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Evaluation of Anti-termitic Properties of Nigerian-Grown *Eucalyptus camaldulensis* for the Treatment of Selected Susceptible Timbers

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ABSTRACT

This study addresses the protection of Nigerian-grown lower-class timbers (Afara-N6, Abura-N4, Ayure-N5, Mahogany-N5, and Obeche-N6) according to the Nigerian NCP2 classification. Subterranean termites, particularly Coptotermes formosanus, are recognized as significant destroyers of timber and timber products in tropical regions. To combat this, higher-class (N1) Nigerian-grown Eucalyptus camaldulensis timber was utilized to develop non-synthetic anti-termite extracts for treating the susceptible lower-class timbers. These extracts offer advantages over synthetic chemicals by minimizing harm to non-targeted organisms in the ecosystem. Phytochemical analysis revealed significant concentrations of tannin (0.440mg/100g), phenol (0.402mg/100g), saponin (0.208mg/100g), flavonoids (0.025mg/100g) and alkaloids (0.024mg/100g) in the aqueous solution extracts. Graveyard tests, conducted according to ASTM D 1758-74, demonstrated effective treatment of Ayure, Abura, and Mahogany, with minimal percentage weight loss of 0.08, 0.31, and 0.48 respectively. However, Obeche and Afara exhibited higher percentage relative weight loss of 1.05 and 9.05 respectively, possibly due to the absence of phlobatannins and hydroxyl anthraquinone phytochemicals in the extracts. Overall, the Eucalyptus camaldulensis extract shows promise in significantly reducing termite damage in Nigerian-grown timbers such as Ayure, Abura, and Mahogany.

1. **Introduction**

Termite activities in tropical countries are of serious concern. The annual losses accrued to termite attacks in Nigeria are not certain because of inadequate assessment and data, but in the United States, the damage done to cellulose materials (which is the main constituent of any wood or wood product) has been estimated to exceed $3billion annually [1]. The authors reported that termites are responsible for huge yield losses in agriculture and the major constraint in reforestation, especially in the semi-arid and sub-humid tropics. The Anatomy of termites puts them among the few organisms that are capable of digesting cellulose which contributes to their ecological and evolutionary success [2]. Termites are destructive pests to a variety of materials - crop plants and also cause damage to green foliage, forests, seedlings, wooden structures, pasture, fibers, and household cellulose-based materials, including post-harvest stored products [3,4]. They have a significant impact on the structural stability of timber structures and are a major constraint in timber structures. The perceived threats of termites to structural stability create psychological fear of possible attack on the structural element which generally affects the livelihood of dwellers.

Regular repairs of timber products caused by termite damage led to the use of barrier treatments for the prevention of termite damage to buildings. The first treatment was first developed in the 1940s and has changed very little since then. The treatment involves the use of synthetic chemicals which are labor-intensive and require a relatively high concentration of chemicals to be effective in the soil. [5] reported that synthetic chemicals are extensively used in agriculture and are known to provoke major environmental problems in the world. They pollute the air, soil, and water which are natural resources, and also contaminate the food chain. These chemicals act as neurotoxins or inhibitors of mitochondrial respiration termiticides.There are six main insecticide classes currently used in the field namely - organophosphate, carbamate, pyrethroid, neonicotinoid, phenylpyrazole, and avermectin termiticides. [6] noted that the use of proper application methods of termiticides is important to reduce their negative impact on the environment.

Baiting programs are another popular control practice for the prevention of termites which involves the use of non-repellent termiticides to attract termites in their locality [7]. Subterranean termite colonies have extensive underground gallery systems, and it is difficult to eliminate entire colonies using soil insecticides. Baiting programs have been used successfully to eliminate subterranean termite colonies [8]. The goal of a baiting system is to eliminate the entire termite colony from an area with the least possible cost and harm to non-targeted organisms in the environment [9,10] posited that the success of the baiting system is more variable than that of the liquid soil termiticides as it depends on environmental factors such as temperature, humidity, soil type, and soil moisture which affects termite activity at bait stations. Although baiting is the most environmentally friendly way of controlling termites, about two-thirds of the treatments by pest control companies rely on the use of liquid insecticides in soil.

Synthetic chemical preservatives such as solignum, aldrin, chlordane, dieldrin, endrin, heptachlor, mirex, and lots of others are prevalent termiticides that are currently used for controlling termites. Despite their advantages, they pose environmental concerns because of their toxicity and persistence. They have been identified to have persistent organic pollutants (POPs) and have been known to cause negative impacts on global environments, including health hazards to humans and other non-targeted species [11,12]. The application of these chemicals now tends to be restricted in some countries United Kingdom [13].

To avoid these impacts, bio-pesticides are regarded as safer alternatives to chemical pesticides in pest management [14] and as a result, has stimulated much attention among researchers and has been advocated as a potentially good alternative to synthetic pesticides. Many phytochemicals are known to possess anti-termitic or repellent activities. Among them, plant essential oils and plant extracts constitute a rich source of bioactive chemicals and may provide potential alternatives to termite-controlling agents currently in use. Recently, essential oils have been considered potent and safe insecticides whose main components are monoterpenes and sesquiterpenes, and some of them are termiticidal. According to [15], timber preservation strategies with lower environmental impacts and reduced effects on non-targeted organisms such as extracting toxic fractions from naturally durable termite-resistant wood species should be investigated as wood preservatives to treat timber-susceptible species.

Plant extracts, chemically called phytochemicals, have long been explored traditionally to preserve wood. Oils, tars, and extracts have been used to impregnate wood structures, though their availability and economic feasibility have not promoted their extensive use. Naturally durable wood species are capable of causing delays in bio-deterioration by fungi and insects [16]. Extractive content from the heartwood region of plants is the contributor to the inherent durability of these wood species [17]. The phytochemicals are produced by plants through metabolism. Metabolites include flavonoids, alcohols, terpenes, alkaloids, glycosides, esters, stilbenes, phenols, polyphenols, and water-soluble compounds having insecticidal, antifungal, and antimicrobial activities [18,19,20]. Neem tree (*Azadirachta indica*) extracts were used to investigate its effect on some commonly present plant products on the termite species *Heterotermis indicola*, which is a worldwide problem. It was concluded that the efficiency of neem and garlic extracts have insecticidal properties against termites [21]. Anti-termite responses of *Capparis* decidual stem, root, flower, and fruit extracts, and pure compounds have been tested against *Odontotermes obesus* in various bioassays. Crude stem extract has shown very high susceptibility [22]. Also, extract prepared from seed (neem seed oil) with chlorpyriphos (chemical) to treat susceptible *Khaya senegales* was successful; but achieved better results when combined with extracts (to replace chlorpyriphos) [23].

The aqueous solution of extracts from the sapwood and heartwood of the *Eucalyptus camaldulensis* plant therefore holds an auspicious chance as an anti-termite agent. On this note, this study aimed to investigate the extracts from the heartwood of *Eucalyptus camaldulensis* as termite-resistant material to preserve termite susceptible timbers. Five lower-class, termite-susceptible Nigerian-grown timbers Afara-N6, Abura-N4, Ayure-N5, Mahogany-N5, and Obeche-N6 were used as the case study [24]. While the Nigerian-grown *Eucalyptus camaldulensis* timber was selected to extract a non-synthetic anti-termitic solution to treat the lower-class timbers. The graveyard field test was used for evaluating the preservative-treated wood with stakes. The [25] standard test was used for the laboratory evaluation of wood for its resistance to subterranean termites.

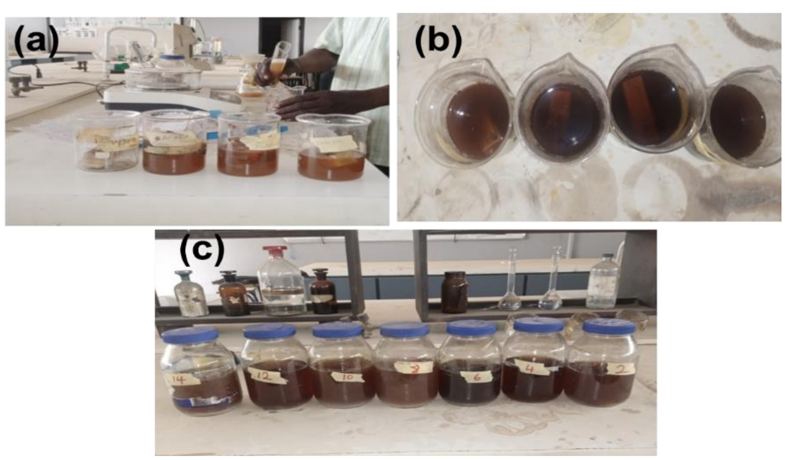
2. Materials and Methods

2.1 Sample Collection

The termite-susceptible timber species used for this study are Abura (*Mitragyna ciliata*), Afara (*Termnalia superba*), Ayure (*Albizia lebbeck*), Mahogany (*Khaya ivorensis*), and Obeche (*Triplochiton scleroxylon*). The termite-resistant timber was selected from the upper-class N1 following [24]. This timber was sourced from the green timber of *Eucalyptus camaldulensis* planted as an afforestation scheme (green areas) and boundary demarcation of the National Eye Center Kaduna. The tree was propagated in the nursery in August 1993 and transplanted to its permanent position in November 1993. The tree was harvested for this research on 2nd February 2023 at the age of 30 years. It grew to a height of 18m and a maximum measured girth circumference of 2.74m (0.8m diameter) at ground level. At a breast level of 1.58m high, it was 2.05m in circumference (0.65m diameter). Samples of the *Eucalyptus camaldulensis* taken from the field were freed from foreign particles and sun-dried in preparation for laboratory extract production and phytochemical presence tests. The specimen for the extracts was taken from the sapwood and the heartwood region of the termite-resistant eucalyptus tree by radial cross-cutting of the green timber at several positions within the trunk. This was done to get the desired quantity required for the research work. Distilled water was used for the phytochemical analysis.

2.2 Extracts Preparation

Extract preparation was carried out at the Applied Chemistry laboratory of Kaduna Polytechnic. The pulverized *Eucalyptus camaldulensis*, sapwood, and heartwood samples were dried at room temperature in the laboratory for one week. The dried pieces were pulverized and 10 litres of distilled water was used for the phytochemical extraction and analysis. Extraction techniques used were cold maceration and decoction. 1g of the completely dried pulverized timber was weighed and soaked in 10ml of distilled water for about 15 days. The extract dissolution process from the fabrics of the solutes was progressively measured at intervals of two days for concentration determination as shown in Plate 1.



Plates 1. (a) Weighing samples for soaking; (b) Solution of samples; (c) Apparatus for decoction procedure at 2-days interval.

2.3 Laboratory Analysis (Phytochemical Screening)

The phytochemical screening of *Eucalyptus camaldulensis* extracts was conducted using a standard procedure as described by [19,26] with little or no modification to identify the constituents. Identification and biochemical analyses (quantitative and qualitative) of the extracted phytochemicals were carried out to test for the presence of alkaloid, tannin, flavonoid, terpenoid, saponin, phenol, phlobatannins, and hydroxyl anthraquinone.

2.4 Termite-Susceptible Specimens

The termite-susceptible timbers (Abura, Afara, Ayure, Mahogany, and Obeche) were chosen from the moderately durable class of timbers (between N4 and N6). They were sourced from the building materials market (Pantaka) in the Kaduna metropolis. Samples were prepared in the timber Laboratory of NDA and the carpentry workshop of the National Eye Centre Kaduna. About 15 samples each of Abura, Afara, Ayure, Mahogany, and Obeche species were sawn to 25mm x 25mm x 450mm (tangential x radial x longitudinal) following the [25] standard. All the stakes were free of knots and showed no infection by moulds, stains, or wood-destroying fungi and insects. Some specimens were also prepared for density determination and extract absorption. The timber samples were weighed (Plate 2a) and kept in an oven (Plate 2b) at 1050C for 24 hours for moisture content and density determination.

Plate 2. (a) Weighing field samples and density samples for oven drying (b) Oven-dried density samples

2.5 Field Extraction of Aqueous Extracts and Impregnation

20kg of the dried pulverized *Eucalyptus camaldulensis* sapwood and heartwood were soaked for about two weeks in a plastic cylindrical calibrated drum containing 200ltrs of water to form a solution of the extracts. The aqueous extract was filtered using a filter net to get rid of the chaff of the solute. Subsequently, the timber-susceptible samples were weighed after oven-drying for 24 hours and arranged in the cylindrical plastic drum with adequate representation of samples at every level in the container till it was filled. The aqueous solution of the extract was then used to soak the timbers for ten days. The soaked susceptible timbers were removed after ten days for extract absorption test and were thereafter air-dried as shown in Plate 3 before being taken to the graveyard site.

Plate 3. Air-drying of soaked susceptible timbers before the graveyard test

2.6 Graveyard Test

The graveyard field test was done following the [27] standard test method of evaluating the preservative-treated wood with stakes. The [25] standard test method was used for the laboratory evaluation of wood for its resistance to subterranean termites. The soaked and air-dried specimens of 25mm x 25mm x 450mm (tangential x radial x longitudinal) were buried in the graveyard earlier marked out with evidence of termite infestation. The stakes were pegged at a depth of 225mm into the soil with inter and intra spacing of 300mm and 600mm as shown in Plate 4. They were left for a targeted period of 6 weeks during which observation of the samples was carried out every 2 days. At the end of the third week of the field testing, termite actions were very visible for assessment. The samples were withdrawn, oven-dried, and weighed to obtain the gravimetric weight loss as a measure of the extent to which the samples were attacked by termites. The results were then compared against the control specimens.

Plate 4. Grave-yard preparation and establishment of sample-specie positions

3. Results and Discussion

3.1 Phytochemicals in *Eucalyptus camaldulensis*

Table 1 shows the presence of alkaloids, flavonoids, tannins, saponin, and phenol that are anti-termitic as well as other phytochemicals present in *Eucalyptus camaldulensis*. They were further subjected to biochemical (quantitative and qualitative) tests.

Table 1. The available phytochemicals in *Eucalyptus camaldulensis*

Substance	Result 2 days	4 days	6 days
Alkanoids	++	++	++
Tannins	+++	+++	+++
Carbohydrate	+	++	+++
Flavonoids	+	++	+++
Protein	+	++	+++
Terpenids	+	+	+
Phlobatannins	--	--	
Saponins	++	++	++
Cardiac glycosides	+	+	+
Phenol	++	++	++
Steroids	+	+	+
Hydroxyl anthraquinone	--	--	--

Key: +++highly positive; ++ moderately positive; +mildly positive; -- negative

The single positive (+) marks indicate phytochemicals present in trace amountswhile the intensity of presence increases with the number of marks. Also, the negative sign indicates the absence of anti-termitic phytochemicals in the extracts. As seen from Table 1, the result shows that tannin, phenol, alkaloid, saponin, and flavonoids are present in high quantities while terpenoids, steroid, and cardiac glycoside were only present in traces. Some important anti-termitic phytochemicals like phlobatannins and hydroxyl anthraquinones were completely absent from the extracts of *Eucalyptus camaldulensis* timber. Decoction is the process of dissolving phytochemical extracts from the fabrics of the solute into the water to form an aqueous solution of extracts. Figure 1 shows the progressive dissolution with time (in days). The optimum concentration was attained at six (6) days of decoction with tannin being the highest (0.440 mg/100g) followed by phenol (0.402 mg/100g), saponin 0(.208 mg/100g), flavonoids (0.025 mg/100g) and the least at being alkaloid (0.024 mg/100g). The decoction tends to reduce to negligible values after fourteen (14) days. This indicates that the minimum duration for the extraction of the extracts should not be less than 6 days while the maximum duration should be fourteen days.

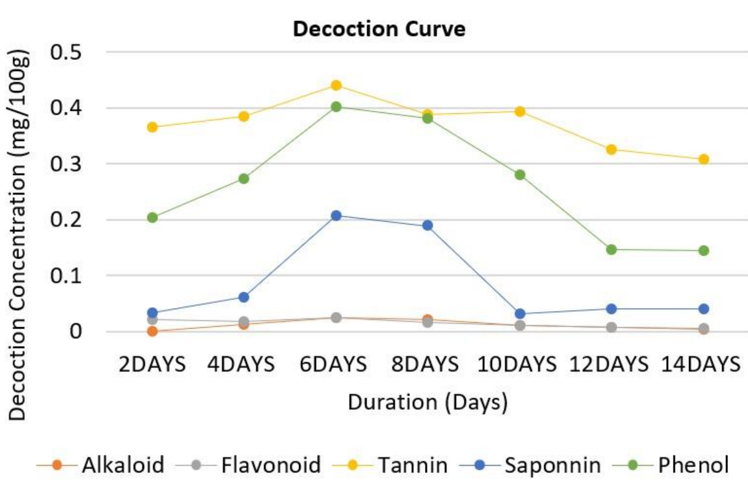


Figure 1. Concentration-time decoction curve

3.2 Impregnation/Absorption of Extracts

Impregnation is the process whereby aqueous extract moves into the termite-susceptible timber sample by absorption at atmospheric pressure. The result of the absorption of aqueous solution into the fabrics of the termite susceptible timber samples is presented in Figure 2.

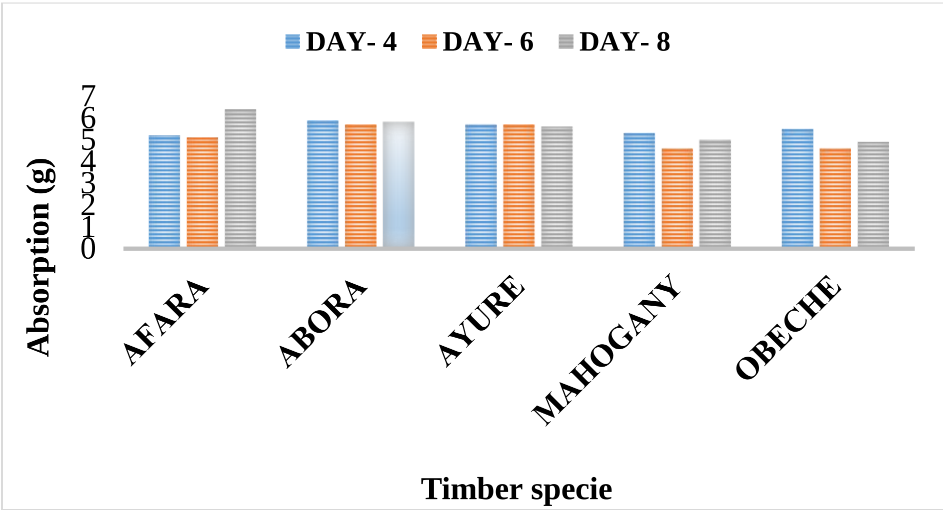


Figure 2. Absorption of extracts into the termite susceptible timber samples

The results of extract absorption into the termite-susceptible timber samples are shown in Figure 2. It can be seen that there is a decline in the rate of extract absorption for most of the timbers between days 6 and 8 therefore additional two days were allowed for possible further absorption hence, ten days were used to ensure adequate absorption. Also, limiting soaking to ten days is a precautionary measure because wood rot can ensue when timbers are soaked in a solution of water solvent longer than necessary. The absorption rate is reflective of how packed the wood fibres are and reflects the density of each sample. This suggests that samples with a faster absorption rate or precipitous absorption gradient are less dense than samples with a slower absorption rate or gentle absorption gradient. This phenomenon further confirms the grade classes of the sample species as Abura exists at the top N4 while Obeche and Afara are at the lower N6 class.

3.3 Analysis of the Graveyard Results

The analysis of the graveyard experiment applies Equation 1 [28] to calculate the weight loss of the specimen (both treated and untreated (control) due to termite action after the application of extract. The X-value was calculated following Equation 2 to determine the gravimetric weight loss due to termite attack. The results are displayed in Table 2.

$$\text{Weight loss (\%)} = \frac{w_3 - w_4}{w_3} \times 100 \qquad (1)$$

Where w_3 = conditioned weight after treatment and w_4 = weight of conditioned timber sample after exposure to termite attack

The X-value is calculated thus,

$$\text{X-value} = \frac{\text{average corrected mass loss of test specimen}}{\text{average mass loss of reference specimens}} \quad (2)$$

Table 2. The data obtained from Equations 1 and 2

Specimen	Weight before test (w_3)	Weight after test (w_4)	Weight diff. (w_3-w_4)	Weight loss of treated (%)	Weight of control Before test (B)	Weight of control after test (B')	Weight loss of control Test (B-B')	Weight loss of control (%)	X-value
Afara	379.4	303.8	75.6	19.9	380	371.8	8.2	2.2	9.05
Abura	709	674	35	4.9	629	529	15.89	25	0.31
Ayure	876.3	848.5	27.8	3.2	807.5	466	341.5	42.3	0.08
Mahogany	767	741.9	25.1	3.38	699	650	49	7.1	0.48
Obeche	553.1	433.7	119.4	21.6	524	416.3	107.7	20.55	1.05

From Table 2, it can be seen that Obeche manifested the highest weight loss (21.6%), followed by Afara (19.2%), Abura (4.9%), Mahogany (3.38%), and Ayure (3.2%). Also, Obeche displayed the highest weight loss for the control sample (20.55%), and Afara the least (2.2%). Comparing the weight loss of Ayure for example, as illustrated in Figure 3, it can be observed that the percentage weight loss of the control sample was 42.3%, while the treated Ayure timber suffered only 3.2% translating to 0.08 X-value (being the least X-value), indicating the best efficiency of the treatment. From this, it can be hypothesized that Ayure, though susceptible, possibly possesses traces of anti-termitic phytochemicals that have been boosted by the absorbed extracts. The same trend can also observed in the case of the weight loss of treated (4.9%) and control (25%) Abura timber species. Furthermore, the control samples of Mahogany suffered a weight loss of 7.1% compared to the treated samples' weight loss of 3.38%. These results show the treatment was effective and efficient for these timber species. However, the treatment was ineffective for the Afara-treated sample which suffered 19.9% weight loss while the untreated control suffered only 2.2%. Also, treated Obeche samples suffered almost the same weight loss as the untreated (control) samples at 21.6% and 20.55% respectively. This signifies the ineffectiveness of aqueous extract in treating the Obeche and Afara timbers against subterranean termites. The inefficacy of the eucalyptus extract observed in treating Obeche and Afara timbers is possibly owing to the absence of phlobatannins and hydroxyl anthraquinone in the extract. It could also be due to certain peculiar phytochemical compositions in Afara and Obeche which functioned either to resist or inhibit the antitermitic effect of the eucalyptus extract.

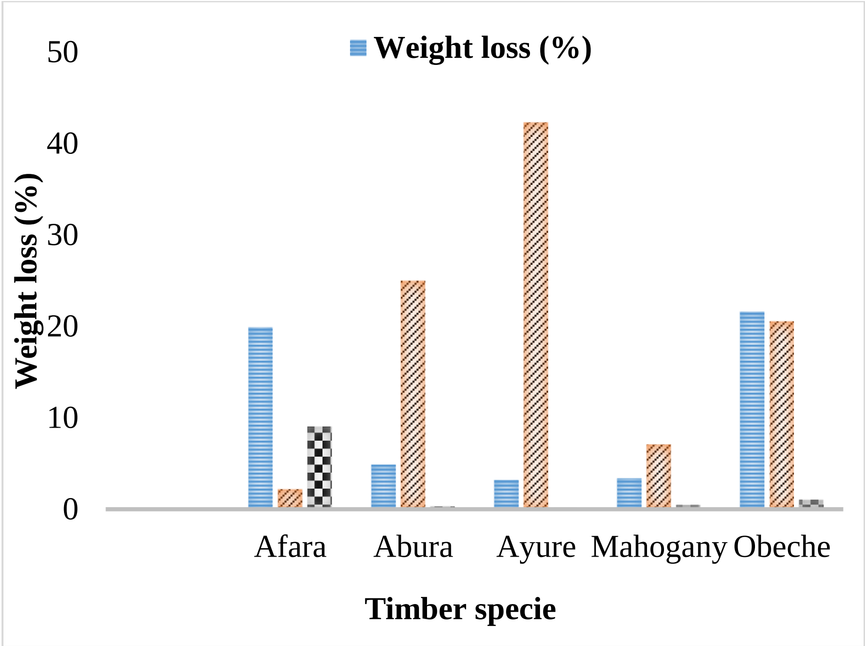


Figure 3. Comparison of the weight loss (treated and control) and X-value of the timber samples

4. Conclusion

Eucalyptus camandulensis was selected from the N1 class as the termite-resistant Nigerian-grown timber from which aqueous solution extract was successfully obtained. Selected termite-susceptible lower-class timbers namely Afara-N6, Abura-N4, Ayure-N5, Mahogany-N5, and Obeche-N6 were then impregnated with the resulting extract as the treatment protocol. Based on the findings of this study, the following deductions can be made.

Anti-termitic phytochemicals like phlobatannins and hydroxyl anthraquinone were completely absent from the aqueous solution extract of *Eucalyptus camaldulensis*.

The results of the graveyard test show the efficacy of the treatment with the extract does not provide complete protection to the susceptible timbers against *Coptoterm fermosan* termites. The measured resistance of deterioration concerning the control timber species indicates that the weight loss is highest in Obeche (21.6%) followed by Afara (19.9%) compared to their controls (20.55% and 2.2%). Hence, the aqueous solution extract treatment on Afara and Obeche showed no improvement and was considered ineffective, making these timber species still vulnerable to subterranean termite attacks.

The aqueous solution extract was successful in treating Ayure, Abura, and Mahogany timber species. The treated Ayure sample experienced a 3.2% weight loss against 42.3% of its untreated/control. The treated Abura sample manifested a 4.9 % weight loss against 25% of its untreated/control. The Mahogany sample displayed a 3.38% weight loss against 7.1% of its untreated/control. Furthermore, based on the x-values i.e., the average relative weight loss of the treated specimens compared to their controls following 0.08, 0.31, and 0.48 for Ayure, Abura, and Mahogany respectively, it was concluded that the treatment is most effective for Ayure followed by Abura and lastly Mahogany.

Finally, even though the resistant species *Eucalyptus camaldulensis* is from the N1 class of timber, it was only effective on Ayure, Abura, and Mahogany timber species which belong to the class N5, N4, and N5 respectively. This suggests that an N1 class may not necessarily work efficiently for all lower classes unless proper laboratory screening is carried out to check the phytochemical match in both termite susceptible and resistant timbers.

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References

[1] Su, N.-Y., and R. H. Scheffran. 1990. Comparison of eleven soil termiticides against Formosan subterranean termite and eastern subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol. 83: 1918 Ð1924.
[2] Messenger, M.T., Su N.-Y., Husseneder C., and Grace J.K. (2005). Elimination and reinvasion studies with Coptotermes formosanus (Isoptera: Rhinotermitidae) in Louisiana. Journal of Economic Entomology. 98: 916–929.
[3] Eko Kuswanto, Intan Ahmad and Rudi Dungani, 2015. Threat of Subterranean Termites Attack in the Asian Countries and their Control: A Review. Asian Journal of Applied Sciences, 8: 227-239.
[4] Siramon P., Ohtani Y., Ichiura H. (2009). Biological performance of Eucalyptus camaldulensis leaf oils from Thailand against the subterranean termite Coptotermes formosanus Shiraki The Japan Wood Research Society 55:41–46.
[5] Ansari I., El-Kady M.M., [2], Arora C., Sundararajan M., Maiti D., Khan A. (2021). A review on the fatal impact of pesticide toxicity on environment and human health 2021, Global Climate Change, 2021, pp. 361-391.
[6] Forschler B. T. and Jenkins T. M., (2000). Subterranean Termites in the Urban Landscape: Kluwer Academic Publishers Urban Ecosystems, 4: 231–251.
[7] Henderson G., 2001 Practical considerations of the Formosan subterranean termite in Louisiana: A 50-year-old problem Sociobiology 37(2):281-292.
[8] Su et al 1995., Monitoring/Baiting Station To Detect and Eliminate Foraging Populations of Subterranean Termites (Isoptera: Rhinotermitidae) Near Structures Journal of Economic Entomology 88(4):932-936.
[9] Su N. Y and Scheffrahn R. H. (1998). A review of subterranean termite control practices and prospects for integrated pest management programmes Integrated Pest Management Reviews 3(1):1-13.
[10] Lewis, Vernard (1997) Alternative Control Strategy for Termite Journal of Agricultural and urban Entomology Volume 14 pages 291-307.
[11] Ahmed N., Huma, Z., Haq M. U., Rehman S., Ullah M., Ahmed S. (2016). Effect of Different Plant Extracts on Termite Species (Heterotermis indicola), Journal of Bioresource Management, 3 (2): p.9-16.
[12] Fatima Z., Ahmed S., Hassan B. (2021). Combined effects of neem (Azadirachta indica) and sesame (Sesamum indicum) oil as a wood preservative on subterranean termites in the field Maderas, Cienc. tecnol. vol.23.
[13] Coudert L., Blais J-F., Mercie G., Cooper P., Janin A. (2013). Remediation processes for wood treated with organic and/or inorganic preservatives Woodhead Publishing Series in Civil and Structural Engineering Pages 526-554.
[14] Samada, L. H. & Tambunan, U. S. F. (2020). Biopesticides as Promising Alternatives to Chemical Pesticides: A Review of Their Current and Future Status. OnLine Journal of Biological Sciences, 20(2), 66-76.
[15] González-Laredo R.F., Rosales-Castro M., Rocha-Guzman E., Gallegos-Infante J.A., Moreno-Jimenez M.R., Karchesy J.J. (2015). Wood preservation using natural products Madera y Bosques, vol. 21, pp. 63-76.

[16] Ahmed S., Tabassum M. H., Hassan B. (2022). Evaluation of Antitermite Properties of Wood Extracts from Pongamia pinnata (L.) Pierre (Leguminosae) against Subterranean Termites Annals of the Brazilian Academy of Sciences 94(1)p, 1-11:
[17] Bignell D.E., Eggleton P., (2000). Termites in Ecosystems. in: T. Abe, D.E. Bignell, M. Higashi (Eds.). Termites: Evolution, Sociality, Symbioses, Ecology. Kluwer Academic Publishers, Dordrecht, , pp. 363-387.
[18] Verma M., Sharma S., Prasad R. (2009) Biological alternatives for termite control-"a review" International Biodeterioration & Biodegradation 63(8):959-972.
[19] Abdulkadir I. S., Nasir I. A., Sofowora A., Yahaya F., Ahmad A. A., Hassan I. A. (2015). Phytochemical Screening and Antimicrobial Activities of Ethanolic Extracts of Moringa oleifera Lam on Isolates of Some Pathogens Journal of Applied Pharmacy Volume 7 • Issue 4 • 1000203 p.1-7.
[20] Adeyemi M.M. (2023) Natural product Chemistry as a Defence Mechanism Nigerian Defence Accademy 18th Professorial Inaugural Lecture.
[21] Ahmed S., Ahmad M. S., Yousaf A.M., Mothana R. A., Al-Rehaily A. J. (2015). Evaluation of Acute Toxicity and Anti-Inflammatory Effects of Baccharoides Schimperi (Dc.) In Experimental Animals., Afr J Tradit Complement Altern Med. 12(1):99-103.
[22] Upadhyay R.K.,Jaiswal G., Ahmad S., Khanna L. and Jain S.C. (2012). Antitermite Activities of Cappis deciduas Extracts and pure compounds against Indian White Termite Odontoterms obedus (Isoptera: Odontotermitdae) Hindawi publishing corporation Psyche.820245 1-9.
[23] Satannde O.A., Yager G.O., Zira B.D., Usman A. (2011). Termiticidal Effect of Neem Extracts on the Wood of Khaya Senegalese Research Journal of forestry 5(3):128-138.
[24] NCP2 (1973). Nigerian standard code of practice, NCP 2: Grade stresses for Nigerian Timbers
[25] American Society for Testing and Materials (ASTM) ASTM D 3345-08, (2008). Standard Test Method for Laboratory Evaluation of Wood and Other Cellulosic Materials for Resistance to Termites. ASTM International, West Conshohocken, Pennsylvania.
[26] Edeoga, H. O., Okwu, D. E., & Mbaebie, B. O. (2005). Phytochemical constituents of some Nigerian medicinal plants. African journal of biotechnology, 4(7), 685-688.
[27] American Society for Testing and Materials, ASTM, (1974). Standard D 1758-74: Standard Methods of Evaluating Wood preservatives by field test with stake. ASTM International. Philadelphia pp 490−498
[28] Ekhuemelo D. O., KiyamA.S., and Abu V. E. (2020). Antitermite properties of Vitellariaparadoxa (C. F.Gaertn) Stem Barck extract on Daniellia (Rolf) Hutch. &Dalzeil And VitexDoniana sw. woods. Jfewrpublications ISBN: 2141-1778.