ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 22 N° 2 2026
pp. 3-15

# BIO-PROTECTIVE LEAF EXTRACT OF *Tectona grandis* AGAINST TERMITE DETERIORATION IN *Alstonia boonei* WOOD

***Ekemini OKON***[*]
University of Uyo, Nigeria
Department of Forestry and Wildlife
Address: Uyo 532105, Akwa Ibom-Nigeria
E-mail: ekeminiufia@gmail.com

***Michael AKPAN***
University of Uyo, Nigeria
Prof - Department of Forestry and Wildlife
Address: Uyo 532105, Akwa Ibom-Nigeria

***Kufre Edet OKON***
University of Uyo, Nigeria
Associate Prof - Department of Forestry and Wildlife
Address: Uyo 532105, Akwa Ibom-Nigeria

***Abstract:***

*Efforts are made to extend the service life of wood using plant-based, non-toxic, environmentally friendly biocides due to its susceptibility to agents of biodegradation. This research investigated the bio-protective efficacy of teak (Tectona grandis) leaf ethanol-extract impregnation of Alstonia boonei wood against termite attack. The air-dried teak leaves were ground and macerated in absolute ethanol, and four extract concentrations 25%, 50%, 75% and 100% were prepared. Alstonia boonei blocks with dimensions 25mm x 50mm x 150mm and 25mm x 50mm x 60mm were oven-dried and impregnated with each extract concentration using non-pressure cold-soaking for 72 hours while non-impregnated samples served as control. Both impregnated and control samples were evaluated for extract retention, color change and field durability under termite-infested conditions after 28 weeks of exposure with weight loss taken. Data were analysed using analysis of variance (ANOVA) at $p < 0.05$. Extract retention was highest at 100% concentration (18.08kg/m³, F = 7.43, p = 0.002). Color changes were visually observed in the samples impregnated with teak leaf extract. The highest weight loss occurred in the control (52.87%) while 100% extract concentration showed the lowest weight loss (4.06%) after termite exposure. Teak leaf extract proves to be an effective bio-preservative, capable of enhancing the durability and performance of Alstonia boonei wood.*

***Key words:*** *Color change; Preservation; Retention; Teak leaf extract; Termite resistance.*

## INTRODUCTION

Wood is the most sought-after natural and renewable resource in forests due to its versatility. Wood and wood products are used in various structural and decorative applications, while also serving as a significant carbon reservoir. Globally, the demand for wood has increased pressure on forests, leading to widespread decline. A major challenge facing wood is its susceptibility to agents of biodegradation, and efforts are made to extend its service life with regard to the structural, usability and overall integrity of the wood during service (Woods and Watts 2019, Spear *et al.* 2021, Okon *et al.* 2025).

Degradation of wood by termites poses a major threat to wood utilization and its sustainability due to the favourable climatic conditions that promote their activity. The high temperature and humidity characteristic of the tropics accelerate termite reproduction and wood decay, leading to significant structural and economic losses (Kalleshwaraswamy *et al.* 2022, Zanne *et al.* 2022). Since dead wood serves as the primary food source for most termite species, untreated woods are at risk (Cheesman *et al.* 2018) especially the light weight wood (Mahari *et al.* 2024). Consequently, termite degradation not only reduces the lifespan and quality of wooden materials but also threatens sustainable forest management and the economic viability of wood industries (Okon *et al.* 2025).

Enhancing its durability and performance against biotic and abiotic damage, wood can serve as a reliable material in many applications (Ong *et al.* 2025). In an effort to protect wood from termite degradation, numerous preservation technologies and techniques have been developed and deployed to preserve wood against deterioration. To reduce the effects of various biodegradation agents, and to prolong the lifespan of wood, methods such as chemical preservatives and modifications have employed to extend the service life of wood (Bi *et al.* 2021, Hill *et al.* 2021, Kirker and Lebow 2021). Although effective, they are not environmentally

---

[*] Corresponding author

friendly and have raised significant concerns regarding environmental and human health, leading to regulatory restrictions in several European and North American countries (Khademibami and Bobadilha 2022, Fritz and Garay 2025). Many traditional preservatives, such as chromated copper arsenate (CCA), pentachlorophenol (PCP), and creosote, contain heavy metals, organochlorines, and polycyclic aromatic hydrocarbons that can leach into soil and water, causing ecotoxicological effects (Nesto *et al.* 2025, Changotra *et al.* 2024, Meena 2022). This reflects mounting evidence of adverse outcomes and the unsustainability of many synthetic preservatives (Khademibami and Bobadilha 2022, Fritz and Garay 2025), prompting a global shift toward bio-based, non-toxic, environmentally friendly biocides that can still provide effective protection for wood.

Mitigating the shortcomings of synthetic preservatives can be achieved through the application of plant-based bio-protectives, which stand out as a promising approach, capable of replacing synthetic preservatives (Adebawo 2019). This is because extracts from plants, seeds, or fruits have the potential to protect non-durable wood by acting as biocides against termites and decay fungi (Calovi *et al.* 2024). Extractives from hardwood or other plant parts, such as teak heartwood, eucalyptus bark and heartwood, and neem, have been isolated and used in treating some non-durable woods against wood-degrading organisms (Brocco *et al.* 2017, Brocco *et al.* 2020, Niamké *et al.* 2021, Zayyanu *et al.* 2025). Therefore, the exploration of plant-based preservatives is not only timely but also aligned with research on sustainable materials. Literatures have reported the effectiveness of some plant extracts in protecting non-durable woods against biodegradation, but well-documented information is limited on the bio-protective effect of *Tectona grandis* (Teak) leaf extract against termite attack in wood, despite reports on the antimicrobial efficacies of its leaf extracts.

*Tectona grandis* is considered a durable wood species (Niamke *et al.* 2021), and its leaves are valued due to their antifungal chemical constituents (Budianto *et al.* 2023), rich phytochemical content, and documented bioactivity of its extracts against wood-destroying organisms. The heartwood and leaves of *T. grandis* contain naphthoquinones, anthraquinones such as tectoquinone and various phenolic compounds (flavonoids and triterpenoids) (Ogunmefun *et al.* 2017, Abdullah *et al.* 2019, Rosamah *et al.* 2020, Budianto *et al.* 2023; Balasubramanian *et al.* 2024, Oksari *et al.* 2025), which are linked to antimicrobial, antifungal and insecticidal potentials. Tectonaquinones, tectoquinone, and deoxylapachol are reported as new naphthoquinone derivatives from the heartwood of *T. grandis* (Vyas *et al.* (2022). Tectoquinone, lapachol, and deoxylapachol are identified among the main active ingredients responsible for termite and fungal resistance in teak (Vyas *et al.* 2019). Naphthoquinones from *T. grandis* exhibited repellent and insecticidal activity against dry-wood termite (*Incisitermes marginipennis*) (Velázquez-Becerra *et al.* 2023). Thus, the choice of *T. grandis* leaves is justified by the expectation that their extract will impart bio-protective properties (some natural compounds) when applied to non-durable wood such as *Alstonia boonei.*

*Alstonia boonei* wood is abundant across most West African countries, including Nigeria. It is classified as a non-durable wood, and it is notably susceptible to attack by termites. *Alstonia boonei* wood was chosen because of its valuable wide spectrum of utilization (Akpan *et al.* 2022), particularly for medicinal purpose and physically soft nature with relatively low durability. According to CEN (Comité Européen de Normalisation) (2016), *Alstonia boonei* is ranked 5 (on a scale where 1 = very high durability and 7 = very low) in the natural durability index, hence the need for preservative treatment. Furthermore, a previous study affirmed the susceptibility of *Alstonia boonei* to degrading agents under service conditions (Otoide *et al.* 2017), recommending seasoning and chemical treatment to protect the wood for extensive utilization.

## Objective

The main objective of this study was to evaluate the bio-protective leaf extract of *Tectona grandis* against termite deterioration in *Alstonia boonei* wood. The specific objectives of the study were to:

i. determine the extract retention of teak leaf extract in *Alstonia boonei* wood at different treatment concentrations;
ii. examine the color changes in *Alstonia boonei* wood after impregnation with teak leaf extract;
iii. evaluate the resistance of treated *Alstonia boonei* wood to termite attack.

## MATERIALS AND METHODS

### Materials

Knot-free logs of *Alstonia boonei* (De Wild) wood were purchased from Itam Timber Market, Itu, Akwa Ibom State, Nigeria. *Tectona grandis* (L. f.) leaves (Teak leaves) were obtained from the Teak plantation of the Department of Forestry and Wildlife, University of Uyo, Uyo, Nigeria. Laboratory-grade absolute ethanol was purchased in a commercial chemical outlet in Uyo, Nigeria.

### Preparation of wood test blocks

The logs of *Alstonia boonei* wood were 70cm in length and were transported to the wood workshop of the Department of Forestry and Wildlife, University of Uyo. The logs were converted to sawn timber with dimensions of 4cm x 12cm x 70cm (T - tangential x R - radial x L - longitudinal). The sawn logs were further converted to test blocks according to the grain orientation of the wood, with dimensions 25mm x 50mm x 150mm for field durability under termite-infested conditions tests and 25mm x 50mm x 60mm for extract retention tests. A total of 25 sample blocks were prepared, with 5 samples used for each treatment. The blocks were oven-dried in the oven for 24 hours at 103.2°C to attain equilibrium moisture content (EMC). The initial and the oven-dry weights of the samples were recorded using an analytical weighing balance.

### Collection and preparation of teak leaves

The plantation was purposively selected for Teak leaves collection due to the availability of *Tectona grandis* stands. The collection process was carefully done to maintain the quality and integrity of the leaves. Fallen leaves were targeted for collection to align with sustainable and environmentally friendly research practices, which ensure that no harm is done to the trees while utilising naturally shed biomass. Only leaves free from fungal growth, excessive dirt, or decay were picked. The leaves were air-dried at room temperature (28 ± 2ºC) for 10 days. The dried leaves were milled to powder using a laboratory blender, and the powder was stored in airtight containers to prevent moisture absorption and contamination.

### Preparation of teak leaf extracts

Teak leaf extracts were prepared by soaking the pulverised leaves in absolute ethanol at different concentrations (25%, 50%, 75%, and 100%) for 72 hours. Absolute ethanol was used due to its effectiveness in extracting a broad spectrum of bioactive compounds from plant materials, including polar and non-polar substances. For the extract prepared at 100% concentration, 1000g of the pulverised Teak leaves measured into a clean, dry container was soaked with 1000mL absolute ethanol solution at a ratio of 1:1 (weight-to-volume ratio). To ensure that the ethanol solvent was saturated with the pulverised leaves and extract numerous phytochemicals at the highest concentration. For 75% concentration, 750 g of the pulverised Teak leaves was soaked with 1000mL of ethanol solution in a ratio of 3:4 ratio. For 50% concentration, 500g of the pulverised Teak leaves was soaked with 1000 mL of absolute ethanol solution in a ratio of 1:2. For 25% concentration, 250g of the pulverised Teak leaves was soaked with 1000mL of absolute ethanol solution in a ratio of 1:4. The mixtures were stirred thoroughly to enable interaction between the solvent and the leaf particles and then allowed to stand at room temperature for 72 hours. To enhance extraction efficiency, the resultant mixtures were periodically stirred. The mixtures were filtered using Whatman No. 1 filter paper. The prepared Teak leaf extract solutions were stored in labelled, amber glass bottles to prevent light-induced degradation and refrigerated at 4°C to preserve their stability.

### Teak leaf extract impregnation of the wood

The weight of *Alstonia boonei* wood blocks was weighed and recorded ($W_1$) before the impregnation. Non-pressure cold-soaking method was employed for the treatment of *Alstonia boonei* wood with Teak leaf extract. The test blocks were completely immersed in the Teak leaf extract solutions at 25%, 50%, 75%, and 100% concentration for 72 hours to obtain an appreciable amount of absorption and retain an appreciable quantity of the extract. After the impregnation, each test block was removed from the Teak leaf extract solution and drained of excess liquid using paper towels and reweighed ($W_2$) and the dimensions recorded.

### Determination of extract retention of *Alstonia boonei* wood

Impregnated *Alstonia boonei* block with dimensions 25mm x 50mm x 60mm was used to determine extract retention of the wood after the mass of each impregnated block was recorded ($W_3$) The blocks were then oven-dried at 103°C ± 2°C to a constant weight.

Extract retention (SU) was calculated using the oven-dry weight difference method and expressed in kg/m³, following standard wood preservation procedures (American Wood Protection Association 2021), equation (1).

$$SU\ (kg/m3) = \frac{W_2 - W_1}{V} \qquad (1)$$

where:

$W_1$ = oven-dry weight before impregnation (kg)
$W_2$ = weight after impregnation (kg)
$V$ = volume of the impregnated wood block in $m^3$

### Field exposure of impregnated wood blocks

The teak leaf extract impregnated and control wood blocks were subjected to field exposure in a termite-infested area at the Arboretum of the Department of Forestry and Wildlife, University of Uyo, for 28 weeks for effective termite infestation according to the method described by (Okon *et al*. 2025). The test site was selected based on the observed termite activities, primarily dominated by *Macrotermes bellicosus*, a subterranean termite species common in the tropics. The installation was done by placing the wood blocks 75 mm deep into the soil, and they were 1m apart between each stake to allow for uniform exposure to termites and partially buried (i.e. half of the wood block length buried) (Fig. 1). Weekly inspections were conducted to evaluate the activities of termites on the exposed wood blocks.

During weekly inspections, evidence consistent with termite activity was recorded on exposed samples, including soil sheeting, surface galleries, and characteristic feeding patterns. The test site was known to be inhabited predominantly by *Macrotermes bellicosus*. These observations confirm termite interaction with the specimens during the exposure period, although other soil organisms were not excluded.

At the end of the experiment, the buried wood blocks were exhumed, and all adhering substances were carefully removed. The test blocks were oven-dried at 60°C for 24 hours to remove excess water absorbed during the rainy period.

***Fig. 1.***
***Field layout of wood blocks exposed to termites' attack. The blocks were left under termite attack for 196 days.***

### Color assessment of *Alstonia boonei* wood samples

A visual assessment of the control and teak leaf impregnated samples was conducted for any observable color change in the wood.

### Weight loss determination

The termite resistance of the impregnated and control *Alstonia boonei* wood blocks was evaluated according to American Wood Protection Association Standard E26-21 (2021) procedures. At the end of 196 days of exposure to termites' actions. All exposed blocks were removed, oven-dried at 103°C for 48 hours, and finally reweighed to determine the weight loss. Percentage weight loss and visual damage rating were used to evaluate the effectiveness of the teak extract impregnation in protecting the wood against termite attack. Weight loss was calculated using equation (2) according to Okon *et al.* (2025):

$$Mass\ loss\ (\%) = \frac{M_1 - M_2}{M_2}\ X\ 100 \qquad (2)$$

where:

$M_1 =$ weight of Teak leaf impregnated wood blocks before exposure to termite attack $(g)$
$M_2 =$ weight of Teak leaf impregnated wood blocks after exposure to termite attack $(g)$

The extent of the termite's tunnelling/damage was scored using Table 1 (EN 252 1989 and Okon *et al*. 2025). This rating system provided information on the impregnated wood resistance to termite attack, with scores indicating the level of damage sustained after exposure to termite attack.

*Table 1*

***Termite visual damage rating system***

| Termite resistance class | Description |
|---|---|
| 0 | No attack |
| 1 | Minor attack |
| 2 | Moderate attack |
| 3 | Severe attack |
| 4 | Failure (test block crumble) |

Table adopted from Okon *et al.* (2025)

### Data analysis

The experimental data generated were subjected to both descriptive and inferential analyses. A One-way analysis of variance (ANOVA) was used to analyse extract retention, and a factorial experiment in a completely randomised sampling design was used for the analysis of termite resistance. The mean separation was carried out using Least Significant Difference (LSD). All the analyses were implemented in R version 4.3.1 statistical software (Team 2016).

## Results

### Extract retention by the impregnated wood

The ANOVA in Table 2 showed a significant difference ($p<0.05$) in extract retention by the wood ($F = 7.43$; $p = 0.002$). Post-hoc comparison using LSD (6.28) indicated that the extract retention at 100% (18.09kg/m³) was significantly higher than at 25% (4.62kg/m³) concentration (Fig. 2). This demonstrates that the wood impregnation at 100% concentration resulted in the most effective uptake, indicating superior interaction between the wood matrix and the impregnated solution.

*Table 2*

***ANOVA of Extract retention of teak leaf impregnated Alstonia boonei wood***

| Source of Variation | Sum of Squares | Degree of freedom | Mean Square | F-statistics | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 500.0488 | 3 | 166.6829 | 7.428691 | 0.002461 | 3.238872 |
| Within Groups | 359.0036 | 16 | 22.43773 | | | |
| Total | 859.0525 | 19 | | | | |

Significant at $P < 0.05$ (LSD test)

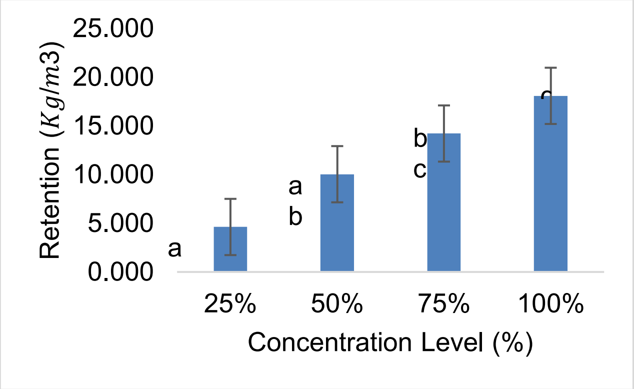

***Fig. 2.***
***Extract retention of teak leaf impregnated Alstonia boonei wood.***

### Color changes in *Alstonia boonei* wood

It was qualitatively observed that the wood samples impregnated with teak leaf extract appeared to have a darker color and possessed more or less the characteristic light color of the *Alstonia boonei* control samples (Fig. 3). The color changes in wood samples impregnated at 75% and 100% concentrations were more pronounced than the color change observed in samples impregnated at 25% and 50% concentrations. Treated samples exhibited observable color changes compared to untreated wood, particularly at higher concentrations. Thus, progressive color changes from light to dark-brown to darken color wood was observed from the control sample to impregnated at various concentrations.

***Fig. 3.***
***Color changes in Alstonia boonei wood impregnated with teak leaf extract compared with the Untreated (control).***

### Evidence of Termite Interaction

Field-exposed samples showed visible signs consistent with termite activity, including tunnelling, soil sheeting, and localized material removal on wood surfaces. These observations support that termites interacted with the wood samples during the test period (Fig. 4).

***Fig. 4.***
***Evidence of termite attack on the wood sample.***

### Weight loss (termite resistant test) of wood samples after exposure to termites

The results of the mean weight loss of the wood samples after exposure to termite attack for 28 weeks are displayed in Table 3. The control wood samples had the highest weight loss (52.87%) after exposure to termite's attack, this was followed by the impregnated wood samples at 25% concentration (45.55%), while impregnation at 100% concentration had the least weight loss (4.06%).

*Table 3*

***Termite resistance and visual damage rating system of Teak leaf impregnated Alstonia boonei wood***

| **Treatments (%)** | **Weight loss (%)** | **Resistance rating** | **Visual rating** | **Damage level** |
|---|---|---|---|---|
| 100 | $4.06^b \pm 0.59$ | Highly resistant | 4 | No attack |
| 75 | $5.38^b \pm 1.06$ | Highly resistant | 3 | Slightly attack |
| 50 | $8.90^b \pm 4.13$ | Moderately resistant | 2 | Moderately attack |
| 25 | $45.55^a \pm 18.31$ | Not resistant | 1 | Heavily attack |
| Control | $52.87^a \pm 36.77$ | Not resistant | 0 | Severe attack (failure) |

LSD ($P<0.05$) = 24.37 mean ± standard deviation. Means with the same superscript are not significantly different from each other at $\alpha = 0.05$.

The visual damage rating system in Table 3 and Fig. 5 showed that the control samples were severely attacked (failure) and were rated 0, compared to the impregnated samples after exposure to termites. Teak leaf impregnated *Alstonia boonei* wood at 25% concentration was heavily attacked (1), impregnated samples at 50% concentrations showed traces of attack by termites (moderately attacked - 2 and slightly attacked - 3), while at 100% concentration, the impregnated wood was not attacked (no attack - 4) after exposure to termites.

***Fig. 5.***
***Wood samples of untreated (control) and treated Alstonia boonei after exposure to termite attack.***

ANOVA in Table 4 showed that significant difference between the impregnated *Alstonia boonei* wood samples and the control samples ($p < 0.05$). *Alstonia boonei* wood impregnated with Teak leaf extract recorded significantly lower weight loss compared to the control. The impregnation of *Alstonia boonei* wood with Teak leaf extract significantly improved its resistance to termites' attack. The post hoc analysis (LSD = 24.37) indicated that the impregnation of *Alstonia boonei* wood with Teak leaf extract at 100%, 75%, and 50% concentrations significantly reduced the weight loss of the wood compared to the control.

*Table 4*

***ANOVA for termite resistance of Teak leaf impregnated Alstonia boonei wood***

| **Source of variation** | **Sum of Squares** | **Degree of freedom** | **Mean Square** | **F-stat** | **P-value** | **F crit** |
|---|---|---|---|---|---|---|
| Treatment | 11340.26 | 4 | 2835.064 | 8.309 | 0.0004 | 2.866 |
| Error | 6824.028 | 20 | 341.2014 | | | |
| Total | 18164.28 | 24 | | | | |

Significant at $P < 0.05$

Based on the termites' resistant classification of wood in Table 5, the control samples with mass loss of 52.87 % after exposure to termites' attack were classified as not durable wood. The Teak leaf impregnated *Alstonia boonei* wood at 25% concentration with mass loss of 45.55% was classified as not durable. However, wood samples impregnated at 75% and 100% concentrations were classified as durable and very durable respectively.

*Table 5*

***Termites resistant classification of wood based on mass loss (%)***

| **Resistant class** | **Description** | **Mass loss - ML (%)** |
|---|---|---|
| 1 | Very durable | ML ≤ 5 |
| 2 | Durable | 5≤ ML ≤ 10 |
| 3 | Moderately durable | 10≤ ML ≤ 20 |
| 4 | Slightly durable | 20≤ ML ≤ 30 |
| 5 | Not durable | 30≤ ML ≤ 40 |

Table adopted from EN 350-1 (European Committee for Standardisation (1996)

## DISCUSSION

### Extract retention by *Alstonia boonei* wood

The extract retention of *Alstonia boonei* wood increased progressively with increasing concentration of teak leaf extract, with the highest retention observed at 100% concentration (18.09kg/m$^3$) and the least retention recorded at 25% concentration (4.62kg/m$^3$). The significant difference observed among the treatment concentrations ($p < 0.05$) indicates that concentration had a strong influence on the quantity of extract retained by the wood. The higher retention at 100% concentration suggests improved uptake and stronger interaction between the wood structure and the preservative solution at higher extract strengths. This may be attributed to the increased availability of active phytochemical constituents and preservative compounds in the concentrated extract, which enhanced absorption and deposition within the vessels and pores of the wood and this agrees with a study which reported that *Alstonia boonei* extracts and wood extractives have shown that phenolic-rich extracts possess strong interaction abilities with lignocellulosic materials (Mollica *et al*. 2022). The finding is also in consonant with a study that reported higher concentrations of ebony and soursop leaf extracts resulted in increased preservative retention in *Durio zibethinus* wood. They explained that increasing extract concentration supplied more preservative substances capable of occupying the wood voids and capillaries, thereby increasing retention values (Asniati and Muthmainnah 2022).

The significant increase in retention with concentration further suggests that the viscosity of the extract at the tested levels did not adversely limit penetration into the wood. Instead, the concentrated extract appeared to favour deposition of preservative compounds within the wood structure. This contrasts with some studies where extremely high preservative concentrations reduced uptake because of excessive viscosity and poor diffusion (Tondi et al. 2013; Temiz et al. 2009). Study explained that wood behaves like an ultra-filter, and highly viscous preservative solutions containing large particles may plug the wood pores during impregnation, thereby limiting preservative penetration and uptake (Temiz *et al.* 2009). However, within the concentration range used in this study, the extract maintained sufficient mobility for effective impregnation. Similar trends were reported that bio-based preservatives can achieve efficient retention and fixation when the interaction between preservative composition and wood anatomy is favourable (Barbero-López *et al.* 2021).

The findings of this study also agree with a study that reported higher extract retention at lower to moderate concentrations, owing to reduced molecular aggregation and more efficient movement through the wood vessels (Ekhuemelo *et al*. 2020). Therefore, the impregnation of the wood at 100% teak leaf extract concentration was the most efficient and sustainable treatment level for *Alstonia boonei* wood, providing optimal retention while minimising resource use. The strong compatibility between the wood structure and the extract medium supports the use of teak leaves as a viable, eco-friendly preservative source and reinforces the treatability of *Alstonia boonei* wood by natural impregnation processes. The main drawback of natural extractives is their ease of leaching away, but retention is a good index of permanence (Dias and Barreiros 2021).

### Color changes of impregnated wood

Qualitative observation of treated samples showed progressive darkening of the wood surface with increasing extract concentration. The color change were more pronounced at higher concentrations, likely due to increased deposition of extractives within the wood structure. However, color alteration was assessed qualitatively based on visual observation only, and no instrumental color measurements were conducted. The findings of this study agree with the study that observed significant darkening of light-colored wood species impregnated with teak heartwood extracts (Brocco *et al.* 2020). They reported that teak extract treatment altered the colorimetric properties of treated wood, producing darker and more uniform color tones similar to naturally durable teak heartwood. They attributed the color modification to the presence of extractives such as quinones, tannins, and phenolic compounds contained in teak tissues. Recent studies on teak leaf pigments have shown that teak leaves produce reddish-brown pigments with high color intensity and stability because of their rich phytochemical composition. The increased darkness observed at higher concentrations therefore suggests that larger quantities of these pigment-containing extractives were deposited within the wood matrix as concentration increased (Charoensit *et al.* 2021). Similar color changes have been reported in thermally treated and extract-treated wood materials where chemical modifications in lignin and extractives altered wood color parameters. Teak wood became progressively darker following treatment due to chemical changes involving lignin and extractive compounds (Gašparík *et al.* 2019). Likewise, recent investigations into teak discoloration mechanisms demonstrated that changes in lignin composition and extractive accumulation significantly contribute to the darkening and color transformation of teak wood (Feng *et al.* 2026).

### Termite Resistance of the Wood Samples

*Alstonia boonei* wood impregnated with teak leaf extract had the lowest weight loss, while the control samples had significantly higher weight losses. This suggested that impregnated wood samples after exposure to termites were resistant to attack compared to the control, justifying the effectiveness of teak leaf extract. The high weight loss obtained in the control samples after 28 weeks of exposure to termites' action further supports the non-durability of *Alstonia boonei* wood and the need to always treat it with preservatives, particularly in medium or high-risk environments, using eco-friendly preservatives. According to EN 350-1 (European Committee for Standardisation 1996), wood exhibiting mass loss of less than or equal to 30% or greater than or equal to 40%, after attack by wood-degrading organisms, is classified as non-durable woods (Table 5). Based on the classification, teak leaf extract significantly protects the wood, as the weight losses of the impregnated samples were reduced after exposure to termites. This could be explained by the constituents and concentration of biocides in the extract, as it determines the effectiveness of the treatment, which invariably has a direct effect on the field durability under termite-infested conditions of the wood. The results of this study are in line with earlier reports (Altemimi *et al.* 2017, Ahmed *et al.* 2022, Ramesh *et al.* 2024, Mamoona *et al.* 2025).

The findings show that *Tectona grandis* bio-protective extract significantly enhanced the termite resistance of *Alstonia boonei* wood. Furthermore, the observed reduction in mass loss with increasing extract concentration corroborates earlier studies that reported improved durability of non-resistant wood species through impregnation with plant-based extracts (Brocco *et al.* 2017, Hassan *et al.* 2019, Velázquez-Becerra *et al.* 2023, Yingprasert *et al.* 2023, Kirker *et al.* 2024). The improved resistance at higher concentrations 75% and 100% treatments is attributed to increased loading of teak phytochemicals such as tannins, lapachol, tectoquinone, naphthoquinones, phenolics, flavonoids, and terpenoids, all known for antitermitic and anti-feedant properties (Ozarde *et al.* 2022, Zubairu and Suberu 2024, Montri *et al*. 2025). Similar studies reported enhanced termite resistance in extract-impregnated wood, linking effectiveness to phytochemicals that interfere with termite digestion and feeding (Balasubramanian *et al.* 2024, Wilson *et al.* 2025). Also, a study recorded <4% mass loss in non-durable wood treated with teak heartwood extract (Brocco *et al.* 2020), and identified high levels of bioactive flavonoids, tannins, phenols, and saponins in teak leaves (Daramola 2022). These compounds may have contributed to reduced wood deterioration under field conditions through their reported bioactive and preservative properties. Although the mass-loss of the impregnated wood decreased from 8.90% (50%) to 4.06% (100%), with no significant differences among the treatments at higher concentrations. This suggest a performance threshold at 50% concentration, beyond which additional extract confers a limited effect. This may be due to the saturation of the cell wall binding sites or restricted penetration under passive soaking. This trend aligns with a study that observed diminishing incremental effects at very high extract concentrations in *Pongamia pinnata*-treated poplar wood (Ahmed *et al.* 2022). Hence, the results of this research affirmed that teak leaf extract has significant potential as a natural wood preservative against termite attack, indicating its potential as an environmentally friendly supplementary alternative to conventional synthetic wood preservatives.

## CONCLUSION

Bio-protective effectiveness of teak (*Tectona grandis*) leaf ethanol extract used for impregnation of *Alstonia boonei* wood was investigated in this study. The research examined extract retention, color change, and resistance to biodeterioration under termite-prone field conditions after 28 weeks of exposure. Results showed that extract retention increased progressively with increasing concentration, with the highest retention observed at 100% concentration. Impregnation with teak leaf extract altered the wood color, with darker coloration occurring at higher concentrations. Treated wood samples exhibited substantially reduced mass loss compared with the untreated control, particularly at 50–100% concentrations. Although numerical reductions in mass loss occurred with increasing concentration, the higher treatment levels showed no statistically significant differences, suggesting a protection threshold beyond 50% concentration. The findings demonstrate that teak leaf extract possesses strong potential as an eco-friendly bio-based wood preservative for improving the durability of *Alstonia boonei* wood under field exposure conditions.

## LIMITATIONS OF THE STUDY

This study has several limitations that should be acknowledged:

1. The impregnation of the extract into the wood samples was done using non-pressure method.
2. The field test does not isolate termite activity from other biodegrading agents such as fungi and microorganisms.
3. No direct termite bioassays (e.g., feeding or repellency tests) were conducted to confirm mechanism of action.
4. Termite identification and activity were not quantitatively verified.

Despite these limitations, the field-based approach provides practical insight into wood performance under natural exposure conditions.

## ACKNOWLEDGMENTS

This research was conducted by the corresponding author during his Master's degree at the Department of Forestry and Wildlife under the supervision of Prof. M. Akpan and Dr. K. E. Okon. The authors gratefully acknowledge institutional support from the University of Uyo and every individual that was resourceful during this study.

## REFERENCES

Abdullah AH, Syafiq AH, Ghani MA, Idris AB (2019) Antifungal properties of teak leaf extract against wood-rotting fungi. J Adv Res Mater Sci 61:14-21.

Adebawo FG (2019) Fungal resistance of obeche (*Triplochiton scleroxylon* K. Schum) wood treated with neem (*Azadirachta indica* A. Juss) seed oil extract. J Res For Wildl Environ 11:90-96.

Adeduntan SA (2015) The termicidal effect of some plant material on some selected wood species. Int J Biol Chem Sci 9:986-995.

Advancing Standards Transforming Markets International (2022) ASTM D3345-22: Standard test method for laboratory evaluation of wood for resistance to subterranean termites. ASTM International. Online at: https://www.astm.org/d3345-22.html

Ahmed S, Tabassum MH, Hassan B (2022) Evaluation of antitermite properties of wood extracts from *Pongamia pinnata* (L.) Pierre (Leguminosae) against subterranean termites. An Acad Bras Cienc 94:e20190591

Akpan M, Buba ZY, Uko MM (2022) Assessment of forest resources and socio-economic livelihood in Uruan local government area of Akwa Ibom State, Nigeria. Proc 45th Annual Conference of Forestry Association of Nigeria (FAN), Abeokuta, pp. 65-80.

Altemimi A, Lakhssassi N, Baharlouei A, Watson DG, Lightfoot DA (2017) Phytochemicals: Extraction, isolation, and identification of bioactive compounds from plant extracts. Plants 6:42.

American Wood Protection Association (2021) Standard field test for evaluation of wood preservatives to be used in ground contact (E26-21). AWPA, Birmingham, AL.

Asniati M (2022) Pengaruh konsentrasi ekstrak daun eboni dan daun sirsak terhadap retensi bahan pengawet pada kayu durian (*Durio zibethinus*) [Effect of ebony and soursop leaf extract concentration on preservative retention in durian wood (*Durio zibethinus*)]. KOVALEN: Jurnal Riset Kimia 8(3):292-297.

Balasubramanian A, Krishnan SN, Sivaprakash M, Ravi R, Swathiga G, Anjali KS (2024) Chromatographic profiling and phytomedicinal properties on heartwood extractives of farm grown teakwood (*Tectona grandis* Lf). Ann Phytomed 13:1145-1151.

Barbero-López A, Akkanen J, Lappalainen R, Peräniemi S, Haapala A (2021) Bio-based wood preservatives: Their efficiency, leaching and ecotoxicity compared to a commercial wood preservative. Sci Total Environ 753:142013.

Bi W, Li H, Hui D, Gaff M, Lorenzo R, Corbi I, Corbi O, Ashraf M (2021) Effects of chemical modification and nanotechnology on wood properties. Nanotechnol Rev 10:978-1008.

Brocco VF, Paes JB, Costa LGD, Kirker GT, Brazolin S (2020) Wood color changes and termiticidal properties of teak heartwood extract used as a wood preservative. Holzforschung 74:233-245.

Brocco VF, Paes JB, da Costa LG, Brazolin S, Arantes MDC (2017) Potential of teak heartwood extracts as a natural wood preservative. J Clean Prod 142:2093-2099.

Budianto P, Suroto S, Wasita B, Mirawati DK (2023) *Tectona grandis* leaves: determination of total flavonoid content, phenolic content, characterization of the leaves, and compound identification in GC-MS. Pharmacogn J 15:165-170.

Calovi M, Zanardi A, Rossi S (2024) Recent advances in bio-based wood protective systems: a comprehensive review. Appl Sci 14:736.

CEN (2016) Durability of wood and wood-based products – Testing and classification of the durability to biological agents of wood and wood-based materials (EN 350:2016). European Committee for Standardization, Brussels.

Changotra R, Rajput H, Liu B, Murray G (2024) Occurrence, fate, and potential impacts of wood preservatives in the environment: challenges and environmentally friendly solutions. Chemosphere 352:141291.

Charoensit P, Sawasdipol F, Tibkawin N, Suphrom N, Khorana N (2021) Development of natural pigments from *Tectona grandis* (teak) leaves: Agricultural waste material from teak plantations. Sustain Chem Pharm 19:100365.

Cheesman AWC, Cernusak LA, Zanne AE (2018) Relative roles of termites and saprotrophic microbes as drivers of wood decay: a wood block test. Austral Ecol 43:257-267.

Costa MA, Costa AF, Pastore TCM, Braga JWB, Gonçalez JC (2011) Characterisation of wood decay by rot fungi using colorimetry and infrared spectroscopy. Cienc Florest 21:567-577.

Daramola OT (2022) Proximate composition and phytochemical screening of teak (*Tectona grandis*) leaves as phytogenic feed additive in poultry diets. Niger J Anim Sci 24:121-127.

Dias KB, Barreiros RM (2021) Preservative treatments on wood and their effects on metal fasteners. In: Engineered Wood Products for Construction. IntechOpen. Online at: https://www.intechopen.com/chapters/77689

Ekhuemelo DO, Kiyam AS, Abu VE (2020) Antitermitic properties of *Vitellaria paradoxa* (C.F. Gaertn.) stem bark extracts on *Daniellia oliveri* (Rolfe) Hutch. and Dalziel and *Vitex doniana* Sw. woods. J Res For Wildl Environ 12:145-153.

European Committee for Standardization (1996) Durability of wood and wood-based products. Natural durability of solid wood. Guide to the principles of testing and classification of natural durability of wood (EN 350-1). European Committee for Standardization, Brussels.

Feng Q, Yan L, Appelt J, Radtke S, Koch G, Cheng X, Zhao R (2026) Insights into the lignin and extractives changes and the discoloration mechanism in plantation teak wood under xenon exposure. Ind Crops Prod 242:122908.

Fritz C, Garay R (2025) Advancing sustainable timber protection: a comparative study of international wood preservation regulations and Chile’s framework under environmental, social, and governance and sustainable development goal perspectives. Buildings 15:1564.

Goktas O, Mammadov R, Duru E, Ozen E, Colak MA, Yilmaz F (2007) Introduction and evaluation of the wood preservative potentials of the poisonous *Sternbergia candidum* extracts. Afr J Biotechnol 6:982-986.

Hassan B, Mankowski ME, Kirker G, Ahmed S, Bishell A (2019) Ex-situ performance of extracts from naturally durable heartwood species and their potential as wood preservatives. Eur J Wood Wood Prod 77:869-878.

Hill C, Altgen M, Rautkari L (2021) Thermal modification of wood—a review: chemical changes and hygroscopicity. J Mater Sci 56:6581-6614.

Kalleshwaraswamy CM, Shanbhag RR, Sundararaj R (2022) Wood degradation by termites: ecology, economics and protection. In: Science of Wood Degradation and its Protection. Springer, Singapore, pp 147-170.

Khademibami L, Bobadilha GS (2022) Recent developments studies on wood protection research in academia: a review. Front For Glob Change 5:793177.

Kirker GT, Hassan B, Mankowski ME, Eller FJ (2024) Critical review on the use of extractives of naturally durable woods as natural wood protectants. Insects 15:69.

Kirker GT, Lebow S (2021) Wood preservatives. In: FPL-GTR-282. USDA Forest Products Laboratory, Madison, WI, pp. 15-26.

Mahari A, Eshete G, Kolleh D, Watson AT, Watson R (2024) Evaluation of naturally grown termite resistant tropical wood species. Asian J Environ Ecol 23:1-7.

Mamoona, Nosheen S, Riaz S, Shah SI, Shahid S (2025) Optimizing extraction methods: the role of solvent polarity in enhancing phenolic content and antioxidant activity in biowaste. Biomass Convers Biorefin 15:16721-16736.

Meena RK (2022) Hazardous effect of chemical wood preservatives on environmental conditions, ecological biodiversity and human being and its alternatives through different botanicals: a review. Environ Ecol 40:1137-1143.

Mollica A, Zengin G, Sinan KI, Marletta M, Pieretti S, Stefanucci A, Mahomoodally MF (2022) A study on chemical characterization and biological abilities of *Alstonia boonei* extracts obtained by different techniques. Antioxidants 11(11):2171.

Montri N, Wanapat M, Kang S, Cheas S, Cherdthong A, Gunun P, Polyorach S (2025) Exploring *Tectona grandis* Linn. f. leaf extract as a functional feed additive with antioxidant and nutraceutical potential for livestock. Animals 15(23):3498.

Nesto N, Marčeta T, Cassin D, Acri F, Pesce A, Moschino V (2025) Ecotoxicological effects of innovative wood protection treatments on freshwater bioindicator organisms. Environ Sci Pollut Res 32:1-15.

Niamké FB, Amusant N, Augustin AA, Chaix G (2021) Teakwood chemistry and natural durability. In: The Teak Genome. Compendium of Plant Genomes. Springer, pp 83-102.

Ogunmefun OT, Ojo OA, Fadimu OY, Fasina OM (2017) Phytochemical screening and antibacterial activities of *Tectona grandis* L.f. (teak) leaves on microorganisms isolated from decayed food samples. Trop Plant Res 4:376-382.

Okon KE, Ukpabio PF, Iyiola E (2025) Combined effect of spent engine oil and kerosene preservative treatment on some tropical wood. Niger J Agric Food Environ 21:9-18.

Oksari AA, Uzhmiyyah R, Susanty D, Rizki FH, Wanda IF, Dadang D, Arinana A (2025) Efficacy of biopesticides from the leaves of *Dioscorea bulbifera* L. in the control of drywood termites (*Cryptotermes cynocephalus* Light). J Korean Wood Sci Technol 53:225-241.

Olajuyigbe SO, Ogunsanwo OY, Adegeye AO (2010) Compressive strength in heartwood extract of teak (HWE) treated hardwoods after exposure to white rot attack. Int J Biol Chem Sci 4:571-591.

Ong Z, Arip M, Nasir M, Lee HL (2025) Advances in wood preservation technology: a review of conventional and nanotechnology preservation approaches. BioResources 20

Otoide JE, Jonathan O, Nwankwo SI (2017) Evaluation of selected Nigerian wood species for suitability in furniture and construction works. Donnish J Agric Res 4:42-47.

Ozarde YS, Gadhave RV, Karadkhedkar GM, Wani MS, Mehta PP (2022) Use of *Tectona grandis* (teak) leaves extract as an indicator in acid-base titrations. Int J Biol Pharm Allied Sci 11:1425-1432.

R Core Team (2016) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Online at: http://www.r-project.org

Ramesh MM, Shankar NS, Venkatappa AH (2024) Driving/critical factors considered during extraction to obtain bioactive enriched extracts. Pharmacogn Rev 18:68-81.

Rosamah E, Ferliyanti F, Kuspradini H, Dungani R, Aditiawati P (2020) Chemical content in two teak woods (*Tectona grandis* Linn. F.) that has been used for 2 and 60 years. J Biol Sci Technol Manag 2:15-19.

Spear MJ, Curling SF, Dimitriou A, Ormondroyd GA (2021) Review of functional treatments for modified wood. Coatings 11:327.

Tondi G, Thévenon MF, Mies B, Standfest G, Petutschnigg A, Wieland S (2013) Impregnation of Scots pine and beech with tannin solutions: effect of viscosity and wood anatomy in wood infiltration. Wood Sci Technol 47(3):615-626.

Velázquez-Becerra C, Ambriz-Ortiz GY, Torres-Martínez R, Martínez-Pacheco MM (2023) Repellent and insecticidal activity of naphthoquinones from the heartwood of *Tectona grandis* on *Incisitermes marginipennis* (Latreille). Phyton 92:0031-9457.

Vyas P, Wadhwani BD, Khandelwal P, Araya H, Fujimoto Y (2022) Tectonaquinones A, B and C: three new naphthoquinone derivatives from the heartwood of *Tectona grandis*. Nat Prod Res 36:1707-1715.

Vyas P, Yadav DK, Khandelwal P (2019) *Tectona grandis* (teak) – a review on its phytochemical and therapeutic potential. Nat Prod Res 33:2338-2354.

Wilson UN, Muhammed NY, Adisa MA, Odeyemi SO (2025) Investigating the anti-termite property of African birch extract for treatment of some selected susceptible timbers. Discov Appl Sci 7:708.

Woods AJ, Watts M (2019) The extent to which an unforeseen biotic disturbance can challenge timber expectations. For Ecol Manag 453:117558.

Yingprasert W, Cherdchim B, Peaklin S (2023) Effects of *Acacia mangium* bark extracts on dimensional stability, termite resistance, and fungal decay resistance of rubberwood. Biomass Convers Biorefin 13:7623-7632.

Zanne AE, Flores-Moreno H, Powell JR, Cornwell WK, Dalling JW, Austin AT, Classen AT, Eggleton P, Okada K, Parr CL, Adair EC, Adu-Bredu S, Alam MA, Alvarez-Garzón C, Apgaua D, Aragón R, Ardon M, Arndt SK, Ashton LA, Barber NA, Beauchêne J, Berg MP, Beringer J, Boer MM, Bonet JA, Bunney K, Burkhardt TJ, Carvalho D, Castillo-Figueroa D, Cernusak LA, Cheesman AWC, Cirne-Silva TM, Cleverly JR, Cornelissen JHC, Curran TJ, D'Angioli AM, Dallstream C, Eisenhauer N, Evouna Ondo F, Fajardo A, Fernandez RD, Ferrer A, Fontes MAL, Galatowitsch ML, González G, Gottschall F, Grace PR, Granda E, Griffiths HM, Guerra Lara M, Hasegawa M, Hefting MM, Hinko-Najera N, Hutley LB, Jones JB, Kahl A, Karan M, Keuskamp JA, Lardner TJ, Liddell MJ, Macfarlane C, Macinnis-Ng C, Mariano RF, Méndez MS, Meyer WS, Mori AS, Moura AS, Northwood M, Ogaya R, Oliveira RS, Orgiazzi A, Pardo J, Peguero G, Penuelas J, Perez J, Posada LI, Prada JM, Přívětivý C, Prober SM, Prunier S, Quansah GW, Resco de Dios V, Richter R, Robertson MP, Rocha LF, Rúa MA, Sarmiento C, Silberstein R, Silva RP, Siqueira MC, Stillwagon FF, Stol MG, Taylor J, Teste FP, Tng DY, Tucker DPY, Türke D, Ulyshen MD, Valverde-Barrantes OJ, van den Berg E, van Logtestijn RSP, Veen GF, Vogel JG, Wardlaw TJ, Wiehl G, Wirth C, Woods MJ, Zalamea P-C (2022) Termite sensitivity to temperature affects global wood decay rates. Science 377:1440-1444.

Zayyanu U, Nasiru AM, Bello AG, Bandiya HM (2025) Efficacy of neem seed oil and *Khaya senegalensis* bark extracts on *Afrormosia axiflora* wood species exposed to termite infestation. Caliphate J Sci Technol 7:189-193.

Zubairu SU, Suberu HA (2024) Efficacy of aqueous leaf extract of *Tectona grandis* (teak) in growth inhibition of *Rhizopus stolonifer* and *Aspergillus niger*. Int J Microbiol Appl Sci 3:66-71.