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PROTECTION MEASURES OF *JUNIPERUS PROCERA* HOCHST. EX ENDL. (CUPRESSACEAE) AND *EUCALYPTUS DEGLUPTA* BLUME (MYRTACEAE) SAWN TIMBERS AGAINST SUBTERRANEAN TERMITES AND FUNGAL ATTACK AT MIESSO, EASTERN ETHIOPIA

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ABSTRACT: Bio-deterioration of forest products in the construction and furniture sectors is considered an economically important problem in Ethiopia. A study was carried out on treatability (laboratory test) of *Juniperus procera* and *Eucalyptus deglupta* sawn timber stakes with preservatives against subterranean termites and fungi at Miesso locality. There was significant difference ($P<0.01$) in Copper Chromium Arsenate (CCA) uptake and retention between the two timbers. The absorption and retention of *E. deglupta* pressure treated with CCA was 200.77 kg/m^3 and 6.02 kg/m^3, respectively while that of *J. procera* stakes was 2.06 kg/m^3 and 0.06 kg/m^3. Significant differences ($P<0.01$, multi-factor ANOVA) were observed between CCA treatments and the untreated control; among preservative application techniques; between the timber species and length of field exposure periods and in the interactions between timber species and preservatives. Sapwoods were more deteriorated than heartwoods for both species. All the control stakes of *E. deglupta* deteriorated and were felled by termites during the first year and *J. procera* was deteriorated by termites to 27.5% but were not attacked fungi up to third year. Termites and fungi attacked majority (80%) of *E. deglupta* stakes pressure treated with CCA to 37.5% and 7.5%, respectively, during the third year, while *J. procera* stakes were degraded to 5% by termites but intact by fungi. Termites showed more degradation than fungi. Treatments with used motor oil were less effective than CCA but much better than the control. The timbers are recommended for different construction and furniture uses after adequate preservation measures and large scale plantations establishment.

Key words/phrases: Bio-deteriorating agents, Copper chromium arsenate (CCA), *Eucalyptus deglupta*, *Juniperus procera*..

INTRODUCTION

Bio-deteriorating agents' damage on forest products in the area of construction and furniture sectors and standing trees is an economically important problem in Ethiopia (Holmgren, 1963; Zawde Berhane and Yusuf, 1974; Wood, 1986). This is one of the major causes in the country that has led to inappropriate utilization and destruction of forests and

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endangering of certain valuable timber species such as *Juniperus procera*, *Hagenia abyssinica*, *Cordia africana*, *Podocarpus falcatus* and *Pouteria adolfi-friederici*. The first four have been proclaimed not to be harvested from both federal and regional forests of the country (TGE, 1994) while the last one has been similarly proclaimed not to be harvested by the Oromiya Regional State (Oromiya Regional State, 2003).

The major sources of material in the country for construction, forest industries and wood-based energy sectors are the natural forests while plantations contribute about 10% (PTA, 1990). In Ethiopia, there are more than 320 timber species that can supply sawn log/lumber, but have been improperly utilized without knowing at least their major timber properties and application of preservation measures. The projected gap between total demand (about 80 million m^3) and supply (about 12 million m^3) of industrial, construction and fuel wood for the year 2008 was about 68 million m^3 (EFAP, 1994), where demand exceeded the supply by more than 660%. This has led to excessive and illegal cutting of trees and utilization of more agricultural residues to meet the high deficit that has been faced, which in turn has a negative impact on soils and agricultural crops.

Wood quality requirements for sawn timber end production can be categorized into five main groups: strength properties, dimensional stability, performances of biological (durability), manufacturing (working properties) and log processing (conversion) (Armstrong, 2003).

Among the overlooked major causes of forest destruction in the country are severe degradation of wood, wooden structures and commodities both in service and in storage in the country that occur by bio-deteriorating agents, moisture, shrinkage, seasoning defects and mechanical wear. The losses stated above have led to low quality of sawn wood, low recovery rate at sawmills, further processing and manufacturing of products, and short service life of structures and products. This in turn has resulted in frequent and excessive mining of the remaining forests for different construction, industry and furniture purposes. This has resulted in more deforestation and loss of considerable amount of forest, labour, finance and other resources.

In all tropical and sub-tropical regions of the world, macro- and micro-organisms such as termites, beetles/borers, wood staining and wood -decaying fungi (brown, white and soft rots) and marine borers and especially subterranean ones (Termitidae, Rhinotermitidae and Hodotermitidae) at larval stage are the most wood destructor pests (chew and feed wood and wood-based products and cause great losses) (Nicholas, 1985; Grace *et al*., 1998; Wong and Cheok, 2001). Thus, the potential damage of termites on forests/standing trees and forest products is an important economic consideration throughout the tropics, both in the selection and growth of plantation species and the manufacture and utilization of the resulting wood products (Grace *et al*., 1998). Fungi also cause the greatest economic losses by discolouring and decomposing wood (Nicholas, 1985; Groves, 1990). The wood-deteriorating fungi groups largely belong to the Families of Basidiomycetes (brown and white rots), Ascomycetes and Deuteromycetes (soft rots) (Shrivastava, 1997; Eriksson *et al*., 1990 cited in Adane Bitew, 2002).

The bio-deteriorating agents of wood, forests and crops found in the country are diverse and their damages and losses are economically important to standing trees, forest products and agricultural crops. Sixty-one species representing 25 genera and four families, namely Kalotermitidae, Hodotermitidae, Rhinotermitidae, and Termitidae have been reported in the country, out of which 10 species are indigenous to Ethiopia and the adjacent regions (Krishna and Weesner, 1970; Cowie *et al*., 1990; Abdurahman Abdulahi, 1991). From Menagesha, Munessa-Shashemene and Teppi forests of the country, wood-decaying 142 species of Basidiomycetes have been recorded on *P. adolfi-friederici*, *J. procera* and *P. falcatus* fallen logs (Adane Bitew, 2002).

Macrotermitinae, especially subterranean termites, have been considered as the only cause of greatest threat to wooden houses and other construction in the country, which leads to partial or complete rebuilding in 3-5 years (Wood, 1986). According to personal observations and communications in the different parts of the country, destruction of wood-based construction have occurred with soil and moisture contact applications even within short time of 1-2 years. These were caused by subterranean termites and/or mutual fungal attack. In the country, the damage caused by termites on crops and wooden construction has been estimated at 20-50%, which in some places has led to total crop and construction losses (Wood, 1986).

Some timber species are more vulnerable to bio-deteriorating agents than others. Natural durability is variable within and between trees of the same species (Nicholas, 1985; Shrivastava, 1997). Preservative treatments can open the opportunity to new and wide application of timber species, which are susceptible for bio-deterioration and refractory to treatments (Willeitner and Liese, 1992). Where natural durability and a good technical design alone could not guarantee long durability for wooden structures, the service life of construction and furniture can be significantly increased by proper wood preservative treatments (Willeitner and Liese, 1992).

Researches for the evaluation of termites and fungal damages, timbers natural durability and performance of applied preservatives in Ethiopia are scarce. There are only a few protection/preservation research activities carried out on a few timber species, in very few agro-ecological zones and majority for short periods, less than five years (Holmgren, 1963; Zawde Berhane and Yusuf, 1974; Wood, 1986; Melaku Abegaz and Addis Tsehay, 1988; Cowie *et al*., 1990; Abdurahman Abdulahi, 1991; Wood, 1991; WUARC, 1995; Tsegay Bekele, 1996; Adane Bitew, 2002; Getachew Desalegn *et al*., 2003; Getachew Desalegn *et al*., 2007; Ofgaa Djirata *et al*., 2007; Wubalem Tadesse and Getachew Desalegn, 2008; Getachew Desalegn *et al*., 2012).

Although *J. procera* has been considered as one of the most versatile, prominent structural/construction, furniture, invaluable industrial and aesthetic material in the country, it has been used without adequate knowledge of its durability and other properties. *J. procera* is among the few highly exploited, improperly-utilized and endangered species while *E. deglupta* is an introduced, fast-growing species used for promotion and sustainable utilization. *E. deglupta* is not yet known by the development sectors, manufacturers and end users in the country. Besides, wood properties and silvicultural research results have not been adequately disseminated and popularized.

Among the challenges and gaps in forest products processing and appropriate utilization are lack of information on: (i) treatable and naturally durable construction and furniture timber species, (ii) effective control measures and application techniques against bio-deteriorating agents in each agro-ecological zone and locality, and (iii) substitutes for the endangered timber species. Therefore, the seasoning and preservative treatments of wood should be given higher priority, as seasoning and preservation measures are better than curing and can decrease large economic losses and replace and maintain the degraded wood and wood-based structures/products under economic threshold.

The objectives of the study were to: (i) determine treatability of *J. procera* and *E. deglupta* sawn timbers with preservatives (laboratory test), (ii) investigate natural durability of the two sawn timber species in the field, (iii) evaluate performance of the applied bio-deteriorating protection measures on timber stakes against subterranean termites and fungal attack at Miesso research station, and (iv) select effective wood preservatives and application techniques that can improve durability and endure utilization of the two timber species in the area and elsewhere.

MATERIALS AND METHODS

Study site

The field test was conducted at a graveyard station in the vicinity of Miesso town, Eastern Hararge Zone. Miesso is located about 24 km northwest of Assebe teferi town and about 300 km from the capital city, Addis Ababa. The station is geographically located at 09° 14′ N and 40° 45′ E (Fig. 1). In the area indicators of occurrence of termites were observed and the damages of bio-deteriorating agents on wooden structures and furniture were serious.

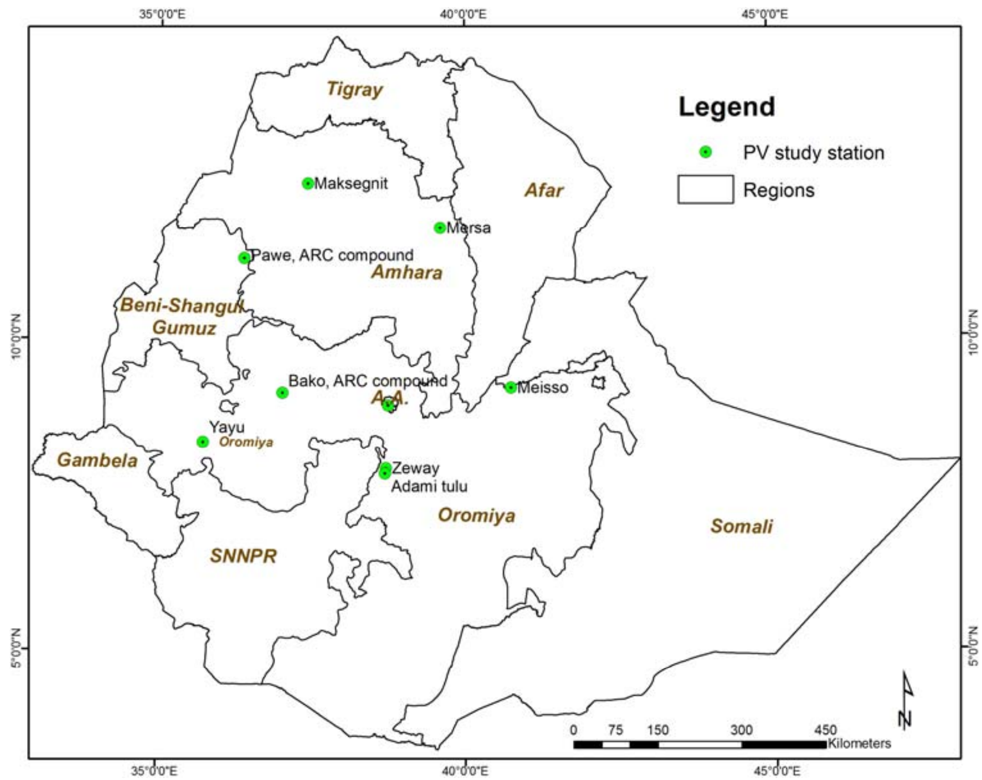


Fig. 1. Location of the timber preservation study site Miesso.

Miesso belongs to the hot to warm arid-lowland plains major agro-ecological zone and hot to warm arid plains sub agro-ecological zone (Anonymous, 2001). It has an altitude of 1349 m and bimodal rainfall with a mean annual rainfall of 717 mm. April and August receive the maximum rainfall and October to February is the dry spell (Alelign Kefyalew *et al*., 1996). The mean annual minimum and maximum temperatures were 14.1°C and 33°C, respectively.

Study materials

The test materials were prepared from lumbers of *Juniperus procera* Hochst. ex Endl. 1847 (Family Cupressaceae), and *Eucalyptus deglupta* Blume (Myrtaceae). The former is an indigenous softwood while the latter is homegrown exotic hardwood. Nomenclature of the trees respectively follows that of Friis (1992) and Lamprecht (1989). The common and vernacular names for *J*. *procera* are African pencil cedar, red-wood (English), tidh (Amharic-Ethiopian National Language), gatira, daughera (Oromo), nerret, zahadi, (Tigre), dayib (Somalia) (Breitenbach, 1963; Woldemichael Kelecha, 1987), and for *E*. *deglupta* the names are: deglupta (English), mindanao gum (Australia) (Mebrate Mihertu, 2004; Anonymous, 2004) and bahirzaf (Amharic).

The test was conducted on the specimens (hereafter stakes) collected from matured trees of the two timber species. The selection and logging of sample trees of *J*. *procera* was from Arba-Gugu (Arsi) natural forest while *E*. *deglupta* was from Forestry Research Centre (FRC) growth trials research at Aman site (Mizan-Teferi). Samples of *J*. *procera* and *E*. *deglupta* were harvested and collected from 10 matured and morphologically defect-free trees having 50 and 14 years of age, a mean height of 50 m and 35 m, and mean breast height diameter (dbh) of 65 cm and 37 cm, respectively. Trees were felled and bucked into 5 m logs. For the preparation and treatments of stakes, logs (> 30% MC) were transported to Forest Products Utilization Research Laboratory (Addis Ababa) while green.

Water-borne commercial wood preservative, Copper Chromium Arsenate (hereafter CCA), and oil-borne type preservative, namely, used motor oil from vehicles with three application techniques were used for treating the stakes in addition to the control. CCA was composed of 34% arsenate pentoxide (As_2O_5), 26.6% chromium trioxide (CrO_3) and 14.8% copper oxide (CuO) as active ingredients, and the rest 24.6% contained water and other ingredients. The acute oral (ingestion) and acute dermal (skin) LD_{50} (rat) of CCA were 300 and 800 mg/kg, respectively (Laporte, 1996).

Preparation of stakes for treatability treatment and graveyard tests

The logs were bucked into 2.5 m bolts and sawn to 3 cm thickness and width equal to log diameter. Tangential boards were prepared at mobile circular sawmill by applying through-and-through type of sawing method. In this method, tangential, radial and longitudinal surfaces were made clear. All the treatability (laboratory) and field (graveyard) test stakes were made free from damages and visible defects. Stakes were prepared and selected proportionally from each tree and log along height at 0.5 m interval, and marked with identification codes using an indelible pencil. A total of 140 stakes i.e., ten stakes per timber species having dimensions of 2 x 5 x 50 cm each from different planks of the species (NWPC, 1971) were used for the treatment with preservative (absorption and retention), permeability (penetration) tests, as well as field studies (natural durability and effectiveness of preservatives).

The basic density of the species was determined from the oven dry weight/nominal green volume of each stake. Oven drying of stakes was conducted until about 15% moisture content (hereafter MC) was obtained (IUFRO, 1972, cited in Willeitner and Liese, 1992). Mean density of each species was determined from the ten stakes having a dimension of 2 x 2 x 3 cm in the tangential, radial and longitudinal directions, respectively (ISO/DIS 4469, 1975). For the different treatments and tests, stakes with comparable densities and MC were used to minimize variation among stakes and preservative treatments.

Treatability and permeability tests

Preservative treatments were applied in the laboratory on stakes after sawing and cross cutting wood to the final dimensions, and seasoning them to about 15% MC. Since the species were different, stakes for chemical treatability, permeability and chemical effectiveness of field tests were separately immersed into the Rentokil Impregnation Machine (1985 Sweden brand), filled with a solution containing 24.5 kg of CCA mixed with 820 litres of water in a 1:33 ratio of solute to solvent at 3% concentration. In this paper, CCA uptake (kg/m^3) refers to the weight of CCA preservative absorbed per m^3 of wood and retention (kg/m^3) refers to the amount of absorbed and retained CCA salt at 3% concentration per m^3 while penetration (mm) is the depth to which there has been penetration of preservative (Shrivastava, 1997).

Pressure treatment of stakes

For both laboratory treatability and field stakes treatments, the major 11 impregnation (pressure treatment) procedures of CCA preservative (Willeitner and Liese, 1992; FAO, 1994) applied at ambient temperature were: (i) preparing standard stakes, coding of each stake with aluminum metal sheet/tag and fixing at 5 cm from the top end; (ii) measuring initial (before treatment) weight of each stake; (iii) mixing CCA with appropriate solvent, water and adjusting the required concentration (3%); (iv) stacking timber stakes in the bogie, loading into the impregnation cylinder/vessel and closing the door firmly; (v) setting initial vacuum at 0.06 N/mm^2 for 30 minutes to avoid/reduce air from the wood stakes so as to provide maximum space for the preservative; (vi) filling impregnation cylinder with preservative solution, increasing pressure to maximum, adjusting treatment pressure to 1 N/mm^2 and maintaining for 1 hour to induce preservative into wood; (vii) releasing pressure and draining the preservative from the impregnation cylinder; (viii) setting final vacuum at 0.06 N/mm^2 for 30 minutes to drain surplus preservative from the treated stakes and get clean surface; (ix) releasing vacuum and withdrawing treated stakes from the machine; (x) measuring the final (after treatment) weight of each stake, its uptake, retention and permeability, respectively; and (xi) drying (seasoning) treated stakes by stacking using stickers at least for two weeks to about 15% MC so that the solvent is evaporated and preservative is re-settled and fixed into the wood before field installation.

Non-pressure treatment of stakes

Cold dipping

The stakes were sunk into a dipping barrel containing CCA and water solution. The tests were maintained for 24 hours. The treated stakes were then withdrawn from the dipping barrel, weighed and air-dried for two weeks so as to allow fixation of the preservative and solvent evaporation.

Hot and cold dipping

Stakes of both timbers were treated with used motor oil preservative, a mixture of Shell Rimula diesel oil 40 and Helix Ultra 40 engine oil were used for the study with equal proportion. The stakes were treated using the hot and cold dipping open tank thermal method (FAO, 1994). According to FAO (1994), next to pressure treatment, hot and cold dipping offers a very satisfactory method of impregnation. The stakes were submerged in a dipping tank containing 100 kg of cold used motor oil. The solution was gradually heated by burning wood under the dipping tank to about 90°C to reduce viscosity of the oil and maintained for four hours (FAO, 1994). The treated stakes were withdrawn from the dipping tank after 24 hours cooling. As the stakes cool down, the preservative is absorbed (BS, 1975). Finally, the stakes were drained from excess oil with cloth rags and air-dried for two weeks before field installation to allow re-settling and fixation of the preservative inside the stakes (Willeitner and Liese, 1992).

In both pressure and non-pressure treatments, treatability of stakes (sapwood and heartwood) with preservatives was determined by weighing the stakes before and after treatment by using the following adapted formulae (Willeitner and Liese, 1992; FAO, 1994):

Preservative Solution Absorption (PSA) (kg/m^3) = (A - B)/V (**Equation 1**)

Where A = saturated weight of stakes after treatment (kg); B = air-dried weight of stakes at about 12% MC before pressure treatment (kg); V = volume of stakes before impregnation (m^3).

Retention (kg/m^3) = [Weight of CCA/volume of stake] x concentration of CCA (%) = Absorption (kg/m^3) x Concentration **(Equation 2)**

Mean permeability of each species or penetration of preservative into stakes was determined by crosscutting the treated stakes into 20 cm pieces, 20 cm inwards from both ends, as well as measuring and averaging the depth of chemical penetration of the two sections. Average permeability/penetration (AP) of the species was determined using the adapted formula (FAO, 1994):

Average permeability/penetration (AP) (mm) = $[a_{max} + b_{min}]/2$ **(Equation 3)**

Where, a_{max} = average maximum depth of penetration (mm) and b_{min} = average minimum depth of penetration (mm).

Each species was then assigned to one of the four permeability grades (Table 1) based on the extent of average chemical penetration (Willeitner and Liese, 1992). Permeability grades applied were: Permeable (> 18 mm penetration), moderately resistant (6-18 mm penetration), resistant (3-6 mm penetration) and extremely resistant (< 3 mm penetration) (Farmer, 1987).

Treatment of natural durability stakes

Untreated (control) stakes for testing the natural durability of each species were not subjected for treatments with preservative chemicals but got proper handling during storage, seasoning and processing. This was done to avoid discolouration and deterioration before field installation.

Field tests

Stakes installation at graveyard

Graveyard tests are types of accelerated field tests since stakes were small in size and exposed to actual field/service conditions of wood. At the field, the contributing effects of wood, preservative, weather, termite fauna, and fungus flora were all interacting as they would occur on treated and untreated wood in practical commercial and local uses. The trial station was demarcated with an area of about 20 x 20 m² and fenced with barbed wire and live thorny vegetation. For the installation of stakes, holes (hereafter pits) were dug 25 cm deep having a spacing of 25 cm between the stakes and 50 cm between rows (NWPC, 1971).

The test stakes were installed randomly in the prepared installation pits with half their lengths (25 cm) in the ground and the other half remaining above the ground bearing identification tags fixed 5 cm from the top end (Fig. 2).

J. procera and *E. deglupta* plots were laid out where each plot was divided into 10 sections for the five sapwood and five heartwood stakes per treatment type. The position of the stakes where each stake was located in each test plot was marked on the layout/sketch map of the experiments. All the stakes had their identification tags facing the same direction so that they were replaced easily in exactly the same position after every inspection (Fig. 2). Tests on the natural durability of stakes and performance of preservatives were conducted simultaneously in the field.

Evaluation of field stakes and effectiveness of preservatives against bio-deterioration

The resistance and/or deterioration rate of each test stake against subterranean termites and fungal attack was determined by visual inspection/observation supported by sounding and indenting methods. This was done according to the criteria/parameters and symptoms of bio-deterioration attack outlined by Nicholas (1985) and Eaton and Hale (1993). In this study, earthen tunnels, termites mud tubes, and exit holes or galleries on the stakes were used to signify the presence and damage of subterranean termites. Hyphae growth/decayed external appearance (assessed visually), and softness, a hollow and/or dull sound while jabbing stakes with blunt end of the inspection knife and indenting with thumbnail were used to indicate fungal damage.

Fig. 2. Field stakes layout at Miesso station.

Bio-deteriorating resistance of untreated stakes and performance of preservatives over the study period were the main data collected in the field. In this study, damage grades from 1-5 were used to determine bio-deterioration rate of stakes, where 1- sound, no decay and/or termite attack (100% resistance); 2-local, superficial/moderate attack (75% resistance); 3-slight attack, limited attack (50% resistance); 4-severe and deep attack (25% resistance); and 5-failure/complete attack (0% resistance or ≥ 50% of the cross-section destroyed) (Gjovik and Gutzmer, 1986; Highley, 1995).

The untreated and treated stakes inspection and evaluation of performance of preservatives was carried out at 3, 6 and 12 months after installation of the stakes, and thereafter every year (Zawde Berhane and Yusuf, 1974; Purslow, 1976; Getachew Desalegn *et al*., 2003) for three years. The inspections were carried out mostly after rainy seasons and by the same experts. Each stake was carefully removed from its pit, the part that was placed under ground was scraped off to facilitate inspection, the presence and extent of damage by termites and/or fungal attack was assessed, evaluated and recorded (Table 2) following the method used by Gjovik and Gutzmer (1986) and Highley (1995) before its reinstallation into the original pit of the plots, unless its condition indicated complete damage and removal.

Natural durability of each species and effectiveness of preservatives under tropical conditions were assessed and categorized as very perishable (< 6 months), perishable (6 months-1 year), non-durable (1-5 years), moderately durable (5-10 years), durable (10-15 years) and very durable (> 15 years) against bio-deteriorating agents, based on Bryce (1967), Purslow (1976), Melaku Abegaz and Addis Tsehay (1988), Willeitner and Liese (1992), Eaton and Hale (1993) and Getachew Desalegn *et al*.(2003). However, the classification of timber natural durability in this study refers only up to three years.

Experimental design and data analysis

The design for the laboratory treatability experiment was completely randomized design (CRD) with replication of 10 stakes per study species. The design used in the field experiment was split-plot in a completely randomized design (CRD) with one main plot factor (species) and subplot factor preservatives with the same replication as laboratory tests.

One-way analysis of variance (ANOVA) was used to determine significance of preservative treatability and penetration of each timber species. To determine natural durability of stakes and performance of preservatives against subterranean termites and fungal attack, multifactor ANOVA was used. For the analysis, mean of the 10 stakes that became continuous values were used in the standard ANOVA (SAS Institute, 2000).

RESULTS AND DISCUSSION

Treatability with preservative and permeability of stakes

The results indicated that the mean absorption (uptake) and retention of *E. deglupta* stakes pressure treated with CCA preservative was 200.77 kg/m^3 and 6.02 kg/m^3, respectively, while that of *J. procera* stakes was 2.06 kg/m^3 and 0.06 kg/m^3, respectively. Stakes of *E. deglupta* cold dipped with CCA showed 10.73 kg/m^3 and 0.32 kg/m^3, absorption and retention, respectively, while that used by motor oil treated stakes with hot and cold dipping method was 91.21 kg/m^3 and 2.74 kg/m^3, respectively (Table 1). Absorption and retention varied with timber density, proportion of sapwood-heartwood proportions as anatomical reasons and with application methods of the preservative (Nicholas, 1985; Eaton and Hale, 1993; FAO, 1994). Wood/timber can absorb much preservative, but what is important with regards to resistance to bio-deterioration is the retention (the amount fixed in the wood after treatment). The recommended retention of CCA for above ground construction and external joinery work ranges between 5 and 12 kg/m^3. Stakes of *J. procera* cold-dipped with CCA and used motor oil treated with hot and cold dipping methods revealed superficial coatings and no deep penetration. This could be attributed to *J. procera*'s higher age and density (540 kg/m^3), more heartwood and extractive content. The higher the CCA preservative absorption and retention of *E. deglupta*, the higher was its sapwood content and low density.

Table 1. Mean treatability and permeability of timbers with different preservatives and application techniques.

Timber species	Density (Kg/m^3)	Treatments[1]	Treatability		Permeability	
			Absorption (Kg/m^3)	Retention (Kg/m^3)	Permeability (mm) [2]	Classification of permeability[3]
Eucalyptus deglupta	493.42	CCAP	200.77	6.02	12.30	MR
	427.5	CCAD	10.73	0.32	SC	SC
	412.15	UMO	91.21	2.74	8.30	MR
Juniperus procera	579.81	CCAP	4.17	0.13	SC	SC
	526.81	CCAD	2.06	0.06	SC	SC
	569.91	UMO	5.07	0.15	SC	SC

[1] CCAP-Pressure treated; CCAD-Cold dipping with CCA preservative and UMO-Used motor oil dipping; [2]SC-Superficial coating; [3] MR-Moderately resistant.

There was significant difference ($P<0.01$) in CCA absorption and retention between the two study timber species. *E. deglupta* absorbed and retained CCA better than *J. procera*. The results revealed that the chemical absorption and retention of stakes were dependent on the density of each species (Table 1). Species *E. deglupta* with low density (410 kg/m^3) absorbed more chemical than *J. procera* with high density (540 kg/m^3) (Getachew Desalegn *et al*., 2005; 2012). *E. deglupta* absorbed and retained CCA better than *J. procera* but its resistance against termite and fungal attack was less than *J. procera*.

Mean permeability of *E. deglupta* stakes pressure treated with CCA and hot and cold dipped with used motor oil was 12.3 mm and 8.3 mm, respectively. Superficial coating was observed on *J. procera* stakes treated with pressure and non-pressure methods using CCA and used motor oil. Basic density and chemical permeability of each species were negatively correlated. Hence, *E. deglupta* with low density (410 kg/m^3) was more permeable to CCA preservative penetration than *J. procera* (540 kg/m^3) (Getachew Desalegn *et al*., 2005; 2012).

Performance of used motor oil treatment against bio-deteriorating agents

During the third year of inspection/evaluation, about 60% of used motor oil treated stakes of *E. deglupta* underground parts were attacked up to 22.5% and 2.5% of their area by termites and fungi, respectively. Twenty percent of *J. procera* stakes treated with used motor oil were attacked and fell down to the ground while 80% of the stakes were degraded on average to 35% by termites and 12.5% by fungi (Table 2). The resistance of *J. procera* stakes treated with used motor oil against termites and fungi was less than that of *E. deglupta* which may be attributed to the matured age and high density that led *J. procera* stakes to superficial coating with used motor oil treatment. Treatments with used motor oil were less effective than CCA which was in agreement with Getachew Desalegn *et al*. (2003; 2007). At Zeway graveyard research station, stakes of *J. procera* treated with used motor oil showed extended service life of more than five years in the ground contact (Getachew Desalegn *et al*., 2003).

Table 2. Mean resistance results (%) of *E. deglupta* and *J. procera* field stakes treated with different preservatives and application techniques against termite and fungal deterioration at each period of inspection and evaluation.

Timber species	Treatments	Duration (3rd month-3rd year)*									
		3rd month		6th month		1st year		2nd year		3rd year	
		Termite	Fungi	Termite	Fungi	Termite	Fungi	Termite	Fungi	Termite	Fungi
Eucalyptus deglupta	Control	22.5	100	15	100	0	90	0	0	0	0
	CCAP	100	100	92.5	100	75	97.5	72.5	97.5	62.5	92.5
	CCAD	100	100	100	100	100	100	85	100	82.5	100
	UMO	100	100	100	100	100	100	95	97.5	77.5	97.5
Juniperus procera	Control	67.5	100	57.5	100	45	100	37.5	100	27.5	100
	CCAP	100	100	100	100	100	100	100	100	95	100
	CCAD	100	100	100	100	100	100	100	100	97.5	100
	UMO	97.5	100	95	100	87.5	92.5	82.5	90	65	87.5

CCAP- CCA pressure treated; CCAD- CCA Cold dipping with CCA preservative and UMO-Used motor oil dipping; Control-untreated. *- 0 means fell down to the ground due to termite and/or fungal attack.
N.B: The durability grades in Table 2 have not been presented since the duration of the test is short and the majority of the stakes were not yet felled.

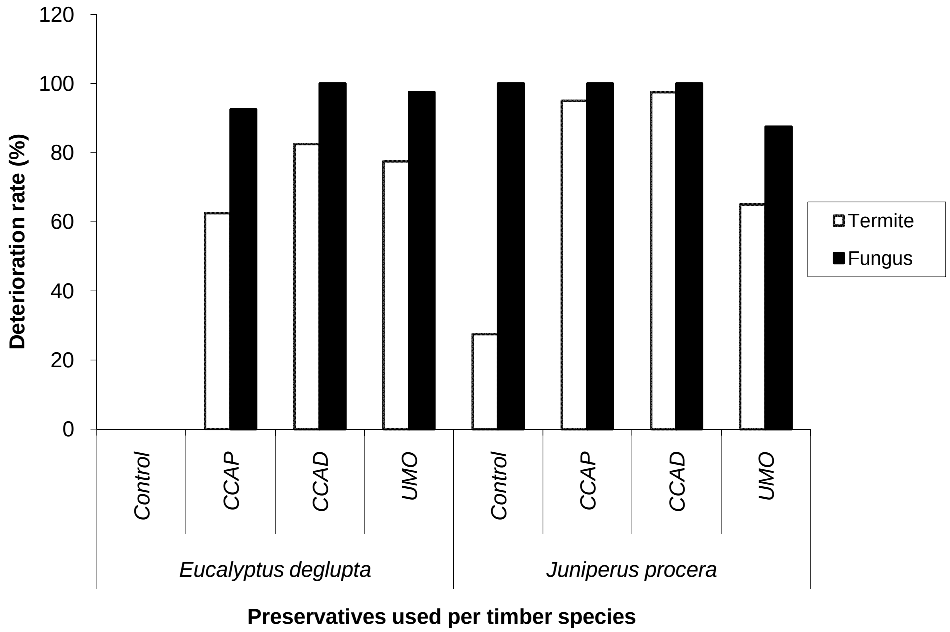
Natural durability and effectiveness of CCA treatments against bio-deteriorating agents

Results of the multi-factor ANOVA indicated significant differences ($P<0.01$) between many factors - CCA treatments and the control, pressure treated and cold dipped, hot and cold dipped with used motor oil, between sapwoods and heartwoods; between the timber species and length of field exposure and evaluation periods (1/4th-3 years) and in the interactions between timber species and preservatives. All the control stakes of *E. deglupta* underground parts were 100% degraded and fell to the ground by termites during the first year field exposure and evaluation period (perishable) while *J. procera* stakes were degraded by termites to 55% but were intact by fungi (Table 2).

Natural durability of *E. deglupta* was low. Sapwood stakes having glucose palatable to termites were more attacked than heartwood ones having dead cells. The sapwood of most woods is readily susceptible to bio-deterioration whereas the heartwood of many woods is resistant (Nicholas, 1985; Eaton and Hale, 1993; FAO, 1994). For both species no failure was observed among CCA pressure treated stakes. No significant difference occurred ($P<0.01$) between the treated sapwood and heartwood parts, which could be attributed to the short period of exposure time. More than 95% of pressure treated and cold dipped stakes of *J. procera* stakes with CCA preservative were 100% intact by both subterranean termites and fungal attack. During the third year, termites and fungi attacked the majority (80%) of the *E. deglupta* stakes pressure treated with CCA to 37.5% and 7.5%, respectively, while *J. procera* stakes were degraded to 5% by termites but were intact by fungi (Table 2).

The resistance of *J. procera* stakes treated with CCA against termites and fungi was better than that of *E. deglupta*, which may also be attributed to the higher density, more heartwood, natural resistance/extractive content of *J. procera*, although treatability/retention of *E. deglupta* (6.02 kg/m^3) was much better than that of *J. procera* (0.06 kg/m^3). Out of the CCA cold dipped *E. deglupta* stakes, 20% fell down to the ground line zone and the other 20% were attacked to 70% by termites while the rest 60% were intact. Among *J. procera* CCA cold dipped stakes, only 10% were attacked to 70% by termite and were free from fungal attack (Table 2 and Fig. 3).

The performance of untreated stakes and effectiveness of preservatives against subterranean termites and fungal attack were different. The resistance of stakes treated with CCA and used motor oil against bio-deterioration in the ground and moisture contact applications were significantly prolonged compared with those of the controls (Table 2 and Fig. 3). The results indicate that termites are the superior agents of bio-deterioration at the Miesso station. There was significant difference ($P<0.01$) between the natural durability of *E. deglupta* and *J. procera* stakes (Table 2 and Fig. 3). At Miesso station, *J. procera* was more durable than *E. deglupta* timber, since underground parts of all the untreated *E. deglupta* stakes were completely (100%) degraded and fell down to the ground line zone by termites during the first year field exposure period, while *J. procera* stakes were 27.5% resistant up to third year inspection and evaluation (Table 2 and Fig. 3).



a

b

Fig. 3. Mean results of timbers and preservatives against termite and fungal damage up to 3rd year evaluation (3a), and deterioration trend of *E. deglupta* and *J. procera* timber stakes (mostly attacked by termite) (3b). Control is zero indicating that trees fell to the ground due to termite and/or fungal attack in *E. deglupta*.

The results from Bako site (Ethiopia) indicated that untreated stakes of *J. procera* and *H. abyssinica* were the most resistant, while *Podocarpus falcatus*, *Ekebergia rueppeliana* and *Pouteria adolfi-friederici* were very sensitive to attack by termites. *Olea capensis* subsp. *macrocarpa* and *J. procera* were least attacked by decay fungi while *P. adolfi-friederici* and *E. rueppeliana* were highly attacked (Holmgren, 1963). Studies at Zeway showed that all species stakes, except *J. procera*, were completely destroyed, while *J. procera* was moderately attacked after five years of exposure. In all cases, the degree of termite attack was less at Zeway site than at Bako site (Zawde Berhane and Yusuf, 1974). Studies on resistance of treated timbers at Bako revealed that *J. procera* was completely sound during the five years investigation period while *P. falcatus* and *P. adolfi-friederici* were slightly attacked. *Eucalyptus globulus* and *E. rueppeliana* were completely attacked after five years of exposure (Zawde Berhane and Yusuf, 1974).

J. procera was one among the 12 best naturally durable timber species at Ziway site (*J. procera*, *Manilikara butugi*, *Eucalyptus camaldulensis*, *Eucalyptus saligna*, *Ocotea kenyensis*, *Cupressus lusitanica*, *Morus mesozygia*, *Prunus africana*, *Fagaropsis angolensis*, *H. abyssinica*, *P. falcatus* and *Warburgia ugandensis*). These species resisted termite and fungal attack for more than 10 years at Zeway site (Getachew Desalegn *et al*., 2003; Getachew Desalegn and Alemu Gezahgne, 2010) while at Bako station, the best seven naturally durable timber species, which resisted termite and fungal attack for more than four years were *M. butugi*, *E. camaldulensis*, *Mimusops kummel*, *M. mesozygia*, *O. capensis* subsp. *macrocarpa*, *Olea welwitschii* and *Albizia gummifera* (Getachew Desalegn *et al*., 2007; 2012). The extent of bio-deterioration attack varied with timber species, preservatives and application techniques, field station, bio-attacking agents (termite and or fungi), treatability (absorption and retention) of stakes, penetration of the preservative, and length of exposure time (Nicholas, 1985; Eaton and Hale, 1993; FAO, 1994; Getachew Desalegn *et al*., 2003; 2007). Compared with the site at Zeway (Getachew Desalegn *et al*., 2003; 2012), the site at Miesso was more favourable for termite attack. The more durable timber species may owe their resistance mainly to their extractives and densities, which serve them as natural preservatives and resistance (Nicholas, 1985; Eaton and Hale, 1993; FAO, 1994; Shrivastava, 1997) against bio-deterioration.

The variation in the extent of damage against termites between the timbers was very significant, which may be attributed to the age and density of timbers (Nicholas, 1985; Eaton and Hale, 1993; FAO, 1994), while in the majority of the stakes, the extent of fungal damage and the variation between the timber species was very low (Table 2 and Fig. 3). CCA treated stakes of *J. procera* resisted fungal attack for more than 13 years at Zeway station (Getachew Desalegn *et al*., 2003). For both sapwood and heartwood parts, untreated and preservative treated stakes, subterranean termites were the main agents, indicating more significant damage than fungi (Table 2 and Fig. 3). As the duration of exposure increased, the extent of attack also increased (Table 2). The third year was the highest attack recorded as compared to the duration of the third month and up to second year. The comparative results at Miesso and Zeway for *J. procera* stakes revealed that the termites of Miesso were more aggressive than Zeway site. Compared to the control and used motor oil treatments, CCA treatments both with pressure and non-pressure methods were the best effective preservative and application techniques to control termite and fungal attack at Miesso area. Resistance of timbers against bio-deterioration varied with preservatives and application techniques, field station and length of exposure time (Nicholas, 1985; Eaton and Hale, 1993; FAO, 1994; Getachew Desalegn *et al*., 2003; 2007; 2012).

CONCLUSION AND RECOMMENDATION

The mean absorption, retention and mean permeability of *E. deglupta* stakes pressure treated with CCA was better than that of *J. procera* stakes. Mean permeability of *E. deglupta* stakes treated with used motor oil was 8.3 mm and superficial coatings were observed for *J. procera* stakes. There was significant difference ($P<0.01$) in CCA uptake and retention between the two study timber species. *E. deglupta* absorbed and retained CCA better than *J. procera* but its resistance against termite and fungal attack was less than *J. procera*. Results of multi-factor ANOVA indicated significant differences ($P<0.01$) between CCA treatments and the control, preservative application techniques, between the timber species and length of field exposure periods. Termites were better deteriorating agents than fungi. From the previous tests conducted on 32 timber species at Bako and on Zeway sites, it was proved that termites were better deteriorating agents than fungi (Getachew Desalegn *et al*., 2003; Getachew Desalegn *et al*., 2007). Compared to the control and used motor oil, CCA was the best effective preservative to control termite and fungal attack at Miesso area.

Timber preservation measures against the various bio-deteriorating agents have to be considered at Miesso in particular and in Ethiopia in general as a necessary measure to increase the durability of wood in service. Preservation also can open the opportunities of using less durable indigenous and home-grown exotic timber species of the country. The pressure impregnation and hot and cold dipping methods were better to control termite and fungal attack on the studied timber species. The results will have practical application not only to Miesso area but also in areas with similar timber species, agro-ecological zones and bio-deteriorating agents. This could be of potential to anticipated beneficiaries such as farmers, rural and urban households, furniture factories, forest industries, sawmills and joineries, end-users of forest products, construction enterprises/sectors, civil engineers, vocational training colleges, investors, concessionaires, development agents, foresters, researchers, policy makers, the public, NGOs, individuals and the nation at large. The result from this study can be useful to initiate large scale planting, management and proper utilization of the two timber species. *E. deglupta* should not be used at Miesso and similar areas for moisture and soil contact construction applications without applying adequate preservation measures.

In order to select and use CCA, used motor oil and other potential wood preservatives, the service life intended for the purpose (short or long service life), place of use (ground contact, above ground, damped), application techniques (pressure, non-pressure) and its cost have to be taken into account. The industrial and construction wood production programs in Ethiopia, especially at Miesso and similar areas, should give high priority to the treatable and naturally durable as well as potentially valuable and fast-growing timber species such as *E. deglupta* and *J. procera* to augment considerable advantages for end users and other potential stakeholders.

Further research activities involving prolonged time (> five years), other timber species, other potential preservatives and application techniques are recommended to fill the information gap in wood durability, preservation measures and rational utilization of timbers in the Miesso area and in the different agro-ecological zones of Ethiopia where biodegradation has economic significance.

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