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NATURAL DURABILITY OF *GMELINA ARBOREA* LUMBER AND EFFICACY OF USED MOTOR OIL AGAINST CONTROLLING *SUBTERRANEAN TERMITES* AND FUNGAL DAMAGE

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Abstract:
Biodegrading organisms such as termites, beetles, and fungi have been causing damage to forest products in Ethiopia's industrial and construction sectors. This study aimed to assess the natural durability of Gmelina arborea lumber and evaluate control methods against subterranean termites and fungal damage. Ninety samples of G. arborea lumber underwent treatment with used motor oil (UMO) using hot-and-cold dipping (HCD) and brushing application methods, in addition to untreated controls. Stakes were installed and study conducted at Bako and Adami Tulu Research Stations for six years. Results from multi-factor ANOVA analysis indicated significant differences (P<0.001) in the extent of damage caused by subterranean termites and fungi among control methods, research stations, and exposure periods. Fungal damage showed no significant variation by station (P=0.1587). At Bako station, termite damage on UMO-treated stakes using HCD and brushing methods, as well as untreated controls, was 83%, 83% and 100%, respectively, at the six-year evaluation mark, while fungal damage was 58%, 58% and 75%, respectively. At Adami Tulu station, termite damage on UMO-treated stakes using HCD and brushing methods, and untreated controls was 50%, 58% and 67%, respectively, while fungal damage was 50%, 50% and 58%, respectively. Compared to untreated control stakes, the service life of G. arborea lumber stakes treated with UMO doubled. Therefore, the application of used motor oil treatment using the HCD method is recommended to extend the service life of G. arborea lumber for ground and moisture contact applications.

Key words: *Bio-detractors, control measures, fungi, lumber stakes, natural durability, subterranean termites.*

INTRODUCTION

Ethiopian forests have traditionally supplied renewable resources and key ecosystem services, thus playing an essential role in meeting the needs of its people. This trend is likely to increase as the demand for forest products rises with population and economic development (Desalegn et al. 2020). However, sustainability is increasingly threatened by biodeterorating agents like termites, powder-post beetles, and fungi. These agents present serious problems, especially to the construction and industrial sectors, whose destructive impacts result in improper utilization and overexploitation of forest products (Antwi et al. 2017). This has placed several key native tree species, including *Juniperus procera, Hagenia abyssinica, Cordia africana, Podocarpus falcatus* and *Pouteria adolfi-friederici*, under heavy pressure and at risk of

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overexploitation (Desalegn et al. 2015). Though their role has highly contributed to the degradation of forests in Ethiopia, they have been overgrown (Desalegn et al. 2015).

Subterranean termites have traditionally been regarded as the most important threat to wood and wood products in Ethiopia. However, recent evidence suggests that fungi, alongside termites, are also a major cause of deterioration in wood. Both agents can cause extensive damage in a relatively short time, leading to the need for frequent repairs and rebuilding (Wood 1986; Desalegn et al. 2024). This repeated cycle of wood replacement not only increases the demand for forest products but also contributes to economic losses and heightened pressure on native forests. Despite the severity of the issue, limited research has been conducted to assess the extent of biodegradation across various lumber types and geographic regions in Ethiopia, leaving a critical knowledge gap (Desalegn 2014; Desalegn et al. 2015). If biodeterioration is attended to, then a meaningful increase in the service life of the products along with reduction of harvest frequency and easing the economic burden can be attained. This further heightens the need for effective control measures against these agents. There is an increased interest in investigating the opportunities that may exist in substituting wood species from alternative species that can satisfy the demand while switching from over-harvested native ones.

Gmelina arborea, also referred to as Gamhar, is a quick-growing, deciduous Verbenaceae tree that grows to a height of 30-40 meters with a cylindrical, usually curved bole that is 80-140cm in diameter. The bark is smooth to corky and grey to yellowish-grey or pale brown in color. *G. arborea* has wide and spread branches and is noted for its rapid growth and high yield, producing 20-25m³/ha/year with some producing over 30m³/ha/year. The tree is also frost and termite resistant and can coppice. It typically lives for 30–50 years, producing straight stems with natural pruning in dense stands under optimal conditions (Mihretu 2004; Iwuoha et al. 2021; Owoyemi et al. 2023; Adam & Krampah 2005).

Native to regions in Asia, *G. arborea* has been farmed widely on tropical regions in Africa, Asia and America, including grand plantations on many African countries. In Ethiopia, the species was introduced at the beginning of the 1980s into Bonga, Aman, Bebeka, and Tole Kobo, where its high adaptability and growth rate were exhibited (Mihretu 2004). This species has economically gained importance at the global level due to its role in industrial wood, light construction timber, fodder, and as a secondary resource for paper and pulp production. The wood is light to medium weight with a minimum basic density ranging from 345 to 620kg/m³ (Sulaiman & Lim 1989).

Despite *G. arborea* is valuable for these uses, not much work has been conducted in Ethiopia to identify its natural durability and resistance to attack by termites and fungi. To fill this gap, the research was conducted to evaluate its resistance to such bio deterioration organisms and establish control measures that would prolong the life of the wood. The findings are crucial to the sustainable use of *G. arborea* as an alternative to over-exploited native species, thus reducing pressure on native forests. Reducing biodegradation and promoting long-term, fast-growing timber is of paramount importance for sustainable forest management and overcoming the bio-deterioration issues of Ethiopia.

G. arborea is a multi-use species that provides multiple products, including timber, forest-derived products, and cultural non-wood products. Depending on such conditions as seasoning, moisture content, and weight, its wood is utilized for general utility, light framing, structural work, carpenter's work, plywood work, boxes and packaging, carvings and tools, utility furniture and building poles, decorative veneers. *G. arborea* wood is also utilized in light flooring work, musical instrument construction, matchsticks, particle board, mine timbering, and auto body work. In preservative-treated wood form, it may be utilized as telephone poles. The wood produces high-quality short fiber pulp, and the semi-chemical pulp is used for carton board and low-grade writing paper, while Kraft pulp can be used for higher-grade writing papers. The wood is also utilized as firewood and charcoal (Adam & Krampah 2005).

The roots, bark, leaves, fruits, and seeds of *G. arborea* are utilized in traditional medicine in tropical Asia. The tree is a honey flora source, and its leaves and bark are utilized as cattle fodder. The bark and fruit are utilized in the management of bilious fever, and the leaf sap is utilized as a demulcent in gonorrhea and coughs. The roots are tonic, stomachic, and laxative, and the flowers are utilized in the management of leprosy and blood diseases. It is edible fruit, and leaves are used as feed to cattle and silkworm. Wood ash and fruit yield a permanent yellow dye, and flowers yield nectar for premium honey (Adam & Krampah 2005).

MATERIALS AND METHODS

Study Stations

The study sites were Bako and Adami Tulu 258km and 167km away from Addis Ababa respectively. Bako is geographically located at 090 06’ and 370 09’ (Fig. 2) in the Sub-humid, mid latitude sub-tropical climate, Shewa plateau. It is found in the tepid to cool sub-humid highland major agroecological zone and tepid to cool sub- humid mountains sub-agro ecological zone (Anonymous 2001). It has an altitude of 1650m, total annual rainfall of 1210mm, and the mean annual minimum and maximum temperatures of 13.20C and 27.9^{0}C, respectively and major soil types are nitisols. Adami Tulu is geographically located in the

709´N and 3807´E and it is found Semi-arid climate, in the hot to warm sub-humid hot land major agroecological Zone, and hot to warm hub-humid gorges sub-agroecological zone (Anonymous 2001). It has an altitude of 1645m, total annual rainfall of 766mm and annual mean minimum and maximum temperatures of 12.30C and 27.7^{0}C, respectively and major soil type is sandy soil.

For this study, 32-year-old G. arborea trees from Bonga's growth trial site, with a mean height of 20.6m and a mean diameter at breast height (dbh) of 36.2cm, were selected. These trees had good morphological quality with straight, cylindrical stems and no visible defects (Desalegn et al. 2020). Accordingly, a total of 16 mature trees that yielded a volume of 9.3m³ of merchantable timber were felled. The logs were cross cut into 2.5m sections with a top diameter of 20cm, maintaining moisture content of over 30%, and transported to the Forest Products Innovation Center of Excellence (FPICE) for testing preparation (Fig. 1a, Fig. 1b).

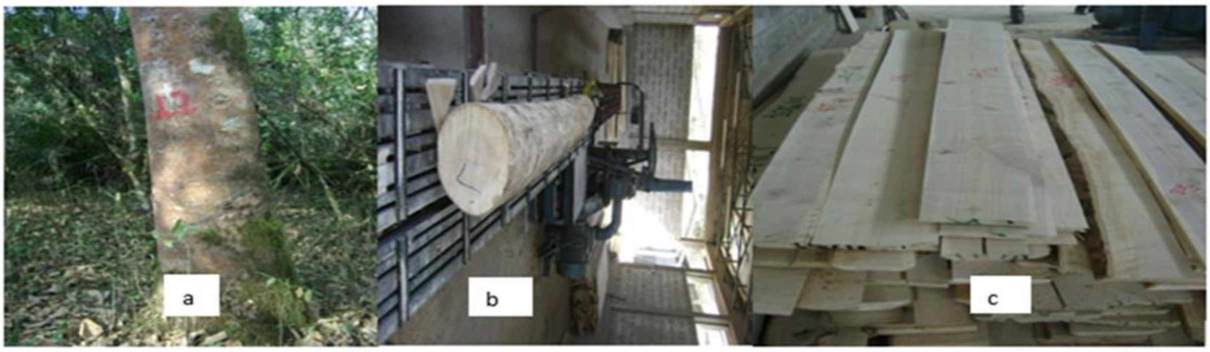

Fig. 1.
a - Gmelina arborea tree with a clear trunk; b - Log sawing, c - Conversion of sawn logs into 3cm thick boards at FPICE using a mobile circular sawmill and the plain sawing method.

The boards were then processed into test samples with suitable dimensions, quantity, and quality for various wood characteristics, including moisture content, and density tests. Laboratory tests were conducted according to the relevant ISO standards/protocols (ISO 3129, 1975; ISO 3130, 1975; ISO 3131, 1975). The sawn boards were seasoned to a moisture content of 12%, after which 90 lumber sample stakes with dimensions of 2x5x50cm (thickness, width, and length, respectively) were prepared, coded, and treated using hot and cold dipping (HCD) methods and brushing with used motor oil (UMO), in addition to untreated controls. Following the treatments, the stakes were tested at the Bako and Adami Tulu research stations.

Experimental Design

The experiment was a split-plot design within a completely randomized design (CRD). The main plot factor was the origin of the stakes, and two sub-plot factors included were control measures and positions along the height of the tree. In the main plot, the factor was one, namely the lumber stakes. In combined data analysis, the two study locations were treated as block factors. The sub-plot factor in the graveyard tests consisted of one factor related to the control measures with three levels, namely: (i) used motor oil with both hot and cold dipping methods; (ii) used motor oil with the brushing method; and (iii) untreated controls. The second sub-plot factor was the position of the stakes along the tree's height, which also had three levels: stakes from the bottom, middle, and top sections.

Treatments of Lumber Stakes with Control Measures

A preventive measure utilizing a mixture of used motor oil from vehicles, specifically Shell Rimula diesel oil 40 and Helix Ultra 40 engine oil in equal parts, was employed to combat damage from bio-deteriorating agents on lumber stakes. This treatment involved immersing the stakes in a tank containing cold used motor oil, gradually heating the oil to 90°C, for over four hours to reduce viscosity, and then allowing the stakes to cool for 24 hours before cleaning off excess oil and air-seasoning them for a week prior to installation. Detailed procedures for this hot-and-cold dipping method with used motor oil can be found in prior works (Desalegn et al. 2003; Kebede et al. 2011). Additionally, half-sized stakes were brushed with used motor oil and left to air dry for a week.

In treating the lumber stakes against bio-deteriorating agents, a mixture of Shell Rimula diesel oil and Helix Ultra 40 engine oil-in equal ratios of 1:1 was used. HCD is a non-pressure treatment method applied to lumber stakes as a preventive/control measure. The stakes were dipped in a tank containing 25 liters of cold used motor oil. A fire was lit under the tank, and the oil was gradually heated to about 90°C to reduce its viscosity, maintaining this temperature for four hours (Desalegn et al. 2007). After cooling for 24 hours, the treated stakes were removed, wiped to remove excess oil using cloth rags, and air-dried for a week before installation at the research sites. The detailed procedure for this treatment method is described in Desalegn et al. (2007) and Desalegn et al. (2021). The stakes were also treated by brushing half of their length with used motor oil (UMO).

As controls, untreated lumber stakes of *G. arborea* were also prepared to assess the natural durability of the lumber species. The durability of the lumber species and effectiveness of the control measures were evaluated according to adapted grades from British standards, ranging from very perishable to very durable, based on resistance against subterranean termite and fungal damage (Leroy et al. 2023).

Lumber stakes installation and evaluation at grave- yard stations

Each stake had a dimension of 2x5x50cm (thickness, width, and length). The treated stakes were left to air-dry for a week before being placed at the research stations.

The control stakes, used for assessing the natural durability of the lumber species, were not treated with used motor oil. Instead, prophylactic treatments against discoloration and deterioration were made before being installed at the various research stations. These controls were then handled in storage, transport, processing and seasoning properly to about 15% moisture content. According to Desalegn et al. (200) the natural durability of the species and effectiveness of the control measures was classified as follows: Very Perishable (< 6 months), Perishable (6 months - 1 year), non-durable (2-5 years), Moderately Durable (5-10 years), Durable (10-15 years), and Very Durable (>15 years) based upon its resistance to *subterranean termites* and fungal damage.

Each of the research stations was demarcated with a 20x20m² fenced area in order to avoid interference from human beings and animals. The stakes of lumber were installed in pits that were dug to 25cm deep, at a distance of 25cm between stakes and 50cm between rows (Fig. 2a). The stakes were labelled with identification codes and positioned regularly into the pits, having 25cm of their length buried in the ground and the other half above the surface (Fig. 2b).

a b

Fig. 2.
Gmelina arborea stakes arrangement in the Adami Tulu research station.

The stakes were then kept under open field conditions that included a similar amount of rain, sun rays, weather, under growth, weeds and grass during a particular time, at their respective research station. In fact, those environmental variables contribute to either deterioration or resistance of the treated and untreated stakes respectively to an abiotic agent and/or biotic one (Rabbi 2015). The testing of natural resistance of the stakes was conducted simultaneously with the evaluation of the efficiency of control measures and methods of application at graveyard stations.

Evaluation of Lumber Stake Control Measures at Graveyard Stations

Subterranean termites have long been notorious for causing widespread damage to wood and wood products. However, some recent studies show that fungi and termites are the cause of widespread wood rot in Ethiopia particularly in regions with high humidity levels, and warm environment such as Bako Tibe and Adami Tulu. Both termites and fungi are capable of causing great damage within a short period of time, and this leads to the necessity of constant repairs and reconstruction (Wood 1986; Desalegn et al. 2024).

The loss rate of the treated and untreated lumber stakes due to *subterranean termites* and fungal decay was measured visually, supplemented with sounding and indenting, respectively, as described by Desalegn et al. (2007). The stake performance and protection treatments were monitored at three, six, and twelve months after the beginning of the test, and then annually for further protection period. The bio deterioration of the stakes was evaluated using a grading scale ranging from 1 to 5: Grade 1-no decay or no termite damage, which means 100% resistance; Grade 2-moderate or superficial damage, meaning 75% resistance; Grade 3-light and limited damage, meaning 50% resistance; Grade 4-severe and deep damage, meaning 25% resistance; Grade 5-total failure or complete damage, meaning 0% resistance (BS EN 252 2014). After every rainy season, the stakes were carefully removed from their pits, and the extent of damage caused by termites or fungi was inspected, evaluated, and recorded using the visual evaluation of the damage method described by Highley (1995). Inspection continued at the graveyard until at least 50% of the underground portions of the untreated stakes had been completely degraded or had fallen to the ground.

Data analysis

Data were analyzed with the SAS statistical software. A multi-factor ANOVA/joint analysis was used to compare subterranean termite and fungi damages and preservative performances. The damage mean values for stakes in a continuous form were evaluated using the standard ANOVA methods. For convenience, results are shown as percent after retransforming the values.

RESULTS AND DISCUSSION

The appearance of lumber from which the grave yard stakes prepared was heartwood pale brown to yellowish brown, sometimes with a pinkish tinge, and indistinctly demarcated from the whitish, 5-7cm wide sapwood, which has sometimes a greenish or yellowish tinge (Fig. 3). The grain was straight to interlocked, while texture coarse. The wood is somewhat oily to touch (Adam and Krampah 2005).

Fig. 3.
Appearance of Gmelina arborea lumber.

Moisture content and Density

The mean initial moisture content (MC) of *G. arborea* lumber, before air and kiln seasoning commenced, was 132%, while the final mean MC both air and kiln seasoning was 12.99% (Desalegn et al. 2020). It took up to 210 days with air seasoning to reach the required moisture content level of 3cm thick G. arborea sawn timbers, whereas the kiln seasoning required the duration of 13.5 days. Mean green (initial) and dry density of *G. arborea* lumber species at 12% MC was 940kg/m^3 and 420kg/m^3, respectively. The density of *G. arborea* (420kg/m^3) at 12% MC, classified as light density lumber species (Getachew Desalegn et al. 2020). According to Adam and Krampah (2005), *G. arborea* is a lightweight hardwood, the density of G. arborea ranges between 400-510kg/m^3 at 12% MC.

Damage of Bio deteriorating agents and effectiveness of control measures

Subterranean termites mean damage at Bako research station on control stakes of *G. arborea* treated with UMO using hot and cold-dipping and brushing methods and untreated controls at year six inspection and evaluation period was 83%, 83% and 100%, respectively while that of fungi was 58%, 58% and 75%, respectively. The results revealed that damage of *subterranean termites* and fungi on *G. arborea* lumber vary with treatment methods, graveyard stations and time of exposure (Fig. 4).

After 6 year of exposure and evaluation period, termites mean damage at Adami Tulu research station on stakes of *G. arborea* treated with UMO using hot and cold-dipping and brushing methods and untreated controls was 50%, 58% and 67%, respectively while that of soft rot fungi was 50%, 50%, and 58%, respectively (Table 1 and Fig. 4). Degradation increased in time (3rd month to 6th year). Some of the control samples at Bako station failed starting from the end of first year. *Subterranean termites* at Bako station have been Micro terms and *Pseudacanthoterms militarious* while that of Adami Tulu, having the same agroecology as that of Batu dominant are the subterranean and mound building termite species namely Marco terms bellicose (Berhane and Yusuf 1974).

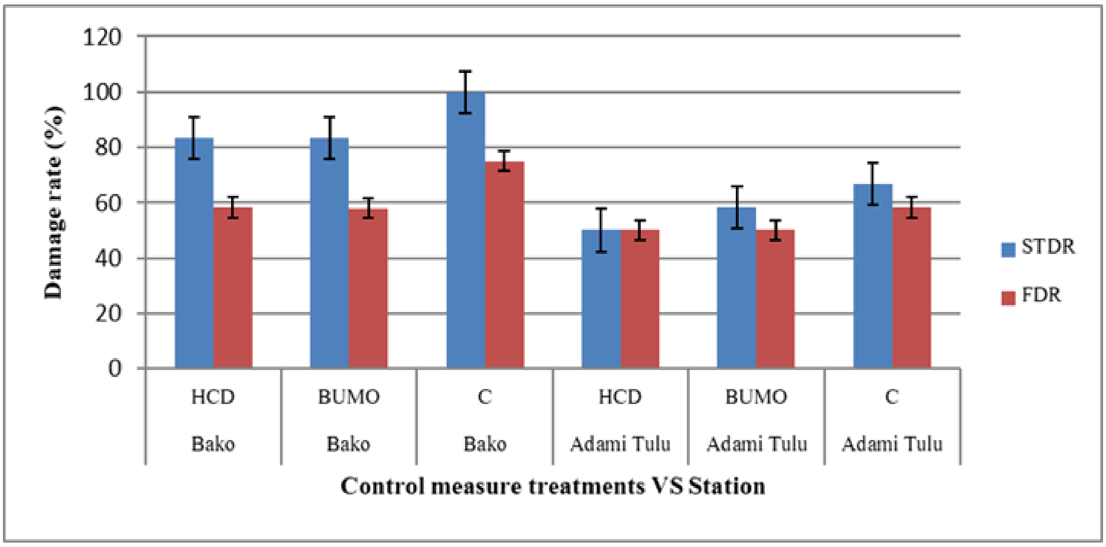

Fig. 4.
Subterranean termite and fungal damage rate on G. arborea treated and un-treated lumber stakes.

Note: HCD-Hot and Cold Dipping vehicles spent used motor oil; BUMO-Brushing with used motor oil; C-Control (Untreated); STDR- Subterranean termite damage rate; FDR- fungal damage rate.

The analysis of multi-factor ANOVA revealed significant difference (P<0.001) in *subterranean termites* and fungal damages on *G. arborea* lumber, graveyard stations and duration of exposures. There was no significant difference (P=0.1587) in fungal damages at Adami-Tulu research station (Table 1).

Table 1
ANOVA values on G. arborea treated and un-treated lumber stakes damage rates by subterranean termite and fungi

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Termite damage					
Control measures	2	9345.24	4672.62	53.24	<.0001
Duration	13	23842.59	1834.05	20.9	<.0001
Station	1	3601.19	3601.19	41.03	<.0001
Control measures* Duration	26	2784.39	107.09	1.22	0.3077
Control measures* Station	2	7996.03	3998.02	45.56	<.0001
Duration* Station	13	3482.14	267.86	3.05	0.0075
Fungal damage					
Control measures	2	2511.57	1255.79	22.21	<.0001
Duration	13	16259.92	1250.76	22.12	<.0001
Station	1	119.05	119.05	2.11	0.1587
Control measures* Duration	26	2951.39	113.51	2.01	0.0407
Control measures*Station	2	2604.17	1302.08	23.03	<.0001
Duration*Station	13	3862.43	297.11	5.26	0.0002

There existed a synergistic relationship between *subterranean termites* and fungal decay to the stakes. Subsequently, the fungi would have a decaying effect on the wood; this eventually created easy conditions for a successful deteriorating of *subterranean termites* after some time. On untreated control check stakes, damage due to *subterranean termites* was significantly more extensive after six years compared to those brought by fungi. The highest level of termite damage occurred at Bako station, 100%, compared to 67% at Adami-Tulu station. In cases where both *subterranean termites* and fungi caused damage to *G. arborea* lumber stakes at Bako station, the oil treatment with both methods led to good protection after 6 years against termites, obtaining a damage rate of 83%. On the other hand, these treatments had a weaker effect on fungi, as the damage rate was higher 58%. The natural durability of *G. arborea* lumber is considered non-durable and highly vulnerable to fungi, termites, and marine borer attacks.

According to Adam and Krampah (2005) and Orwa et al. (2009), the wood is unsuitable for contact with the ground in tropical conditions; however, the heartwood, which is denser, is moderately durable.

The effectiveness of the brushing application method using vehicles' spent motor oil in controlling damage from termites and fungi was not significantly better than the untreated control. In similar research, the brushing method applied to *Trichilia dregeana* stakes over four years showed similar results to the untreated control (Getachew et al. 2021). The brushing treatment did not have deep penetration into the internal parts, and neither did it result in a good fixation within the stakes. The longer the exposure time to bio-deteriorating agents, the less effective the brushing treatment became, no better than the untreated control. It might be related to leaching of the treatment, poor penetration into the stakes. Thus, treatment of vehicles' spent motor oil using the brushing application method can only be recommended for comparatively short service periods of around three years.

The hot and cold dipping method with used motor oil is recommended for prolonging the service life of *G. arborea* lumber in ground and moisture-contact applications. This experiment focused on one type of control (vehicles' spent motor oil), two application methods (hot - and cold - dipping and brushing), two graveyard stations (Bako and Adami-Tulu), and a limited period of six years.

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CONCLUSION AND RECOMMENDATIONS

Biodegradation increased time of exposure (3rd month to 6th year). Some of the control samples at Bako station failed starting from the end of first year. Complete biodegradation of *G. arborea* caused by stakes occurred at year six on control stakes by *subterranean termites (*100%) than fungi (75%) at Bako station, while at Adami Tulu station 67% degradation occurred by *subterranean termites* and 58% by fungi. In general, damage of *subterranean termites* on control stakes was higher compared to fungi and high deterioration occurred by *subterranean termites* at Bako station (100%) than Adami-Tulu station (67%).

Used motor oil (UMO) treatment of *G. arborea* wood stakes by hot and cold dipping was found to be very effective in the protection against subterranean termite and fungal attack. It significantly increased the lifespan of wood in ground and moisture-contact services, with the durability of wood nearly twice that of untreated stakes. In comparison, brushing of wood with UMO was inferior and provided little enhancement over untreated controls for termite and fungal protection. Therefore, the hot and cold dipping method with used motor oil is recommended to enhance the service life of *G. arborea* wood in ground contact and moisture-exposed conditions.

Thus, further applied research recommended, involving different commercial and traditional alternative treatment methods, at different research stations and for prolonged time to add more information and technological gaps on natural durability of lumber species *G. arborea.* The effective control measures including application techniques could increase the service life and promote also the rational utilization of the resource in the different agro ecological zones of Ethiopia where biodegradation and wood-based products utilization have a high economic importance.

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