukey HSD test.

3. RESULTS AND DISCUSSION

The results for mortality, antifeedant and repellency tests against *H. indicola* are shown in Table 1.

Table 1: Mortality, antifeedant and repellent activity (± SE) of *T. grandis* heartwood extractives against *H. indicola*

<table>
<thead>
<tr>
<th>Conc. (mg/ml)</th>
<th>Mean (%) mortality ± S.E</th>
<th>Mean (%) repellency ± S.E.</th>
<th>Absolute coefficient of anti-feedancy (A %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.33 ± 0.33$^d$</td>
<td>5.60 ± 0.52$^d$</td>
<td>-</td>
</tr>
<tr>
<td>1.25</td>
<td>3.33 ± 0.88$^d$</td>
<td>21.66 ± 0.33$^c$</td>
<td>6.95 ± 0.50</td>
</tr>
<tr>
<td>2.50</td>
<td>59.00 ± 3.51$^c$</td>
<td>34.00 ± 2.00$^c$</td>
<td>15.3 ± 1.10</td>
</tr>
<tr>
<td>5.00</td>
<td>75.00 ± 0.33$^b$</td>
<td>58.00 ± 7.57$^b$</td>
<td>21.5 ± 0.99</td>
</tr>
<tr>
<td>7.50</td>
<td>80.66 ± 1.2$^b$</td>
<td>63.67 ± 1.33$^{ab}$</td>
<td>35.54 ± 0.11</td>
</tr>
<tr>
<td>10.0</td>
<td>95.33 ± 0.66$^a$</td>
<td>80.33 ± 2.4$^a$</td>
<td>76.93 ± 0.51</td>
</tr>
</tbody>
</table>

The data indicate that termite mortality is dependent on extractive concentration. All concentrations tested performed differently from one another except 5.0 and 7.50 mg/ml (F= 646.93; p < 0.005; df= 5, 12). Teak heartwood extractives showed antitermitic activity with an LC$_{50}$ of 3.21 mg/ml (n=50; $x^2$ =141.83; Slope ±SE = 2.53 ± 0.17; FL 95% = 2.99 – 3.4) after 15 days of exposure. The highest mortality rate (95.3%) was observed at an extract concentration of 10 mg/ml. Results also show that when exposed to filter paper treated with 1.25 mg/ml, 21.6% termites moved to untreated filter paper. As the concentrations increased fewer termites were observed to stay or move to the treated filter paper. Both the control treatment and the solvent treatment alone did not significantly repel termites. However, at the 10 mg/ml extractive concentration, most of the termites (80.3%) were present on untreated filter paper indicating the strong repellent activity of heartwood extractives. *Tectona grandis* heartwood extractives showed minimal to strong antifeedant activity at the different concentrations. The highest absolute coefficient of antifeedancy of 76.9% (very strong activity) was observed at the high extract concentration of 10 mg/ml. While the lowest absolute coefficient of antifeedancy of 7.0% (minimum activity) was observed at the lowest concentration of extractives (1.25 mg/ml) (Table 1).
Figure 2: Percentage of filter paper area consumption and weight loss (%) treated with different concentrations of *T. grandis* extractives after 15 days exposure to *H. indicola*.

At the end of the 15 day exposure time, the average consumption of filter paper was significantly lower compared to the controls (Fig. 2). Results showed a strong correlation between the amounts of filter paper consumed (area loss) and termite mortality. A maximum consumption (area loss) of 40.4% was observed in control treatments and a minimum consumption (11.9%) was recorded for the high extractive concentration of 10 mg/ml. There were statistically significant concentration effects on termite feeding ($F= 22.68; p < 0.005; df= 5, 12$). A parallel trend was observed for termite mortality and percent weight loss of filter paper. Minimum weight loss (1%) was found at the highest concentration (10 mg/ml) where there was maximum termite mortality (Fig. 2). Area loss was greater than weight loss as we counted area loss as area where the termites had just grazed the surface without eating all the way through the filter paper.

The heartwood of *T. grandis* is well known for its natural resistance to biodegradation and this natural durability is largely due to the presence of quinones in the heartwood (Lukmandaru and Takahashi 2009, Niamke *et al.* 2011). Recent reports on the environmental impacts of plantation teak production indicate that wood durability can differ due to site of origin (Haupt *et al.* 2003) and stand management practices (Bhat and Florence 2003). Although the origin and growth characteristics of wood were not considered, extraction yield was calculated per gram of wood shavings (Ordonez *et al.* 2006) and the mean extractive content was 5.5%. Lukmandaru 2011 found 1.9-2.7% average ethyl acetate-soluble extractive and 1.8-3.7% n- hexane soluble contents from the heart wood of *T. grandis*. Bhat *et al.* (2010) found 9.7 to 13.1% in outer and inner portion of heartwood of *T. grandis* using ethanol as a solvent. This difference is probably due to solvent selection and solubility of extractives.

Results of our filter paper bioassay were similar to Dungani *et al.* (2012) who tested the effectiveness of various extractives of teak heartwood by using discs of treated filter paper against attack from the subterranean termite *Coptotermes curvignathus* and showed that
extractions in acetone: water (9:1) at a concentration of 2-10% were the most effective. Paper discs treated with ethanol, chloroform and acetone extractives of *T. grandis* heartwood under no-choice feeding tests showed limited feeding activity and increased toxicity to the subterranean termite, *Reticulitermes speratus* (Kolbe) (Ismayati et al. 2016). These and similar results have confirmed dose-dependent mortality of termites after feeding on teak extractive treated filter paper against *Incisitermes marginipennis* (Latreille), *Coptotermes gestroi* (Wasmann) and *H. indicola* (González et al. 2013, Se Golpayegani et al. 2014, Kadir et al. 2014, 2015, Hassan et al. 2016). Extractives of *T. grandis* were found to be lethal to termites due to the presence of quinones and tectoquinones (Sandermann and Simatupang 1966). Our results are also in agreement with Lukmandaru and Takahashi (2008) who found several repellent chemicals in the bark and heartwood of *T. grandis* to *R. speratus* (Kolbe). Anthraquinone (24%) was found to be the major chemical responsible for repellency to *Cryptotermes brevis* Walker after GC-MS characterization (Wolcott 1947). Other authors have also reported that quinones have repellent and toxic properties against termites (Ganapty et al. 2004, Dungani et al. 2012). The antifeedant activity of extractives obtained from *T. grandis* was 6 to 76.9%, which is similar to an earlier study on Purkwakarta teak extracts (Dungani et al. 2012).

Figure 3: Wood consumption (a) and mortality (%) (b) of *H. indicola* in choice and no-choice bioassay on extractive free wood.
Mortality and wood consumption rates from the bioassays using un-extracted and extractive-free wood of *T. grandis* are shown in Figure 3a-b. In the choice test, termites generally did not feed on the un-extracted wood, instead consuming more of the extracted wood (15.6%), while in the no-choice test weight losses for extracted wood were similar (13.5%) to the choice test. In the case of un-extracted wood, consumption was less than 1% in both the choice and no-choice tests after 28 days of exposure. Complete mortality (100%) was observed in the no-choice test with un-extracted wood while on extracted wood mortality was 76%. In no-choice test, exposure to the extracted and un-extracted wood resulted in a mortality of 74 and 100% respectively, while in choice test, where both extracted and un-extracted wood were offered together termite’s mortality was 77%.

Solvent and water extracted blocks of *T. grandis* wood resulted in a relatively high termite mortality. This indicates that the extractive removal efficiency of the solvent system we used was not complete in removing all toxic heartwood components. This durability may also be attributed to high wood density and hardness. Wood density can affect wood permeability, hence the solvents used may not have been able to remove all of the compounds sequestered in the heartwood. This is in agreement with Peralta *et al.* (2003) who deduced that wood density was an important factor of natural resistance of wood to termites. Natural resistance of wood could be attributed to hardness, extractive contents and specific gravity of wood (Arango *et al.* 2006). Previous studies show that there is a significant correlation between specific gravity, cellulose, density, hardness, total bioactive ingredients in wood and destruction of wood by *H. indicola* (Rasib *et al.* 2014). It has been suggested that an increase in density and specific gravity of wood is directly proportional to the resistance level. Similarly, hardness, lignin content and other bioactive ingredients also resulted in higher resistance; whereas cellulose content increased the feeding preference of *H. indicola*. It was also observed that *D. sissoo* and *S. cumini* were highly resistant to *H. indicola*, due to hardness and presence of natural bioactive compounds (Manzoor *et al.* 2009, Shanbhag and Sunararaj, 2013, Rasib *et al.* 2014, Afzal *et al.* 2017). Solubility of the extractives may have also affected the removal of the extractives from the wood. Results supporting this were found by Taylor *et al.* (2006) who observed that most extractives in the heartwood of *Thuja plicata* Donn ex D. Don and *Cupressus nootkatensis* D. Don were methanol soluble and their removal reduced the durability of those wood pieces to fungal decay and termite attack.

*Tectona grandis* heartwood extractives were lethal to termites at all concentration tested and caused 98.8% mortality of *H. indicola* at the maximum concentration (10 mg/ml) after feeding on treated southern pine. At the lowest concentration, mortality was 25.0% ($F= 2390, p < 0.05; df= 4, 20$; Fig. 4). A similar trend for termite mortality was found after feeding on cottonwood treated with extractives. At the maximum concentration (10 mg/ml), there was 100% termite mortality while at the lower concentrations, mortality was significantly lower ($F= 432.10, p < 0.05; df= 4, 20$; Fig 4). The average weight loss of treated and un-treated southern pine and cottonwood exposed to *H. indicola* is shown in Fig. 5. Solvent and water treated southern pine controls lost 28 and 25%, respectively, while cottonwood showed a weight loss of 42.5 and 42.2%, respectively for solvent and water treated blocks. At the highest concentration, weight loss of southern pine and cottonwood were reduced up to 3.6 and 3.5%, respectively.
Southern pine and cottonwood treated with *T. grandis* heartwood extractives did not show any significant difference in mortality of *H. indicola* after feeding on leached and un-leached samples. However, leached specimens of both southern pine and cottonwood became more susceptible to attack by *H. indicola* and there was a significant difference in weight losses of both woods after termite exposure (Table 2).
Table 2: Mean mortality of *H. indicola* and weight losses of Southern pine and Cottonwood after leaching and un-leaching tests of extractives.

<table>
<thead>
<tr>
<th>Wood species</th>
<th>Treatments</th>
<th>Mean Mortality (%)</th>
<th>Mean Weight Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Un-leached</td>
<td>Leached</td>
</tr>
<tr>
<td>SP</td>
<td>Solvent</td>
<td>24.73 ± 0.51</td>
<td>27.52 ± 0.92</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>27.10 ± 0.75</td>
<td>27.08 ± 0.85</td>
</tr>
<tr>
<td></td>
<td><em>T. grandis</em></td>
<td>93.98 ± 3.16</td>
<td>83.26 ± 3.79</td>
</tr>
<tr>
<td>CW</td>
<td>Solvent</td>
<td>34.95 ± 1.03</td>
<td>36.20 ± 2.29</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>31.84 ± 3.24</td>
<td>32.10 ± 5.07</td>
</tr>
<tr>
<td></td>
<td><em>T. grandis</em></td>
<td>79.58 ± 2.57</td>
<td>73.30 ± 12.2</td>
</tr>
</tbody>
</table>

*Wood species Treatments Mean Mortality (%) Un-leached Leached t p
Solvent 24.73 ± 0.51 27.52 ± 0.92 -3.47 NS 0.35
Water 27.10 ± 0.75 27.08 ± 0.85 0.01 NS 0.99
*T. grandis* 93.98 ± 3.16 83.26 ± 3.79 1.73 NS 0.15

<table>
<thead>
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<th>Mean Mortality (%)</th>
<th>Mean Weight Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Un-leached</td>
<td>Leached</td>
</tr>
<tr>
<td>SP</td>
<td>Solvent</td>
<td>25.37 ± 0.39</td>
<td>24.44 ± 1.05</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>26.81 ± 0.82</td>
<td>24.60 ± 0.47</td>
</tr>
<tr>
<td></td>
<td><em>T. grandis</em></td>
<td>5.53 ± 1.17</td>
<td>10.52 ± 0.58</td>
</tr>
<tr>
<td>CW</td>
<td>Solvent</td>
<td>35.52 ± 1.59</td>
<td>34.00 ± 1.16</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>37.53 ± 2.00</td>
<td>36.29 ± 1.08</td>
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<tr>
<td></td>
<td><em>T. grandis</em></td>
<td>7.36 ± 1.41</td>
<td>17.91 ± 2.08</td>
</tr>
</tbody>
</table>

Previous work has shown that the removal of extractives decreased the durability in different wood species (Agatha et al. 2012, Kirker et al. 2013). By pooling extractives from a durable species, this durability may be transferred and distributed more evenly into a non-durable species, such as southern pine or cottonwood. Utilization of extractives can also include non-marketable portions of the tree, which allows for more efficient utilization of the resource and a potential secondary value added product obtained from teak harvest. Thévenon et al. (2001) treated blocks of *Pinus sylvestris* L. with extractives of *T. grandis* and solutions of commercialized lapachol and tectoquinone and found protection of non-durable wood against fungi through these treatments. Similar results were also found by Tascioglu et al. (2012) who found minimum feeding and high termite mortality from mimosa and quebracho extract-treated scots pine at a 12% concentration level. In another study, Asamoah et al. 2011b treated five less used timber species in Ghana with the extractives of *T. grandis* and *Distemonanthus benthamianus* (Bonsamdua) and found that *D. benthamianus* extractives improved the durability of these woods more than *T. grandis*. The results of our study were also similar to Brocco et al. 2015. Theses authors treated *Pinus sp.* with *T. grandis* extractives in ethanol and hot water and showed treated wood to be resistant to feeding by *Nasutitermes corniger* Motschulsky. In our tests, leaching the specimens did not reduce resistance against *H. indicola* as there was no significant difference between mortality in termites on leached versus un-leached samples. However there was a significant difference in weight loss.
4. CONCLUSIONS

The results from our experimental assays indicates that *T. grandis* extractives could be a potential wood preservative against attack by *H. indicola*. Transferring durability using toxic *T. grandis* heartwood extractives to non-durable wood species improved the resistance against *H. indicola*. We showed that crude extracts had significant effects on termite mortality and feeding. Future studies should examine single extractive component isolates to determine if they are susceptible alone or act in synergy with other heartwood components. This would provide a more detailed understanding of the response of termites to teak extractives.

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6. REFERENCES


