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DURABILITY OF ETHIOPIAN BAMBOO CULMS AND ALTERNATIVE DAMAGE CONTROL MEASURES AGAINST BIODETERIORATING AGENTS

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ABSTRACT: High susceptibility of the bamboo stems (culms) to biodeteriorating agents are among the major challenges in processing, value addition, marketing and rational utilization of the bamboo resource in Ethiopia. A study was conducted to investigate culms' natural durability, treatability of bamboo culms with and effectiveness of damage control measures in controlling the biodeteriorating agents' damage. Samples of *Arundinaria alpina* culms were collected from Hagere Selam, Injibara, Tikur Inchini and Masha sites. *Oxytenanthera abyssinica* samples were obtained from Asossa, Dedessa and Pawe. Tanalith preservative, borax-boric acid solution, used motor oil, kerosene and common table salt were used to treat the bamboo stakes. Graveyard studies were conducted for five years at Pawe, Bako, Adami Tulu and Addis Ababa research stations. The non-ground contact test was conducted in Addis Ababa station under shade without direct contact with soil, moisture, rain and sunlight. The results indicated that bamboo culms were non-durable, having high treatability potential with the control measures used in this study. Significant difference ($P<0.01$) was found on damage caused by subterranean termites on the bamboo species stakes obtained from different localities, control measures and field (graveyard) stations. Mean damage on controls and treated stakes with control measures caused by subterranean termites for all stations varied from 24 to 80%, while damage caused by fungi varied from 11 to 66%. This indicated that termites caused the highest damage at all stations both on the controls and treated stakes. The non-ground contact stakes were intact against aboveground dwelling termites, beetles and fungi. Tanalith and used motor oil treatments were found to be the most effective alternative control measures in resisting biodegrading agents attack and prolonged bamboo culms service life to more than five times compared with controls.

Key words/phrases: *Arundinaria alpina*, Control measures, Culms, Graveyard stations, *Oxytenanthera abyssinica*, Stakes.

INTRODUCTION

Bamboo is a fast growing, high yielding and renewable perennial plant of the world including Ethiopia. Globally, it has 1500 species and 1500 versatile socio-economic uses and environmental/ecological services. It provides construction, food, fodder, handicrafts, furniture, musical

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instruments, flooring and versatile industry materials, environmental benefits and other services (Liese, 1985; Janssen, 1995; LUSO Consult, 1997; Rao and Rao, 1998; Ensermu Kelbessa *et al.*, 2000; Kassahun Embaye, 2000; Ahmad and Kamke, 2003; Sastry, 2004; Bowyer *et al*., 2005; Kigomo, 2007; Tesfaye Hunde, 2008; Biras and Tesfaye Hunde, 2009; Yigardu Mulatu and Mengistie Kindu, 2009; Anonymous, 2010a; 2010b; Gatóo *et al*., 2014; INBAR, 2014). According to archeological evidences, bamboos appeared 200 million years ago and have been in use for at least 6000–7000 years. They have played important socio-economic, cultural, ecological and environmental roles in the development of human societies. No plant is known in the tropical zone, which could supply so many technical advantages as the bamboo (Sastry, 2004; INBAR, 2014). Bamboo is one of the oldest building materials used by mankind and at least 1/3–1/2 of the human race uses bamboo in one way or another (Kumar *et al*., 1994; Jayanetti and Follet, 1998; Yuming and Jiru, 1998; Ahmad and Kamke, 2003; Sastry, 2004; Li, 2004; Anonymous, 2010a). Bamboo is "green" building material and poor man's timber since it is less expensive than construction materials such as steel, cement and even wood (Kumar *et al*., 1994). It is wood of the poor (India), friend of the people (China) and brother (Vietnam) and there is no banquet without bamboo (Sastry, 2004; Bowyer *et al*., 2005).

Bamboo's growth is faster than any other plant on the planet (about 1.2 m height in 24 hours period in Japan), even faster than *Eucalyptus* species (Bowyer *et al*., 2005). Growth to full height and diameter is completed in one growing season of 2–3 months' time. It has a short rotation life and maturity age of about 3–7 years for construction and furniture purposes and can be harvested in 3–5 years versus 10–50 years rotations for most softwoods and hardwood tree species. It attains annual biomass increment of 10–30% versus 2–5% for trees. It can be annually self-renewable and harvestable if managed properly (Yuming and Jiru, 1998; Ahmad and Kamke, 2003; Sastry, 2004; Bowyer *et al*., 2005; Gatóo *et al*., 2014).

Why are bamboo culms susceptible to biodeteriorating agents (termites, beetles and fungi) and why does the need arise for effective protection measures? Bamboo species culms in general consist of 50–70% hemicelluloses, 30% pentosans, 20–25% lignin, other organic compounds such as 2–6% starch, 2% deoxidized saccharide, 2–4% fat, 0.8–6% protein and 0.5–4% silica, and minor amount of resins, waxes, organic salts and tannins. The total bamboo comprises about 60% parenchyma, 40% fibers and 10% conducting tissue (vessels and sieve tubes). The fibers contribute

60–70% of the weight of the total culm tissue. The main constituents of bamboo culms are cellulose, hemi-cellulose and lignin, which amount to over 90% of the total mass. The minor constituents of bamboo are resins, tannins, waxes and inorganic salts. Compared with wood, bamboo has higher alkaline extractives, ash and silica contents. However, none of the extractives in bamboo have enough toxicity to reveal any natural durability. On the other hand, the abundance of moisture, presence of large amount of hemicellulose and starch (carbohydrates) which act as nutrients for the biodegrading agents (white, brown and soft-rots, staining fungi, insects like borers, powder post beetles and termites) make it more attractive and ready food source, highly susceptible and vulnerable starting from the time of harvesting (Tamolang *et al*., 1980; Liese, 1992; Yuming and Jiru, 1998; Li, 2004; Salam and Deka, 2007; Schröder, 2014). During utilization and storage of bamboo in untreated conditions, more than 40% of it is destroyed due to biological agents' damage (Salam and Deka, 2007).

The natural durability of bamboo varies between 1 and 36 months, depending on the species, climatic conditions and type of use. Durability classification of bamboo culms thus falls in non-durable category with little variation in durability among different species. Treated bamboo culms with water-borne preservatives can serve as a construction material for about 10–15 years outdoors and indoors; with ground and moisture contact applications for 30–40 years, a service life increment of about 4–5 times compared to the untreated bamboo culms (Tesoro and Espiloy, 1988; Kumar *et al*., 1994; Janssen, 1995; Jayanetti and Follet, 1998; Kumar and Dobriyal, 1988; Younus-Uzzaman, 1998; Lahiry, 2001; Islam *et al*., 2002; Li, 2004; Bowyer *et al*., 2005; Hall and Inada, 2008; Inada and Hall, 2008; Anonymous, 2009a). Good chemical preservation can increase the natural durability of bamboo to more than 50 years service life (Schröder, 2014). In Ethiopia, the ceilings of Emperor Menilik II Palace at Entoto in Addis Ababa that were constructed during 1889, may be from untreated split bamboo culms, are still intact (personal observation and communication).

Bamboos are anatomically different from both hardwoods and softwoods in their mode of growth and tissue organization. The outer wall is covered by a thin and hard layer and less permeable than the inner layer. Due to these differences in anatomical structure, bamboo behaves entirely differently from wood during treatment with preservative (Kumar and Dobriyal, 1988). The vascular bundles (vessels and thick-walled fibers) play an important role in preservative treatment. The axial flow is quite rapid in green bamboos, because of the end to end alignment of vessels. The degree of penetration decreases as the distance from the conducting vessel increases. The larger vessels (metaxylem) tend to get a larger amount of preservative than the smaller vessels (protoxylem) (Kumar and Dobriyal, 1988).

Treatments that improve the durability of bamboos thus include traditional (non-chemical) methods such as curing, smoking, white washing, soaking, heating over open fire, harvesting of bamboo during low-sugar content season, and chemical methods (non-pressure by fumigation, brushing, soaking and spraying, butt treatment, green tank, dipping, Boucherie and the pressure treating methods). Coal tar, crude table salt and Paris green were used as preservatives for treating bamboo posts against subterranean termites (Tesoro and Espiloy, 1988).

Thus, preserving bamboos increases the durability of the culms and increases the lives of the products and structures they are used to produce. It also increases the safety of any structure when bamboos are used as load bearing members. If preserved bamboo is used as a structural component, durability increases, it will fetch higher prices than non-preserved bamboos, and need to be replaced less often which reduces costs and frequent harvesting (Anonymous, 2009a). Techniques for application of preservatives include non-pressure and pressure methods, depending on the facilities available at or near the construction sites.

Protecting bamboo, wood and other forest products from biodegrading organisms by treating them with the appropriate damage control measures and application techniques has been imperative (Willeitner and Liese, 1992; Shrivastava, 1997). Termites, beetles, fungi and other micro-organisms, besides the economic damage, have great role in nutrient recycling by decomposing wood, bamboo and other plant materials (Nicholas, 1985; IOMC, 2000).

The income from sale of bamboo culms outweighs more than twice that of the crops from the same plot of land and eucalypt wood lots (personal observation) while farmers of the Shedem Kebele/locality in Bale Zone generate 47% of their annual income from harvesting and selling of bamboo culms (Arsema Andargachew, 2008). In many localities of Ethiopia such as Injibara, Tikur Inchini, Hagere Selam, Asossa, Pawe, Bale, etc, rural communities largely depend on raw bamboo culms. Bamboo at Banja/Injibara, and districts surrounding Bahir Dar city contributed up to 38% of the annual cash income of households while at Masha it contributed 3.4% (Zenebe Mekonnen *et al*., 2014).

In Ethiopia, biodeterioration of bamboo is very fast (<1–2 years) and has economic importance (personal communication with bamboo growers and processors). The fast deterioration of bamboo culms has resulted in frequent harvesting that in turn has imposed high pressure and depletion on the remaining bamboo stock and commercial timbers of Ethiopia (Getachew Desalegn and Melaku Abegaz, 2012; Getachew Desalegn and Wubalem Tadesse, 2014; Hu, 2014). According to Getachew Desalegn and Melaku Abegaz (2012), Getachew Desalegn and Wubalem Tadesse (2014), Zenebe Mekonnen *et al*. (2014), utilization of bamboo in the country has been limited mainly due to its fast deterioration but currently the demand has increased.

Damage control measures to protect and rationally utilize this versatile resource of the country are needed. Adopting engineered processing and rational utilization techniques, including proper drying (seasoning) and damage control measures of culms and other bamboo-based products against biodegrading agents could be among the necessary measures towards increasing its service life, value addition and rational utilization thereby reducing the high pressure encountered on the indigenous tree species such as *Podocarpus falcatus*, *Juniperus procera*, *Hagenia abyssinica*, *Cordia africana* and *Pouteria adolfi-friederici*, and bamboo itself.

Therefore, the damage control measures research on bamboo culms against biodegrading agents was initiated as an important thematic and regional research area in Ethiopia and Kenya and implemented by their respective research institutes, namely, the Ethiopian Institute of Agricultural Research under the previous Forestry Research Centre now Central Ethiopian Environment and Forest Research Centre (CEE-FRC)/the previous Forest Products Utilization Research Case Team now Wood Technology Research Centre (WTRC), and Kenya Forestry Research Institute (KEFRI). *Arundinaria alpina* and *Oxytenanthera abyssinica* were studied in Ethiopia, while *A. alpina* and *Dendrocalamus giganteaus* were studied in Kenya. The first year progress results on natural durability of the study bamboo species stems (culms) of Ethiopia and Kenya, treatability with- and- performance of control measures against biodeterioration were reported (Getachew Desalegn *et al*., 2010; Nellie *et al*., 2010a; 2010b; Getachew Desalegn and Melaku Abegaz, 2012; Getachew Desalegn and Wubalem Tadesse, 2014).

This article presents the five year results of the Ethiopian part only, unless otherwise stated. This article has focused on subterranean and above ground termites, beetles and fungal attack, natural durability of bamboo species culms and performance of control measures at four different agro-ecological zones and four stations in Ethiopia. Therefore, the general objective of this study was to investigate natural durability of *Arundinaria alpina* and *Oxytenanthera abyssinica* culms, performance of control measures and application techniques against biodeteriorating agents' damage, and select appropriate control measures that can enhance service life and rational utilization of bamboo and bamboo-based products and structures in Ethiopia. The specific objectives of this research were to: (i) study natural durability of bamboo species culms against termites (subterranean and above ground dwelling), beetles and fungal degradation, (ii) test treatability with control measures (absorption, penetration and retention) of *A. alpina* and *O. abyssinica* species culms, (iii) investigate performance of damage control measures (commercial and traditional), application methods (pressure and non-pressure) on bamboo culms against termites, beetles and fungal degradation, and (iv) select appropriate control measures that can enhance service life and rational utilization of bamboo culms.

MATERIALS AND METHODS

Study species

The study species were the two indigenous bamboo species, namely, *Arundinaria alpina* K.Schum. and *Oxytenanthera abyssinica* (A.Rich.) Munro (Bambuseae). Synonyms of *A. alpina* are *Yushania alpina* (K.Schum.) W.C. Lin and *Sinarundinaria alpina* (K.Schum.) C.S. Chao & Renvoize. Synonyms of *O. abyssinica* are *O. macrothyrsus* K.Schum., *O. braunii* Pilg., *O. borzii* Mattei. Vernacular and common names of *A. alpina* are kerkeha (Amharic), lemana, shikaro (Oromo), anini (Awi); African alpine bamboo, mountain bamboo (English), Bambou creux (French), Mianzi, mwanzi (Swahili). Vernacular and common names of *O. abyssinica* are shimel (Amharic), betre (Sodo Guragie), arkay (Tigregna and Amharic), Shimela (Oromo), Savanna bamboo, Bindura bamboo, West African bamboo (English), Bambu africano (Portuguese), Mwanzi (Swahili) (von Breitenbach, 1963; Wolde Michael Kelecha, 1987; Hall and Inada, 2008; Inada and Hall, 2008; Anonymous, 2012).

The two indigenous bamboo species cover over one million ha of land in Ethiopia. Highland bamboo (*A. alpina*) is estimated to cover over 300, 000 ha and the lowland bamboo (*O. abyssinica*) covers between 700,000−

850,000 ha (about 85%) of the bamboo-covered land in the country. The two species represent the highest (67%) bamboo resource in Africa. The resource base in some areas has been under high pressure (improper utilization), while in others under promotion (regeneration, development and management). Bamboo based industries are emerging and have started producing different engineered products. Due to its fast growth and shortage of wood, bamboo has become economically important as an alternative and/or supplementary to wood (Anonymous, 2010a). Major distribution areas of highland bamboo are Injibara, Ambo, Gurage, Masha, Dawro, Sidama and Bale while that of lowland bamboo are Pawe (formerly Metekel), Asossa, Dedessa and Gimbi (Anonymous, 2012).

There are also more than 25 introduced bamboo species (such as *Bambusa balcoa*, *B. vulgaris*, *B. tudla*, *Dendrocalmus asper*, *D. brandisii*, *D. hamitoni*, *D. membraceous*, *Guada amplexifolia* and *Phyllostachys pubescens*, etc. (Tesfaye Hunde, 2008; Yigardu Mulatu and Mengistie Kindu, 2009; Alemu Gezahgne *et al*., 2011; Hu, 2014). Some of them adapted and others are still under investigation for the species site-matching and suitability for different applications. The natural durability and effective controlling measures for culms and other products of these species have to be complemented as well.

Harvesting of bamboo culms and sample preparation

The appropriate standards and other relevant publications applied in the materials and methods section (…sample selection, determination of moisture content and density, treating culms with control measures, installation of culms stakes at field, evaluation of damage, data collection and analysis…) were from different publications including standards and books. The available lists of references followed while conducting all activities, as cited and included in the references, were: Purslow, 1976; Panshin and de Zeeuw, 1980; Nicholas, 1985; Gjovik and Gutzmer, 1986; Melaku Abegaz and Addis Tsehay, 1988; Mishra, 1988; Willeitner and Liese, 1992; Eaton and Hale, 1993; FAO, 1994; Kumar *et al*., 1994; Highley, 1995; Shrivastava, 1997; Tesoro and Espiloy, 1988; Janssen, 2000; ISO, 2001; SAS, 2004. Treatment processes found suitable in case of timber (both in dry and green conditions) can also be applied to bamboos (Kumar and Dobriyal, 1988).

The highland bamboo samples were harvested and collected from the stations, specific localities and altitudes, namely, Hagere Selam (Meleya-Fincha Sefere) (3000 m), Injibara (Banja Zone) (2300 m), Tikur Inchini

(Woldo-Indie) (2300 m) and Masha (Soleschiu) (2400 m). The lowland bamboo samples were collected from Asossa (Komoshiga) (1540 m), Dedessa (Aba-Sena) (1500 m), and Pawe (Agricultural Research Centre compound) (1200 m). All samples were collected during low sugar content dry period. Matured (3−5 years old) bamboo stems (culms) free from visible defects and with good morphological qualities were selected and harvested from the stated bamboo stands of the respective localities.

Culms were sized to sample billets/stakes of 1 m length (structural size) and 3−5 cm diameter (top and bottom) along the culms merchantable height and transported to WTRC laboratory while green. The samples from Masha station were all self-split after cutting and thus used only for the split tests. The graveyard stakes were 1 m length and 3−5 cm diameter (top and bottom). The non-ground contact and laboratory tests were the same diameter as graveyard stakes and had 0.5 m and 3 cm length, respectively. To designate the different stakes and treatments, aluminum stainless steel identification codes were used. The numbers of stakes were 18 per control measure/treatment, 90 stakes per graveyard station and a total of 360 stakes in the case of graveyard tests, and 126 for the non-ground contact.

Treatments of bamboo culms

Alternative control measures/treatments (traditional and commercial) were applied using chrom-arsenic free and environmental friendly Tanalith E (Copper-azole) water-borne commercial wood control measure, borax ($Na_2B_4O_7.10H_2O$-disodium tetraborate decahydrate) - boric acid (H_3BO_3-Orthoboric acid) solution, used motor oil, common table salt, kerosene and the untreated control (Anonymous, 2005a; 2005b; Archer and Lebow, 2006). Toxicity of Tanalith is LD_{50} (oral, rat) >500 mg/kg, and LD_{50} (skin, rat) >2000 mg/kg (Anonymous, 2005a). Toxicity of boric acid, LD_{50} (oral, rat) is 2660 mg/kg. The LD_{50} of table salt in rats is 3.75 g/kg (Anonymous, 2005a; 2005b).

Tanalith can provide excellent performance against the whole range of destroying fungi and insects both in ground contact and non-ground contact for hazard class 1−4, gives service life of 15−60 years and in marine environments with hazard class of 5 guarantees for 15−30 years' service life (Anonymous 2005a). Copper provides protection against most decay fungi and termites while the synthetic azole type co-biocide provides protection against copper-tolerant organisms such as brown rot fungi (Anonymous, 2005b). For the treatments with used motor oil, a mixture of Shell Rimula diesel oil 40 and Helix Ultra 40 engine oil in a ratio of 1:1 was used

(Jayanetti and Follet, 1998; Anonymous 2009b). Crude table salt with ingredients of edible common salt, potassium iodized and permitted anti-caking agent was used besides Tanalith and used motor oil.

Experimental design

The experimental design was split-plot design under complete randomized (CRD) design. The study included one main plot factor (origin of stakes) and two sub-plot factors (control measures and culm positions). The main plot had six levels and it included stakes from Hagere Selam, Tikur Inchini, Injibara, Asossa, Dedessa and Pawe. The four study stations (Addis Ababa, Adami Tulu, Bako and Pawe) were taken as block factors for the combined analysis of data. Control measures, one of the sub-plot factors in case of graveyard tests had five levels and consisted of (i) Tanalith at 3% concentration under solvent water, (ii) Tanalith at 6% concentration under solvent water, (iii) a mixture of borax-boric acid under solvent water in a ratio of 1:1:54, (iv) used motor oil, and (v) untreated control. The second sub-plot factor (culm positions along height) involved three levels (stakes from the bottom, middle and top sections). For the off-ground (non-ground contact) tests, common table salt and kerosene were used in addition to other treatments. For accelerated decay test, stakes were treated with Tanalith E, borax-boric acid and used motor oil except the control.

Treatment of bamboo stakes

Stakes treatment with pressure method

Pressure treatment of stakes using Tanalith and borax-boric acid solution was applied separately with the same Sweden Brand Rentokil pressure impregnation machine and procedures (Tesoro and Espiloy, 1988; Willeitner and Liese, 1992; Kumar *et al*., 1994). Non-pressure treatments of stakes with hot and cold dipping method using crude table salt, soaking and sap-displacement with kerosene were used only for the non-ground contact tests.

Test categories of natural durability and control measures performance in brief were: (i) outdoor (graveyard) tests having external construction purposes, ground contact test with atmosphere and soil, (ii) indoor (above ground/non-ground contact) tests having furniture and internal construction purposes. Tests applied under shed without direct contact with atmosphere, moisture/rain, sunlight and soil, (iii) laboratory (accelerated decay) tests conducted to obtain quick results on biodeterioration so as to check and compare with graveyard and non-ground contact conditions. Accelerated decay test results on inoculated *Wolfipria cocos* (fungus) have been earlier reported (Getachew Desalegn and Melaku Abegaz, 2012).

Control measures treatment application techniques, namely, pressure and non-pressure (hot-and-cold dipping, soaking and sap displacement) methods were used to treat round and half split dry and green stakes separately. Bamboo culms were air seasoned, except the culms used for sap displacement (green) tests. Stakes for air seasoning were kept standing upright under shed for two months until an average MC of less than 20% was achieved. Moisture content was determined using the adapted formula (Panshin and de Zeeuw, 1980; ISO, 2001).

Pressure treatment of bamboo culms was done to force the control measures to be absorbed by the culms (Fig. 1). Tanalith (at 3% and at 6% concentrations) and borax- boric acid (1:1 ratio) treatments were separately used for pressure tests for 30-minutes for highland bamboo, relatively hollow and 1 hour for lowland bamboo, relatively solid. The impregnation pressure applied in both cases was 1 N/mm^2. The stakes were then removed out from the machine and air seasoned for a week to allow fixation of the control measure into the culms and solvent evaporation.

a. Rentokil Impregnation Machine

b. Bamboo culms loaded on bogie before entering the impregnation machine

Fig. 1. Pressure treatments of bamboo culms (Photo: Getachew Desalegn).

Treatability (absorption and retention) and permeability of stakes with control measures (Figs. 1 and 2) were determined based on Willeitner and Liese (1992) and FAO (1994). Control measure solution absorption rate (kg/m^3) was determined by subtracting saturated weight (kg) of stakes after treatment from weight (kg) of air seasoned stakes before pressure treatment and dividing by the volume of stake (m^3). Retention of control measures into stakes was determined by multiplying the amount of control measures absorbed by the control measures strength/concentration (toxic capacity) and expressed in kg/m^3.

Extent of control measures permeability (penetration) into the culms was determined (FAO, 1994) by cross-cutting two discs from treated stakes into 20 cm pieces, 20 cm inwards from both ends, measuring maximum and minimum depth of chemical penetration (mm) and to obtain mean penetration value (mm) dividing the summation of maximum and minimum depths of penetration (mm) by two.

Non-pressure treatment of bamboo stakes

Hot-and-cold dipping treatment of stakes

Hot-and-cold dipping tank atmospheric pressure treatments were done by submerging stakes in separate dipping tanks containing used/spent motor oil of vehicles and table salt solution (Fig. 2a, b). Treatments were gradually heated to 90°C. Stakes of *A. alpina* (hollow) were kept in the tank for 30 minutes and that of *O. abyssinica* (solid) for one hour. The stakes were allowed to cool for 24 hours. The stakes were then removed from the machine and air seasoned for a week to allow fixation of the control measures into the culms.

Soaking treatments

Air seasoned round stakes of *A. alpina* and *O. abyssinica* were soaked separately in a drum containing kerosene to a length of 30 cm from the bottom portion and kept in the drum for 4 and 8 days, respectively. The same was done for the half split stakes. The stakes were then removed out of the machine and air seasoned for a week to allow fixation of the control measures into the culms. Application of preservative by soaking is the cheapest and simplest method of chemical treatment of bamboo for uses where higher absorptions are required. This method requires very little technical knowledge, simple equipment and minor investment. The process gives satisfactory results if the samples are properly prepared, seasoned and treated. Moreover, both dry and green samples can be treated by this method

(Younus-Uzzaman, 1998).

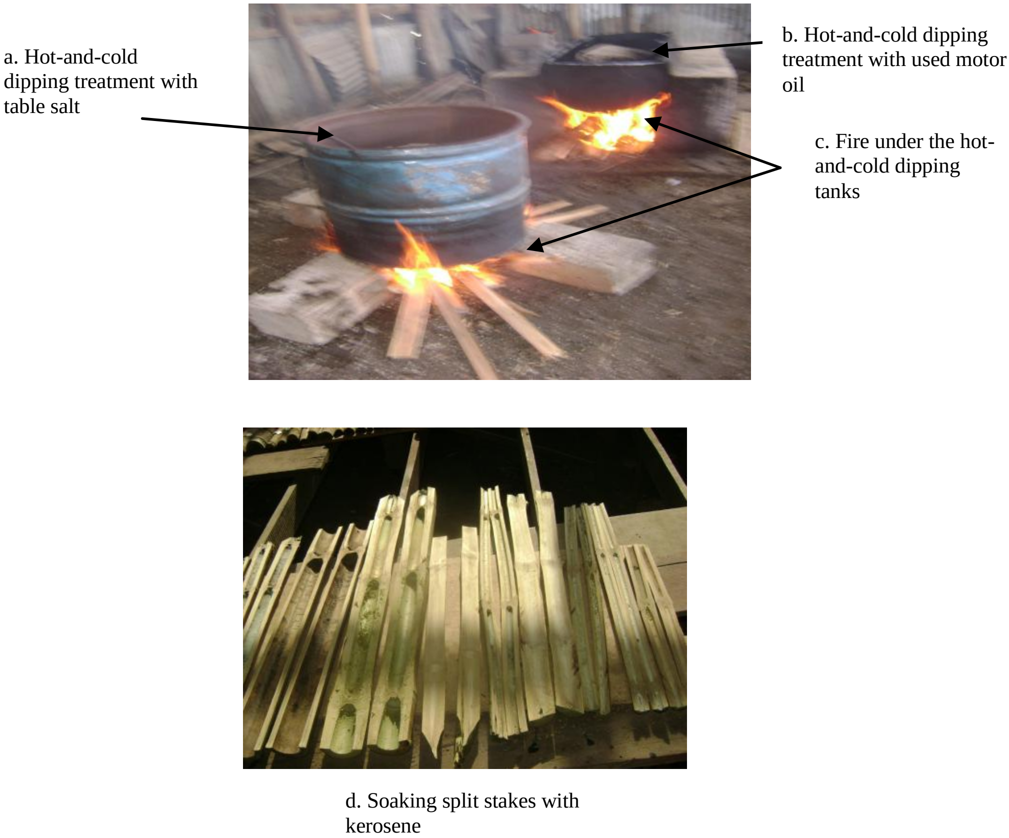

Fig. 2. Hot-and-cold dipping treatment of bamboo culms with table salt (2a), and use motor oil (2b, c) and soaking split stakes with kerosene (2d) (Photo: Getachew Desalegn).

Sap displacement treatment

Freshly cut/green (89% MC) and round form culm stakes prepared to size were immersed to 30 cm of the bottom part using kerosene held in an oil-barrel and left standing in a barrel containing kerosene for four days. They were then removed from the barrel and air seasoned for a week to allow fixation of kerosene into the culms.

Split stakes treatment with pressure and non-pressure methods

Stakes prepared to size, split into half and air-seasoned were pressure treated using Tanalith and borax-boric acid solutions separately and the 3rd batch were soaked in kerosene for 4 and 8 days, respectively (Fig. 2d). Stakes were then removed from the impregnation machine and soaking barrel and air seasoned for a week to allow fixation of the control measures into the culms.

Controls

Control (untreated) stakes were not treated with control measures but received proper seasoning, moisture management and proper handling. Controls provide information about the natural durability of the species.

Test stations

The tests included field/graveyard study, above ground (non-ground contact) and accelerated decay (laboratory) tests. Accelerated decay test on bamboo culms of Ethiopia was conducted in the Kenya Forestry Research Institute (KEFRI) laboratory and reported (Getachew Desalegn and Melaku Abegaz, 2012). The field tests were conducted in four agro-ecological zones, at four graveyard sites (hereafter stations namely, Addis Ababa, Bako, Adami Tulu and Pawe). Records collected using Global Positioning System (GPS) (Table 1) were used to indicate the latitude and longitude coordinates of the stations on the map of Ethiopia. Field stations were located in hazardous areas of bamboo degrading agents (termites and fungi).

Table 1. Descriptions of graveyard stations.

Graveyard station*	**Latitude and Longitude**	**Altitude (m)**	**Total annual rainfall (mm)**	**Mean annual temperature (Min. and Max.)**	**Agro-ecologies****	**Major soil type**
Adami Tulu, ARC compound	7°5´N and 38°42´E	1645	766	12°C and 27°C	Hot to warm sub-humid gorges agroecology- mid rift valley	Sandy
Addis Ababa, FPURC compound	8°57′N and 38°45´E	2228	1225	9.5°C and 22.5°C	Tepid to cool humid mid-highlands	Vertisols-black soil
Bako, ARC compound	9°09′N and 37° 02′E	1628	1210.1	9°C and 34.4°C	Mid altitude sub-humid mid-highlands	Nitosols-Red soil
Pawe, ARC compound	11°19´N and 36°24′E	1100	1000-1500	25°C and 30°C	Hot to warm most gorges	Nitosols, vertisols and Lvesols- red and black soils

*ARC- Agricultural Research Centre; FPURC- Forest Products Utilization Research Case Team.
**Source: Anonymous (2000).

Graveyard installation of stakes

Graveyard studies of stakes were conducted for five years (2009−2014) at Pawe, Bako, Adami Tulu and Addis Ababa research stations. The off-ground tests were conducted at Addis Ababa station under shade without direct contact of soil, moisture, rain and sunlight. Graveyard tests were designed to simulate actual field and service conditions of bamboo culms. Pits were dug for the installation of stakes with 25 cm depth at a spacing of 25 cm between stakes and 50 cm between rows. Plots per station and treatments were subdivided into 18 sections. Stakes were fixed randomly in the prepared pits with their bottom parts up to 30 cm lengths (Fig. 3).

Fig. 3. Bamboo stakes field lay out and installation partial view at the different graveyard stations [Stakes at Bako Station (a); stakes at Adami Tulu Station (b); stakes at Pawe Station (c), stakes at Addis Ababa Station (d)] (Photo: Getachew Desalegn).

Position of all stakes in each test plot were pegged facing in one direction following the position/direction of code plates and sketched to provide reference for the respective/continuous data collection work. Graveyard stations were fenced with barbed wire, seasoned and preserved wood. Stakes for the off-ground tests were kept on shelves under shade with no direct ground, sunlight, rainfall and moisture contact.

Stakes evolution against biodeteriorating agents damage and data analysis

Data collection was carried out at 3rd, 6th, 9th and 12th months in the first year, and thereafter at six months interval and up to year five. Resistance and/or deterioration rate of each test stake and control measures against subterranean termites and fungal attack was determined by visual inspection/observation supported by sounding/acoustic and indenting methods. Earthen tunnels, termites mud tubes, and exit holes or galleries on the stakes were used in this study to signify the presence and damage of subterranean termites. Fungal decay was characterized by colour changes, softening, brashness, brittleness and the development of hyphal growth/decayed external appearance (assessed visually) and in later stages of decay culms shrunk and crack developed along and across the grain. Fungal damage was indicated by hollow seen and/or dull sound heard while jabbing the stakes with blunt end of the inspection knife and indenting with thumbnail (Nicholas, 1985; Eaton and Hale, 1993; Shrivastava, 1997). This was done to check for their natural resistance/durability, effectiveness of applied damage control measures and application techniques.

Stakes after rainy season were carefully withdrawn from their pits one by one; the presence and extent of attack by termites and/or fungi were inspected, evaluated and recorded following the method used by Gjovik and Gutzmer (1986) before re-installation into the pit. Graveyard inspection continued until the underground parts of at least 50% of the untreated and/or control measures treated stakes were completely degraded or fell down to the ground (Gjovik and Gutzmer, 1986; IUFRO, 1972; cited in Willeitner and Liese, 1992).

Biodeterioration rate was evaluated following (Purslow, 1976; Gjovik and Gutzmer, 1986; Melaku Abegaz and Addis Tsehay, 1988; Willeitner and Liese, 1992; Eaton and Hale, 1993; Highley, 1995; Getachew Desalegn *et al*., 2003). This was done based on a nominal scale of 1−5, 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).

For convince of data analysis and presenting results, scaled values after the data analysis were converted to percentage values and *vice-versa*. Stakes mean damage values that became continuous values were used in the standard ANOVA. Data were analyzed using SAS (2004), version 9 statistical software package for windows. Combined analysis using multifactor ANOVA was done to determine damage by subterranean termite and fungi and effectiveness of control measures. Least significance difference (LSD) and Duncan's Multiple Range analyses were used to check significance of the damage difference among biodeteriorating agents/mean separation among treatments including the controls.

RESULTS AND DISCUSSION

Major physiognomic characteristics of bamboo culms

Mean height and diameter of *A. alpina* sample culms were 8.4 m and 5.20 cm and that of *O. abyssinica* were 6.1 m, and 3.9 cm, respectively. Diameter of stakes for bottom section along the culms height was 4.5 cm, middle 4.1 cm and top sections 3.6 cm. Internodes length of *A. alpina* and *O. abyssinica* were 42.2 cm and 33.7 cm, respectively. Internodes length of the Pawe site was relatively short (30 cm). Mean number of nodes per 1 m length of both species culms was 3.

Physical characteristics

Moisture content of *A. alpina* and *O. abyssinica*

Mean green (initial) moisture content of *A. alpina* and *O. abyssinica* were 117.40% and 59.53%, respectively. Dried (seasoned) culms moisture content of *A. alpina* and *O. abyssinica* were 12.40% and 15.40%, respectively. Bamboo samples collected from Hagere Selam, Injibara and Tikur Inchini had initial moisture content of 103%, 115% and 134%, respectively and that of Asossa, Dedessa and Pawe bamboo culms had 56%, 54% and 69%, respectively. Seasoned moisture content of Hagere Selam, Injibara and Tikur Inchini bamboo culms were 11%, 12% and 14%, respectively, and that of Asossa, Dedessa and Pawe bamboo culms were 19%, 14% and 14%, respectively. According to Melaku Abegaz *et al*. (2005), *O. abyssinica* of Mandura which is nearby Pawe has an initial and final moisture content of 60% and 12%, respectively. Moisture contents of the two bamboo species were in agreement with other reports which indicated that the initial moisture content of bamboo ranged from 57 to 150% (Kumar and Dobriyal, 1988; Ahmad and Kamke, 2003).

Density of *A. alpina* and *O. abyssinica*

Density and moisture content are the major factors that can influence the mechanical and other properties (Ahmad and Kamae, 2003). Density of *A. alpina* and *O. abyssinica* culm walls at 12% moisture content were 615 kg/m^3 and 673 kg/m^3, respectively. Density of Hagere Selam originated *A. alpina* culms at 12% moisture content was 630 kg/m^3 and according to Seyoum Kelemwork *et al*. (2008), *A. alpina* from Bore site, which is found nearby Hagere Selam had the same density of 630 kg/m^3. According to Chew *et al*. (1992; cited in Ahmad and Kamke, 2003), *Bamboo vulgaris* has the same density of 630 kg/m^3 as that of *A. alpina*.

According to Seyoum Kelemwork (2012), the Asossa bamboo had density of 535 kg/m^3 and the Dedessa bamboo had a density of 615 kg/m^3. This indicated that *O. abyssinica* of Dedessa has the same basic density as that of *A. alpina* of this study, while Pawe culms have a density of 658 kg/m^3. According to Melaku Abegaz *et al*. (2005), *O. abyssinica* of Mandura has density of 720 kg/m^3 at 12% moisture content. Density results of this study were in agreement with other reports which indicated that seasoned density of bamboo ranges between 300 and 900 kg/m^3 (Kumar and Dobriyal, 1988; Ahmad and Kamke, 2003).

Treatability of bamboo culms

Absorption/uptake and retention (kg/m^3) in this case refer to the amount of Tanalith E salt concentration in bamboo culms. Retention is more important than absorption, since what is effective in controlling biodeterioration attack is the retained amount. Mean absorption of Tanalith per volume of treated *A. alpina* and *O. abyssinica* culms at 3% concentration was 525.4 kg/m^3 and 504.2 kg/m^3, respectively. Tanalith absorption of *A. alpina* stakes from Hagere Selam site was 575.3 kg/m^3, Tikur Inchini 528.6 kg/m^3 and Injibara 472.2 kg/m^3. Stakes of *A. alpina* from Hagere Selam site indicated relatively high absorption (575.3 kg/m^3) and Injibara low absorption (472.2 kg/m^3). Absorption of *O. abyssinica* stakes from Asossa site was 659.4 kg/m^3, Dedessa 733.4 kg/m^3 and Pawe 119.7 kg/m^3. Mean absorption of both species culms along height for bottom position was 214.2 kg/m^3, middle 655.6 kg/m^3 and top section stakes was 674.5 kg/m^3. Top and middle sections absorbed relatively high and bottom the least.

The average control measure retention of *A. alpina* culms was 17.5 kg/m^3. Stakes of *A. alpina* from Hagere Selam site revealed relatively the highest retention (19.3 kg/m^3) and Injibara the least (15.3 kg/m^3). Average control measure retention capacity of *O. abyssinica* stakes was 17.1 kg/m^3. Stakes of *O. abyssinica* from Dedessa site revealed the highest retention (24 kg/m^3) and stakes from Pawe showed the least (5.5 kg/m^3) control measures retention capacity. Mean retention of Tanalith at 3% concentration for both species along the culms height was 21.9 kg/m^3 and the amount of control measures retained at the bottom, middle and top sections of bamboo culms were 8.1 kg/m^3, 21.6 kg/m^3 and 22.3 kg/m^3, respectively. Top section culms revealed the highest retention (22.3 kg/m^3) and bottom sections the least (8.1 kg/m^3). This exhibited that both bamboo species were permeable to Tanalith and other control measures treatments.

A maximum retention of 20.51 and 22.25 kg/m^3 were reported for air seasoned stakes of *Arundinaria flaconeri* and *Sinobambus tootsik* (Younus-Uzzaman, 1998), respectively for water-borne copper-chrome-arsenate (CCA) control measure. According to Younus-Uzzaman *et al*. (2001), bamboo culms having 11−19 kg/m^3 retention when treated with CCA salt, is expected to have a service life span of 15−20 years both when used in the open and in contact with the ground. The retentions of *A. alpina* and *O. abyssinica* obtained in this study were comparable with the results of Younus-Uzzaman (1998) and Younus-Uzzaman *et al*. (2001). Retention of 4−20 kg/m^3 for water-borne control measures such as Tanalith has been recommended to be adequate for various applications (Willeitner and Liese, 1992). Retentions of both study species and species by origin also fell within the required retention limits.

Performance of traditional and commercial control measures

Durability and performance of traditional and commercial control measures against subterranean termite and fungal damages were stated simultaneously in terms of graveyard stations, duration of exposure, bamboo species, and bamboo species origin, position of culms along height. Graveyard results in this case refer to damage up to year five. The majority of the treated and untreated culms at the 3rd month evaluation period indicated that culm stakes at all stations were not significantly attacked by subterranean termites and fungi.

Performance of control measures/treatments against controlling termites and fungal damage significantly varied since the end of the 6th month and up to year five exposure periods. At Pawe station, the 6th month exposure indicated 42.5% termite damage for highland bamboo culms treated with borax-boric acid, and 30% for the controls (Getachew Desalegn *et al*., 2010; Getachew Desalegn and Melaku Abegaz, 2012). In Kenya, within sixth month of field exposure, the *A. alpina* control stakes were degraded from 4.2% to 16%, and that of *Dendrocalamus giganteaus* from 12.5% to 33% (Nellie *et al*., 2010a). In this case, the degradation of *A. alpina* in Ethiopia was higher than in Kenya. This could be attributed to the biodegrading agents and site differences. According to Hall and Inada (2008), seasoned culms of *A. alpina* used in construction and fencing are susceptible to infestation by the powder-post beetle (*Dinoderus minutus*). However, in Congo, stems considered durable, houses and fences made from *A. alpina* to last for more than 20 years (Hall and Inada, 2008). Fences made from *O. abyssinica* seasoned culms were susceptible to termite and borer attack (Inada and Hall, 2008).

The treated culms of this study have indicated relatively longer service life, more than five times increment compared with untreated culms. Biodeteriorating agents (termites, beetles, borers, fungi, etc) independently and/or jointly destroy untreated bamboo culms within one month to three years duration of harvest, storage and utilization, while preserved bamboo based on intended place of utilization will give a service life of 10−40 years, an increment of 4−10 times compared to the untreated bamboo (Tamolang *et al*., 1980; Liese, 1985; Willeitner and Liese, 1992; Kumar *et al*., 1994; Janssen, 1995; Younus-Uzzaman, 1998; Islam *et al*., 2002).

During the 5th year period, the highest (100%) termite damage occurred on controls and borax-boric acid treated stakes installed at Pawe and Bako stations. Highest fungal damage occurred on bamboo culms installed at Bako (80%) and Adami Tulu (70%) stations (Table 2). In all the stations except Addis Ababa, deterioration rate of subterranean termites and fungi has increased significantly through time (3rd month to 5th year evaluations). This could be attributed to the differences in agro-ecological and biodegrading agents. The Addis Ababa station is located in relatively highland (cold) altitude and thus bamboo stakes were less damaged than the warm sites.

Compared to the 6th month, the damage from first to 5th year increased from about twice to more than 13 times in case of subterranean termites and about twice to more than 40 times in case of fungi (Table 2; Fig. 5). The extent varied with species, species by origin, control measure, graveyard station and duration of exposure. For instance, biodeterioration of Tanalith treated stakes at 6% concentration, in the same five year of exposure period and with station varies from 5 to 35% times in the case of subterranean termites attack and 0 to 20 times in case of fungal attack.

Damage of the termite and fungi revealed that culms cut near the ground surface or the underground parts were penetrated, excavated/hollowed, damaged and filled with moist soil by termites and in some cases decayed mutually by fungi as well. At Pawe and Bako stations, during the rainy/moist periods, the above ground parts of bamboo culms were covered with soil sheathing up to 50 cm along the culms height and damage by termites and fungal infestation was observed. According to Wong and Cheok (2001), when termites and fungi occur together they may become associated (symbiotic relationship) in a way so that they influence each other. When comparing the two bamboo species, natural durability of *O. abyssinica* was better than *A. alpina*. The study bamboo species could be classified as non-durable. On the basis of natural durability of bamboo species culms, it can be classified as non-durable species (Kumar *et al*., 1994).

Table 2. Mean deterioration (%) of bamboo culms up to five year graveyard exposure period.

Control measure Treatments	Mean deterioration (%) of culms by graveyard station							
	Pawe		Bako		Adami Tulu		Addis Ababa	
	T	F	T	F	T	F	T	F
Tanalith 3% concentration	95.0	65.0	92.5	60.0	52.5	42.5	27.5	2.5
Tanalith 6% concentration	32.5	15.0	35.0	20.0	22.5	10.0	5.0	0.0
Control	100.0	100.0	95.0	55.0	80.0	67.5	45.0	42.5
Used motor oil	87.5	72.5	97.5	52.5	57.5	52.5	25.0	20.0
Borax-Boric acid	100.0	80.0	100.0	70.0	70.0	22.5	47.5	17.5

T- subterranean termite; F-fungi

The controls and treated stakes with borax-boric acid solution, used motor oil, and Tanalith at 3% concentration were highly affected (mean values range from 88 to 100%) by subterranean termites at Pawe and Bako stations, while the least deterioration (5%) occurred for Tanalith treated stakes at 6% concentration at Addis Ababa station. Fungal damage ranged highest, 72.5 to 100%, at Pawe on used motor oil treated stakes, and controls and the least 0−10% at Addis Ababa and Adami Tulu stations were on Tanalith treated stakes at 6% concentration.

The results indicated that mean subterranean termites deterioration of stakes up to 5th year for both bamboo species, species by origin, positions along the culms height and at all graveyard stations was 80% for controls, 79% for borax-boric acid, Tanalith at 3% concentration and used motor oil treated stakes were equally degraded to 67%, and 24% damage for Tanalith at 6% concentration (Table 2). Mean fungal attack on bamboo culms was 66.25% for controls, 49% for used motor oil, 47% for borax-boric acid, 43% for

Tanalith at 3% concentration, and 11% for Tanalith treated stakes at 6% concentration. Damage of subterranean termites' and fungi along the height of bamboo culms was not significant (Fig. 5d). Bottom section culm stakes resist both subterranean termites and fungal deterioration more than middle and top sections.

Subterranean termites' mean damage on Tanalith treated stakes at 3% concentration at each graveyard station, in a descending order was Bako 84%, Pawe 83%, Adami Tulu station 57% and Addis Ababa 30%. Mean damage of fungi on Tanalith treated stakes at 3% concentration at each graveyard station was Pawe 66.5%, Bako 51.5%, Adami Tulu 39% and Addis Ababa 16.5%. Highest subterranean termites' damage (84%) occurred at Bako and Pawe, and highest fungal attack (66.5%) at Pawe station. At Adami Tulu station, the termite mound extended from time to time and became very sticky around the stakes like cement concrete. At Pawe station, the deterioration of the controls and borax-boric acid treated stakes was 100%, while fungal attack was estimated to be 15 to 100%.

The subterranean termites at Bako station were Microterms and *Pseudacanthoterms militarious* while that of Adami Tulu, having the same agro-ecology as that of Zeway, was dominated by subterranean and mound building termite species, *Marcoterms bellicosus* (Zawde Berhane and Yusuf, 1974). Dominant mound forming termite species at Pawe were the genera *Macroterms* and *Odonototerms*, both belonging to the family Macrotermitinae (personal communication with Pawe ARC researchers).

The trend of termite attack at Pawe station was observed from inner to outer parts and upwards (Fig. 4a), and at Bako from the bottom inner part to the top direction (Fig. 4b).

Graveyard results up to year five revealed that there was significant difference ($P<0.01$) in the mean biodeterioration damage of subterranean termites between the bamboo species (*A. alpina* and *O. abyssinica*), by origin (Hagere Selam, Injibara, Tikur Inchini, Asossa, Dedessa and Pawe), among control measures (Tanalith at 3% and 6% concentration, borax-boric acid, used motor oil and control), among application methods for control measures (pressure, non-pressure and untreated controls), graveyard stations (Pawe, Bako, Adami Tulu and Addis Ababa), and in the interactions among species by origin and control measures; species by origin and graveyard stations; control measures and graveyard stations. There was significant difference ($P<0.01$) for fungal damage too, especially on control measures and graveyard stations and in the interactions between control measures and graveyard stations, species by origin and graveyard stations.


a


b

Fig. 4. Trend of termite attack on bamboo stakes treated with borax-boric acid and installed at Pawe (a) and Bako (b) stations (Photo: Getachew Desalegn).

The overall mean damage caused by subterranean termites for both species, all species by origin, control measures and stations varied from 24 to 80%, while mean damage caused by fungi varied from 11 to 66%. The results indicated that bamboo species culms were non-durable. Among the studied control measures, Tanalith and used motor oil were found to be most effective in controlling biodegrading attack and prolonging the service life of bamboo culms to more than five times service life time increment compared to the un-treated control and borax-boric acid solution treated stakes (Table 2; Fig. 5).

Least significant difference (LSD) and Duncan's Multiple Range/mean separation analyses to check the mean damage difference among biodeteriorating agents, indicated that the overall mean damage due to subterranean termites and fungi for both bamboo species, stakes from different origins, positions along the culms height, control measures and graveyard stations was 67.5% and 42.5%, respectively (Fig. 5a, b, c, d). Controls and borax-boric acid treated stakes were damaged more than Tanalith and used motor oil treated stakes.

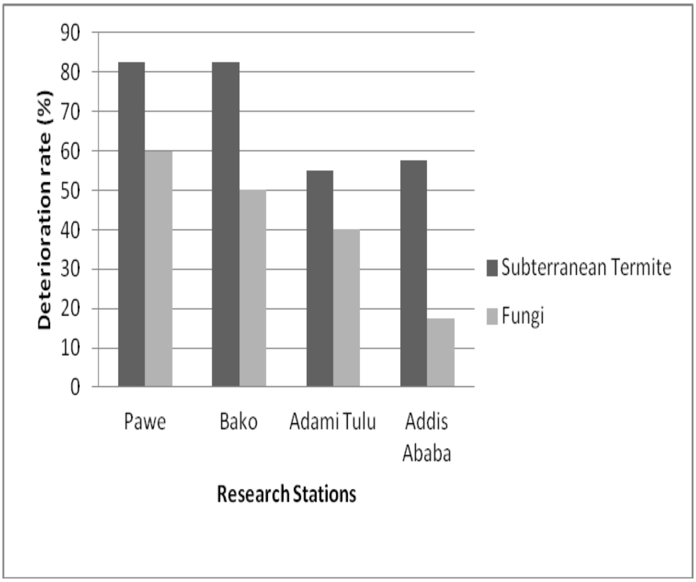

Fig. 5a. Mean deterioration (%) of bamboo culms at different graveyard stations [1st bar graph refers to subterranean termite damage while the 2nd one refers to fungal damage].

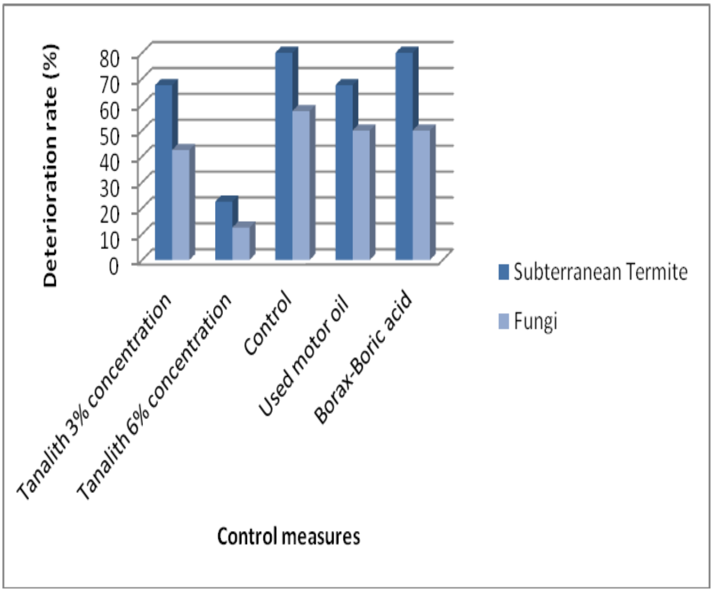

Fig. 5b. Mean deterioration (%) of bamboo culms treated with different control measures [1st bar graph refers to subterranean termite damage while the 2nd one refers to fungal damage].

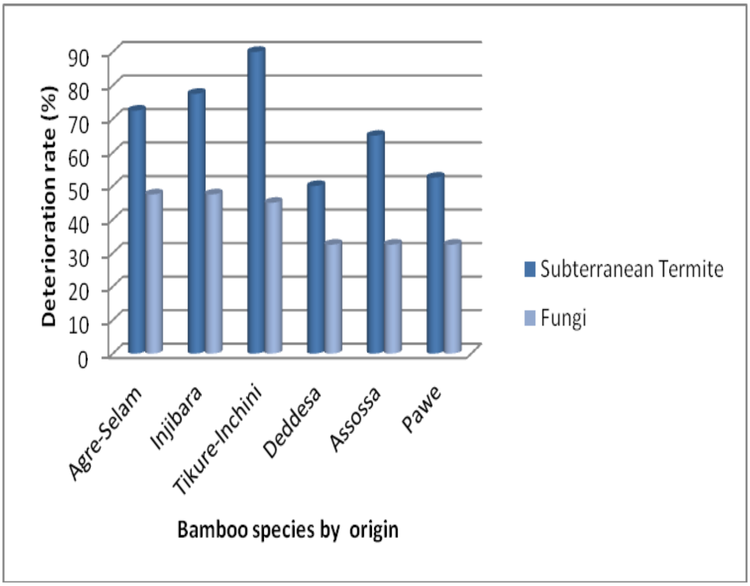

Fig. 5c. Mean deterioration of bamboo culms by species origin [1st bar graph refers to subterranean termite damage while the 2nd one refers to fungal damage].

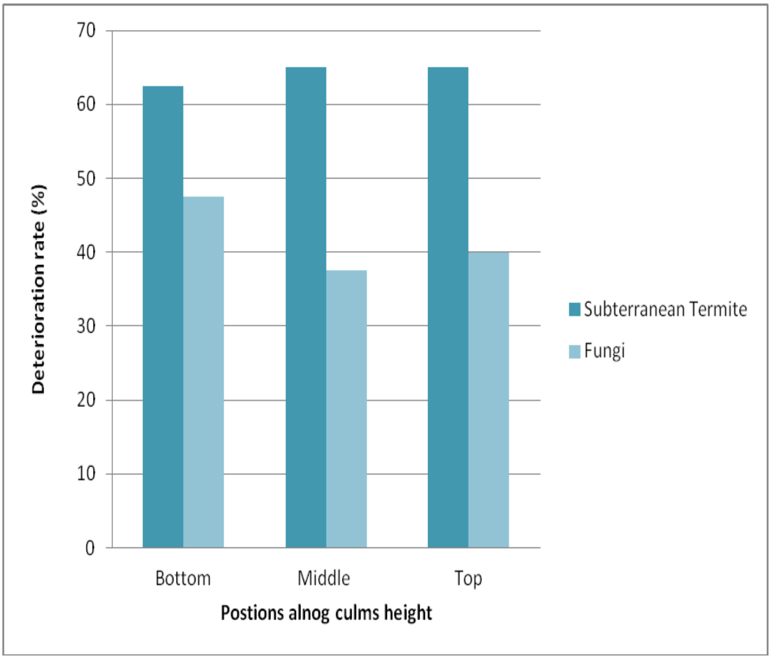

Fig. 5d. Mean deterioration of bamboo culms along height [1st bar graph refers to subterranean termite damage while the 2nd one refers to fungal damage].

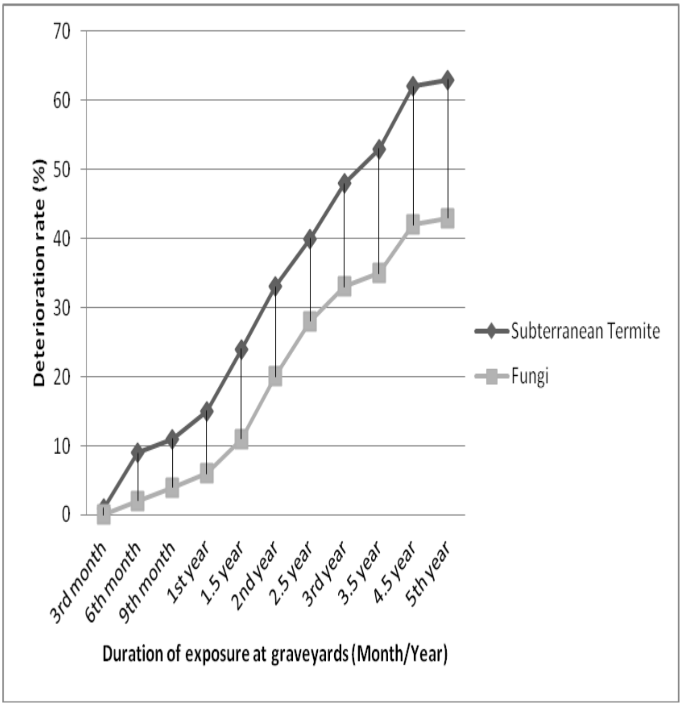

Fig. 5e. Mean deterioration of bamboo culms through graveyard exposure periods [1st line graph refers to subterranean termite damage while the 2nd one refers to fungal damage].

Application of different treatments to control subterranean termites attack showed significant difference between used motor oil, Tanalith at 3% and 6% concentrations. The role of treatments to minimize the damage of fungi showed significant difference between borax-boric acid and Tanalith treatments (Table 2; Fig. 5). Results of the study indicated that Tanalith and used motor oil were effective to control biodeterioration attack. The Tanalith treatment of highland and lowland bamboo culms at 6% concentration with pressure impregnation method was by far the best to control both subterranean termites and fungal damage.

Compared to the controls and borax-boric acid treatments, control measures/treatments such as Tanalith at 3% and 6% concentrations and used motor oil treatments of this study have increased service life of bamboo species culms by more than five times. However, the extent varies with species, species by origin, control measure, and positions along the culms height, graveyard locations and exposure periods.

Treated bamboo culms with water-borne preservatives such as Tanalith can serve as a construction material for about 10−15 years out doors and in doors; with ground and moisture contact applications for 30−40 years, a service life increment of about 4−5 times compared to the untreated bamboo culms (Kumar and Dobriyal, 1988; Tesoro and Espiloy, 1988; Kumar *et al*., 1994; Janssen, 1995; Jayanetti and Follet, 1998; Yunus-Uzzaman, 1998; Lahiry, 2001; Islam *et al*., 2002; Li, 2004; Bowyer *et al*., 2005; Anonymous, 2009a; Hall and Inada, 2008; Inada and Hall, 2008; Anonymous, 2009a). Good chemical preservation can increase the natural durability of bamboo to more than 50 years service life (Schröder, 2014).

Effectiveness of control measures for aboveground dwelling biodegrading agents

The non-ground contact test stakes of all untreated controls and treated with control measures (Tanalith, borax-boric acid solution, used motor oil, common table salt, kerosene) using pressure and non-pressure methods including sap displacement, dipping, soaking with kerosene for 4 and 8 days were intact up to the last evaluation period of year seven against biodeteriorating agents namely above ground dwelling termites, beetles and fungi.

Both the graveyard and accelerated decay laboratory tests of this research indicated that there was high damage when there were no control measures applied indicating non-durability of bamboo and the importance of control measures to increase its durability and service life.

Comparison of bamboo culms durability with timbers

Bamboo has been one of the competent species to replace wood, provided it is well-handled and protected from biodegrading agents. In Ethiopia, people have been using either wood or bamboo as construction and furniture material. There has been no research finding/information on the natural durability of bamboo culms and effective damage control measures in Ethiopia. Comparison of natural durability of bamboo and timbers could be useful to decide which one to use, when and for how long (service life).

The palace ceilings of Emperor Menilik II at Entoto in Addis Ababa that were constructed during 1889 from split bamboo culms that may be untreated, are still intact against biodeteriorating agents (personal communication and observation).

Compared to the controls and borax-boric acid treatments, control measure treatments such as Tanalith at 3% and 6% concentrations and used motor oil treatments of this study have increased service life of bamboo species culms by more than five times. However, the extent varies with species, species by origin, control measure, and positions along the culms height, graveyard locations and exposure periods.

The underground parts of some untreated timber stakes of *Acrocarpus fraxinifolius*, *Antiaris toxicaria*, *Apodytes dimidiata*, *Trilepisium madagascariense*, *Milicia excelsa*, *Croton macrostachyus*, *Ekebergia capensis*, *Fagaropsis angolensis* and *Polyscias fulva* at Zeway station were severely attacked and fell down to the ground line zone mostly by subterranean termites attack during the first three to six months field exposure periods (Getachew Desalegn *et al*., 2003; 2012). *Eucalyptus grandis*, *A. toxicaria*, *E. capensis* and *Podocarpus falcatus* timber stakes at Mersa were degraded and fell down during the 2nd year period (Wubalem Tadesse and Getachew Desalegn, 2008). *A. fraxinifolius*, *A. toxicaria*, *A. dimidiata*, *C. macrostachyus*, *E. capensis*, *E. grandis*, *M. excelsa*, *Pinus patula*, *P. fulva*, *Pouteria adolfi-friederici*, *Syzygium guineense* and *T. madagascariense* at Bako station were degraded and fell down due to termite attack during the first year period (Getachew Desalegn *et al*., 2007; 2012).

All untreated control stakes of *C. macrostachyus* at Mersa, Bako and Pawe stations were degraded and fell to the ground line during the first year (Wubalem Tadesse and Getachew Desalegn, 2008; Behailu Kebede *et al*., 2011), while *Cordia africana* fell during the 2nd year exposure period (Wubalem Tadesse and Getachew Desalegn, 2008). Untreated *Eucalyptus deglupta* timber at Meisso station was degraded and fell down at first year (Getachew Desalegn, 2010; Getachew Desalegn *et al*., 2012). Some of the control stakes of bamboo at Pawe, Bako and Adami Tulu stations fell down at first year, while some others resisted 2.5 to 5 years. This revealed that untreated bamboo species at the same duration (up to first year) were comparable with the stated untreated timber species.

CONCLUSION AND WAY FORWARD

Performance of untreated stakes and effectiveness of stakes against subterranean termites and fungal attack varied. The results revealed that subterranean termites' damage was higher than fungi for species, species by origin, all control measures applied and at all graveyard stations. Compared to the third month exposure period, the deterioration during the 6th month to

5th year significantly increased. The Addis Ababa station was less hazardous since underground parts of all the untreated stakes were attacked to less than 50%, while the Pawe station was more hazardous since 100% of the controls and borax-boric acid treated stakes were severely degraded by termites. The overall mean damage on controls and control measures treated stakes caused by subterranean termites for all species by origin, control measures and stations varied from 24 to 80%, while damage caused by fungi varied from 11 to 66%. This indicated that termites caused the highest damage both on the controls and borax-boric acid treated stakes.

Results revealed that natural durability of the study bamboo species at different graveyards was non-durable. All bamboo culm stakes exposed to the above ground dwelling termites, fungi and beetles were intact. Tanalith and used motor oil treatments were more effective in controlling biodegrading attack and prolonged the service live of bamboo culms by more than five times compared with those of the borax-boric acid treatments and the untreated controls. The overall results are promising, indicating the paramount importance of bamboo culms control measures including proper seasoning to increase service life of bamboo, bamboo-based products and structures, and to promote maximum utilization of the bamboo resources as alternative construction and furniture material.

The results will have practical application not only to the study areas (Pawe, Bako, Addis Ababa and Adami Tulu) but also in areas with similar bamboo species and agro-ecological zones. Results can be applied since there are different locally available protection measures such as used motor oil of vehicles with low price, small investment and some of the techniques of preservation in this case, dipping and soaking can easily be applied with little technical training and practical experience.

Recommended control measures to control/minimize damage of biodeteriorating agents and increase service life of bamboo culms based structures and products as way forward include: (i) felling of mature bamboo culms during the dry period in order to lower the starch/sugar content, (ii) harvested culms should be properly handled and seasoned as soon as possible to the desired moisture content level using air. Kiln seasoning is not recommended for round bamboo culms. Air seasoning shall be done by placing bamboo culms in upright position and in a well-ventilated yard, under shade to avoid direct wind or sun as quick seasoning may cause splitting, (iii) applying proper control measures and application techniques for long time service (>5 years) using pressure and effective non-pressure (hot-and-cold dipping) impregnation methods, (iv) bamboo culms should not be used in hazardous areas for moisture and soil contact constructions, other long-term and aesthetic applications without applying appropriate and adequate preservation measures, and (v) use of more environmental friendly and competent chrome and arsenic free commercial control measures such as Tanalith E, and the cheapest locally available spent motor oil of vehicles.

The different stakeholders of the country have to give proper attention to the versatile bamboo resource. Research and extension institutions have to play their significant role in providing best technologies and practices on propagation, management, products processing and rational utilization.

Finally, intensive and extensive further applied research are recommended, involving different commercial and traditional alternative controlling measures, at different stations and prolonged time to fill the information and technological gaps on durability, control measures, application techniques and rational utilization of bamboo resource in the different agro-ecological zones of Ethiopia where biodegradation and bamboo resource have economic relevance.

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