East African Journal of Forestry & Agroforestry
eajfa.eanso.org
Volume 7, Issue 1, 2024
Print ISSN: 2707-4315 | Online ISSN: 2707-4323
Title DOI: https://doi.org/10.37284/2707-4323

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Effectiveness of Selected Preservatives in Protecting Bamboo Against Termite Attack

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Article DOI: https://doi.org/10.37284/eajfa.7.1.2089

Date Published:

07 August 2024

Keywords:

Bamboo, Macrotermes Bellicosus, Biodegradation, Preservation.

ABSTRACT

Bamboo is highly susceptible to insect attacks. To promote its use as an alternative to wood, it is crucial to assess its preservation methods to increase its service life. This study investigated the effectiveness of preservatives in protecting bamboo against termite attack. Three bamboo species were extracted, air-dried, and pressure-treated with different concentrations of crude-lake salt, borax-boric acid, and tanalith. Preserved and unpreserved samples for each treatment were weighed and exposed to *Macrotermes bellicosus* termites in Kasagala Central Forest Reserve. After 21 days, durability classes and mass loss were determined following European standards. The results showed that termite resistance depends on the type of preservative. All the untreated and crude lake salt-treated bamboo samples were attacked and classified into the not-durable class. Samples treated with Tanalith were classified under the durable class. Borax-boric acid provided moderate resistance to bamboo samples and belonged to the moderately durable class. Crude lake salt did not provide sufficient protection against termites. The difference in species did not influence termite resistance. Untreated *Bambusa vulgaris* had the highest mass loss and *Oldeania alpina* the lowest. The findings from the study will contribute to improved utilisation of bamboo by proper preservation.

APA CITATION

Mwanja, C. K., Ishengoma, R., Banana, A., Terziev, N. & Kalanzi, F. (2024). Effectiveness of Selected Preservatives in Protecting Bamboo Against Termite Attack *East African Journal of Forestry and Agroforestry*, *7*(1), 287-299. https://doi.org/10.37284/eajfa.7.1.2089

CHICAGO CITATION

Mwanja, Christine Kalembe, Romanus Ishengoma, Abwoli Banana, Nasko Terziev and Fred Kalanzi. 2024. “Effectiveness of Selected Preservatives in Protecting Bamboo Against Termite Attack” *East African Journal of Forestry and Agroforestry* 7 (1), 287-299. https://doi.org/10.37284/eajfa.7.1.2089.

HARVARD CITATION

Mwanja, C. K., Ishengoma, R., Banana, A., Terziev, N. & Kalanzi, F. (2024), “Effectiveness of Selected Preservatives in Protecting Bamboo Against Termite Attack”, *East African Journal of Forestry and Agroforestry*, 7(1), pp. 287-299. doi: 10.37284/eajfa.7.1.2089.

IEEE CITATION

C. K., Mwanja, R., Ishengoma, A., Banana, N., Terziev, & F., Kalanzi "Effectiveness of Selected Preservatives in Protecting Bamboo Against Termite Attack", *EAJFA*, vol. 7, no. 1, pp. 287-299, Aug. 2024.

MLA CITATION

Mwanja, Christine Kalembe, Romanus Ishengoma, Abwoli Banana, Nasko Terziev & Fred Kalanzi. "Effectiveness of Selected Preservatives in Protecting Bamboo Against Termite Attack". *East African Journal of Forestry and Agroforestry*, Vol. 7, no. 1, Aug. 2024, pp. 287-299, doi:10.37284/eajfa.7.1.2089

INTRODUCTION

Bamboo contributes to Sustainable Development Goals 13 (Climate Action) and 15 (Life on Land) through its short rotation cycle and ability to prosper in marginal and degraded lands. Bamboo can be selectively harvested without replanting, increasing its carbon storage potential (Choudhary et al., 2022). Additionally, as a natural renewable material, bamboo has distinct characteristics that make it a suitable alternative to wood. Bamboo's strength and uniform grain structure are appropriate for a wide range of applications, including construction, furniture making, and different artefacts (Gao et al., 2022). Replacing wood with bamboo in various applications can be challenging due to its susceptibility to many biodegradable agents, including beetles, fungi, and termites.

Termites, particularly, are social insects with tremendous importance to human life and the environment. Numerous termite species are edible to human beings because of their high nutritional content. The edible termites are distributed across four families: Termitidae, Rhinotermitidae, Kalotermitidae, and Hodotermitidae (Herbert and Kappauf, 2021). In the environment, termites play a crucial role in the ecosystem by breaking down lignocellulosic materials and contributing to bio-recycling (Bishop et al., 2021; Griffiths et al., 2019; Ohkuma, 2003). However, they are known to be a menace to forests, trees and various wooden structures. The global damage caused by termites is estimated at approximately USD 40 billion, mainly on wooden structures (Kim and Chung, 2022). This damage leads to frequent replacement of wooden structures that causes a strain on the dwindling tree resources.

Because of the termite's ecological and socio-economic importance, they should not be eliminated from the environment. Instead, bamboo can be treated to enhance its resistance to termite attack and extend its service life (Adier et al., 2023; Ewart and Cookson, 2014; Sulaeman et al., 2018; Tarmian et al., 2020). There are both modern and traditional preservation methods. Modern preservation involves using heat at high temperatures under controlled conditions to modify the bamboo cell structure (Li et al., 2022) or treating it with chemicals, either with or without pressure (Gauss et al., 2021). The chemicals used in modern preservation include borate compounds, creosote, pentachlorophenol, and copper-based compounds (Tomak and Topaloglu, 2022). Most of these chemicals are expensive and artisans in local communities have long used traditional methods and preservatives that are less costly and readily available (Setiyowati and Mappaturi, 2020). These include smoking, applying engine oil, soaking in crude-lake salt and soaking under running water (Adier et al., 2023; Mwanja et al., 2023; Setiyowati and Mappaturi, 2020). Whereas traditional methods and preservatives are less costly it is important to evaluate their efficacy towards termite attack especially in field conditions (Kaur et al., 2016).

In Africa, research on bamboo is still in its infancy compared to Asia, although there are efforts to promote bamboo as a replacement for wood (Bahru and Ding, 2021; Masisi et al., 2022). Previous studies have examined the degradation of wood by termites (Kalleshwaraswamy et al., 2022) natural susceptibility of wood to termite attack (Nakabonge and Matovu, 2021), the efficacy of various treatments such as use of furfuryl alcohol (Sudo et al., 2021), natural extractives (Syofuna et al., 2012), CCA, used engine oil and neem extract against

Article DOI: https://doi.org/10.37284/eajfa.7.1.2089

termite attack in wood (Ssemaganda et al., 2011). Limited information has been documented on termite attack in relation to preserved bamboo. A few studies have examined the natural durability of *Bambusa vulgaris* (Sadiku et al., 2021) and relation of termite attack with seasonal variations of starch content of *Phyllostachys pubescens* (Yoko et al., 2006). Therefore, this study aimed at providing empirical evidence on the effectiveness of different preservatives (traditional and modern) in protecting bamboo against termite attack. Understanding the effectiveness of traditional and modern preservatives is crucial for promoting bamboo as a sustainable alternative to wood thus fostering sustainable bamboo production and supporting environmental goals.

MATERIALS AND METHODS

Three bamboo species (*Oxytenanthera abyssinica* (A. Rich.) Munro, *Oldeania alpina* K.Schum and *B. vulgaris* Schrad. Ex J.C. Wendl.*)* that are widely grown in Uganda, were used in this study. For each bamboo species, three healthy standing culms were randomly selected and harvested from Metu (3.67° N, 31.76° E), Echuya (1.28° S, 29.81° E) and Kifu (0.43° N, 32.73° E) Central Forest Reserves respectively. The culms were cut 20 cm above the ground, and the mid-section extracted. The extracted sections were air-seasoned for 2 weeks to about 20 % moisture content to ease further sample preparation. Short internodes were obtained from the air-dried pieces by cross-cutting; thereafter, bamboo test pieces (length×width×thickness: 100mm × 20 mm × culm thickness) were extracted (Figure 1) and treated with preservatives detailed in Table 1. A total of 210 bamboo test pieces were prepared, 70 for each species.

Figure 1 Illustration of the sample extraction process

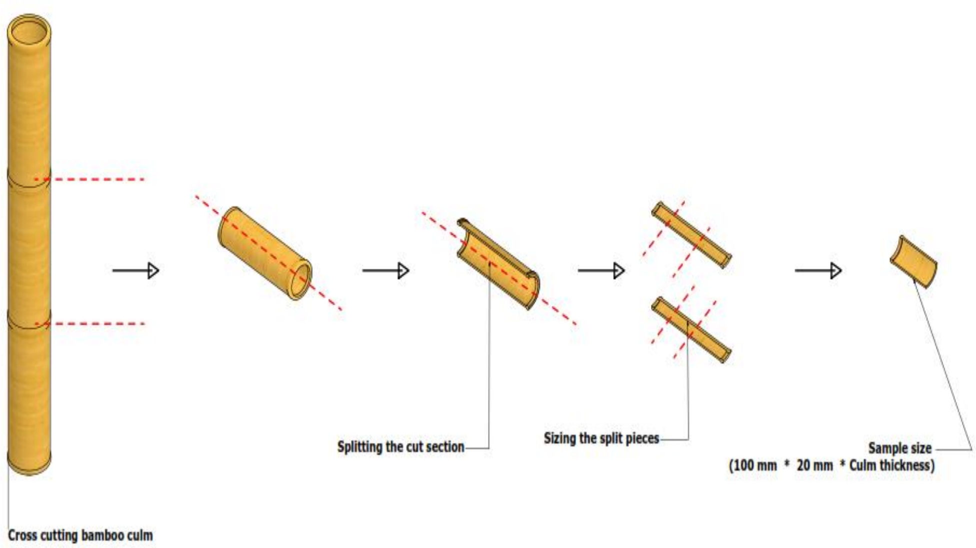

Table 1: Preservative composition and concentrations used in the study

Preservative	Description	Classification	Conc (%)
Crude Lake Salt (CLS)	Mined from Lake Katwe (0.13°S, 29.87° E) and sourced locally in the Ugandan market. CLS is highly alkaline and rich in Sodium chloride and Sodium hydro carbonate (Kasedde et al., 2014)	Traditional	2 and 6
Borax and boric acid (BBA) mixture	Known as Disodium octaborate tetrahydrate $Na_2B_8O_{13}\cdot 4H_2O$ is available locally on the market, borax and boric acid were mixed in a ratio of 1.5:1, respectively.	Conventional	2 and 6

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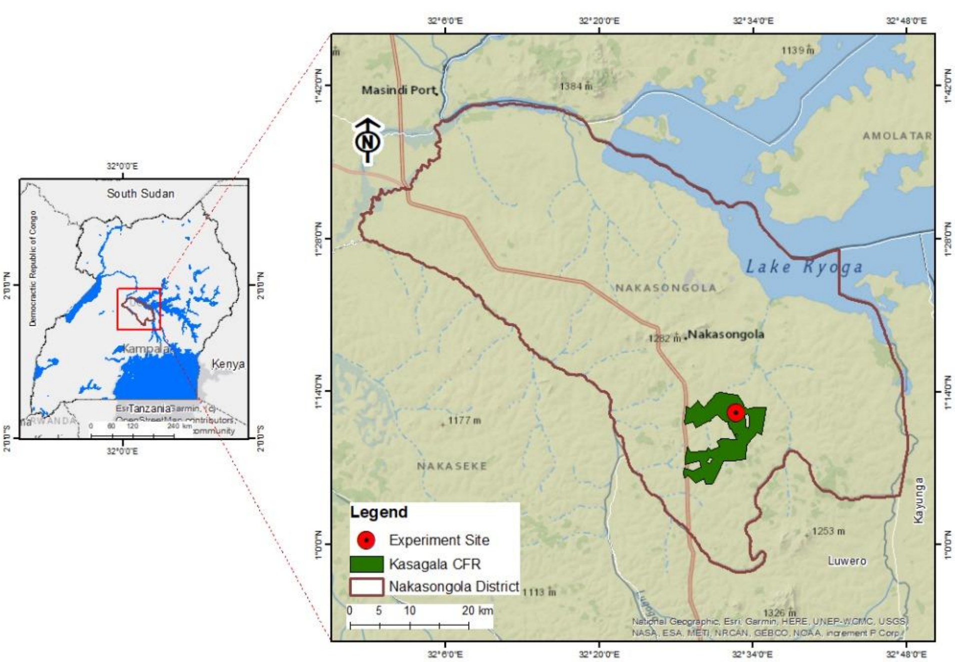
Preservative	Description	Classification	Conc (%)
Tanalith®-E (Tan E)	Tan E is composed of Copper carbonate, boric acid, Tebuconazole, Propoconazole, Monoethanolamine, Polyethyleneamine, 2-Aminoethanol, Di-2-ethylhexylphthalate (Helsen et al., 2007)	Conventional	2 and 3

Vacuum-pressure impregnation was performed following Wahab et al. (2006). An initial vacuum of -600 mmHg was applied for 30 minutes to expel air from the bamboo cells. The preservative solution was let into the cylinder, and a pressure of 5.09 $kgcm^{-2}$ (5 bar) was applied for 2 hours to force the preservative solution into the bamboo. A final vacuum of -600 mmHg for 30 minutes was introduced to remove the excess preservative solution. After preservation, retention of the different samples was determined as described by Gauss et al. (2021). The treated bamboo samples were then dried at 60 °C to constant mass (Initial weight, IW) before exposure to the termites in the field.

The experiment was conducted in Kasagala Central Forest Reserve which is located in Nakasongola district, Uganda (Figure. 2). The location was selected due to the high incidence of termite infestation reported in the area (Ssemaganda et al., 2011). Bamboo test samples were tagged with metal plates for easy identification. The experiment design was a completely randomized design set up with the following factors: three bamboo species, *O. abyssinica*, *O. alpina* and *B. vulgaris*, preservatives at seven levels, CLS 2 %, CLS 6%, BBA 2 %, BBA 6%, Tan E 2 %, Tan E 3% and a control giving a factorial pattern of 3 × 7. Ten repetitions by factor were performed totaling to 210 samples (Figure. 3a). The samples were then covered with grass, and tree branches to attract termites and prevent grazing animals from disturbing them. Visual observations were made daily and termite species were collected from the samples and identified as *Macrotermes bellicosus* (Smeathman) (Figure 3b).

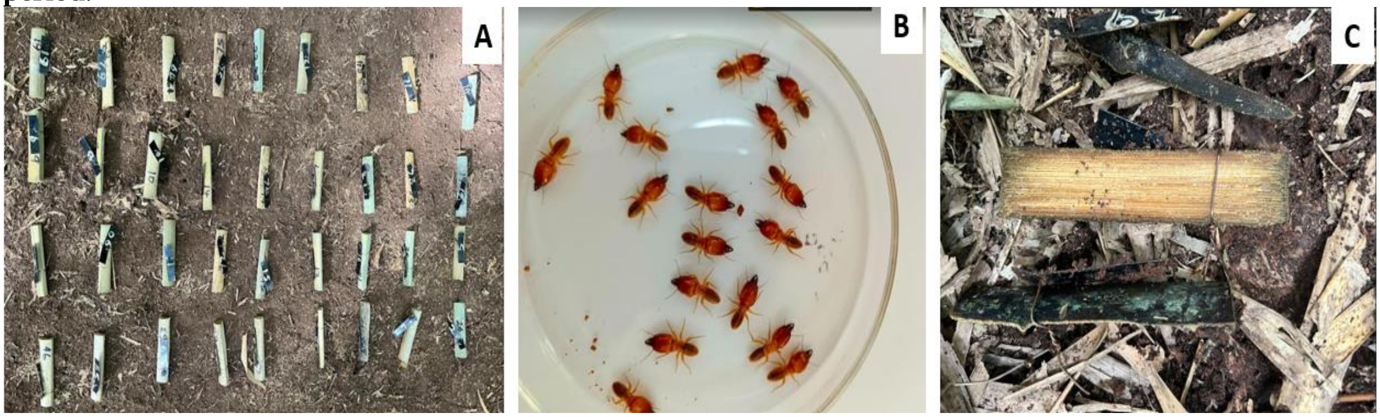
Figure 2: A map of Uganda showing the experiment site



Source: *Author's elaboration*

Article DOI: https://doi.org/10.37284/eajfa.7.1.2089

Figure 3: a) layout of samples in the field, b) *M. bellicosus* termites, c) samples at the end of the test period.



At the end of the exposure period (21 days), Figure 3c samples were collected from the field, and the soil was cleaned off using a brush. Each specimen was examined and visually scored using the scale in Table 2. Durability classes were assigned to the test groups with reference to Table 3. After visual rating, samples were dried at 60 °C to constant mass and final mass (FW) readings taken. The mass loss due to termite activity was determined gravimetrically according to Equation 1

Table 2: Visual rating scheme of test pieces

Score	Description
0	No damage
1	*Attempted attack*: (i) superficial erosion of the test specimen, (ii) attack to a depth of 0.5 mm provided that this is restricted to an area, not more than 30 mm^2 in total, or a combination of (i) and (ii).
2	*Slight attack*: (i) erosion of 1 mm in depth limited to not more than 1/10 of the surface area of the test specimen, (ii) single tunneling to a depth of up to 3 mm, or a combination of (i) and (ii).
3	*Average attack*: (i) erosion of < 1 mm in depth over more than 1/10 of the surface area of the test specimen, (ii) cross-sectional erosion of >1mm to <3 mm in depth limited to not more than 1/10 of the surface area of the test specimen, (iii) isolated tunneling of a depth >3 mm not enlarging to form cavities or any combination of (i), (ii) and (iii).
4	*Strong attack*: (i) erosion of >1 mm to <3mm in the depth of more than 1/10 of the surface area of the test specimen, (ii) tunneling penetrating to a depth >3mm and enlarging to form a cavity in the body of the test specimen, or combination of (i) and (ii).

Source*: European standard EN 117*

Table 3: Durability classes of bamboo samples to termite attack

Durability class	Description	Rating
DC D	Durable	≥ 90 % "0 or 1" and max 10 % "2" [a]
DC M	Moderately durable	< 50 % "3, 4"
DC S	Not durable	≥ 50 % "3, 4"

[a] 90 % of the test samples rated 0 or 1 and a maximum of 10 % of the test samples rated 2 and 0 % "3 and 4"

Source*: European standard EN 350 and EN 117*

The percentage mass loss (ML) was determined according to Equation 1

$$ML\ (\%) = \{IW - FW)/ IW\} \times 100 \quad (1)$$

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Where IW is the mass before exposure; FW is the mass after exposure

Data analysis

To evaluate the effect of preservative treatments on termite resistance of bamboo, the percentage mass loss data were checked for normality using Kolmogorov-Smirnov test and Levene's test for homogeneity of variance before conducting factorial analysis of variance (ANOVA). Factorial analysis of the mean ML was conducted at 95% level of significance. All analyses were performed using Minitab statistical packages.

Table 4 displays the visual scores given to both the treated and untreated bamboo samples in the study, with reference to EN 117 (Table 1). Generally, all the untreated bamboo samples from all species were categorized as "strong attack" (category 4). Samples treated with 3% Tan E received a score of 1, indicating "attempted attack" due to superficial erosion. Meanwhile, samples treated with 2% and 6% BBA fell into the categories of "average" and "slight attack", respectively. The majority of CLS-treated samples were scored 4, denoting "strong attack", except for the *O. abyssinica* samples treated with 6%, which were scored 3 for "average attack".

RESULTS

Table 4: Scores for the bamboo samples from the visual assessment

Preservative		Species		
		O.abyssinica	*O. alpina*	*B. vulgaris*
Control		4	4	4
BBA	**2%**	3	3	3
	6%	2	2	3
CLS	**2%**	4	4	4
	6%	3	4	4
Tan E	**2%**	1	1	1
	3%	1	1	1

BBA: Borax and boric acid; CLS Crude lake salt; Tan E Tanalith

Table 5 presents the preservative retention and durability classes assigned to the treated and untreated bamboo samples in the study, with reference to EN 117 and EN 350 (Table 3). It was observed that all untreated bamboo samples, regardless of the species, were not durable against termite attacks. Samples treated with 2% and 3% Tan E were categorized as durable (durability class D), while those treated with both concentrations of CLS were classified as not durable.

Table 5: Retention of Preservatives and Durability Class for Bamboo Samples

Preservative		Species					
		O.abyssinica		*O. alpina*		*B. vulgaris*	
		PR (kg/m^3)	DC	PR (kg/m^3)	DC	PR (kg/m^3)	DC
Control			S		S		S
BBA	**2%**	5.2 (0.5)	S	6.0 (1.2)	S	5.5 (1.1)	M
	6%	18.3 (1.1)	S	20.6 (1.8)	M	19.1 (2.2)	M
CLS	**2%**	10.5 (1.5)	S	13.3 (2.4)	S	13.1 (1.5)	S
	6%	14.7 (1.9)	S	18.8 (3.4)	S	18.8 (1.8)	S
Tan E	**2%**	7.1 (1.9)	D	9.5 (1.4)	D	7.7 (1.0)	D
	3%	15.9 (2.0)	D	18.5 (2.6)	D	19.4 (2.2)	D

PR: Preservative Retention; DC Durability Class, S Not durable, M Moderately durable, D durable; BBA: Borax and boric acid; CLS Crude lake salt; Tan E Tanalith

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Figure 4 shows that all three bamboo species were susceptible to termite attack. The untreated *B. vulgaris* registered the highest ML of 83.4% and *O. alpina* had the lowest ML of 71.9%. Across the three preservatives, bamboo samples treated with CLS had the highest ML, while those treated with Tan E had the lowest ML.

Figure 4: Percentage mass loss of bamboo samples after termite attack

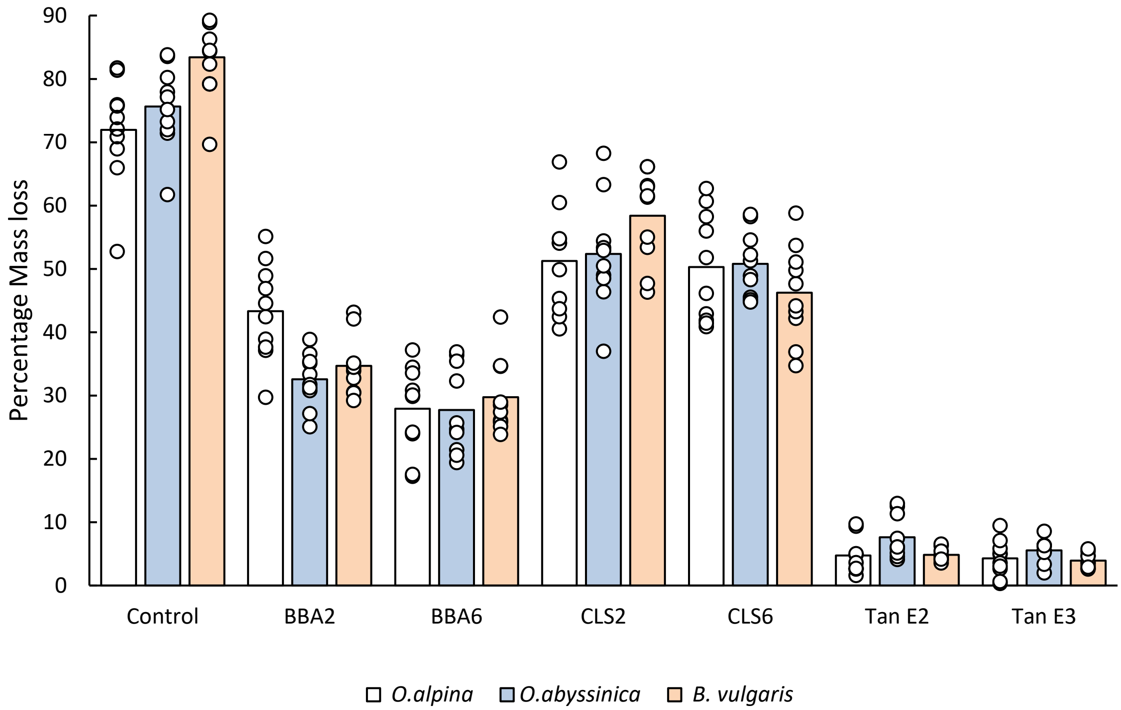

Table 6 summarises the analysis of variance results. The results indicate that the effect of type of preservative on the resistance to termite attack was significantly different (p<0.000), but the effect of bamboo species was not significant. This means that the resistance to termite attack was dependent on the type of preservative applied. The interaction between the two variables (species and preservatives) was significant (p<0.000) at 5%. The Dunnett multiple comparison test with a control showed significant differences in termite resistance between untreated and treated samples Table 7. A difference in protective effect was observed between the Tanalith which is made of copper salts and the two alternative preservatives.

Table 6: Analysis of variance of mean mass loss of treated and un bamboo samples after termite attack

Source of variation	DF	Adj SS	F-Value	P-Value
Model	20	126489	171.47	0.000
Specie	2	74	1.00	0.369
Preservative	6	124629	563.16	0.000*
Two-way interactions				
Specie* Preservative	12	1785	4.03	0.000*
Error	189	6971		
Total	**209**	**133460**		

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Table 7: Dunnett comparison of means

Preservative	Mean	Grouping
Control	76.9	A
CLS 2 %	54.0	
CLS 6 %	49.0	
BBA 2 %	36.8	
BBA 6 %	28.4	
Tan E 2 %	4.7	
Tan E 3 %	4.2	

Means not labelled with letter A are significantly different from the control.
BBA: Borax and boric acid; CLS Crude lake salt; Tan E Tanalith

DISCUSSION

The study findings according to EN 117 and EN 350 show that bamboo is highly susceptible to termite attack which in turn limits its utilisation. The high susceptibility of bamboo is closely attributed to its chemical composition which includes cellulose, hemicellulose, lignin, limited quantities of resins and waxes (Brito et al., 2020). Yet cellulose and hemicellulose are the main components eaten by termites (Ewart and Cookson, 2014; Yoko et al., 2006). Bamboo equally lacks natural extractives such as polyphenols and terpenoids that enhance resistance of some wood species to termite damage (Ameka et al., 2022; Ewart and Cookson 2014; Nakai and Yoshimura, 2020; Syofuna et al., 2012). Our result findings are a confirmation of previous studies that *B. vulgaris* was susecptable with upto 80% mass loss (Ayodele et al., 2022; Ogutuga et al., 2020). Our results indicated no significant variation ($p< 0.369$) in susceptibility to termite attack as a result of difference in species Table 6. However, Subekti et al. (2015) reported variation in five bamboo species with *Dendrocalamus asper* being more resistant than *B. vulgaris, Gigantochloa atter, Gigantochloa atrolviolascea*, and *Gigantochloa apus*. Variations in susceptibility to termite attack among different wood species has also been reported. *E. grandis* exhibits more resistance to termite attack than the hybrid clones (Nakabonge and Matovu, 2021). Beech and polar wood were reported to be more resistant than Scots pine to termite attack (Şen et al., 2017).

Hassan (2021) reported that while visual ratings according to EN 117 and EN 350 are useful for assessing termite attack, mass loss measurements provide more reliable results. From this study, significant differences in the mass loss as a result of preservative type were recorded (Table 6 and 7). The results revealed that Tan E was effective in increasing resistance to termite degradation with mean mass loss in a range acceptable by the AWPC protocols. The AWPC protocals specify toxic limit for each termite species and preservative under test that achieves a mass loss of less than 5 % (Hassan, 2021). This resistance could be attributed to the chemical composition of Tan E, which is a copper azole salt. Copper is toxic to the termites and azole improves the retention and penetration of the copper making the salt less leachable from the bamboo tissues. These findings align with other studies that found that bamboo treated with Tan E and exposed to termites had a mass loss range of 0 to 8.78% (Ayodele et al., 2022). Ghani (2021) reported that water-borne copper azole preservative offers resistance against subterranean termite attack. Copper azole is a preferred wood preservative because it is less toxic to the environment.It has good penetration and can treat refractory wood, which makes it effective for treating therefore it can be used to treat bamboo. It has been previously reported that bamboo is difficult to preserve due to its outer skin, which limits the penetration of chemicals (Lee et al., 2001). However, Ogunsanwo

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et al. (2015) reported that *B. vulgaris* has good treatability with copper-based preservatives.

Based on the findings of our study, it was observed that all concentrations of BBA provided moderate durability to bamboo samples. The moderate durability could be due to insufficient toxicity of borates to deter termites. Our findings are contrary to Gentz and Grace (2006) who reported toxicity from both low and high concentrations of borate compounds to termites. Equally, according to Ahmed et al. (2004), laboratory assays showed that extremely low concentrations of borate chemicals as low as 0.24 % caused significant termite mortality. Additionally, the mild resistance of bamboo samples treated with BBA could have resulted from the preservative not fully diffusing into the bamboo tissues. This is in agreement with Wanishdilokratn et al. (2022) who reported that even when borate-based wood preservatives provide protection, their ability to diffuse deeper especially in wood is somewhat limited. Besides BBA has also been reported to be highly leachable in outdoor environment (Furuno et al., 2003; Ghani, 2021; Mohareb et al., 2010; Tarmian et al., 2020). Istriana and Priadi (2021) reported that whereas boric acid is toxic to termites it needs to be combined with other treatments such as tall oil derivatives (Temiz et al., 2008), hydrophobic agents (Ghani, 2021) chitosan/glycerol (Istriana and Priadi, 2021) to form hydrophobic complexes and avoid leaching (Mohareb et al., 2010). On the other hand the moderate durability of bamboo samples treated with BBA could have resulted from borates which are reported to be more poisonous to lower termites than higher termites such as *M. bellicosus* (Mohareb et al., 2010). The authors further suggest that higher termites can survive at a higher concentration of borate-based preservatives without significant termite mortality.

The study found that using crude lake salt was not effective in protecting bamboo species against termite attack during field exposure. CLS is an unrefined highly alkaline salt with a combination sodium chloride and sodium hydrogencarbonate salts (Kasedde et al., 2014). While sodium chloride has been reported in some studies as a preservative, in our study, the concentration of this salt in CLS was probably not high enough to hinder termite attack. Our results are similar to those reported by Chiu et al. (2021), who found that termites are tolerant to salinity, especially during transoceanic dispersal. On the contrary researchers have shown that NaCl provided protection to wood against termites (Alkali and Muktaar, 2011; Li and Pan, 2021a, 2021b). According to Prabawa and Damayanti (2024), a 4 % concentration of NaCl was sufficient to offer protection to *Crypha utan* palms used for construction in Indonesia against termites.

The experiment findings noted small mass losses observed in samples treated with Tan E and BBA, these losses could be attributed to mode of action from these two preservatives where the samples have to be ingested before exhibiting termicidal properties (Gentz and Grace, 2006). Also notable is the use of pheromones by termites to transmit various context-dependent information, thus resulting in coordinated communication against danger of toxic material (Mitaka and Akino, 2021).

CONCLUSION

As a final consideration in promoting bamboo as a suitable alternative to wood, this study has shown that Tanalith E offers resistance to bamboo against attack from *Macrotermes bellicosus*, classifying it in the durable class. Borax - boric acid, on the other hand, offers moderate resistance, with a classification of moderately durable and not durable. Crude Lake Salt did not provide sufficient protection to bamboo as all samples treated with it were in the not durable class.

ACKNOWLEDGMENTS

The authors acknowledge the funding provided by Sida Grant Number 13394 through the Regional Research School in Forest Sciences (REFOREST), College of Forestry, Wildlife and Tourism, Sokoine

Article DOI: https://doi.org/10.37284/eajfa.7.1.2089

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DECLARATION OF COMPETING INTERESTS

The authors declare no potential conflicts of interests

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