Protection of Mahogany Wood (*Swietenia macrophylla* King) from Dry Wood Termite (*Cryptotermes cynocephalus* Light) Using Permethrin Dipping Treatment

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Abstract. Mahogany (*Swietenia macrophylla*) wood from community forests is widely utilised in construction and furniture manufacturing due to its aesthetic qualities and strength. However, its moderate natural durability (class II–III) makes it susceptible to dry-wood termite infestation. Preservative treatment is therefore required to enhance its resistance. Permethrin, a synthetic pyrethroid insecticide, demonstrates strong insecticidal properties and potential for wood preservation. This study investigated the effects of permethrin concentration and dipping duration on the protection of mahogany against dry wood termites (*Cryptotermes cynocephalus* Light). Mahogany samples (5 × 5 × 5 cm) were immersed in 36.8% permethrin solution. A completely randomised factorial design was employed to test two factors: permethrin concentration (0.5%, 1.5%, 2.5%) and dipping duration (1, 3, 5, 7 minutes). Following treatment, samples were air-dried and exposed to 50 termites in a glass tube for 30 days. Preservative absorption, retention, termite mortality, weight loss, and degree of wood damage were measured. Data were analysed using analysis of variance (ANOVA) at a 5% significance level. Permethrin concentration significantly affected absorption, while dipping duration influenced retention. No significant interaction was observed between the two factors. Treatment with 0.5% permethrin for 1 minute effectively protected mahogany from termite attack.

1 Introduction

Wood remains one of the most important renewable materials for construction and furniture, particularly in tropical regions where fast-growing species such as mahogany (*Swietenia macrophylla* King) are widely utilised. Mahogany is one of the most important tropical hardwood species widely utilised in furniture, construction, and interior applications due to its aesthetic appearance, dimensional stability, and moderate mechanical properties. In Indonesia, mahogany sourced from community forests has become a strategic raw material that supports the sustainability of the wood industry. However, its moderate natural durability

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(Class II–III) limits its resistance to biological deterioration, particularly against dry-wood termites [1, 2].

Dry-wood termites such as *Cryptotermes cynocephalus* Light are among the most destructive wood-deteriorating agents in tropical regions. Unlike subterranean termites, they attack wood without soil contact, making early detection difficult and causing gradual yet severe structural damage. Their infestation significantly reduces the service life, structural integrity, and economic value of wood products, especially under tropical climatic conditions favourable to termite activity [3]. Therefore, enhancing mahogany's durability through effective preservation treatments is essential to improving its long-term performance.

Wood preservation is a widely applied approach to protect wood against biological degradation. Among available techniques, the dipping (immersion) method is considered practical, cost-effective, and suitable for small- to medium-scale industries. This method allows preservative penetration into wood depending on factors such as exposure time, preservative concentration, and wood anatomical characteristics [4]. In the Indonesian context, integrating preservation with processing stages, such as drying, is critical to achieving optimal treatment efficiency, as emphasised by Listyanto [5], who noted that appropriate processing technologies significantly influence the success of wood protection strategies in tropical environments.

Permethrin, a synthetic pyrethroid insecticide, is widely recognised as an effective wood preservative due to its high insecticidal efficacy, relatively low mammalian toxicity, and greater environmental compatibility than conventional preservatives [6]. Its mode of action involves disruption of insect nervous systems, leading to paralysis and mortality. Previous studies have demonstrated its effectiveness in protecting wood from termite attack; however, its performance is strongly influenced by retention level, concentration, and treatment duration, which determine its distribution and persistence within the wood structure [7].

Despite the growing use of permethrin in wood protection, studies on mahogany treated by dipping methods, particularly against *Cryptotermes cynocephalus* Light, remain limited. Furthermore, there is a lack of comprehensive evaluation on the interaction between preservative concentration and immersion time, which are critical parameters influencing treatment effectiveness and practical applicability in tropical wood industries.

Therefore, this study aims to evaluate the effectiveness of permethrin-based preservation using the dipping method on mahogany wood in improving its resistance to dry-wood termite attack. The findings are expected to contribute to the development of efficient, practical, and scalable preservation technologies, supporting the sustainable utilisation of mahogany resources and enhancing the durability of wood products in tropical environments.

2 Material and Method

Mahogany (*Swietenia macrophylla* King) logs were harvested and processed into 1 m sections, from which sapwood was selected due to its higher susceptibility to termite attack. Test specimens were prepared into dimensions of 5 × 5 × 5 cm in accordance with the *Protocol for Assessment of Wood Preservatives*. A total of 36 specimens were assigned for preservative treatment and termite bioassay, along with 3 untreated controls. Additional samples measuring 2 × 2 × 2 cm were prepared to determine moisture content and density in accordance with the British Standards Institution [8]. All specimens were sanded to obtain smooth surfaces, and four surfaces (two transverse and two radial) were sealed using wood coating to control preservative penetration and simulate practical conditions. The specimens were then air-dried until reaching constant weight prior to treatment.

Permethrin-based preservative with an active ingredient concentration of 38.6% was used in this study. Three concentrations were prepared: 0.5%, 1.5%, and 2.5%, diluted in water. The dilution followed the equation:

$$M_1V_1 = M_2V_2 \quad (1)$$

where $M$is concentration and $V$is volume. Each solution was prepared to a final volume of 1000 mL.

Prior to treatment, all air-dried specimens were weighed to obtain the initial weight and measured for volume. The preservation treatment was conducted using a dipping method, in which specimens were immersed in preservative solutions at different concentrations for 1, 3, 5, and 7 minutes, respectively. To ensure uniform penetration, all specimens were fully submerged using weights. After treatment, the specimens were removed, wiped to eliminate excess solution, and reweighed to determine the amount of preservative absorbed.

To simulate long-term field performance, treated specimens underwent accelerated weathering per ASTM D 1413 [9]. This involved cyclic oven drying at 49°C for 24 hours, followed by immersion in distilled water for 2 hours, repeated for 2 weeks, and then air-drying for 48 hours prior to further testing.

The resistance of treated wood against drywood termites (*Cryptotermes cynocephalus* Light) was evaluated using a laboratory bioassay. A glass tube (2.5 cm in diameter and 4 cm in height) was attached to the uncoated surface of each specimen to confine termite activity. Each specimen was exposed to 50 drywood termites and maintained in a controlled, dark environment to simulate its natural habitat. Termite mortality was recorded daily over a 30-day period, and dead individuals were removed regularly to prevent cannibalism. The specimens were weighed before and after exposure to determine weight loss as an indicator of feeding damage.

Several parameters were evaluated to assess preservative performance, including absorption, retention, termite mortality, weight loss, and degree of damage. Absorption was calculated as the amount of preservative solution absorbed per unit volume immediately after treatment, while retention represented the amount of active preservative remaining in the wood after treatment. Termite mortality was expressed as the percentage of dead termites relative to the initial number introduced. Weight/mass loss was calculated as the difference between the specimen's weight before and after termite exposure, and the degree of damage was determined relative to untreated controls, allowing classification of resistance levels.

The experiment was arranged in a completely randomised factorial design with two factors: preservative concentration (0.5%, 1.5%, and 2.5%) and dipping time (1, 3, 5, and 7 minutes). Untreated specimens served as controls. Statistical analysis was performed using two-way analysis of variance (ANOVA) to evaluate the effects of concentration, dipping duration, and their interaction on all measured parameters. When significant differences were observed, Tukey's honestly significant difference (HSD) test was used for multiple comparisons at the 5% significance level.

3 Results and Discussion

3.1 Absorption

The absorption results indicate a clear increase with increasing permethrin concentration. The graph demonstrates a clear and consistent increase in wood absorption (kg m^{-3}) with increasing permethrin concentration (Fig. 1). At a concentration of 0.5%, the absorption is 1.179 kg m^{-3}, which increases to 1.353 kg m^{-3} at 1.5%, and reaches 1.679 kg m^{-3} at 2.5%. This rising trend indicates a strong positive relationship between preservative concentration and the amount of solution absorbed by the wood. This behaviour is expected because higher concentrations increase the availability of active ingredients in the treating solution, thereby

enhancing the diffusion gradient and facilitating deeper penetration into the wood's porous structure, including vessels, fibres, and cell lumens.

The ANOVA analysis supports this observation. The results indicate that concentration has a significant effect on absorption at the 5% significance level ($p < 0.05$). This means that variations in concentration lead to statistically significant differences in absorption values. In contrast, the dipping duration (immersion time) has no significant effect, and the interaction between concentration and dipping time is also not significant. This suggests that within the range of immersion times tested, the wood reaches a near-equilibrium state of absorption relatively quickly, and extending the dipping duration does not substantially increase preservative uptake. Therefore, the absorption process appears to be primarily influenced by concentration rather than time.

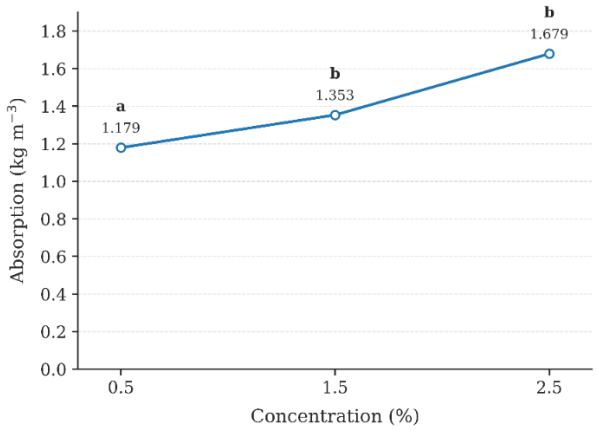

Fig. 1. Absorption of permethrin in three concentrations. Different lowercase letters above the data points indicate statistically significant differences among concentrations ($p < 0.05$), whereas the same letter indicates no significant difference.

This finding is consistent with previous research [5] on wood preservative systems, which highlights that chemical concentration is one of the most critical factors influencing retention and penetration, especially in non-pressure treatments. Similarly, a previous study reports that fluid movement in wood is largely influenced by capillary action and permeability, which dominate the initial stages of liquid uptake, whereas prolonged exposure contributes only a marginal increase in absorption once the accessible void spaces are filled [10]. Furthermore, studies on dipping and soaking treatments report that increasing preservative concentration significantly improves retention, whereas extending treatment time often yields diminishing returns [11,12].

The lack of a significant interaction effect between concentration and dipping time further indicates that the influence of concentration is independent and dominant. In other words, increasing concentration consistently improves absorption regardless of immersion duration, whereas increasing dipping time alone has no meaningful effect. This reinforces the idea that the process is diffusion- and permeability-driven rather than time-dependent.

These results show two key points about the dipping method for wood preservation. Immersion time does not affect absorption, so treatment can be shorter. Optimising preservative concentration is the main way to improve performance. This approach benefits industry and field use by reducing processing time, labour, and costs while maintaining high preservative uptake.

3.2 Retention

Preservative retention increases progressively with longer dipping times. The graph (Fig. 2) demonstrates that retention (kg m^{-3}) generally rises with increased immersion duration. At 1 minute, retention is 0.514 kg m^{-3}, increasing sharply to 0.767 kg m^{-3} at 3 minutes. Retention rises slightly to 0.788 kg m^{-3} at 5 minutes and further to 0.993 kg m^{-3} at 7 minutes. These results indicate that extended immersion enhances preservative retention in wood, although the rate of increase is not strictly linear.

Mechanistically, this behaviour reflects time-dependent diffusion and capillary absorption processes within the wood. During the initial immersion period (1–3 minutes), the wood rapidly absorbs the preservative solution due to strong capillary forces and the presence of empty lumens and void spaces. This accounts for the substantial increase in retention between 1 and 3 minutes. Between 3 and 5 minutes, the increase is not significant, indicating that easily accessible voids are nearing saturation. The continued increase up to 7 minutes suggests that additional preservative is retained through slower diffusion into less accessible regions, such as smaller capillaries and, to a lesser extent, cell walls.

The analysis of variance results are consistent with these findings. Dipping time significantly affects retention ($p < 0.05$), demonstrating that immersion duration influences preservative uptake. Concentration does not significantly affect retention, and there is no interaction between concentration and dipping time. Within the tested concentration range, the amount of preservative retained depends on exposure duration rather than solution concentration. Thus, retention is primarily time-dependent rather than concentration-driven.

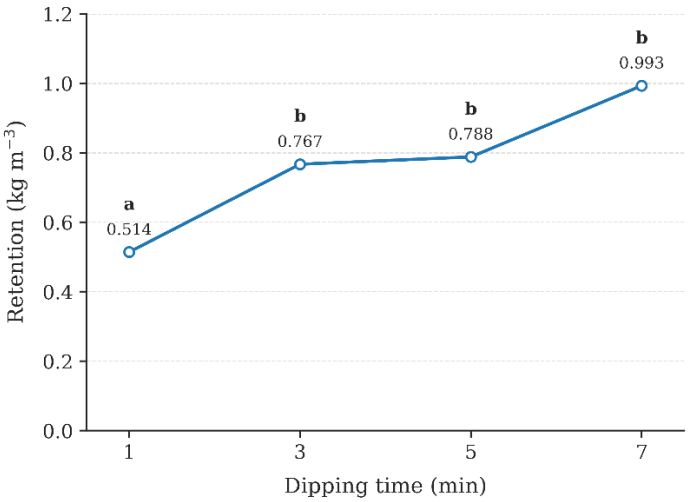

Fig. 2. Retention of permethrin in four dipping times. Different lowercase letters above the data points indicate statistically significant differences among dipping times ($p < 0.05$), whereas the same letter indicates no significant difference.

This finding supports previous research on non-pressure wood preservation methods. Longer dipping times significantly increase chemical retention, particularly in permeable wood species [11]. Concentration can influence surface deposition, retention within the wood matrix is primarily governed by treatment duration, thereby enabling deeper preservative penetration and fixation [12]. Preservative diffusion into wood is time-dependent, especially as the mode of transport shifts from bulk flow in large voids to slower transport within microcapillaries and cell-wall regions [10].

The consistent absence of an interaction effect indicates that dipping time is the primary determinant of preservative retention across all concentrations. Increasing immersion time consistently improves retention, whereas higher concentration alone does not enhance retention unless adequate time is provided. Therefore, treatment duration is the principal factor influencing preservative loading.

From a practical and industrial perspective, these results underscore the importance of optimising dipping duration to achieve sufficient retention levels. Increasing concentration does not substantially improve retention, whereas extending dipping time offers a more reliable method for enhancing preservative uptake. The diminishing rate of increase observed between 3 and 5 minutes suggests an efficiency threshold, beyond which additional time results in marginal gains. Selecting an optimal dipping time of 5 to 7 minutes in this context may balance treatment effectiveness with processing efficiency.

3.3 Termite Mortality and Mass Losses

The biological performance of the treatment was evaluated based on mass loss and termite mortality. The treated samples showed no measurable mass loss, corresponding to 100% termite mortality. This indicates that the permethrin treatment was highly effective in preventing drywood termite feeding activity.

The results clearly demonstrate a strong effect of the preservative treatment on termite-induced mass loss. The treated samples showed no measurable mass loss, indicating that mass loss was effectively prevented. This outcome is directly associated with the 100% mortality of termites observed in the treated specimens, confirming that the permethrin treatment provided complete protection against termite feeding activity. Since drywood termites were unable to survive, no wood consumption occurred, and consequently, the structural integrity and mass of the wood remained unchanged.

In contrast, the control samples exhibited a measurable mass loss of 0.16 g with a standard deviation of 0.03 g. This indicates that in the absence of preservative treatment, termites actively fed on the wood, resulting in material degradation. The relatively low standard deviation suggests that the mass loss was consistent across replicates, reflecting uniform susceptibility of the untreated wood to termite attack. Although the absolute mass loss appears relatively small, it is significant in the context of short-term laboratory testing, as it represents the early stage of biodeterioration that would likely increase with prolonged exposure.

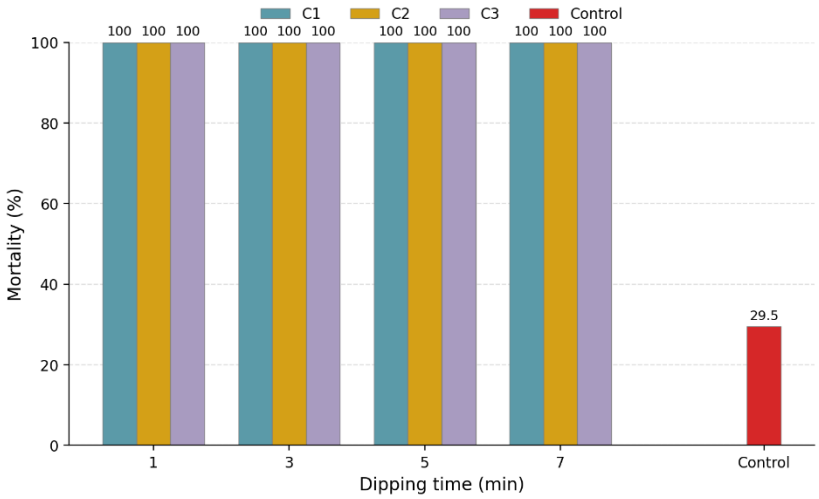

Fig. 3. Termite mortality in various concentrations and dipping times. Symbol of C1, C2, and C3 in the legend above the bar represent preservative concentration levels of 0.5%, 1.5%, and 2.5%, respectively.

From a biological and toxicological perspective, this difference underscores permethrin's effectiveness as a synthetic pyrethroid insecticide. Permethrin acts as both a contact and stomach poison. It disrupts sodium channel function in the insect nervous system, leading to paralysis and rapid death. As a result, feeding activity is immediately inhibited when termites are exposed to treated wood. This mechanism is well documented in wood protection studies. High termite mortality is directly correlated with negligible mass loss in treated specimens.

These findings are strongly supported by previous international studies. Pyrethroid-treated wood led to near-complete termite mortality [13]. They also found that such treatment effectively eliminated feeding damage, as indicated by minimal or zero mass loss. Similarly, effective termiticides significantly reduced termite wood consumption [14]. Treated samples showed negligible mass loss compared to untreated controls. In another study, wood treated with insecticidal preservatives exhibited significantly lower mass loss [9]. This was attributed to the rapid onset of toxic effects in termites. In contrast, untreated samples experienced substantial degradation. Furthermore, mass loss is a reliable quantitative indicator of termite resistance. Lower values indicate higher preservative efficacy.

The observed mass loss in control samples (0.16 ± 0.03 g) is consistent with findings from laboratory bioassays such as ASTM D3345. In these tests, untreated wood typically shows measurable degradation due to active termite feeding. The consistency of mass loss (low standard deviation) further indicates stable test conditions. It also suggests that termite activity was uniform across samples.

4 Conclusion

The findings indicate that permethrin-based preservation through the dipping method is highly effective in increasing the resistance of mahogany wood (*Swietenia macrophylla* King) to dry-wood termite (*Cryptotermes cynocephalus* Light) attack. The results confirm that preservative concentration and dipping duration show important roles in determining treatment efficacy.

Permethrin concentration emerged as the primary factor influencing absorption, with higher concentrations significantly enhancing the uptake of preservative solution into the

wood structure. Conversely, dipping duration was the dominant factor affecting retention, reflecting the time-dependent diffusion and fixation processes within the wood matrix. The lack of a significant interaction effect indicates that both factors operate independently, enabling flexible optimisation of treatment parameters for practical applications.

Biological assessment demonstrated complete protection, as evidenced by 100% termite mortality and zero mass loss in all treated specimens. These results confirm the high efficacy of permethrin as a termiticide, which effectively inhibits termite feeding and preserves the structural integrity of the wood. In contrast, untreated samples showed measurable degradation, emphasising mahogany's vulnerability to termite attack.

The results indicate that a low concentration (0.5%) combined with a short dipping duration (1 minute) is sufficient to achieve optimal protection. This demonstrates that the dipping method is both effective and highly efficient, offering advantages such as reduced chemical usage, shorter processing times, and lower operational costs. Such efficiency is particularly relevant for small- to medium-scale wood industries in tropical regions.

These findings provide a scientific basis for the application of permethrin dipping treatment as a practical, scalable, and cost-effective wood preservation strategy. The results contribute to improved mahogany durability and support its sustainable use in the construction and furniture industries. Future research should address long-term field performance, environmental impacts, and integration with other wood processing technologies to further enhance treatment effectiveness and industrial applicability

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