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PERFORMANCE OF PRESERVATIVE TREATMENTS ON 32 TIMBER TREE SPECIES AGAINST TERMITES AND FUNGAL ATTACK AT BAKO, SOUTHWESTERN ETHIOPIA

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ABSTRACT: In Ethiopia, wood damage in construction and furniture sectors caused by biodegrading agents is economically important. Experiments were carried out on 32 timber species to study preservative treatablility (laboratory test) and natural durability of construction timbers, and effectiveness of preservatives against subterranean termites and fungal deterioration at Bako. *Antaris toxicaria* (681.14 and 20.43 kg m^{-3}) and *Eucalyptus camaldulensis* (37.33 and 1.12 kg m^{-3}) indicate the highest and the lowest chemical absorption and retention properties, respectively. *A. toxicaria* (25 mm) and *Fagaropsis angolensis* (1.5 mm) had the highest and lowest chemical penetration, respectively. Significant differences ($P < 0.01$) were found in the absorption, retention and permeability of Copper Chromium Arsenate (CCA) among the timbers. In the damages caused by termites and fungi, significant differences ($P < 0.01$) were also found between stakes treated with CCA and the controls among the study species and field exposure times, and in the interactions between preservatives and study species as well as preservatives and field exposure times. The extent of attack varied with species, preservatives, application methods and length of field exposure periods. The majority of stakes (> 62%) treated with CCA by pressure method resisted degradation by termite and fungi for more than 11 years, those treated with used motor oil for more than five years and the untreated stakes for one to four years. Therefore, timbers from matured trees should be selected and rationally utilized for furniture and construction purposes with appropriate protection measures taking into account place/environment of use, the costs of preservation, the service life of each timber species and the service life intended.

Key words/phrases: Copper chromium arsenate, effectiveness of preservatives, natural durability, timbers, treatability

INTRODUCTION

The natural forests of Ethiopia are the major sources of material for construction, forest industries, and wood-based energy sectors. There are more than 320 timber species in the country that can provide lumber, but have been irrationally used without knowing their timber properties and how they can be preserved. Some species are more susceptible for biodegradation than others.

The supply of wood in the country based on annual incremental yield of forests was only about 13 million m^3 (EFAP, 1994) while the annual demand of solid wood for 2005 has been projected to reach about 73 million m^3, indicating demand exceeding the supply by more than 560%, and deficit of about 60 million m^3 of wood. This high demand and irrational utilization of wood without applying protection measures against degradation resulted in excessive and illegal harvesting of trees and frequent replacement of wood-based constructions.

Large wood degradation and loss, both in service and during storage, is caused by biodegrading agents (termites, beetles, fungi, bacteria and marine borers) due to lack of moisture content management and severe timber-seasoning defects. Though often overlooked, these problems are among the major causes of forest destruction and rapid wood degradation in the country. Wood/timber, the renewable biological forest product and a versatile material (Willeitner and Liese, 1992), is biodegradable, *i.e.,* an ecological habitat for a wide range of termites and fungi

(Shrivastava, 1997). Hence, it has to be protected and rationally utilized as round wood and lumber (sawn wood/saw timber) (Helms, 1998).

The most important wood degrading pests in all tropical and sub-tropical regions of the world are termites (Isopetra) that cause more damage to houses than all other natural disasters combined (Anonymous, 1997; Shrivastava, 1997). The subterranean termites (Family *Termitidae* and sub-family *Macrotermitinae*, species of *Macroterms*, *Microterms* and *Pseudanthoterms*, etc.), especially the worker caste, are the most destructors of woody and other species containing cellulose (Eaton and Hale, 1993), which can be often seen when infested wood is broken open (Nicholas, 1973).

Wood has been decomposed by different organisms where fungi play the major role in degrading the cellulose and lignin parts (Richardson, 1978; Wong and Cheok, 2001). Decay fungi are harmful organisms to structural timber and wood in storage and cause large economic losses of wood having great value to man. Decay fungi, especially *basidiomycetes* (brown- and white-rot), *ascomycetes*, *deutromycetes*, are capable of producing wood degrading enzymes (Shrivastava, 1997; Eriksson *et al*., 1990 cited in Adane Bitew, 2002).

Biodeteriorating agents of wood found in Ethiopia are diverse and their damages and economic losses are considerable. Sixty-one species representing 25 genera and four families *Kalotermitidae, Hodotermitidae, Rhinotermitidae* and *Termitidae* have been reported in the country, out of which 10 species are indigenous to Ethiopia and the adjacent regions (Cowie *et al*., 1990; Abdurahman Abdulahi, 1991).

Termitidae are morphologically higher termites representing 53 species, out of the 61 species, the largest pest proportion of the Ethiopian fauna. Moreover, 142 wood decaying fungi (*basidiomycetes*) species have been recorded from fallen logs of *Pouteria adolfi-friederici*, *Juniperus procera* and *Podocarpus falcatus* sampled from Menagesha, Munessa-Shashemene and Teppi forests in Ethiopia (Adane Bitew, 2002).

The damage on crops and wooden constructions caused by termites in Ethiopia has been estimated to be between 20–50% (Wood, 1986). Wood (1986) also indicated that the greatest threat to wooden houses in the country is caused by the *Macrotermitinae*, which often lead to at least partial rebuilding every 3–5 years.

In some parts of the country, destruction of wood-based constructions, which have direct contact with soil and moisture, can occur even within 1–2 years by subterranean termites and fungal attack. Thus, it is imperative to protect wood/timber from destructive agents and increase its service life by using some preservatives.

Nonetheless, in Ethiopia, few wood protection/preservation studies were carried out. These studies focused on only limited timber species, and were, often, conducted for less than five years (*e.g.* Holmgren, 1963; Zawde Berhane and Essa Yusuf, 1974; Melaku Abegaz and Addis Tsehay, 1988; Tsegay Bekele, 1996; Adane Bitew, 2002). The longest timber preservative research in the country, which spanned for 13 years, was carried out at Zeway involving 32 timber species and three preservation measures (Getachew Desalegn *et al.*, 2003), while this study is the second longest. There are other nine on-going research trials in the same discipline in six different agro-ecological zones of the country at nine graveyard test stations (Fig. 1) and involving the natural durability of 43 timber species and effectiveness of eight chemical and non-chemical (traditional) wood protection measures and application methods.

Waterborne preservatives are often used when cleanliness, paint ability and long-term service of the treated wood are required (FPL, 1999). More environmental friendly, socio-economically accepted and effective preservatives such as water borne preservatives/Tanalith and used motor oil are better options for application against both termite and fungal attack.

The challenge facing the forestry sector in Ethiopia is to investigate and select treatable and naturally durable construction timber species and effective preservatives against biodegrading agents to substitute the endangered timber species such as *J. procera, Hagenia abyssinica, Cordia africana, P. falcatus*, and *P. adolfi-friederici* (only by Oromyia Regional State), which have been banned not to be harvested from both federal and regional forests of the country (TGE, 1994).

Therefore, the objectives of the study were to: (i) determine treatability and permeability of the 32 sawn timber species, (ii) investigate natural durability of the 32 sawn timber species, (iii) evaluate performance of the applied protection measures against subterranean termites and fungal attack, and (iv) select treatable and naturally durable construction timber species, and effective wood preservatives that can enhance natural durability and prolonged utilization of the 32 timber species.

MATERIALS AND METHODS

Study site

The field experiment was conducted from 1988–2000 at a graveyard station in the vicinity of Bako-Tibe village, which is located at about 240 km from Addis Ababa, an area where indicators of occurrence of termites are common and the damages on construction timbers are serious. The station is geographically located at 09°07′ N and 37°05′ E (Fig. 1).

Bako is found in the tepid to cool sub-humid highland major agroecological zone and tepid to cool sub-humid mountains sub-agroecological zone (Anonymous, 2001). It has an altitude of 1800 m, total annual rainfall of 1342 mm, and annual mean minimum and maximum temperatures of 12.4°C and 27.4°C, respectively.

Study species

The tests were conducted on the samples/specimens (hereafter referred to as stakes) collected form matured trees of 32 timber species, mostly in the south and southwestern parts of the country. Of the study species, four were softwoods and 28 hardwoods. Among the species involved, 24 were indigenous and eight homegrown exotic species (Table 1). Nomenclature of timber species in this paper follows that of Breitenbach (1963); Lamprecht (1989); Friis (1992); Hedberg and Edwards (1989); Edwards *et al*. (2000) and Hedberg *et al*. (2003).

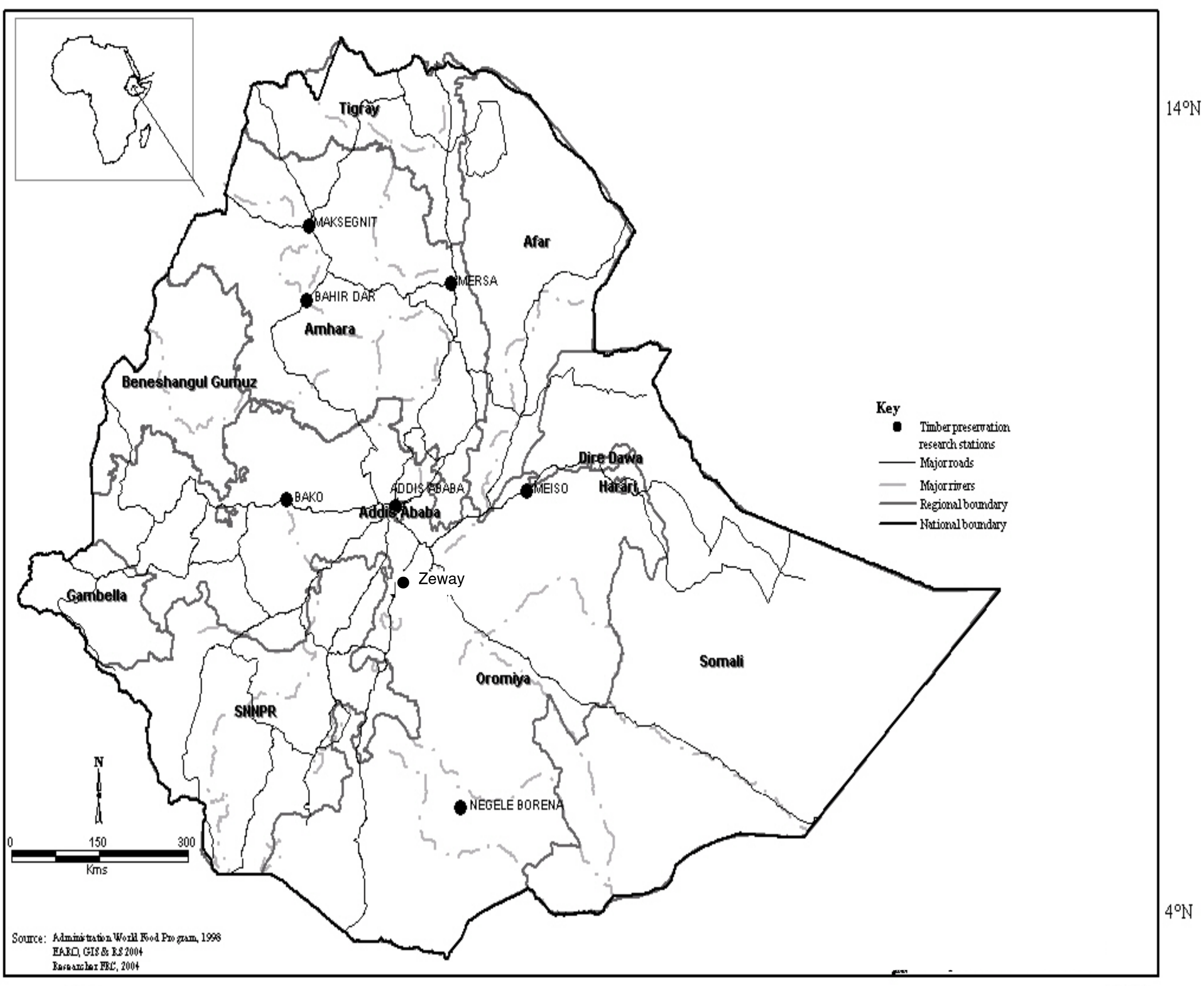

Fig. 1. Location of the study site: Bako [other graveyard test stations: Bahir-Dar (West-Gojam), Mersa (South wello), Maksegnit (North Gondar), Zeway (East Shoa), Bako-Tibe (West Shoa), Negele–Borena and Meisso (Estern Hararge)].

In most cases, about 10 trees with good morphological quality were carefully selected from natural forests and plantations. The mean height (≥ 10 m) and mean diameter at breast height (≥ 15 cm) of the trees, cylindrical stem, clean bole and clear log volume of about 0.25 m^3, free from knots and any other visible defects were the major criteria considered for selecting timber stakes.

Preservatives used

Copper Chromium Arsenate (CCA) and used motor oil were used for treating the stakes. The commercial water-borne preservative CCA composed of 34% arsenate pentoxide (As_2O_5), 26.6% of chromium trioxide (CrO_3) and 14.8% of copper oxide (CuO) as active/toxic ingredients against biodegrading agents, and the rest 24.6% containing the solvent water and other ingredients (Richardson, 1978) was used. The acute oral (ingestion) and acute dermal (skin) LD50s' (rat) of CCA were 300 and 800 mg/kg, respectively (Laporte, 1996).

Timber stakes preparation for laboratory and field tests

Sample trees for preparing timber stakes were felled and bucked to 5 m logs. The logs were cross cut into 2.5 m logs, while green, *i.e.*, above 30% moisture content and converted to boards at the mobile circular sawmill by using flat sawing method for the indigenous tree species. Quarter sawing method was used at the band sawmill for the low-diameter homegrown exotic species to get as many sample stakes as possible. In both methods tangential, radial and longitudinal surfaces were conspicuous. All the laboratory and field stakes prepared were made free from damages and visible defects.

The basic density (oven dry weight/green volume) of each stake was determined from ten stakes with a dimension of 2×2×3 cm in the tangential, radial and longitudinal directions, respectively (ISO/DIS 4469, 1975). This was done after taking initial volume and conducting oven seasoning (drying) of stakes to about 15% moisture content (MC) (IUFRO, 1972). Stakes of each timber species used in the different treatments and tests had comparable densities and MC to maintain uniformity of test stakes.

For the laboratory preservative treatability, namely absorption (kg m^{-3}) and retention (kg m^{-3}) of timber stakes, and field studies (natural durability and effectiveness of preservatives), 660 stakes, *i.e.,* ten stakes per species having dimensions of 2×5×50 cm (NWPC, 1971), and for permeability/penetration (mm) tests, 128 stakes, i. e. four stakes per species with dimensions of 5×5×110 cm (Tack, 1979) and totally 788 stakes were prepared from the 32 timber species. The chemical protective measures that were applied for effectiveness tests were CCA and used motor oil of vehicles (for *A. toxicaria* and *E. camaldulensis*).

In this paper, CCA absorption refers to the weight of CCA preservative absorbed per m^3 of wood, retention refers the amount of absorbed CCA salt at 3% concentration per m^3 while penetration is the depth to which there has been penetration of preservative (Shrivastava, 1997).

Laboratory and field tests

Treatabilty and permeability (laboratory) tests

After sawing and cross cutting wood to the standard final dimensions and seasoning to about 15% MC, preservative treatments were applied on the 32 species stakes (FAO, 1986; Willeitner and Liese, 1992) using the Rentokil Impregnation Machine (1985 Sweden brand). For both laboratory treatability and field stakes treatments, the major 11 impregnation (pressure treatment) procedures of CCA preservative (FAO, 1986; Willeitner and Liese, 1992) used at ambient temperature were: (i) preparing standard stakes and coding of each stake on aluminum metal sheet, which was fixed 5 cm from the top end; (ii) measuring initial (before treatment) weight of each stake; (iii) mixing the chemical preservative with appropriate solvent/water and adjusting the required concentration; (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 (500 mm Hg) 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, and 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 (500 mm Hg) 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; and (xi) 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 fixed into the wood

(Willeitner and Liese, 1992) before field installation.

Since the species and their dimensions were different, stakes for chemical permeability and treatability tests were separately immersed into the impregnation machine, filled with a solution containing 24.5 kg of CCA and mixed with 820 liter of water in a ratio of solute to solvent 1:33 at 3% concentration, and tested using one species at a time.

Treatability of stakes with CCA preservative was determined by weighing the stakes before and after treatment and by using the formulas adapted from FAO (1986) and Willeitner and Liese (1992):

(i) Preservative Solution Absorption (kg m^{-3})
$= (A - B) / V$,

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 (m^3).

(ii) Retention (kg m^{-3})
=[Weight of CCA/volume of stake] x concentration (%) = [(A - B) / V] x [concentration (%)] = absorption (kg m^{-3}) x concentration (%).

The extent of preservative penetration of each species was determined by crosscutting the treated stakes into 20–30 cm pieces, 20 cm inwards from both ends, as well as measuring and averaging the depth of chemical penetration of the two sections and all samples. Average permeability/penetration (AP) was determined according to FAO (1986) using the formula:

$$AP\ (mm) = [b_{max} + a_{min}] / 2$$

where
b_{max} = maximum depth of penetration (mm)
a_{min} = minimum depth of penetration (mm).

Based on the extent of average chemical penetration, each species was, then, assigned to one of the four permeability grades (IUFRO, 1973; Wilkinson, 1979; Willeitner and Liese, 1992; FPL, 1999) (Table 1).

Treatments of stakes used for field tests

Natural durability treatment

For testing natural durability, stakes were not treated with preservative chemicals but received prophylactic treatments such as handling during storage, transportation, seasoning (about 15% MC) and processing to avoid bio-deterioration and discoloration before field installation.

Pressure treatment

The same procedures of laboratory treatability and permeability tests used above were applied to pressure treatment of field stakes while treating them with CCA, and determine their uptake and retention. Treated stakes were air-seasoned (dried) and reconditioned as stated above in the pressure impregnation procedure.

Non-pressure treatment

Stakes of *A. toxicaria* and *E. camaldulensis* have been treated with used motor oil preservative by taking 10 samples from each species. This treatment was applied using hot-and-cold dipping open tank method or thermal process (FAO, 1986). The stakes were submerged in a dipping tank containing 100 kg of cold used motor oil. The top part of the dipping tank was closed with wooden plate. The solution was, then, gradually heated by burning wood under the dipping tank to about 90°C to reduce viscosity of the oil and maintained for four hours. The treated stakes were withdrawn from the dipping tank after 24 hours cooling. As stakes cool down, they absorb the preservative (FAO, 1986). Finally, the stakes were cleaned from surplus oil with cotton rags and air-seasoned for two weeks before field installation to allow fixation of the preservative.

Field tests

Stakes installation at graveyard and evaluation against biodeterioration

The trial station was demarcated within an area of about 20×20 m^2 and double fenced with wire and thorny plant species. For the installation of stakes, holes (hereafter referred to as pits) of 25 cm were dug at 25 cm spacing between stakes and 50 cm between rows. The stakes, for both natural durability and chemical effectiveness tests, were installed randomly in the prepared installation pits with half their lengths (25 cm) in the ground and the rest half remaining above the ground with identification tags fixed 5 cm from the top end. Tests on the natural durability of stakes and performance of preservatives were conducted simultaneously in the field.

To determine the resistance and/or deterioration rate of untreated and treated test stakes against subterranean termites (hereafter referred to as termites) and fungal attack, visual inspection/observation strongly supported by sounding method was applied. This was done according to the parameters/criteria and symptoms of biodeteriorating attack outlined by Nicholas (1973) and Eaton and Hale (1993). In this study, earthen tunnels, termites' mud tubes, and exit holes or galleries signify the presence of and damage of termites. External decay was assessed visually while internal decay was detected by sounding method, jabbing wood with blunt end of the inspection knife and indenting with thumbnail. A hollow and/or dull sound and softness while indenting with thumbnail were used to indicate possible hidden fungal damage.

The inspection and evaluation of performance of stakes was carried out at three, six and 12 months after installation of the stakes, and every year thereafter (Purslow, 1976; Gjovik and Gutzmer, 1986). This was continued until the underground parts of 50% of the untreated stakes were completely degraded and fell down to the ground (Gjovik and Gutzmer, 1986).

Natural durability of timber species and performance of preservatives against termites and fungal attack were expressed from durable to very perishable (Table 2) based on the modified and adapted grades (Purslow, 1976; Melaku Abegaz and Addis Tsehay, 1988; Eaton and Hale, 1993). Grades from one to five were used to determine biodeteriorating rate of stakes: 1=sound, no decay and/or termite attack (100% resistance); 2=local, superficial/moderate attack (75% resistance); 3= light, limited attack (50% resistance); 4=severe and deep attack (25% resistance); and 5=failure/-complete attack (0% resistance) (Gjovik and Gutzmer, 1986). Attacked stakes were classified by taking into account the percentage/portion of stakes of each species free of termite and/or fungal attacks or the remaining amount at the last inspection.

Experimental design

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 completely randomized design (CRD) with the same number of replication as above.

Data analysis

The data collected were subjected to one-way analysis of variance (ANOVA) to determine preservative treatability and penetration of each timber species, and multifactor ANOVA to determine performance of preservatives against termites and fungal attack. Mean of the 10 stakes of each timber species at each inspection period, which became continuous values, were used in the standard one-way and multifactor ANOVA. Linear regression (least squares means, the sum of squared differences between the observed and the predicted biodegrading values equals the minimum = minimum $\sum$ residuls^2) was used to study the association between termites and fungi, and correlation was employed to determine association of termites and fungi (SAS Institute, 2000).

RESULTS AND DISCUSSION

Treatability with CCA preservative and permeability of stakes

The mean CCA preservative absorption ability for all the tested stakes was 335.91 (37.33–681.14) kg m^{-3}, with *A. toxicaria* (681.14 kg m^{-3}) and *E. camaldulensis* (37.33 kg m^{-3}) exhibiting the highest and lowest chemical absorption abilities, respectively (Table 1). The mean CCA retention of all treated stakes at 3% concentration was 10.08 (1.12–20.43) kg m^{-3} and the highest and lowest retention abilities were exhibited by *A. toxicaria* (20.43 kg m^{-3}) and E. *camaldulensis* (1.12 kg m^{-3}), respectively (Table 1). The relationship between CCA preservative absorption and retention was very strong ($r \cong 1.000$). The higher the CCA preservative absorption of the species, the higher was its CCA retention (Table 1).

There was significant difference ($P < 0.01$) in CCA absorption (uptake), retention and permeability among the 32 study timber species (Table 1). *A. toxicaria, Acrocarpus fraxinifolius, Croton macrostachyus, Apodytes dimidiata, Diospyros abyssinica, Eucalyptus grandis, Hagenia abyssinica, Syzygium guineense, Ekebergia capensis* and *Milicia excelsa* were the best 10 species (in a descending order) in absorbing and retaining CCA among all the study species.

The species with the lowest ability in CCA absorption and retention (in a descending order) were *E. camaldulensis, Cordia africana, Eucalyptus globulus, Albizia gummifera, Fagaropsis angolensis, Eucalyptus saligna, Olea capensis* subsp. *macrocarpa, Pinus patula, Manilkara butugi* and *Warburgia ugandensis* while others were intermediate. *A. toxicaria, Pouteria adolfi-friederici, E. capensis, Polyscias fulva, Trilepisium madagascariense* and *Podocarpus falcatus* were permeable to CCA, while others ranged from moderately resistant to extremely resistant (Table 1).

The density of the 32 timber species varied between 410–990 kg m^{-3}. The results indicated that the chemical absorption and retention of stakes were independent of the density of each species (Table 1). Some species with low densities of this experiment did not absorb more chemicals than those species with high densities. However, the relationship between absorption and retention was very strong ($r \cong 1.0000$). The higher the CCA preservative absorption of the species, the higher was its CCA retention. The relationship between density and chemical permeability of each species was moderately strong and inversely related ($r = - 0.5362$). As a result, species with low densities were more permeable to CCA preservative penetration (Table 1). Therefore, the higher the absorption, retention and penetration values of each species, the higher was the resistance of species against biodeteriorating attack. The mean permeability of treated stakes with CCA was 8.9 (1.5–25) mm. The highest and lowest values of chemical penetration were 25 mm for *A. toxicaria* and 1.5 mm for *F. angolensis* species, respectively (Table 1).

Table 1. List of the study species with their local names, families, place of sample collection, mean density, treatability, permeability and permeability grades.

No.	Timber species	Local name*	Family	Place of Sample Collection	Density (kgm^{-3}) **S	Absorption (kgm^{-3})	Retention at 3 % CCA (kgm^{-3})	Permeability (mm)	Permeability grades PG
1	*Acrocarpus fraxinifolius* Wight. & Arn.	Acrocarpus (E)	Fabaceae	Wondo Genet	610	550.78	16.52	---	---
2	*Albizia grandibracteata* Taub.	Alele (O)	Fabaceae	Sigmo-Setma and Meti	600	200.0	6	8.2	MR
3	*Albizia gummifera* (F. Gmel) C.A. Sm.	Sissa (Am)	Fabaceae	Bebeka	580	186.76	5.6	7	MR
4	*Antiaris toxicaria* Lesch.	Tengi (Sh)	Moraceae	Bebeka	470	681.14	20.43	25	P
5	*Apodytes dimidiata* Arn.	Cheleleka (O)	Icacinaceae	Degaga and Jemjem	710	503.85	15.15	5.2	R
6	*Blighia unijugata* Bak.	Tucho (O)	Sapindaceae	Bebeka	700	344.45	10.33	9	MR
7	*Celtis africana* Burm. f.	Kauot (Am)	Ulmaceae	Jemjem	760	349.07	10.47	8	MR
8	*Cordia africana* Lam.	Wanza (Am)	Boraginaceae	Wondo Genet	410	52.27	1.57	4	R
9	*Croton macrostachyus* Del.	Bessana (Am)	Euphorbiaceae	Gambo	560	526.63	15.8	5	R
10	*Cupressus lusitanica* Miller	Yeferngi-Tidh (Am)	Cupressaceae	Degaga	430	363.68	10.91	13.7	MR
11	*Diospyros abyssinica* (Hiern.) F. White	Loko (O)	Ebnaceae	Jemjem and Bebeka	790	452.04	13.56	3	R
12	*Ekebergia capensis* Sparrm.	Sombo (O)	Maliaceae	Bebeka and Jemjem	580	376.15	11.28	20	P
13	*Eucalyptus camaldulensis* Dehnh.	Keyi-Bahirzaf (Am)	Myrtaceae	Munessa	870	37.33	1.12	--	--
14	*Eucalyptus globulus* Labill.	Nechi-Bahirzaf (Am)	Myrtaceae	FPURP - FRC	780	163.4	4.9	7	MR
15	*Eucalyptus grandis* Maiden	Grandis- Bahirzaf (E)	Myrtaceae	Munessa	560	419.45	12.58	8.5	MR
16	*Eucalyptus saligna* Smith	Saligna-Bahirzaf (Am)	Myrtaceae	Munessa and Gimbi	680	220	6.62	5	R
17	*Fagaropsis angolensis* (Engl.) Dale	Dero (O)	Rutaceae	Jemjem and Wondo Genet	700	200	6	1.5	ER
18	*Hagenia abyssinica* (Bruce) J. F. Gmel.	Kosso (Am)	Rosaceae	Tiro Boter-Becho	560	422.4	12.67	8.1	MR
19	*Manilkara butugi* Chiov.	Butugi (E)	Sapotaceae	Teppi	880	299.51	8.99	3	R
20	*Milicia excelsa* (Welw.) C. C. Berg	Dego (An)	Moraceae	Bebeka	570	372.87	11.19	2.5	ER
21	*Mimusops kummel* A. DC.	Kolati (O)	Sapotaceae	Jemjem	880	358.76	10.76	4	R
22	*Morus mesozygia* Stapf	Shamgareza (Am)	Moraceae	Bebeka	690	346.24	10.39	3	R
23	*Olea capensis* subsp. m*acrocarpa* (Baker) Friis and Green	Gagama (O)	Moraceae	Zenbaba-Wadera	990	264.6	7.94	5	R
24	*Olea welwitschii* (Knobl.) Friis and Green	Baha (O/S)	Oleaceae	Jemjem	820	304.1	9.12	3.7	R
25	*Pinus patula* Schlechtendal and Chamisso	Patula (E)	Pinaceae	Degaga	450	290.85	8.73	13	MR
26	*Pinus radiata* D. Don.	Radiata (E)	Pinaceae	Shashemene (Answe)	450	343.9	10.32	14	MR
27	*Podocarpus falcatus* (Thunb.) Mirb.	Zigba (Am)	Podocarpaceae	Wondo Genet	520	352.5	10.58	19	P
28	*Polyscias fulva* (Hiern) Harms	Zingero-wember (Am)	Araliaceae	Degaga	440	325.8	9.77	20	P
29	*Pouteria adolfi-friederici* (Engl.) Robyns and Gilbert	Keraro (Am, O)	Sapotaceae	Bebeka and Jemjem	600	341.32	10.24	20	P
30	*Syzygium guineense* (Willd.) DC.	Dokma (Am)	Myrtaceae	Jemjem and Sigmo-Setma	740	415	12.45	18	MR
31	*Trilepisium madagascariense* DC.	Gabu (O)	Moraceae	Bebeka	560	360.87	10.83	20	P
32	*Warburgia ugandensis* Sprague	Befti (O/B)	Canellaceae	Delomena	770	323.47	9.7	2	ER

*Local names of timbers: Am = Amharic, E = English, O = Oromo, Si = Sidamo, O/B = Oromo – Bale, O/S = Oromo Sidamo, Sh = Shoko. FPURP-FRC = Forest Products Utilization Research Programme – Forestry Research Centre. ** = At 12 % MC (kg m^{-3}); S = Source: WUARC (1995); Getachew Desalegn (1997); PG = Permeability grades: P = Permeable (> 18 mm penetration), MR = Moderately resistant (6–18 mm penetration), R = Resistant (3–6 mm penetration) and ER = Extremely resistant (< 3 mm penetration).

Based on their permeability, six of the present study species namely *A. toxicaria*, *E. capensis*, *P. fulva*, *P. adolfi-friederici*, *T. madagascariense*, and *P. falcatus* were classified as permeable, 11 as moderately resistant, 10 as resistant and three, namely *F. angolensis*, *W. ugandensis*, and *M. excelsa* as extremely resistance species (Table 1). In similar past works, *F. angolensis* had been classified as extremely resistant species (Dale and Greenway, 1961; Getachew Desalegn *et al.*, 2003). Perishable species in these studies were permeable to preservatives. *J. procera* and *E. globulus* were difficult to treat/impregnate while *P. falcatus*, *P. adolfi-friederici* and *E. capensis* were easy to treat and showed high retention values (Zawde Berhane and Essa Yusuf, 1974; Getachew Desalegn *et al.*, 2003).

For aboveground construction and external joinery, the recommended retention for CCA ranges between 5 and 12 kg m^{-3} (Willeitner and Leise, 1992). *E. camaldulensis* and *Cordia africana* exhibited retentions below the recommended limits suggesting their unsuitability for construction application without adequate preservation, even though *E. camaldulensis* has good natural resistance to wood deteriorating agents. Preservative effectiveness is influenced by the protective value of the preservative chemical, method of application and extent of penetration, distribution and retention of the preservative in the treated wood (FPL, 1999). The penetrations of different preservatives into the different wood species were dependent on the density of the stakes and the treatment method (Zawde Berhane and Essa Yusuf, 1974; Getachew Desalegn *et al.*, 2003).

Effectiveness of used motor oil treatment

At the second year of inspection, stakes of *A. toxicaria* treated with used motor oil preservative using hot and cold dipping thank method were completely damaged by termites and fungal attack, and fell to the ground, while mean attack of the same agents on stakes of *E. camaldulensis* treated with used motor oil were 49.5% and 17.5%, respectively. This indicated that the resistance of *E. camaldulensis* treated with used motor oil to termites and fungi was better than that of *A. toxicaria*, which may be attributed to the high density of *E. camaldulensis*, although treatability of *A. toxicaria* was much better than that of *E. camaldulensis* (Table 2).

Table 2. Mean bio-deterioration resistance results (%) and service life of timbers (years) in ground contact application against subterranean termites and/or fungal attack up to the last inspection.

No.	Timber species	Service life of timbers			
		Natural durability of timbers		Effectiveness of CCA preservative	
		Termites*	Fungi*	Termites*	Fungi*
1	*Acrocarpus fraxinifolius*	0 (0.25)	82.5 (0.25)	85 (7)	82.5 (7)
2	*Albizia grandibracteata*	0 (2)	100 (2)	0 (8)	60 (8)
3	*Albizia gummifera*	0 (9)	95 (9)	25 (5)	100 (5)
4	*Antiaris toxicaria*	0 (2)	100 (2)	90 (8)	97.5 (8)
5	*Apodytes dimidiata*	0 (1)	100 (1)	75 (11)	87.5 (11)
6	*Blighia unijugata*	0 (3)	100 (3)	82.5 (10)	92.5 (10)
7	*Celtis africana*	0 (3)	100 (3)	57.5 (11)	82.5 (11)
8	*Cordia africana*	0 (4)	100 (4)	25 (6)	100 (6)
9	*Croton macrostachyus*	0 (1)	72.5 (1)	95 (7)	85 (7)
10	*Cupressus lusitanica*	0 (3)	100 (3)	87.5 (11)	100 (11)
11	*Diospyros abyssinica*	0 (3)	100 (3)	75 (11)	95 (11)
12	*Ekebergia capensis*	0 (1)	100 (1)	75 (9)	92.5 (9)
13	*Eucalyptus camaldulensis*	70 (4)	87.5 (4)	60 (4)	92.5 (4)
14	*Eucalyptus globulus*	0 (4)	100 (4)	30 (11)	75 (11)
15	*Eucalyptus grandis*	0 (0.5)	80 (6)	90 (7)	85 (7)
16	*Eucalyptus saligna*	0 (3)	100 (3)	50 (11)	67.5 (11)
17	*Fagaropsis angolensis*	0 (2)	100 (2)	0 (6)	90 (6)
18	*Hagenia abyssinica*	0 (3)	100 (3)	100 (8)	100 (8)
19	*Manilikara butugi*	30 (6)	55 (6)	87.5 (6)	90 (6)
20	*Milica excelsa*	0 (1)	100 (1)	75 (11)	80 (11)
21	*Mimusops kummel*	0 (6)	100 (6)	50 (10)	92.5 (10)
22	*Morus mesozygia*	30 (11)	90 (11)	75 (11)	100 (11)
23	*Olea capensis* subsp. *macrocarpa*	7.5 (10)	85 (10)	75 (10)	75 (10)
24	*Olea welwitschii*	25 (6)	100 (6)	55 (10)	92.5 (10)
25	*Pinus patula*	0 (1)	100 (1)	30 (11)	92.5 (11)
26	*Pinus radiata*	0 (3)	100 (3)	55 (11)	100 (11)
27	*Podocarpus falcatus*	0 (3)	100 (3)	80 (11)	95 (11)
28	*Polyscias fulva*	0 (1)	100 (1)	75 (10)	92.5 (10)
29	*Pouteria adolfi-friederici*	0 (1)	100 (1)	67.5 (11)	92.5 (11)
30	*Syzygium guineense*	0 (1)	100 (1)	55 (10)	87.5 (10)
31	*Trilepisium madagascariense*	0 (1)	100 (1)	75 (11)	75 (10)
32	*Warburgia ugandensis*	0 (3)	100 (3)	50 (11)	87.5 (11)

* First number = timbers mean result (%) of resistance against subterranean termites and fungal attack, number in brackets = service life of timbers (years).

At Zeway graveyard station, stakes of *A. toxicaria* and *E. camaldulensis* treated with used motor oil indicated extended service life of more than five years in the ground. The untreated control stakes (80%) of *A. toxicaria* resisted termite attack for half a year at Bako and four years at Zeway and that of *E. camaldulensis* during four and five years at Bako and Zeway attacked by termites to 30% and 45%, respectively (Getachew Desalegn *et al.*, 2003).

Natural durability of timbers and effectiveness of CCA pressure treatment

The multi-factor ANOVA on performance of untreated stakes and effectiveness of preservatives against termites and fungal attack indicated significant differences (P < 0.01) between the control and the CCA treated stakes, among timber species and length of field exposure periods, in the interactions between preservatives and timber species, timber species and length of exposure periods as well as preservatives and length of exposure periods.

The underground parts of untreated stakes of 25 species (78%) were attacked and fell on the ground within three months to four years field exposure periods (Table 2). Particularly, all of the ten replicated stakes of *A. fraxinifolius* and *E. grandis* fell on the ground during the first three and six months field exposure, respectively (Table 2).

The untreated stakes of 11 of the study species (34%) were completely degraded by termites and fell on the ground in one year. Stakes of three species (9%), namely *Albizia grandibracteata*, *A. toxicaria* and *F. angolensis* were completely degraded by termites and fell on the ground in two years, while those of nine species (28%) fell on the ground in three years (Table 2).

The untreated stakes of *Cordia africana* and *E. globulus* were degraded by termites and fell on the ground in four years, *Mimusops kummel* in six years and *A. gummifera* in nine years (Table 2). Termites attacked almost all untreated stakes of the 32 timber species. In the exposure periods (Table 2), 24 species (75%) were free from fungal attack, while the rest eight species (25%) exhibited fungal attack between 5% and 45%, but not to the extent of felling.

From untreated stakes, two species (6%), namely *A. fraxinifolius* and *E. grandis* could be classified as very perishable, 12 species (38%) as perishable, 11 species (34%) as non-durable, five species (16%) as moderately durable and two species (6%) namely *Morus mesozygia* and *O. capensis* as durable (Table 3). None of the study species could be graded as very durable.

Table 3. Durability grades of the untreated and CCA preservative treated 32 timber species based on their performance in graveyard tests with respect to termite and fungal deterioration.

No.	Timber Species	Untreated timbers stakes		CCA treated timber stakes	
		Termites*	Fungi*	Termites*	Fungi*
1	*Acrocarpus fraxinifolius*	VP	ND	D	D
2	*Albizia grandibracteata*	ND	MD	MD	D
3	*Albizia gummifera*	MD	D	MD	D
4	*Antiaris toxicaria*	ND	100 (4)	D	D
5	*Apodytes dimidiata*	P	100 (4)	D	D
6	*Blighia unijugata*	ND	MD	D	D
7	*Celtis africana*	ND	100 (4)	D	D
8	*Cordia africana*	ND	100 (4)	MD	MD
9	*Croton macrostachyus*	P	ND	D	D
10	*Cupressus lusitanica*	ND	D	D	D
11	*Diospyros abyssinica*	ND	100 (4)	D	D
12	*Ekebergia capensis*	P	100 (3)	D	D
13	*Eucalyptus camaldulensis*	MD	MD	MD	MD
14	*Eucalyptus globulus*	ND	MD	D	D
15	*Eucalyptus grandis*	VP	ND	D	D
16	*Eucalyptus saligna*	ND	D	D	D
17	*Fagaropsis angolensis*	ND	D	MD	D
18	*Hagenia abyssinica*	ND	D	D	D
19	*Manilkara butugi*	MD	MD	D	D
20	*Milica excelsa*	P	100 (4)	D	D
21	*Mimusops kummel*	MD	100 (5)	D	D
22	*Morus mesozygia*	D	MD	D	D
23	*Olea capensis* subsp. *m acrocarpa*	D	D	D	D
24	*Olea welwitschii*	MD	D	D	D
25	*Pinus patula*	P	100 (7)	D	D
26	*Pinus radiata*	ND	100 (5)	D	D
27	*Podocarpus falcatus*	ND	D	D	D
28	*Polyscias fulva*	P	100 (2)	D	D
29	*Pouteria adolfi-friederici*	P	MD	D	D
30	*Syzygium guineense*	P	MD	D	D
31	*Trilepisium madagascariense*	P	100 (2)	D	D
32	*Warburgia ugandensis*	ND	D	D	D

*durability grades:
VP= Very Perishable (< 6 months), P = Perishable (6 months-1 year), ND = Non-durable (1–5 years), MD = Moderately Durable (5–10 years), D = Durable (10–15 years) and VD = Very Durable (> 15 years).

Note: Very Durable, suitable for long term use in structures exposed to weather and in contact with the ground; Durable, suitable for use on the ground and for unprotected exterior use under normal conditions; Moderately Durable, suitable for protected exterior and/or interior work and not suitable for use in contact with the ground and Non-durable, not suitable for exterior use unless treated with preservatives (Shrivastava, 1997).

The best seven naturally durable timber species, which resisted termite and fungal attack for more than four years at Bako, were *M. butugi, E. camaldulensis, M. kummel*, *M. mesozygia*, *O. capensis* subsp. *macrocarpa*, *O. welwitschii* and *A. gummifera*. In a similar study at Zeway station, the best 12 naturally durable timbers that resisted termites and fungal attack for more than 10 years were: *J. procera, M butugi, E. camaldulensis, E. saligna, Ocotea kenyensis, Cupressus lusitanica, M. mesozygia, Prunus africana, F. angolensis, H. abyssinica, P. falcatus* and *W. ugandensis* (Getachew Desalegn *et al*., 2003).

At Bako *J. procera* and *H. abyssinica* were the most resistive, *P. falcatus, E. capensis* and *P. adolfi-friderici* were very sensitive to attack by termites while *A. dimidiata, O. capensis, P. africana* and *S. guineense* showed intermediate resistance (Holmgren, 1963). *J. procera, P. falcatus*, *E. globulus*, *P. adolfi-friderici* and *E. capensis* were completely destroyed after two years exposure, and *J. procera* was found heavily attacked after five years of exposure at Bako, and at Zeway. After five years of exposure, the same species stated above were completely destroyed while *J. procera* was moderately attacked (Zawde Berhane and Essa Yusuf, 1974).

A. toxicaria, C. macrostachyus, A. fraxnifolius, E. capensis, A. dimidata, Cordia africana, D. abyssinica, E. grandis, M. excelsa, P. adolfi-friederici, P. fulva, A. toxicaria, T. madagascariense, Blighia unijugata, E. capensis and *A. grandibracteata* have been classified as perishable by different authors (Dale and Greenway, 1961; Breitenbach, 1963; Bryce, 1967; Tack, 1969; Farmer, 1987; TRADA, 1979; Webb *et al*., 1984; Chdunoff, 1984) while *F. angolensis, P. Africana, P. falcatus, P. patula* and *P. radiata* were classified as non-durable (Tack, 1969). The same authors stated above classified *J. procera, C. lusitanica, O. welwitschii, E. saligna, H. abyssinica, M. excelsa* and *O. kenyensis* as moderately durable against termites and fungal attack. *E. camaldulensis* was most resistant species to wood decaying agents compared with *E. globulus, Fagus sylvatica* and *Pinus sylvestris* (Tsegaye Bekele, 1996; Getachew Desalegn *et al*., 2003). The more durable timber species may owe their resistant mainly to their extractives and densities, which serve as natural preservatives and resistance (Nicholas, 1973; Shirvastava, 1997) against bio-deterioration. Most of the results on the durability of timbers in this study are in agreement with results reported by other authors (Dale and Greenway, 1961; Breitenbach, 1963; Bryce, 1967; Tack, 1969; Farmer, 1987; TRADA, 1979; Webb *et al*., 1984, Chdunoff, 1984).

The termites at Bako (*Microterms* and *Pseudacanthoterms militarious)* have been considered as more aggressive than those at Zeway site (*Macroterms bellicosus)* (Zawde Berhane and Essa Yusuf, 1974). *Microterms* are more active than *Macroterms* (Buttterworth *et al*., 1960 cited in Zawde Berhane and Essa Yusuf, 1974). Evaluation of treated and untreated stakes of *Cordia alliodora* at Meisso station also revealed that *Microterms* resulted in more damage compared to *Macroterms* at Zeway. At Bako, treatments with used motor oil were less effective than CCA preservative, and the same was true at Zeway site (Zawde Berhane and EssaYusuf, 1974; Getachew Desalegn *et al*., 2003).

CCA pressure treated stakes of the majority of species (> 62%) resisted degradation by termites and fungi for more than 11 years (about four to 10 times better than that of natural durability), those treated with used motor oil resisted for more than five years and the untreated stakes for one to four years. Out of all the stakes treated with CCA preservative, three species (9%), namely *C. lusitanica*, *M. mesozygia* and *P. radiata* showed 100% survival rate during the 11 years period against fungal attack.

CCA treated stakes of *A. gummifera* and *F. angolensis* were the only ones that were completely degraded by termites in eight and six years, respectively. In general, the rates of bio-deterioration of CCA treated species during the 11 years exposure period in the field varied from no damage to complete deterioration (Table 2).

Termites and fungi jointly and equally attacked CCA treated stakes of *T. madagascariense* and *O. capensis* subsp. *macrocarpa*. CCA treated stakes of *C. macrostachyus* and *E. grandis* were more attacked by fungi, while that of *H. abyssinica* were not attacked by both termites and fungi up to eight years (Table 2).

From CCA treated stakes, five species (16%), namely *A. gummifera, M. butugi, E. camaldulensis, M. kummel* and *O. welwitschii* were moderately durable and 27 species (84%) durable against attack by termites, while two species (6%), namely *C. africana* and *E. camaldulensis* were moderately durable and 30 species (94%) were durable against fungal attack (Table 3).

The performance of the different timber species with respect to resistance against termites and fungal attack depended on the type of timber species (32 timber species), and preservative used (CCA, used motor oil or control), the application methods (pressure or non-pressure), treatabilty (absorption and retention) of stakes, penetration of the preservative and the length of exposure periods (¼–11 years) at the graveyard station (Fig. 2 and 3; Tables 1, 2 and 3).

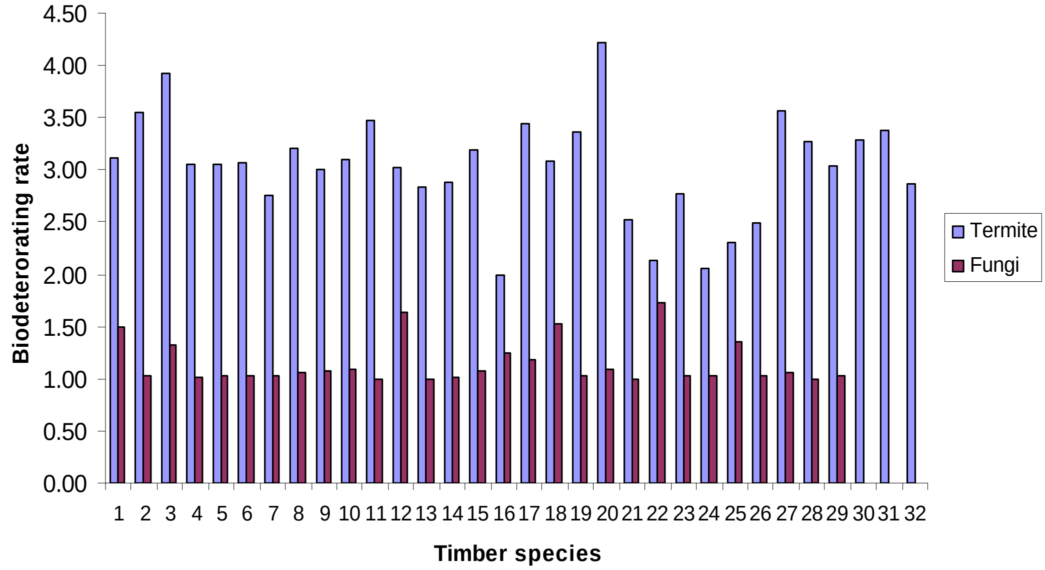

Fig. 2. Rate of attack of the study species by subterrnean termites and fungi expressed as means of least squares [The numbers 1–32 on the X-coordinate stand for the scientific names of timber species as listed in Table 1].

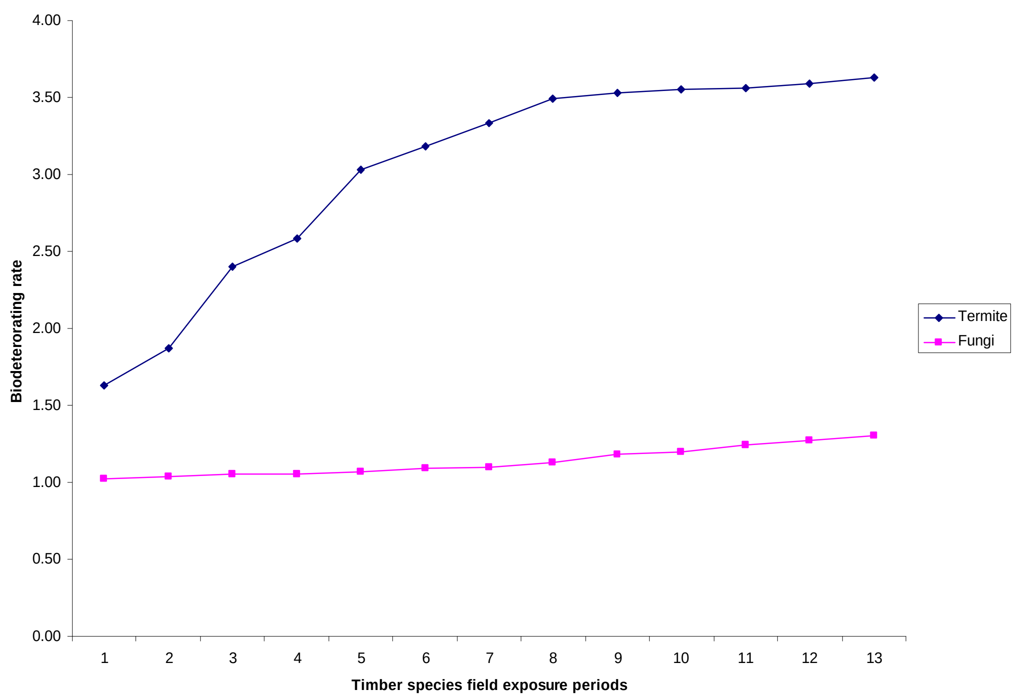

Fig. 3. Deterioration trend of timber stakes by termite and fungi, against time expressed by means of least squares [Exposure periods 1= ¼ year, 2=½ year, 3= 1 year, 4= 2 years, … and 13= 11 years].

Resistance of pressure treated timbers with Tanalith (CCA type) indicated that at Bako *J. procera* was completely sound, *P. falcatus* and *P. adolfi-friderici* were slightly attacked while *E. globulus* and *E. capensis* were completely attacked after five years exposure (Zawde Berhane and Essa Yusuf, 1974). It was also indicated that at Zeway, there were almost no specimens left after five years of exposure and in both cases the degree of termite attack was less at Zeway site than it was at Bako.

Effectiveness of CCA preservative was in agreement with absorption, retention and penetration values of each species (Tables 1, 2 and 3). The biodeterioration resistance of stakes treated with CCA was significantly prolonged or quadrupled compared with those of the controls (Table 2). The results showed that all CCA pressure treated timber species have been classified durable against termites attack except *A. grandibracteata*, *A. gummifera*, *Cordia africana*, *E. camaldulensis,* and *F. angolensis,* which are moderately durable against fungal attack.

The attack rate of timber species by biodeteriorating agents varied with length of field exposure time. According to Duncan's Multiple Range Analysis as the duration of un-treated and preservative treated stakes in the field test increased, damage from bio-deterioration also increased for the majority of the species (Fig. 3). When compared with the third month of inspection, damage at the 11th year increased by 2.2 times. According to this analysis, the highest deterioration rate was observed in year 11 and the lowest at the third month.

In general, when the timber species and field exposure times are considered, damage caused by termites was also greater than that caused by fungi (Table 2 and 3; Fig. 3). This could be attributed to the climatic conditions that favored or disfavored termites and/or fungi. Besides, termites are the most important degrading agents in all tropical and sub-tropical regions of the world (Nicholas, 1973; Anonymous, 1997; Shrivastava, 1997).

Our findings on treatabilty, effectiveness of preservatives and natural durability of the timber species studied are in agreement with findings by different authors (Holmgren, 1963; Zawde Berhane and Essa Yusuf, 1974; Dale and Greenway, 1961; Breitenbach, 1963; Bryce, 1967; Tack, 1969; Farmer, 1987; TRADA; 1979; Webb *et al*., 1984; Chdunoff, 1984; Getachew Desalegn *et al*., 2003).

Our results showed that timber stakes with two centimeters thickness and treated with CCA exhibited more than 11 years of service life. Thus, at Bako station and similar areas, five centimeters thick wood adequately pressure treated with CCA can serve at least for 27 years in the ground and moisture contact applications. According to Nicholas (1973), Purslow (1976) and Shrivastava (1997), the service life of timber structure is directly proportional to its thickness, and not to its cross-sectional area.

Therefore, CCA and used motor oil preservatives could be used as measures to control damage by termites and fungi for treatable (Table 1) and non-durable (Tables 2 and 3) timber species, which are intended for construction purposes that involve moisture and ground contact application. As stated earlier, timber species having good natural durability could also be used for construction purposes (Table 2) taking into account the place/environment of use, the service life of each timber species, the costs of preservation and the service time required.

CONCLUSIONS AND RECOMMENDATIONS

Termites attacked almost all untreated stakes. Most of the CCA treated species were classified moderately-durable to durable. Based on the 11 years results among the CCA treated species, the majority, 25 species (89%) were durable against both termite and fungal attack. Timbers from *E. camaldulensis*, *M. butugi, M. kummel*, *M. mesozygia*, *O. capensis* subsp. *macrocarpa* and *O. welwitschii* could be potential alternatives/substitutes for the endangered species such as *Cordia africana*, *J. procera*, *P. falcatus, H. abyssinica* and *P. adolfi-friederici* (only by Oromyia Regional State), which are banned for harvest, provided that adequate preservation treatments are applied.

The following recommendations are forwarded: (i) timber preservation against the various deteriorating agents has to be considered at Bako in particular and Ethiopia in general as a necessary measure to increase the durability of wood in service, which can open the opportunity of using less durable timbers and to contribute the ever-increasing demand over supply for timber from the threatened forest resources of the country; (ii) susceptible and naturally non-durable timber species such as *C. macrostachyus*, *E. capensis*, *P. fulva*, etc. need rapid extraction from the forest, log conversion and proper seasoning of lumber. Such timber species should not be used at Bako and similar hazardous areas for moisture and soil contact construction applications without applying adequate preservation measures; (iii) CCA and used motor oil shall not be used without considering the service life intended for the purpose, place of use, their cost and applying adequate loading of the preservative; Used motor oil treatment could be a better option since its price is very minimal, it does not need sophisticated treating machine and skilled manpower as well as being effective against termites and fungal attack for the short period protection of construction wood; (iv) the forest conservation, regeneration and production programs in Ethiopia, specially at Bako and similar areas, should give priority to the treatable and naturally durable as well as potentially valuable and fast-growing timber species to enhance the many-fold advantages for the end users; and (v) finally, further research work is recommended in this multidisciplinary and socio-economically important field to fill the information gaps in wood degradation and preservation measures, and rational utilization of timbers in different agroecological zones of Ethiopia including the Bako area.

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