Boric Acid Alternatives for Wood Treatment and Protection Against Eastern Subterranean Termites, Effects of Boric Acids on Termite Populations, and Subsequent Effects on the Surrounding Environment

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Abstract

Outdoor structures can be compromised by the presence of microbes, fouling organisms, and termites in building materials. Traditional measures taken to preserve the integrity of these structures often come at the cost of the local ecosystem and require frequent reapplication and maintenance. This paper reviews the consequences of historically used boric acid treatment on termites and proposes an alternative, low-toxicity intervention. The impact of boric acid treatments on termite physiology and ecological stressors on urban and suburban areas is explored, as well as the environmental consequences of termite eradication in urban and suburban areas. Results from this study show that samples containing SCHN 146 (self-cleaning hydrophobic nanocoating) and SCHN 146 Premium showed no significant difference in termite mortality but no significant effect on the termites' feeding behavior, and therefore a lack of deterrence. Samples

treated with a homogenous mixture of SCHN 146 with borates showed significant termite-killing effects that sealed wood surfaces and eliminated termites quickly. The wood treatment method studied in this paper is concluded to be an appealing alternative in the pest management industry for creating a safer and environmentally sustainable solution to termite infestations.

Introduction

The presence of termites in building materials, primarily wood used in outdoor structures, can lead to significant deterioration and compromise structural integrity. Subterranean termites are especially destructive due to their ability to digest cellulose-rich materials, and weaken structural components over time, resulting in costly repairs and maintenance, resulting in the economic and structural burden associated with termite infestations. The development of effective and environmentally responsible wood preservation strategies remains an important area of study. Subterranean termites are among the most destructive structural pests worldwide, with the eastern subterranean termite, *Reticulitermes flavipes*, being a major threat to wooden infrastructure in North America. Termite foraging behavior causes extensive structural damage, which can lead to substantial economic losses and chronic management challenges, despite the important ecosystem services termites provide, such as organic matter decomposition and soil enrichment[9]. The food source selection decisions of *R. flavipes*, while they may initially appear random, are in fact directed by nutritional ecology, seasonal caste composition, and micronutrient availability.

Wood is composed of three major chemical constituents: cellulose, hemicellulose, and lignin. It refers to the fibrous structural tissue found in the stems and roots of trees and other woody plants and include materials, composites, or products that contain or are partially composed of these fibrous tissues or their chemical constituents. Termite colonies seasonally rely on nutrient-limited wood substrates and must actively seek essential nutrients such as calcium or nitrogen, through selective foraging[2]. These foraging behaviors suggest that termite control strategies that leverage natural caste roles and recruitment pathways may be especially effective, particularly when targeting individuals responsible for habitat exploration and local food source assessment, such as scout termites.

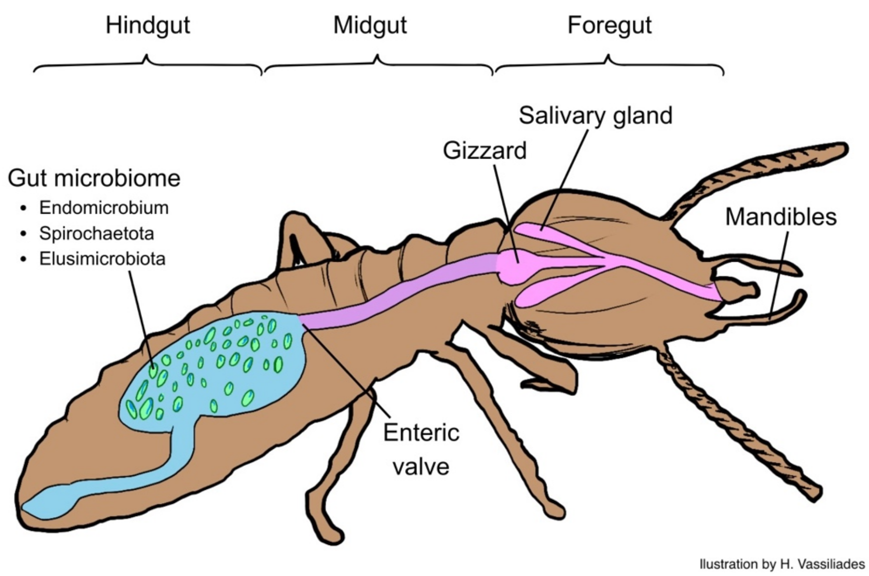


Figure 1. Digestive system of Reticulitermes flavipes*, illustrating the foregut, midgut, and hindgut regions and the hindgut microbiome composed of bacteria, protozoa, and archaea responsible for lignocellulose digestion.*

The use of boron-based formulations for wood preservation has been extensively investigated because of the low acute oral and dermal toxicity of these compounds, as well as their ability to render wood non-flammable when applied with high concentration. Zinc borate hydrate, boric oxide, boric acid, sodium borate, and disodium octaborate tetrahydrate (DOT) have become popular compounds for treating wood because of their ability to render wood resistant to fungi, termites, wood boring beetles, and general household pests. However, due to the high solubility of these borate compounds in water, they are easily leached from the wood treated by environmental water and moisture. Therefore, the use of boron-based treatments is generally limited to indoor use.

Recent conventional termite management has relied heavily on borate-based treatments because of their well-documented toxicity and effectiveness against subterranean termite populations[10]. Originally used to treat termites and other insects, borate-based approaches continue to be refined to address limitations such as slow acting toxicity, uneven distribution within treated wood, environmental leaching, and variability in efficacy across termite species and environmental conditions[8,10]. Furthermore, concerns regarding household use and human health risks, particularly accidental ingestion by children, have led to increased criticism of borate use in residential settings[11]. While boric acid is effective as a slow-acting toxicant that disrupts termite gut symbionts and induces mortality over time, this same mechanism may limit its suitability for targeted, behavior-based deterrence strategies[1,5]. This may also contribute to broader ecosystem disruption, as termites play important ecological roles in decomposing organic matter and improving soil structure and fertility[9]. Given these limitations and potential ecological consequences, there is a growing need for alternative termite management approaches that reduce reliance on toxic compounds.

SCHN offers a novel method consisting of a sol-gel water-repellent base combined with DOT. This combination is designed to protect wood from degradation caused by water damage and aging while also functioning as a non-leachable antifouling termite-deterrent treatment with minimal environmental impact. The treatment remains effective across various deposition techniques, such as spraying or brushing, without the need for pressure treatment. The following study evaluates the use of SCHN 146 with DOT as an alternative to conventional boric acid treatment, specifically examining its ability to interfere with scout-mediated foraging and deter *R. flavipes* from exploiting wooden structures while reducing environmental leaching.

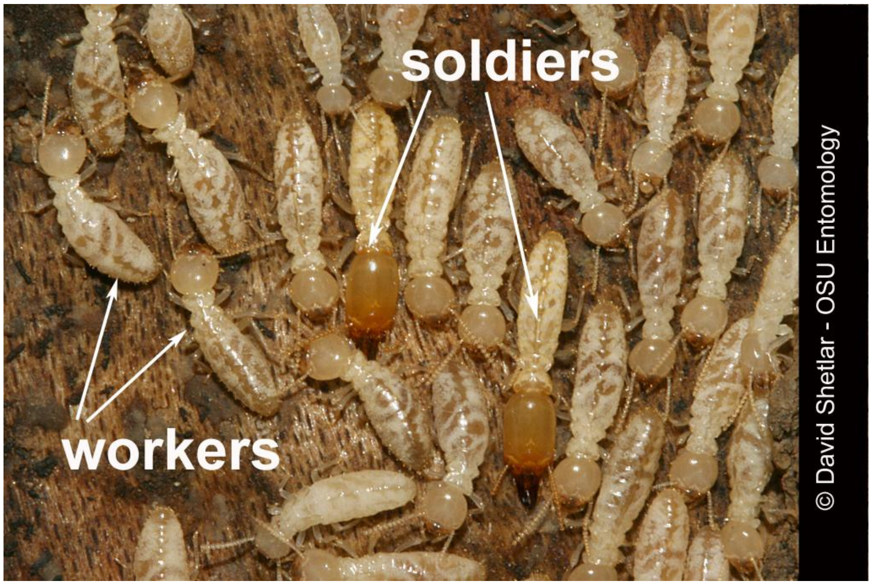


Figure 2. *Worker and soldier castes of* Reticulitermes *flavipes. Workers are responsible for foraging, wood consumption, and trophallactic food sharing within the colony, while soldiers defend the colony using enlarged mandibles.*

Figure 3. *Physogastric queen of* Reticulitermes *flavipes. The greatly enlarged abdomen reflects high reproductive output, allowing colonies to maintain large worker populations capable of sustained wood consumption.*

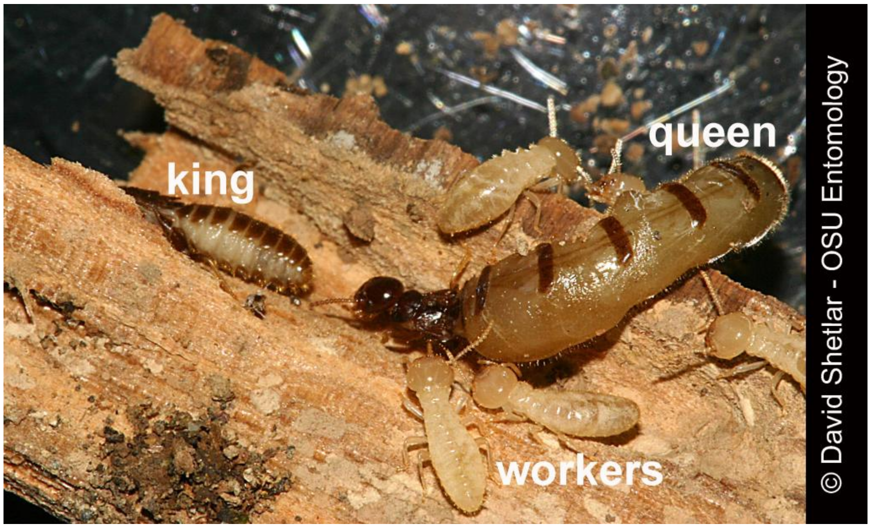


Figure 4. *Primary reproductive pair (king and queen) with worker termites of Reticulitermes flavipes. Workers support the colony through foraging, nest maintenance, and feeding other castes via trophallaxis.*

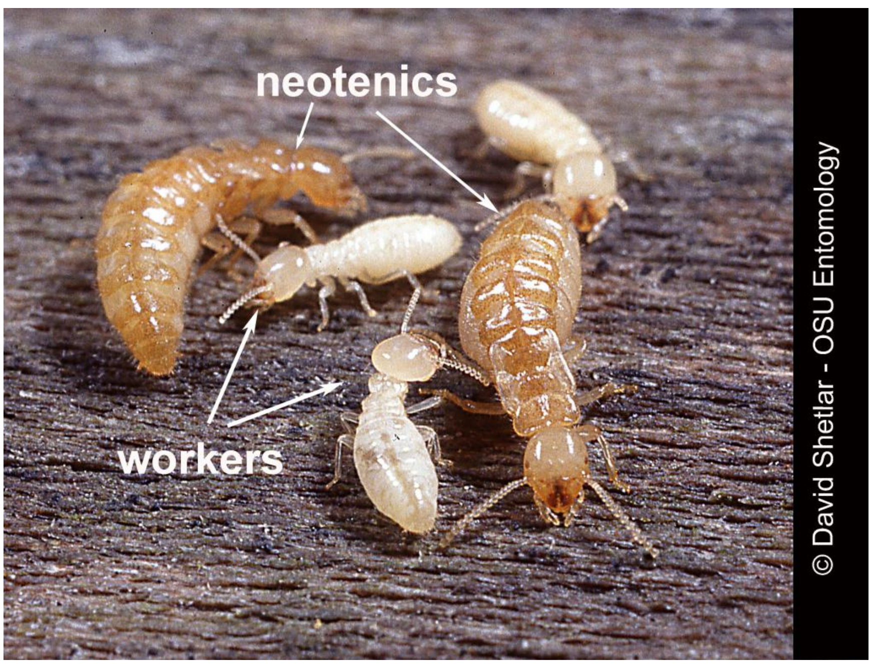


Figure 5. *Workers and neotenic reproductives of Reticulitermes flavipes. Neotenics serve as replacement reproductives that can assume egg-laying roles if primary reproductives are lost, allowing colonies to persist after disturbance.*

Termite Health and Population

Distributed widely across the globe, termites represent one of the most abundant groups of invertebrates in many ecosystems. Based on the global distribution of termite populations around the world—most notably in Africa, Asia, and South America—termites preferentially inhabit tropical and subtropical regions[9]. The widespread distribution of termite populations reflects the environmental conditions required for survival, as subterranean termites are highly susceptible to desiccation when not maintained in adequately moisture-rich environments. Consequently, termite population densities can become especially high in warm, humid regions. In fact, in some ecosystems, termites may reach thousands of individuals per square meter, contributing a large biomass comparable to terrestrial vertebrates[9]. These large termite populations underscore their role as decomposers, accelerating organic matter breakdown through feeding and tunneling while influencing soil structure, water movement, and plant decomposition.

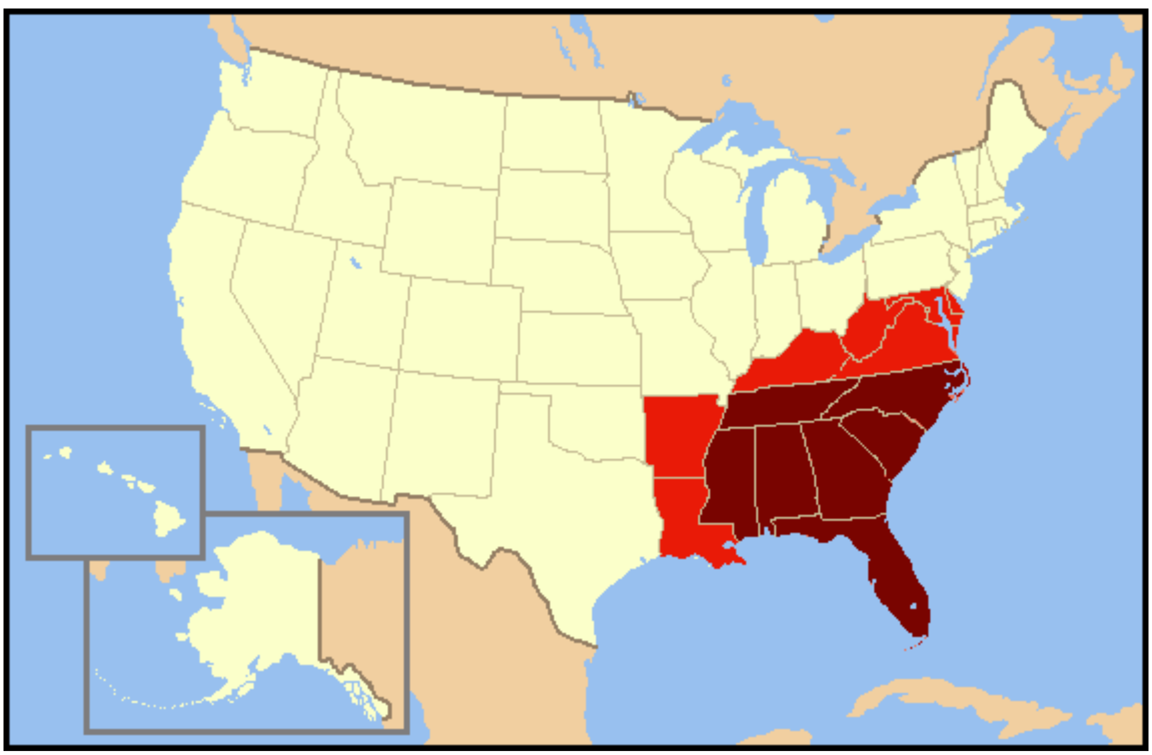


Figure 6. *Map of the United States with the Southeastern areas highlighted. While R. flavipes are present nationwide, they are particularly dense in the highlighted region.*

In North America, *Reticulitermes flavipes*, also known as the eastern subterranean termite, is one of the most widespread and economically significant species. *R. flavipes* is responsible for much of the structural damage credited to termites in the United States, largely due to this species' ability to breakdown man made and organic material. Studies examining termite biodiversity in the Southeastern United States, see figure 6, demonstrate that the Reticulitermes species are found across large geographic areas, with *R. flavipes* representing a substantial portion of the collected samples; in Georgia, *R. flavipes* was found in every county, illustrating the termite population density and distribution characteristic of the southeastern region, often referred to as the "very-high hazard" termite belt[16]. The adaptability of this species is notable, as it can persist across a variety of soil types and climates. Subterranean termites prefer soils capable of retaining moisture because these conditions allow them to construct extensive underground tunnel systems while avoiding desiccation. Additionally, these environments also provide abundant soft wood and other cellulose-rich plant material necessary for colony survival[9]. The colony can sustain itself with the nutrients from the cellulose-rich substrates, allowing it to grow, maintain a large population size, and continue its widespread foraging activity.

Colonies are composed of several castes with specialized roles, including queens, workers, and soldiers[4]. Queens, see figures 3 and 4, handle producing offspring and maintaining colony population size, while workers, reference to figures 2,3, and 4, perform most regulatory tasks like foraging, brood care, and tunnel construction [19]. Workers conduct most of the labor within a colony and play a vital role in colony maintenance, ecosystem decomposers, and nutrient processors. Soldiers, reference to figure 2, primarily function in colony defense and rely on workers for feeding through trophallaxis, a process in which termites exchange food and digestive fluids directly with one another, due to their specialized morphology[15]. The organization of different colonies can be differentiated when comparing populations depending on factors such as colony age and reproductive structure, with some colonies headed by primary a queen and others by replacement queens known as neotenics, leading to variation in colony size and genetic structure[3].

Colony health is further maintained through cooperative foraging and food distribution strategies[18]. In *R. flavipes*, workers forage through extensive subterranean tunnel networks that connect multiple feeding sites, allowing colonies to expand and exploit scattered food resources with efficiency. If colonies can sustain activities most of the time within these tunnels, termites can then access all their needs for food from multiple sources simultaneously and reproduction away from potential predators or other environmental stressors in the soil. Once collected, nutrients are distributed throughout the colony through trophallaxis, supplying individuals of all castes and roles with the nutrients necessary for growth and survival. Food sharing also allows termites to transfer their digestive microbes, which strengthens the colony's social connectedness.

Currently Used Techniques for Termite Control and Detection

Early studies have placed the cost of termite damage in the southeastern United States at $579 million in 1983[29]. Later studies on termite damage have placed the cost at $40 billion in 2010, with the US accounting for nearly half of that estimate[27]. While exact estimates can't be concluded from these studies alone, the financial cost to treat and repair structures that are damaged by termites can be suggested from these studies.

One of the oldest methods of termite detection comes in the form of placing metal shields at the foundation of the building, creating a physical barrier that the termites must work around to continue eating wood. This barrier forces the termites to work around and expose the tunnels that termites create to access the wood[26]. Termite detection in the U.S. can be categorized as either non-invasive or invasive detection of termite infestations. Invasive techniques for termite detection typically involve the removal of drywall or drilling into the wooden infrastructure to have visual confirmation of termite presence within the infrastructure. This form of detection has been on the decline as it can be costly to remove the damaged wood, depending on how extensive the damage is in. More popular methods of termite detection typically consist of non-invasive or minimally invasive techniques to determine termite activity[12]. Examples of non-invasive techniques include infrared scanning where thermal imaging is used to detect any termite activity that may be present in the walls without damaging the surrounding infrastructure. This technique provides an inexpensive alternative to visual scanning without the ambiguity that comes with only sampling a few parts of a structure.

Preventative control of termite infestations typically consists of impregnating wooden components with sealing materials or placing termicidal chemicals at key points in the infrastructure. These techniques are often implemented during construction, as it is the most cost-effective period to treat the wood without further expenses later in project development. Preventative measures are typically favored in projects as they reduce the risk of termite infestation. Active control of termite infestation is typically more expensive than creating the preventative measures before the infestation. The form of control recommended by the USDA during an active infestation in the building: inspection, sanitation, chemical control, and termicidal baits[24]. These are the main guidelines to follow to maintain a safe structure if there is an active infestation occurring, maintaining the safety of people operating in the building and determine if the building is too structurally compromised for safe operation.

Boric Acid Effects on Termite Microbiome

Boric acid has long been utilized as a wood protectant and slow-acting toxicant against subterranean termites. While the mechanics of how boric acid affects on termites were unspecified, its efficacy is increasingly understood to result from the disruption of the gut microbial symbiosis. Disrupting microbial symbiosis is a slow acting, but effective method when managing an unrestrained termite population because this internal system, while complex, is highly sensitive to disruption by boron complexes. The eastern subterranean termite, *Reticulitermes flavipes*, depends on a highly specialized gut microbiome composed of bacteria, protozoa, and archaea that cooperate to expedite lignocellulose degradation, nitrogen recycling, and nutrient acquisition[1]. Because the gut microbiome is highly specialized, unbalancing the internal system can effectively incapacitate termites. Experiments exposing *R. flavipes* to graded doses of boric acid were shown to induce dose-dependent mortality coupled with significant dysbiosis of the microbial community, which also includes major reductions in bacterial diversity and large shifts in the microbiome's community structure[1]. Just as disrupting termite activity can reduce a colony's ability to locate and exploit wooden structures, disruption of the termite gut microbiome can impair the microbial community required for digestion and ultimately compromise termite survival. Just as disrupting termite activity can reduce a colony's ability to locate and exploit wooden structures, disruption of the termite gut microbiome can impair the microbial community required for digestion and ultimately compromise termite survival.

When a large portion of a gut microbiome is eliminated, an ecological gap is left open for other species in the microbiome to populate and disrupt their normal digestion of cellulose. Markedly, higher boric acid concentrations suppress key symbiotic taxa essential for cellulose digestion and metabolic homeostasis, namely *Endomicrobium*, *Spirochaetota*, and *Elusimicrobiota*, while simultaneously encouraging the proliferation of opportunistic and potentially pathogenic genera including *Pseudonomads*, *Lysinibacillus*, and *Mycoplasma*[1]. Previously conducted toxicological studies, while not exclusively focusing on examining microbial dynamics, are consistent with this mechanism, showing that boric acid functions as a non-repellent, slow-acting stomach toxicant that is consumed before mortality occurs[5]. This demonstrates the widespread use of manipulating the gut microbiome of termites to eliminate the colony from destroying the wooden infrastructures.

Taken together, these findings indicate that boric acid's insecticidal action is closely tied to its capacity to destabilize termite gut symbiosis. Given that boric acid works by broadly disrupting the termite gut microbiome, borate treatments are inherently non-specific and affect multiple biological processes, rather than a single precise target, highlighting the need for more targeted termite control strategies methods that inhibit foraging and colony function without poisoning termites or destabilizing their internal microbial communities.

Biochemical Mechanisms of Boric Acid Toxicity in Termites

When termites ingest boric acid (H_3BO_3) from treated wood or bait, the compound dissolves in the aqueous environment of the termites' digestive tract[23]. Chemically, boric acid acts as a Lewis acid by donating its proton when in solution.

$$B(OH)_3\ (aq) + 2H_2O\ (l) \rightleftharpoons B(OH)_4^-\ (aq) + H3O^+\ (aq)$$

This equilibrium forms the tetrahydroxyborate ion $B(OH)_4^-$ which in aqueous biological systems can bind to molecules containing cis-diols, such as those commonly found in sugars and biological cofactors[10]. Borates interfere with microbial metabolism through their ability to interact with hydroxyl-rich biomolecules.

Disruption occurs through several biochemical pathways' effects. Borate ions can form reversible complexes with polyols and sugar molecules like ribose, glucose intermediates, and NAD-related cofactors, interfering with enzymatic pathways involved in carbohydrate metabolism, which are crucial for the cellulolytic bacteria and protozoa in termite guts, therefore blocking the normal microbial fermentation of cellulose[1,10]. interfering with enzymatic pathways involved in carbohydrate metabolism, which are crucial for the cellulolytic bacteria and protozoa in termite guts, therefore blocking the normal microbial fermentation of cellulose[1,10]. Termite digestion depends on specific symbiotic microorganisms, so the dysbiosis of the gut microbiome disrupts cellulose hydrolysis, fermentation pathways, and the production of short-chain fatty acids used by the termite host[1,10].

When boric acid disrupts these symbiotic microorganisms, cellulose cannot be properly degraded; fermentation products decline, and nutrient absorption fails[1]. Thus, the termite starves even though it continues to feed.

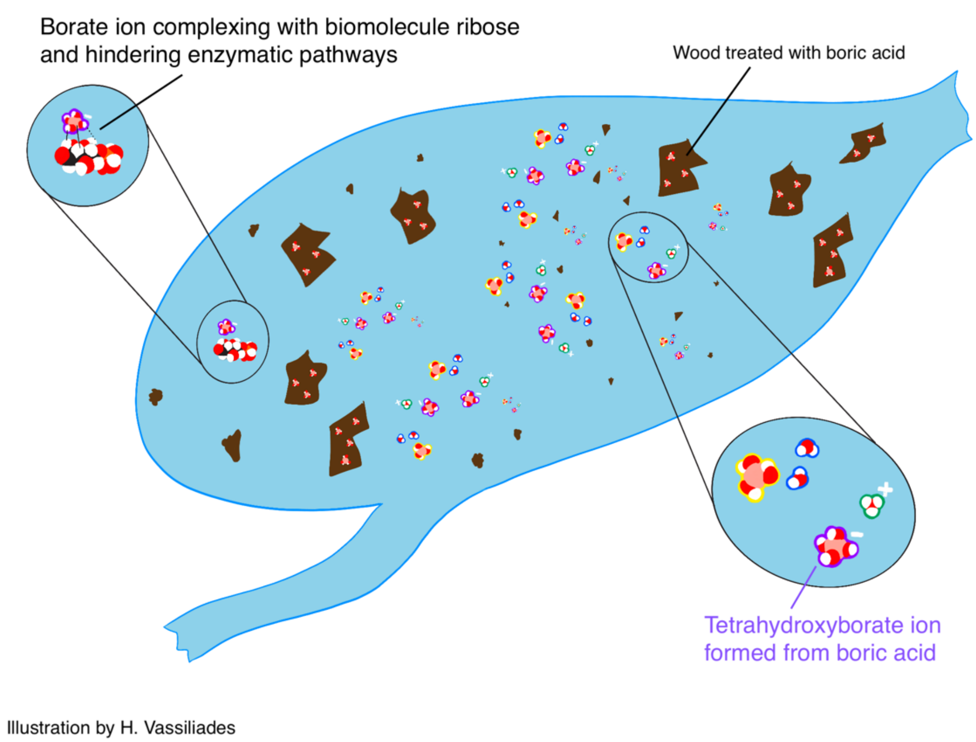


Figure 7. *Conceptual illustration of boric acid activity in the termite gut. Boric acid forms tetrahydroxyborate ions that complex with ribose-containing biomolecules, disrupting enzymatic pathways within gut microorganisms and interfering with cellulose digestion.*

Environmental Effects of Termite Eradication in Urban and Suburban Areas

When comparing the benefits of eradicating termite colonies with conventional control methods, it is necessary to consider how removing decomposers in the area affects the surrounding ecology. Termites are often considered ecosystem engineers because they alter the environment and the effect that climate has on the soil. Previous studies have shown that termites affect the soil in their environment by altering soil compaction, and water permeability[25]. The effects of soil compaction will alter water's ability to permeate into the soil in the area, which can have other effects in the ecosystem, such as issues with leaching of insecticides that are sprayed in residential areas, and potential leaching into municipal sewage systems as excess water runoff into drains. The effects of such insecticides have also been studied and considered for their toxic effects on the microfauna in sewage systems that decompose biomass that may enter the sewage system[28], and while quantitative studies of what termite eradication causes to municipal urban areas are limited, it's important to consider the environmental effects that may be present as a result of these interactions.

Termites play an important role in cycling nitrogen in the soil. They play a role as major decomposers of wood, leaves, and litter in suburban and urban environments[13], returning nutrients into the soil, maintaining a healthy soil microbiome; by exterminating the termites from these suburban environments, the soil cannot provide as many nutrients to plant fauna in the region or could have a deficiency in the nutrients available for use in the ecosystem[13].

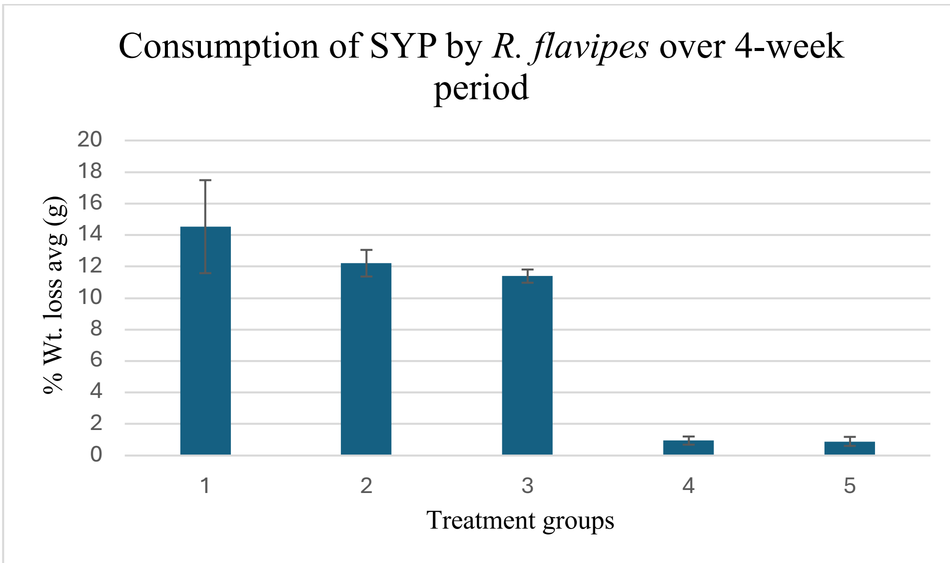
Method and Results

The exact mechanism of action by which borates affect termites and a select number of other potentially detrimental insects (e.g., wood-boring beetles, carpenter ants, etc.) is still somewhat uncertain. However, it is known that when termites consume borate-treated wood, ingested borates act as a gastric poison in the form of free borate ions by effectively disrupting digestive processes through damaging interactions with protozoa residing in the gastrointestinal tract of termites, ultimately leading to starvation of the host[7,17,18]. Notwithstanding their excellent termiticidal properties and low toxicity as wood preservatives, borates are highly susceptible to leaching effects as a result of their intrinsic aqueous solubility[22]. To illustrate this, in a leaching study conducted in accordance with an adaptation of European Standard ENV 1250-2, pine sapwood samples treated with aqueous solutions of DOT via soaking at standard atmospheric pressure and subsequently subjected to aqueous leaching simulation retained a mere 0.5 wt.% of the initial concentration of borate after only 1 hour of leaching[21]. To account for such inevitable leaching effects, structural wood treated with borate preservatives are typically pressure treated to impart the wood with a sufficient concentration of borate groups to maintain minimum retention levels specified by the American Wood Protection Association (AWPA) over its useful lifetime.

In response to these challenges, Integricote has meticulously developed two series of forward-thinking solutions, both specifically designed to address the leaching issue in one of two distinct ways: 1) retroactively enhance the performance of wood previously pressure-treated with borates (SCHN 146) and 2) afford the wood preservative industry with a proprietary, environmentally friendly, water-insoluble penetrating sealer that exhibits, among a host of other attributes, exceptional termiticidal properties (SCHN 146). SCHN 146 effectively functions by forming an interpenetrating network that partially immobilizes water-soluble borate ions while concomitantly repelling moisture away from the wood itself that could be conducive to aqueous leaching. In doing so, SCHN 146 not only significantly decreases the rate of leaching of active termiticidal agents but also inhibits the accumulation and retention of moisture that facilitates the growth of damaging mold/mildew, and in doing so, increases the stability of treated wood. In application, SCHN 146 may be applied retroactively to borate treated structural wood either by the manufacturer, distributor, or by builders onsite via a number of depositional methods. Alternatively, SCHN 146 adopts a more holistic approach towards wood protection by synergistically combining multiple functionalities into one cohesive treatment option. This is effectuated by implementing an integrated system designed to uniquely encapsulate and uniformly disperse our EPA-preferred active termiticidal agent within an advanced penetrating sealer that performs similarly in other aspects to our SCHN 146 (i.e., significant reduction in water absorption, stability, etc.).

Once SCHN 146 is applied to wood (e.g., via pressure-treatment or soaking), a robust cross-linking process that involves both physical and chemical interactions with the wood itself partially immobilizes the active termiticide, eliminating extraneous termiticidal-migration (leaching) through the wood. This complementary system provides a desirable all-in-one proprietary treatment option dissimilar to any other commercially available product on the market.

As an initial evaluation of product efficacy, a termite resistance study was conducted on samples of southern yellow pine (SYP) wood treated with SCHN 146 by an accredited external independent testing facility (Wood Protection Testing Laboratory) at Mississippi State University in accordance with AWPA Test Method E1-13 and American Society for Testing and Materials (ASTM) Test Method D3345-08. In this study, samples of treated wood were subjected to exposure to the subterranean termite species *Reticulitermes flavipes* (*R. flavipes*) for four weeks and compared against standard references samples. After four weeks of exposure, samples were evaluated and graded in terms of the degree of damage inflicted to the wood samples by the termites (block rating), the visual rating of the samples, and the degree of termite mortality. Samples treated with SCHN 146 received a block rating of 9 (Note: A block rating of 0 = failure, 4 = very severe attack, 7 = moderate/severe attack/penetration, 9 = light attack, 10 = sound) and a 100% termite mortality rating. In contrast, pristine samples of SYP wood subjected to identical testing conditions and exposure to *R. flavipes* received a block rating of 5 and only a slight (0% - 33%) termite mortality rating. Currently, Integricote is working with Timber Products Inspection (TPI) Inc., the foremost industry leader in third party independent wood product inspection and testing, to further develop and optimize our SCHN 146 product line. The process for treating the wood followed was the following, procuring a southern yellow pine (SYP) (1"x 1"x 1/4") sample followed by soaking the wafer in 60% Sol-gel solution in MeOH for 1 hour. All samples were dried in the oven at 60 °C for 3d then conditioned at R.T. for 1 d before treatment.



Bar Graph 1. *Comparison of SYP consumption based on the 5 treatment groups evaluated in this experiment.*

Table 1. Rating scale for block ratings, pre-experiment weight of SYP, and post experiment weight for pine samples.

<table>
<tr><td colspan="8">A</td></tr>
<tr><td colspan="8">W1 is the weight of the wafer before exposure to termites</td></tr>
<tr><td colspan="8">B</td></tr>
<tr><td colspan="8">W2 is the weight of the wafer after exposure to termites</td></tr>
<tr><td colspan="8">c (block rating)</td></tr>
<tr><td>10
Sound</td><td>9.5
Trace Nibble Permitted</td><td>9
Light Attack</td><td>8
Moderate Attack</td><td>7
Moderate/Severe Attack Penetration</td><td>6
Severe Attack</td><td>4
Very Severe Attack</td><td>0
Failure</td></tr>
<tr><td colspan="8">d (visual rating)</td></tr>
</table>

T Tunneling	P Majority termite position	M Approximate Termite mortality			
(+) Yes	(u) On surface	"s" Slight (0% to 33%)	"m" Moderate (34% to 66%),	"h" Heavy (67% to 99%)	"x" Complete (100%)
(-) No	(d) Beneath Surface				

Table 2. Treatments used in this experiment with their makeup and concentration.

Treatment number	**Treatment types**	**Makeup of treatment samples**
1	Control group	N/A
2	SCHN 146	(Sol-gel 186-3, 60% in MeOH) 50 mL
3	SCHN 146 Premium	(Sol-gel 186-3, 60% in MeOH) 50 mL + (3% TOS in MeOH) 50 mL
4	SCHN 146 with borate	(Sol-gel 330-18, 60% in MeOH – 2.54 w/v % DOT / 1 w/v % SDBS) 50 mL
5	ACQ	Alkaline copper quaternary

Table 3. Control group SYP digestion results and consumption of wood over 4-week testing period

Control group with untreated southeastern yellow pine (SYP) after 4-week period								
Group	**Sample ID**	**W_1(g)[a]**	**W_2(g)[b]**	**% Wt. loss**	**Visual Block Rating[c]**	**Visual Block Rating[d]**		
						T	**P**	**M**
1	P1	2.51	2.22	11.55	4.0	+	u	s
	P2	2.42	2.11	12.81	6.0	+	u	s
	P3	2.63	2.38	9.51	6.0	+	u	s
	P4	2.52	2.20	12.70	6.0	+	u	s
	P5	2.53	1.87	26.09	4.0	+	u	s
			Average	14.53	5.2			
			STDEV	6.60	1.10			

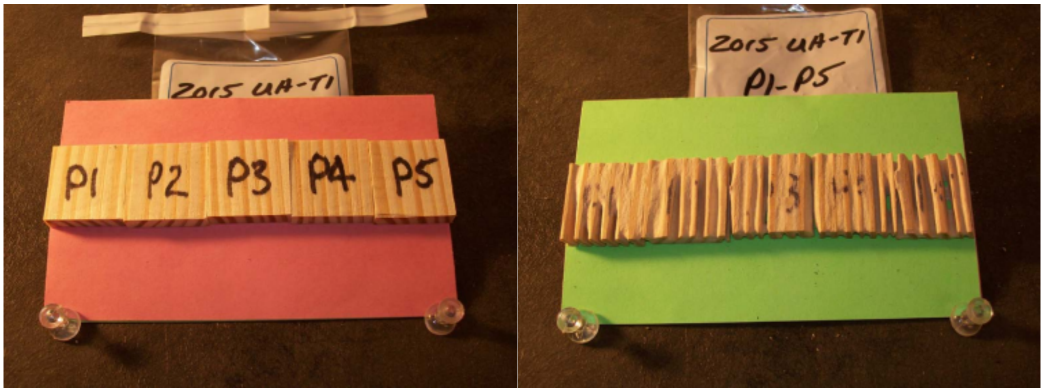


Figure 8. *Before and after 4-week exposure to R. flavipes for control group*

Samples P1-P6 served as the control group for this testing in which the SYP was untreated and consumed by the *Reticulitermes flavipes* (R. *flavipes*) over a period of 4 weeks. Treatment 1 saw the most consumption of wood by the % weight loss of the wafer after the 4-week period. There is minimal mortality of R. *flavipes,* with severe damage to the SYP samples for all trials.

Table 4. Samples A1-A5digestion results and consumption of wood over 4-week period

SYP wood treated with SCHN 146 after 4-week period								
Group	**Sample ID**	**W_1(g)[a]**	**W_2(g)[b]**	**% Wt. loss**	**Visual Block Rating[c]**	**Visual Block Rating[d]**		
						T	**P**	**M**
2	A1	2.40	2.16	10.00	6.0	+	u	s
	A2	2.61	2.24	14.18	4.0	+	u/d	s
	A3	2.47	2.12	14.17	6.0	+	u	s
	A4	2.74	2.42	11.68	4.0	+	u	s
	A5	2.54	2.26	11.02	6.0	+	u	s
			Average	12.21	5.2			
			STDEV	1.89	1.10			

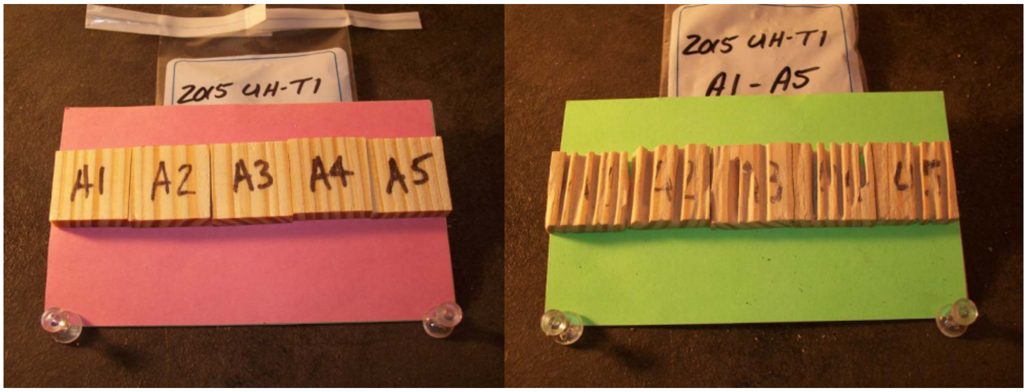


Figure 9. *Before and after 4-week exposure to R. flavipes with SYP wood treated with SCHN 146*

Samples A1-A6 were treated with SCHN 146 in this study this treatment demonstrated some slight toxicity to the *R. flavipes* but the treatment had little to no effect on the termites, with the only noticeable change from the control treatment being a decrease in the consumption of the SYP, while there was consistently less consumption, there was not a significant reduction in the consumption of the SYP with only a 2.32% change by weight of the wafers when compared with the control treatment, which is not statistically significant for deterrence.

Table 5. Samples B1-B6 digestion results and consumption of wood over a 4-week period

SYP wood treated with SCHN 146 Premium following 4 weeks of exposure to *R. flavipes.*								
Group	**Sample ID**	**W_1(g)[a]**	**W_2(g)[b]**	**% Wt. loss**	**Visual Block Rating[c]**	**Visual Block Rating[d]**		
						T	**P**	**M**
3	B1	2.52	2.26	10.32	6.0	+	u	s
	B2	2.51	2.21	11.95	6.0	+	u/d	s
	B3	2.40	2.14	10.83	6.0	+	u	s
	B4	2.52	2.20	12.70	4.0	+	u	s
	B5	2.51	2.23	11.16	4.0	+	u/d	s
			Average	11.39	5.2			
			STDEV	0.94	1.10			

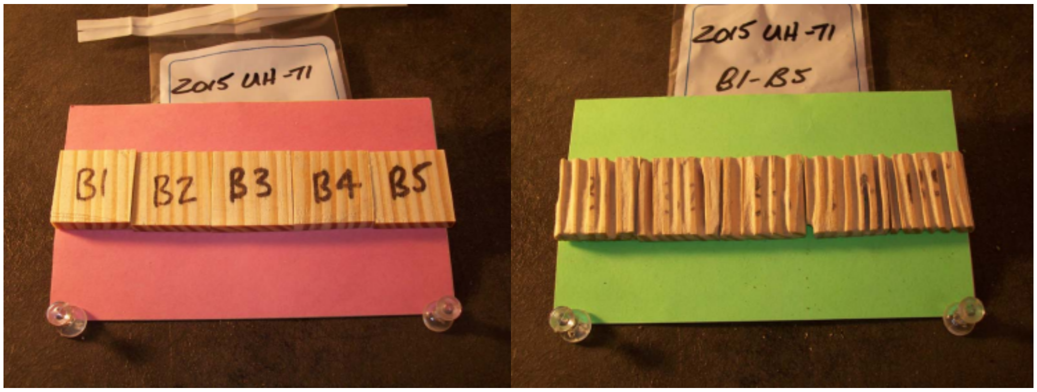


Figure 10. *Before and after 4-week period exposure to R. flavipes with SYP treated with SCHN 146 Premium*

Samples B1-B6 had a treatment of SYP with *SCHN* 146 Premium (Sol-gel 186-3, 60% in MeOH) 50 mL + (3% TOS in MeOH) 50 mL. This group tested similarly to both treatment one and treatment two in the consumption of SYP by *R. flavipes* following the 4-week testing period. Treatment three, although having TOS as an additive in the sealant material, showed no significant changes in its effectiveness of exterminating the termites in this group compared to both treatments one and two. There was a small decrease in the consumption of SYP compared to treatments one and two. This decrease in consumption was not found to be significant enough to find that this samples B1-B6 with treatment three offered any protection from the *R. flavipes*.

Table 6. Samples C1-C5 digestive results and consumption of wood over a 4-week period

SYP wood treated with SCHN 146 with borate following 4 weeks of exposure to *R. flavipes*								
Group	**Sample ID**	**W_1(g)[a]**	**W_2(g)[b]**	**% Wt. loss**	**Visual Block Rating[c]**	**Visual Block Rating[d]**		
						T	**P**	**M**
4	C1	2.62	2.59	1.15	8.0	+	-	x
	C2	2.44	2.43	0.41	9.0	+	-	x
	C3	2.69	2.68	0.37	9.0	+	-	x
	C4	2.80	2.77	1.07	9.0	+	-	x
	C5	2.28	2.24	1.75	9.5	+	-	x
			Average	0.95	8.9			
			STDEV	0.58	0.55			

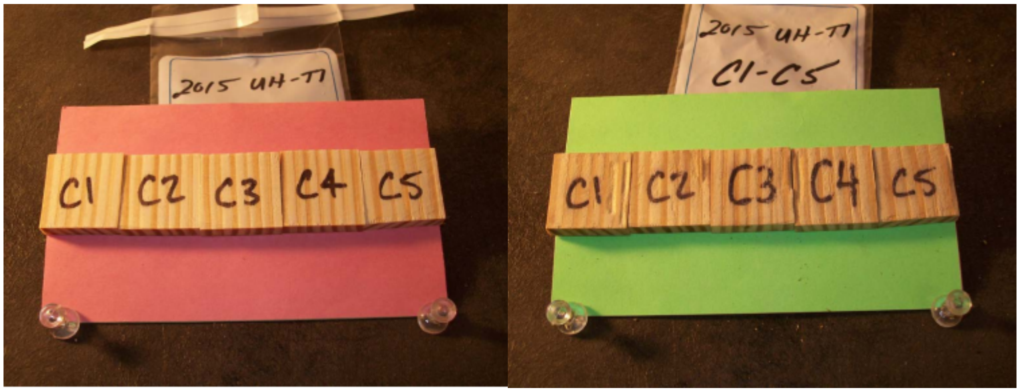


Figure 11. *Before and after 4-week exposure to R. flavipes with SYP treated with SCHN 146 with borate*

Samples C1-C6 from table 6 was tested with a SYP treated with SCHN 146 with Borate (treatment 4), this group proved to be successful at eradicating the *R. flavipes* used in the experiment. This treatment showed excellent termicidal effects to provide an alternative to traditional pest control. There was minimal consumption of the SYP samples C1-C6, indicating the efficacy of the coating at eliminating the termites while maintaining a high degree of protection wood products coated with this mixture. This coincides with our findings on the block ratings with this sample, where the SCHN 146 mixture in control and treatment one treated SYP had a 5.2 on the block rating, while SYP with treatment four received a block rating of 8.9 suggesting its effectiveness at reducing termite consumption of wood.

Table 7. Samples 21-25 results and consumption of wood over a 4-week period

SYP wood treated with alkaline copper Quaternary (ACQ) following 4 weeks of exposure to *R. flavipes.*								
Group	**Sample ID**	**W_1(g)[a]**	**W_2(g)[b]**	**% Wt. loss**	**Visual Block Rating[c]**	**Visual Block Rating[d]**		
						T	**P**	**M**
5	21	1.72	1.72	0.00	10.0	+	u	h
	22	1.83	1.81	1.09	10.0	+	u	h
	23	1.85	1.82	1.62	10.0	+	-	x
	24	1.87	1.86	0.53	10.0	+	-	x
	25	1.59	1.57	1.26	10.0	+	-	x
			Average	0.90	10.0			
			STDEV	0.64	0.00			

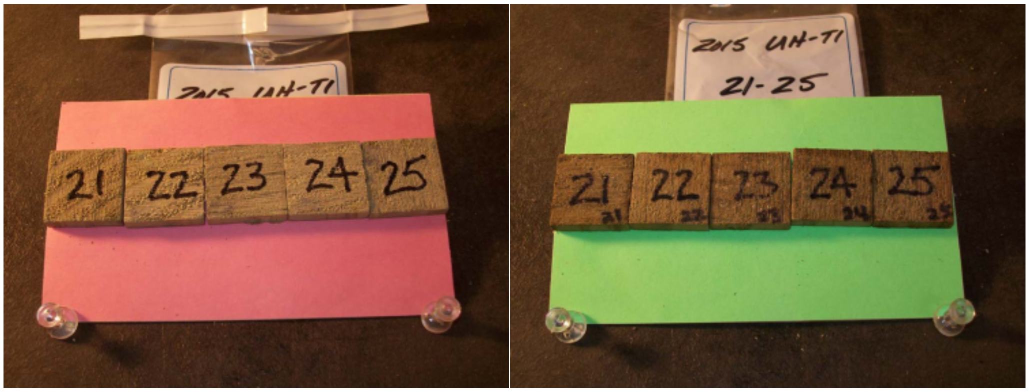


Figure 12. *Before and after 4-week exposure to R. flavipes with SYP treated with alkaline copper quaternary (ACQ)*

Samples 21-25 had SYP treated with ACQ and proved to be successful at eliminating R. flavipes. Sample 21 had no apparent SYP consumption over the 4-week period, but there was a major decrease in the termite population after the 4-week period. This could be caused by either starvation of the termite over the 4-week period or possibly due to leaching of the ACQ from the wood onto the termites leading to their death. For the rest of the samples, we also see minimal consumption of wood, and for samples 23-25, there is complete extermination of the termites, indicating its toxicity for the R. *flavipes*.

Discussion

From the testing on the mortality of the sampled termite population under different treatments on the SYP, it was found that samples C1-C6 with treatment 4, functioned as the best insecticide for the termite sample while minimizing the amount of wood ingested by the termites significantly. This suggests that the SYP in these samples' functions effectively as a toxic agent to the termites in this study, when compared to treatment two and one. These results were in line with our expectations of both SYP with treatment one and two termite prevention forms compared to SYP with treatment four, which is a known termiticide. One notable result was treatment five, which had an abnormally high mortality rate, with sample 21 having a high mortality rate with no clear wood ingestion. This could be a result of the termites not consuming SYP and dying from starvation.

Throughout testing, it was found that treatment four can be utilized as an alternative wood treatment because it consistently limited the ingestion of the wood from *R. flavipes*. Which strongly suggests that treatment four is effective at achieving the wanted toxicity to termites compared to the other treatment performed in this experiment (bar graph 1). While this testing did support the use of SCHN-146 with borate as an alternative treatment process, further testing in field conditions are required to identify the long-term protection of wood with the treatment four, have testing in field conditions to conclusively find that the treatment is completely inert to environmental factors, limits leaching, and is a viable long-term treatment plan for wooden infrastructure with proper maintenance. Results obtained from this testing can still be used to find SCHN 146 with a borate mixture as a proper treatment for termite control. Compared to the other treatment groups in the test, SCHN 146 with the borate mixture still evaluated at the highest mortality rate and the lowest % loss in weight compared to all the other treatment groups in the test.

SCHN 146 with Borate as an Alternative Solution to Conventional Termite Treatment

Modern conventional means to proactively exterminate termites in structural wood are centered on the use of borate-functional pesticides, the most prevalent being disodium octaborate tetrahydrate (DOT), which has been widely accepted by the Environmental Protection Agency (EPA) in the US since the late 1980s[21,34]. It should be noted that the increasing use of borates as wood preservatives and pesticides follow primarily as a result of their comparatively low toxicity to humans, in contrast to more toxic alternatives such as chromated copper arsenate (CCA). As a result of both its acute and chronic toxicity, the use of CCA is in the process (since late 2003) of being slowly phased out by the EPA through more stringent usage guidelines[7]. This is compounded by the notion that existing termiticidal wood preservatives currently available for commercial use are either toxic or appreciably water-soluble (leachable). Together, these challenges not only pose a potentially profitable opportunity but also highlight the need to responsibly modernize the wood preservative industry. In response to these challenges, we have found treatment four (SCHN 146 with borate) to meet these challenges. Treatment four acts as an exceptional termicidal agent with minimal leaching into the surrounding environment, as SCHN 146 has the borate component inside the sealant, which is a glass-like structure inert to water[14], only taking effect once the *R. flavipes* consume it. These benefits are substantial compared to the typical treatment of wood, which often requires constant reapplication every couple of years, increasing the cost over time for termite protection. Treatment four offers protection from termites that is essential for creating long-lasting infrastructure while minimizing the risk of exposure to environmental factors.

Conclusion

Ongoing utilized treatment techniques often come with environmental concerns through the leaching of boric acid. Treatment 4 could be an alternative to conventional wood treatment methods, as it provides a toxicological effect to termites, with reduced potential for the leaching of borate into the surrounding environment when compared to conventional preventative techniques in the industry. Furthermore, reduced activity of the colony near treated infrastructure will allow for the digestion of their natural resources, increasing the concentration of nutrients in the surrounding soil.

This mixture reduces leaching and limits exposure to the environment surrounding the treated area and has the potential to improve both safety and the longevity of the treated material.

While these findings are promising, further research into field conditions is necessary to evaluate the long-term longevity of the material, its durability, and the ecological impact.

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References

[1] Ashbrook, A. R.; Schwarz, M.; Schal, C.; Mikaelyan, A. Lethal Disruption of the Bacterial Gut Community in the Eastern Subterranean Termite Caused by Boric Acid. *Journal of Economic Entomology* **2024**, *117* (5), 2599–2612. https://doi.org/10.1093/jee/toae221

[2] Botch, P. S.; Brennan, C. L.; Judd, T. M. Seasonal Effects of Calcium and Phosphates on the Feeding Preference of the Termite Reticulitermes flavipes. *Sociobiology* **2010**, *55* (2), 489–504.

[3] Bulmer, M. S.; Adams, E. S.; Traniello, J. F. A. Variation in Colony Structure in the Subterranean Termite Reticulitermes flavipes. *Behavioral Ecology and Sociobiology* **1999**, *49*, 236–243. https://doi.org/10.1007/s002650000304

[4] Fajar, A. Foraging Behavior in the Eastern Subterranean Termite, Reticulitermes flavipes (Kollar) (Isoptera: Rhinotermitidae). Master's Thesis, University of Kentucky, Lexington, KY, **2023**. https://doi.org/10.13023/etd.2023.434

[5] Farid, A.; Zaman, M.; Saeed, M.; Khan, M.; Bad Shah, T. Evaluation of Boric Acid as a Slow-Acting Toxicant against Subterranean Termites (Heterotermes and Odontotermes). *Journal of Entomology and Zoology Studies* **2015**, *3* (1), 213–216.

[6] Forschler, B. T.; Ryder, J. C. Colony Response of Subterranean Termites (Reticulitermes spp.) to Baiting with Hexaflumuron. *Journal of Entomological Science* **1996**, *31* (2), 143–151. https://doi.org/10.18474/0749-8004-31.2.143

[7] Freeman, M. H.; McIntyre, C. R. A Comprehensive Review of Copper-Based Wood Preservatives. *Forest Products Journal* **2009**, *59* (11–12), 6–27.

[8] Gentz, M. C. Toxicity of Boron Compounds in the Formosan Subterranean Termite (Coptotermes formosanus). Master's Thesis, University of Hawai'i, Honolulu, HI, **2007**.

[9] Govorushko, S. Economic and Ecological Importance of Termites: A Global Review. *Ecological Economics* **2018**, *147*, 34–45.

[10] Grace, J. K. Review of Recent Research on the Use of Borates for Termite Prevention. In *Proceedings of the Second International Conference on Wood Protection with Diffusible Preservatives and Pesticides*; Forest Products Society, **1997**; pp 85–92.

[11] Hamilton, R. A.; Wolf, B. C. Accidental Boric Acid Poisoning Following the Ingestion of Household Pesticide. *Journal of Forensic Sciences* **2007**, *52* (3), 706–708. https://doi.org/10.1111/j.1556-4029.2007.00420.x

[12] Hassan, B.; Nanda, M. A. Detection and Monitoring Techniques of Termites in Buildings: A Review. *International Biodeterioration & Biodegradation* **2024**, *195*, 105890. https://doi.org/10.1016/j.ibiod.2024.105890

[13] Issoufou, A. A.; Soumana, I.; Maman, G.; Konate, S.; Mahamane, A. Effects of Termites Growth on Litter Decomposition: A Modeling Approach. *International Journal of Recycling of Organic Waste in Agriculture* **2019**, *8* (Suppl 1), S415–S421. https://doi.org/10.1007/s40093-019-00314-7

[14] Livage, J. Sol-Gel Processes. *Current Opinion in Solid State and Materials Science* **1997**, *2* (2), 132–138. https://doi.org/10.1016/S1359-0286(97)80057-5

[15] Janowiecki, M. A.; Vargo, E. L. Effect of Soldiers on Collective Tunneling Behavior in Three Species of Reticulitermes (Blattodea: Rhinotermitidae). *Insectes Sociaux* **2022**, *69*, 237–245. https://doi.org/10.1007/s00040-022-00864-6

[16] Johnson, A.; Forschler, B. T. Biodiversity and Distribution of Reticulitermes in the Southeastern USA. *Insects* **2022**, *13*, 565. https://doi.org/10.3390/insects13070565

[17] Lloyd, J. D. Borates and Their Biological Applications. International Research Group on Wood Protection (IRG/WP 90-3054), **1990**.

[18] Lloyd, J. D. Borate Wood Preservatives. In *Wood Deterioration and Preservation: Advances in Our Changing World*; American Chemical Society Symposium Series, **1998**.

[19] Long, C. E.; Thorne, B. L. Resource Fidelity, Brood Distribution and Foraging Dynamics in Complete Laboratory Colonies of Reticulitermes flavipes (Isoptera: Rhinotermitidae). *Ethology Ecology & Evolution* **2006**, *18* (2), 113–125. https://doi.org/10.1080/08927014.2006.9522717

[20] Mohareb, A.; Thévenon, M. F.; Wozniak, E.; Gérardin, P. Effects of Polyvinyl Alcohol on Leachability and Efficacy of Boron Wood Preservatives against Fungal Decay and Termite Attack. *Wood Science and Technology* **2010**, *45* (3), 407–417. https://doi.org/10.1007/s00226-010-0344-4

[21] Myles, T. G. Laboratory Evaluation of Boron as a Wood Preservative against Termites. *Forest Products Journal* **1994**, *44* (5), 37–40.

[22] Obanda, D. N.; Shupe, T. F.; Barnes, H. M. Reducing Leaching of Boron-Based Wood Preservatives—A Review of Research. *Bioresource Technology* **2008**, *99* (15), 7312–7322. https://doi.org/10.1016/j.biortech.2007.12.077

[23] Oi, F. A Review of the Evolution of Termite Control: A Continuum of Alternatives to Termiticides in the United States with Emphasis on Efficacy Testing Requirements for Product Registration. *Insects* **2022**, *13* (1), 50. https://doi.org/10.3390/insects13010050

[24] Peterson, C. J. Termites. In *Mallis Handbook of Pest Control*, 10th ed.; GIE Media: Cleveland, OH, **2006**.

[25] Peterson, C. J. Review of Termite Forest Ecology and Opportunities to Investigate the Relationship of Termites to Fire. *Sociobiology* **2010**, *56* (2), 313–352.

[26] Potter, M. F. Controlling Termites. *Journal of Light Construction* **1997**.

[27] Rust, M. K.; Su, N. Y. Managing Social Insects of Urban Importance. *Annual Review of Entomology* **2012**, *57*, 355–375. https://doi.org/10.1146/annurev-ento-120710-100634

[28] Sadecka, Z.; Myszograj, S.; Sieciechowicz, A.; Płuciennik-Koropczuk, E.; Włodarczyk-Makuła, M. Impact of Selected Insecticides on the Anaerobic Stabilization of Municipal Sewage Sludge. *Desalination and Water Treatment* **2016**, *57*, 1213–1222. https://doi.org/10.1080/19443994.2014.1002284

[29] Su, N. Y.; Scheffrahn, R. H. Comparison of Eleven Soil Termiticides against the Formosan and Eastern Subterranean Termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology* **1990**, *83*, 1918–1924.

[30] Su, N. Y. Novel Technologies for Subterranean Termite Control. *Sociobiology* **2002**, *39* (3), 1–7.