

# EFFICACY OF SELECTED FIRE-RETARDANT CHEMICALS AS WOOD PRESERVATIVES AGAINST SUBTERRANEAN TERMITES (*COPTOTERMES CURVIGNATHUS*) ON *HEVEA BRASILIENSIS*

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Submitted March 2025; accepted July 2025

Fire retardants such as boric acid, Dricon, and others chemical compound are commonly used to reduce the risk of fire in woody materials and structures. By incorporating such multifunctional compounds, manufacturers can enhance product safety while simultaneously cutting down on production expenses. This approach not only improves the overall quality of the materials but also leads to more sustainable practices in the industry. However, these fire retardants also need to provide protection against other destructive agents such as fungi and insects, including termites. Thus, making wood protection more comprehensive and cost-effective. In order to study the potential of fire-retardant chemicals as wood preservatives, boric acid (BA), diammonium phosphate (DAP), Dricon, and monoammonium phosphate (MAP) at various concentrations (15, 20, and 30 concentrations in % w/w solvent-water) were evaluated as termiticides in Malaysian conditions. All treated samples were then subjected to termite resistance tests according to American Society for Testing and Materials (ASTM) D3345 method using a subterranean termite, *Coptotermes curvignathus* (Rhinotermitidae: Isoptera). The results indicated significant variations in the efficacy of each chemical, with certain concentrations demonstrating superior performance in both repelling and eliminating termite populations. The results indicated varying degrees of efficacy, suggesting that certain concentrations could indeed serve dual purposes as both fire retardants and wood preservatives in protecting against termite infestations. Higher termite mortalities were seen in the wood specimens treated with the fire retardants when compared to the control specimens (*Hevea brasiliensis*). Boric acid and Dricon have great potential as wood preservatives against termites in addition to be used as fire-retardant materials. However, MAP and DAP protected specimens well against termite attack at higher concentration levels tested.

Keywords: Boric acid, dricon, diammonium phosphate, monoammonium phosphate, antitermiticides, *Coptotermes curvignathus*

## INTRODUCTION

Wood is a naturally renewable and structurally versatile material. It holds significant importance in global construction, offering benefits such as a low carbon footprint and aesthetic appeal (He et al. 2025). However, its inherent organic composition renders it susceptible to biotic and abiotic degradation, presenting considerable challenges to its long-term durability in built environments. A primary threat to timber structures worldwide is posed by subterranean termites, which are estimated to cause global economic damage exceeding USD32 billion annually (Liiv et al., 2024), with costs reported at USD40 billion in 2010 by subterranean species alone (Rust & Su 2012). Concurrently, fire incidents continue to represent a severe hazard, necessitating robust thermal protection for lignocellulosic materials in construction.

Consequently, enhancing both the fire resistance and biological durability of wood is paramount for sustainable building practices.

The use of fire-retardant chemicals (FRCs) is a well-established strategy to mitigate the flammability of wood and wood-based composites. These materials function through various mechanisms, including the formation of insulating char layers, dilution of flammable gases, and endothermic reactions that absorb heat (Depczynska & Burawska 2025, Maake et al. 2025). Common FRCs, such as intumescent paints, fabric-based systems, and various salt-based compounds such as phosphorus, nitrogen and boron have demonstrated significant improvements in fire development rate, heat release, and smoke production in laboratory and simulated real-world scenarios (Machado

et al. 2025, Yasar et al. 2024). Despite extensive research on their thermal performance, a comprehensive understanding of the dual efficacy of these FRCs—specifically their capacity to simultaneously deter biological pests like termites, remains underexplored.

Subterranean termites such as *Coptotermes curvignathus* (Family Isoptera) prevalent in Southeast Asia, and *Reticulitermes* species globally are eusocial insects. They primarily consume cellulose, hemicellulose, and lignin, leading to severe structural compromise in timber elements (Liiv et al. 2024, Miyafuji & Minamoto 2025). Traditional chemical treatments have long been employed to combat termite infestations. Historically, chromated copper arsenate (CCA) was widely utilised for its broad-spectrum protection against decay and insects. However, due to significant environmental concerns, including the leaching of heavy metals like arsenic and copper, and associated human health risks, its use has been substantially curtailed (He et al. 2025, Liiv et al. 2024, Miyafuji & Minamoto 2025). This regulatory shift has underscored an urgent need for safer, yet equally effective, multi-functional wood preservatives. While other conventional biocides such as organophosphate have been effective, their environmental persistence and toxicity remain concerns, prompting a search for more benign alternatives.

Intriguingly, certain FRCs possess inherent properties that suggest potential antitermitic activity. For instance, boron compounds, widely recognised for their fire-retardant capabilities, are also known to exhibit insecticidal and fungicidal properties by affecting the nervous system of insects (Lank & Wahl 2014, Depczynska & Burawska 2025). Similarly, some formulations of diammonium phosphate (DAP) and monoammonium phosphate (MAP), primarily used as fire retardants, have shown varying degrees of effectiveness against biological degradation, although often less pronounced than borates (Depczynska & Burawska 2025). Emerging technologies, such as the use of ionic liquids and nanotechnology-derived materials, are being explored for their potential to impart both fire and pest resistance. For example, specific PF6-based ionic liquids have demonstrated both enhanced fire resistance and significant toxicity or feeding deterrence against termites (Miyafuji & Minamoto 2025). Similarly, advancements in

nanotechnology have introduced strategies like quaternary ammonium compounds (QACs) combined with nanoparticles, demonstrating broad-spectrum antimicrobial efficacy that could potentially extend to insect deterrence (He et al. 2025).

Despite these promising indications, a critical knowledge gap exists in the integrated assessment of FRCs for both fire and termite protection. Much of the existing literature on FRCs tends to have a singular focus, primarily evaluating their performance against flammability characteristics (Machado et al. 2025, Yasar et al. 2024). Reviews on FRCs often highlighted their fire-retardant mechanisms and impact on mechanical properties (Depczynska & Burawska 2025), or focused on their application in specific composite materials for fire performance (Maake et al. 2025), without systematically quantifying their concurrent efficacy as termiticides. This narrow scope neglects the potential for synergistic, multi-functional materials that could provide holistic protection for building structures.

Therefore, this study was designed to investigate the dual-purpose efficacy of common fire-retardant chemicals—boric acid, Dricon, monoammonium phosphate, and diammonium phosphate—in enhancing the durability of solid rubber wood (*Hevea brasiliensis*) against subterranean termites (*Coptotermes curvignathus*) under laboratory conditions. The primary objective is to determine if these FRCs can offer significant protection against termite infestation, thus filling a critical gap in the understanding of their comprehensive performance. It is hypothesised that these chemicals may deter termites through mechanisms such as direct chemical toxicity, alteration of wood palatability, or the formation of a physical barrier within the wood structure, thereby offering a cost-effective and environmentally favorable multifunctional treatment for wood in construction.

## MATERIALS AND METHODS

### Materials preparation

Rubber wood (*Hevea brasiliensis* Müll. Arg.) specimen blocks of measuring 19 × 19 × 19 mm were cut from the basal section and conditioned to a moisture content of approximately 12% prior to treatment. The wood samples were treated with each fire retardant chemical: boric

acid (BA-H<sub>3</sub>BO<sub>3</sub>), diammonium phosphate DAP-(NH<sub>4</sub>)<sub>2</sub>HPO<sub>4</sub>, dricon, and monoammonium phosphate MAP-(NH<sub>4</sub>H<sub>2</sub>PO<sub>4</sub>) at three different concentrations (15%, 20%, and 30%) according to the method by Mohamad Nasir et al. (2019) using the Bethel method (full cell pressure). The untreated sample (0%) served as a control. Five replicates were used for each chemical and each concentration, including the untreated sample. Retention of the preservatives was calculated based on the difference in weight before and after the treatment process using the following formula:

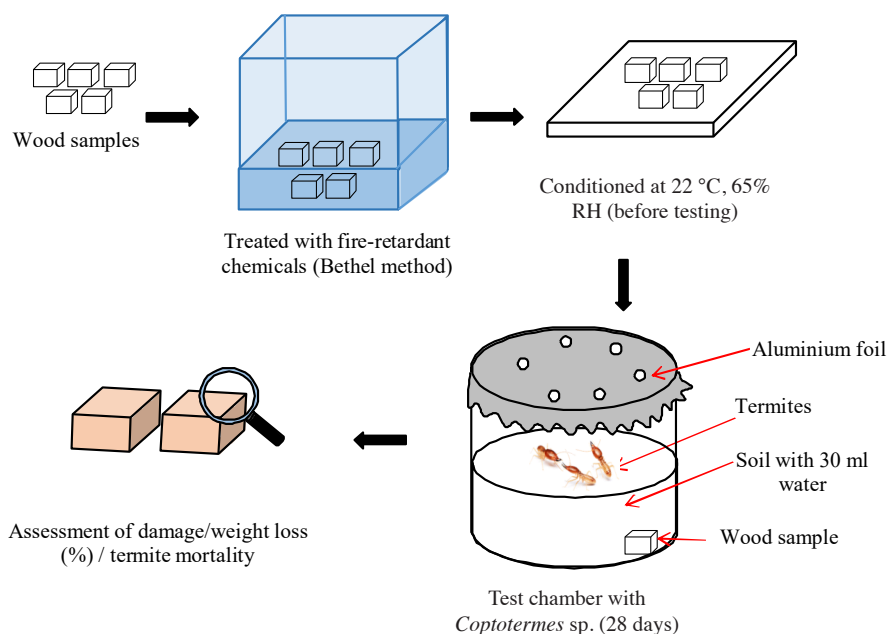
$$\text{Retention (\%)} = \frac{\text{Initial weight (Wi)} - \text{Weight after (Wa)}}{\text{Valume}} \times \text{Solution concentration} \quad (1)$$

### Bioassay termite test

The termite bioassays were performed according to the no-choice test procedure of ASTM D3345 (2017) standard methods with slight modifications. *Coptotermes curvignathus* Wasmann (soldiers and workers) were collected from an active colony infesting *H. brasiliensis* logs placed around the Forest Research Institute Malaysia (FRIM) campus. The log was cut up and brought

to the laboratory to isolate the termites according to their caste (soldiers and workers). All termites were conditioned for two days prior to testing to minimise stress.

Two hundred grams (200 g) of sterilised sand and 30 ml of distilled water were placed in a screw-capped test bottle (8 cm diameter and 13 cm high) and left overnight to equilibrate to laboratory conditions before the test began. In addition, for each treatment, a block was placed in the bottom corner of the test bottle and covered with moist sand, 400 active termites, consisting of 360 individual workers and 40 individual soldiers, were placed in each bottle. All bottles were stored for 28 days in an incubator at 22 ± 2 °C and 65 ± 5% relative humidity. At the end of the fourth week, the blocks were removed, cleaned, dried overnight, and weighed again. Each replicate sample was visually scored using the standard rating system (0 = failure, 4 = very severe attack, 6 = severe attack, 7 = moderate/severe attack with penetration, 8 = moderate attack, 9 = slight attack, 9.5 = trace, and 10 = sound/no attack), concurrently with the weight loss measurements, to evaluate the extent of termite damage to the wood specimens. The process from wood treatment to the final termite bioassay testing is illustrated in Figure 1.



**Figure 1** Schematic representation of the experimental procedure, from wood treatment through to termite bioassay testing

## Statistical analysis

A one-way analysis of variance (ANOVA) was performed using MINITAB 15 software to test for differences in termite resistance between the chemicals used. The mean values were separated at the 95% significance level of the least significant difference (LSD) test.

## RESULTS AND DISCUSSION

### Retention level of fire retardant chemicals

Table 1 presents the comparative retention rates of four fire retardant chemicals (boric acid, Dricon, DAP, and MAP) at three different concentrations applied to *Hevea brasiliensis* wood. Boric acid showed the highest retention at all

wood and the characteristics of the chemical solution. Dricon, although also containing boric acid, includes other additives such as guanyl urea phosphate, which may slightly inhibit borate uptake due to formulation complexity. Meanwhile, DAP and MAP, with phosphate-based structures, may face limitations in wood absorption due to their molecular size and reactivity with cell wall components. The higher concentration facilitating increased retention is a well-established phenomenon in preservative treatment, enhancing chemical uptake through stronger osmotic gradients (Kartal et al. 2009).

### Termite bioassays

The effectiveness of materials that can provide protection against termite infestation is based on

**Table 1** Retention of four fire retardant chemicals

Concentration (% w/v)	Chemical (%)			
	Boric acid	Diammonium phosphate	Dricon	Mono-ammonium phosphate
15	5.21 (1.6)a	4.89 (2.2)bc	5.11 (0.6)ab	4.65 (0.9)c
20	6.78 (3.0)a	5.06 (1.1)c	5.84 (1.8)b	4.46 (2.2)d
30	8.73 (2.3)a	6.39 (0.5)b	6.32 (1.8)b	5.21 (1.1)c

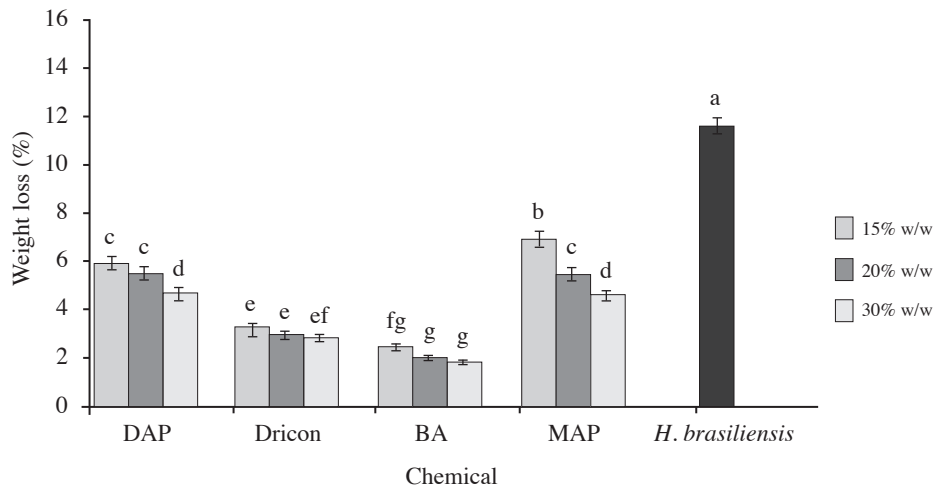
Mean of 5 replicates for each species.

concentrations (5.21% at 15% w/v, 6.78% at 20% w/v, and 8.73% at 30% w/v, respectively), while MAP exhibited the lowest retention values (4.65%, 4.46%, and 5.21% respectively). The results indicate a consistent trend across all treatments: an increase in chemical concentration corresponded with an increase in retention level. This pattern aligns with previous findings by Roszaini et al. (2024), who observed similar trends using Hartindo AF21 on *H. brasiliensis* and *K. malaccensis*. The general retention trend was BA > Dricon > DAP > MAP.

The variation in chemical retention levels can be attributed to differences in solubility, molecular weight, and chemical composition. Boric acid, being a small and highly water-soluble molecule, demonstrates strong penetrability and absorption into the porous wood structure, leading to higher retention values. As supported by Yildiz et al. (2010), retention performance is often linked to the permeability of the

the percentage weight loss of the samples. The lower the percentage of weight loss, the better the resistance of the samples against termites.

The termite bioassay results (Figure 2) indicate that boric acid (BA) consistently conferred the highest resistance to *Hevea brasiliensis* against *Coptotermes curvignathus* attack, as demonstrated by the significantly lower percentage of weight loss across all tested concentrations (ranging from 2.41% to 1.80%). In contrast, MAP-treated samples showed the highest weight loss (6.92% to 4.57%), indicating lower effectiveness. The performance order observed was BA > Dricon > DAP > MAP. This marked difference can be attributed to the chemical composition, mode of action, and retention behavior of each treatment. Boric acid is a well-documented, broad-spectrum wood preservative known for its effectiveness against both fungi and insects (Lloyd et al. 2001). Its high efficacy stems from its ability to disrupt termite metabolic and digestive



**Figure 2** Inhibition of *C. curvignathus* feeding by treatment of *H. brasiliensis* with various fire-retardant chemicals

processes by inhibiting enzyme activity in the gut and interfering with nutrient absorption (Grace & Yamamoto 1994). Furthermore, BA is non-repellent, allowing termites to ingest the treated material, which leads to gradual toxicity, especially in higher concentrations (Farid et al. 2015).

Boric acid's high retention in *H. brasiliensis* (8.73% at 30% w/v) contributes directly to its superior protective capacity. Unlike some other fire retardants, boric acid penetrates deeply and distributes uniformly within the wood matrix, making it more bioavailable to termites (Kozłowski & Przybylak 2001). Its relatively simple molecular structure and solubility in water aid in even distribution during impregnation, which enhances its protective persistence even under environmental stress.

Dricon, though less effective than pure BA, still performed well, which can be explained by its boron content (27–33% boric acid) combined with guanyl urea phosphate. The additional phosphorus component may improve fire retardancy but does not contribute significantly to insecticidal properties. However, the boron content still plays a primary role in termite toxicity (Syed Norridzuan 2000, Kartal et al. 2004). Previous studies have shown that termite species and wood species interactions significantly affect feeding behavior (Iqbal et al. 2015, Grace 1991), which may explain the higher chemical concentrations required in this study to achieve similar protection levels as reported by Evren et al. (2011). The slightly reduced performance

compared to BA may be due to the complex formulation, potentially limiting boron's bioavailability.

DAP and MAP, both inorganic phosphate-based flame retardants, demonstrated limited protective effects against termites. While DAP showed moderate resistance, MAP showed the weakest performance overall. This outcome supports earlier findings (Evren et al. 2011, Iqbal et al. 2015), where both chemicals were reported to be less toxic to termites. These compounds primarily function as fire retardants and lack strong insecticidal properties. Furthermore, their molecular size and bonding behavior may restrict deep wood penetration, reducing long-term efficacy (Grace 1991). It is also plausible that MAP's lower pH and chemical structure are less harmful to termites, allowing them to continue feeding and survive longer, as reflected in both the weight loss and mortality data.

Moreover, species-specific termite behavior and interaction with different wood substrates may explain variability across studies. *C. curvignathus* might exhibit different feeding patterns compared to *C. formosanus*, as suggested by Iqbal et al. (2015), which could influence the extent of damage across chemically treated samples. This species-dependent response further highlights the importance of localised testing under Malaysian conditions to ensure relevance and reliability.

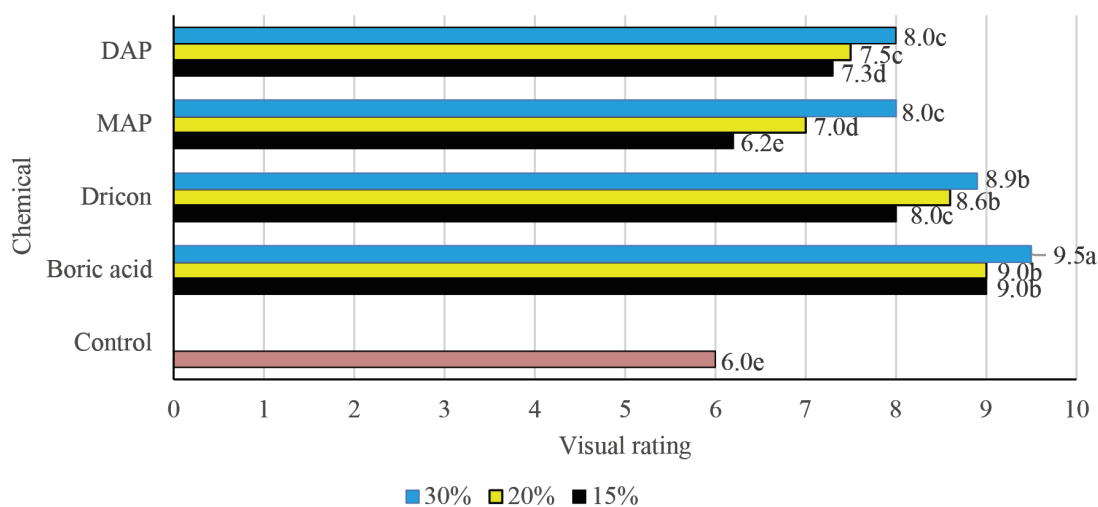
While the results of the visual rating/assessment of samples cannot be used as the main decision in determining the resistance

of wood to termites, they can help to better understand the resistance of a wood species. Visual data evaluation can be used in addition to statistical tests to determine a reliable distribution (Brischke et al. 2023). The visual assessment results obtained in this study are consistent with the weight loss of the samples. The *H. brasiliensis* samples treated with BA obtained a significantly higher visual rating (9.0 to 9.5) at all tested concentrations compared to the other treatments (Figure 3). According to the visual rating based on ASTM D3345 (2017), this infestation is categorised as a light attack or only superficial bites are allowed. Meanwhile, the samples of *H. brasiliensis* treated with MAP showed a lower visual rating (6.2 to 8.0) for treated samples, which was categorised as moderate attack with penetration. The results showed that an increase in chemical concentration improved *H. brasiliensis* resistance to termites based on mass losses and visual observations. Statistical analysis indicated that *H. brasiliensis* treated with BA

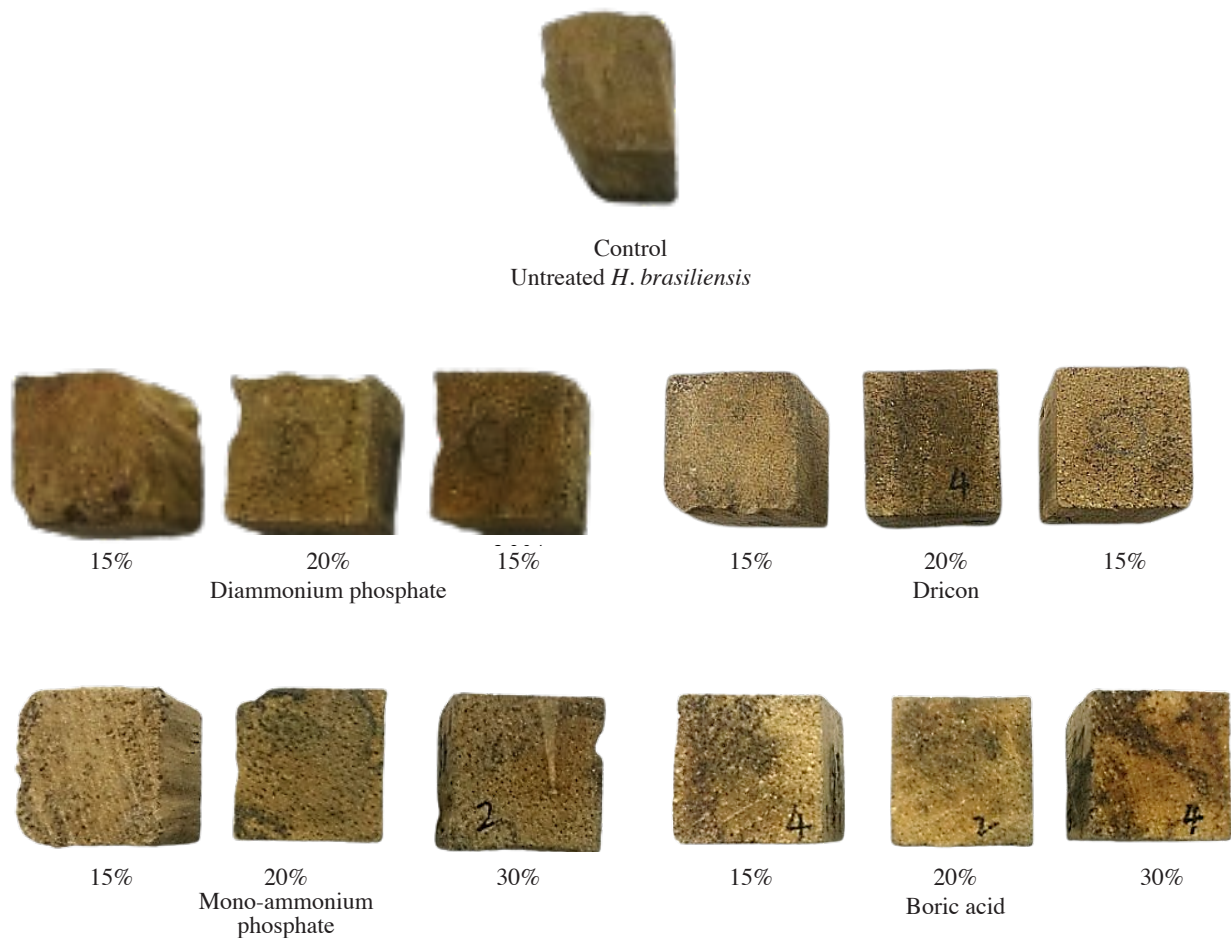
highly significantly reduced the weight loss ( $F = 68.97, df = 4, P < 0.001$ ) of the specimens after attack by the subterranean termite compared to treated with DAP ( $F = 15.47, df = 4, P < 0.001$ ).

Figure 4 shows the general appearance of the treated *H. brasiliensis* specimens after 28 days of exposure to *C. curvignathus*. The untreated and DAP-treated woods showed heavy infestation, MAP-treated samples showed moderate infestation with surface nibbles, while BA and Dricon-treated samples showed only superficial bites or almost no infestation.

Overall, the significantly lower wood weight loss observed with BA treatment confirms its dual functionality as both a fire retardant and a potent termite control agent, making it highly suitable for tropical applications. The consistent relationship between retention level, weight loss reduction, and termite mortality underpins its superior performance, especially at elevated concentrations.



**Figure 3** Average visual rating in laboratory test of untreated and treated *H. brasiliensis* with different concentration levels of fire-retardant chemicals, against *C. curvignathus*



**Figure 4** Inhibition of *C. curvignathus* feeding by treatment of *H. brasiliensis* with various fire-retardant chemicals

### Termite mortality

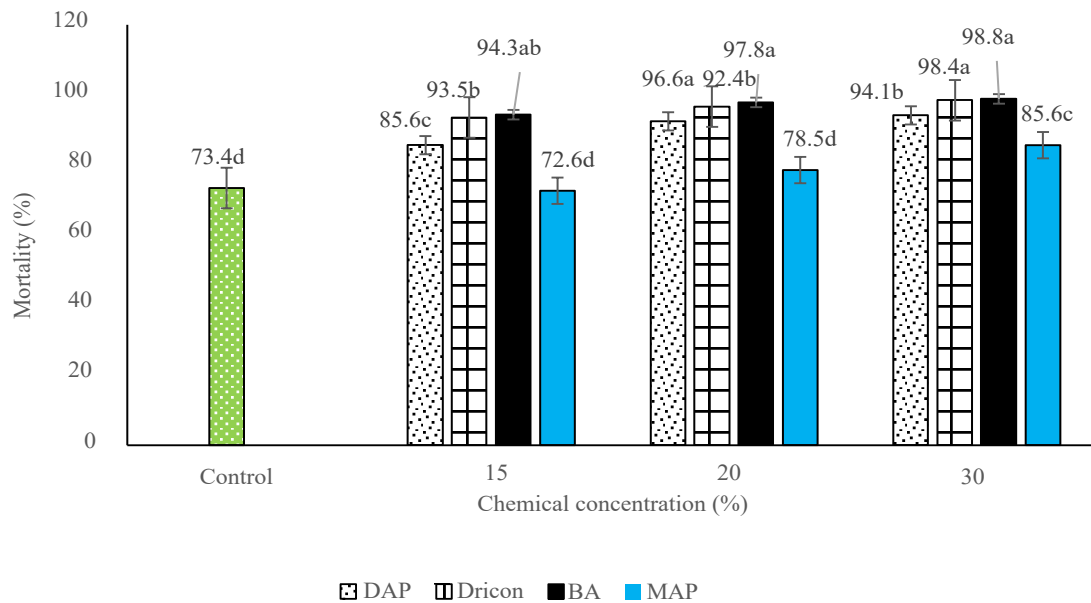
As shown in Figure 5, termite mortality after 28 days of exposure varied significantly among the treatments. BA, Dricon, and DAP (excluding 15% DAP) resulted in high mortality rates exceeding 90%. In contrast, MAP-treated samples consistently showed lower termite mortality, particularly at 15% and 20% concentrations. Notably, termites remained more active and survived longer in MAP-treated and control samples, while visible deaths in BA-treated samples began as early as day 6.

The high termite mortality associated with BA and Dricon-treated samples corresponds closely with the weight loss results, indicating strong toxic effects. Boric acid's slow-acting but cumulative toxicity makes it effective in killing termites over time (Grace & Yamamoto 1994). The delayed mortality aligns with observations of termites clustering near the base of the test

bottles, suggesting ingestion-based action rather than repellent.

MAP's lower mortality rate supports the conclusion that it is less toxic and more repellent, reducing its efficacy as a termite control agent. The fact that termites remained active and inflicted higher damage suggests that MAP's fire-retardant formulation lacks sufficient insecticidal action, requiring complementary treatments for dual protection.

Visual observation further confirmed these outcomes. Termites were visibly more active in DAP, MAP, and control samples, which aligns with lower mortality and higher wood weight loss. In contrast, BA-treated samples showed limited activity and less damage, reinforcing its effectiveness. These observations are consistent with earlier studies highlighting the importance of boron-based compounds in long-term wood protection (Kozłowski & Przybylak 2001, Lloyd et al. 2001).



**Figure 5** Mortality of *C. curvignathus* with vacuum-treated and untreated *H. brasiliensis* after 28 days of exposure

## CONCLUSIONS

Our findings demonstrate that BA and Dricon are highly effective in protecting *H. brasiliensis* wood against *C. curvignathus*. Wood specimens treated with BA and Dricon exhibited significantly lower mass losses and higher visual ratings, indicating minimal to no termite attack, even at lower concentrations tested. Furthermore, these treatments resulted in high termite mortality rates (above 90%).

While MAP and DAP also provided protection, their efficacy was comparatively lower than BA and Dricon, particularly at lower concentrations. Effective protection with MAP and DAP against *C. curvignathus* required higher concentrations (e.g., 30% or more) to achieve results comparable to those observed in other studies. The study confirms that higher concentrations of these chemicals generally lead to better protection and higher retention rates.

In conclusion, this research supports the hypothesis that certain fire retardants, particularly boric acid and Dricon, can effectively serve as dual-purpose treatments, offering both fire retardancy and significant protection against subterranean termites for building structures in Malaysia. This offers a promising alternative for wood preservation, especially given the environmental concerns associated with traditional treatments like CCA.

## ACKNOWLEDGEMENTS

The authors would like to thank the Wood Entomology Laboratory for their help with termite collection and termite bioassays, and the Wood Analytical and Preservatives Laboratory at FRIM for their invaluable support during this project. This work was financially supported by Eleventh Malaysia Plan (Grant No. 23410107002).

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