Leachability and efficacy of CCA, creosote and two durable hardwood extracts in Ceiba pentandra *(L.) Gaertn.-treated stakes against termite attack*

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Journal of the Indian Academy of Wood Science

ISSN 0972-172X

J Indian Acad Wood Sci
DOI 10.1007/s13196-012-0066-3

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ORIGINAL ARTICLE

Leachability and efficacy of CCA, creosote and two durable hardwood extracts in *Ceiba pentandra* (L.) Gaertn.-treated stakes against termite attack

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Received: 18 July 2011 / Accepted: 25 June 2012

Abstract Leaching affects chemical potency of treated wood in service and has generated environmental and health concerns. Attempts to supplant inorganic preservatives with those from organic sources are achievable but their leaching potential is worth-ascertaining. Leaching resistance of two notable conventional preservatives (i.e., CCA and creosote) was compared with that of extracts from two durable hardwoods (i.e., *Erythrophleum suaveolens* bark and *Azadirachta indica* seed extracts) in pressure-treated *Ceiba pentandra* stakes (500 × 50 × 25 mm). Seventy treated stakes each were subjected to leaching in distilled water in the laboratory. Ten replicates were removed every 48 h and the water changed until 336 h. Decay resistance of the leached stakes was then assessed after 5 years of field exposure using visual durability ratings, mass and hardness losses. Ten non-leached treated stakes served as controls. Chemical retention was greater for stakes treated with water-borne preservatives (i.e., the extracts and CCA) than with creosote. Resistance of extract-treated stakes to bio-deterioration for all the durability parameters decreased as leaching periods lengthened. Inorganic preservative components leached and showed less mass losses in a more consistent fashion than their extract-treated counterparts, especially *A. indica*. This study shows that chemical discharge from treated stakes should not be overlooked by the wood treatment industry. Larger treated woods for outdoor construction would leak fewer chemicals than stakes under laboratory conditions, field exposure of the stakes simulates their service performance.

Keywords Chemical retention · Leaching potential · Plant extract · Visual durability rating · Water-borne preservative

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Introduction

Decrease in availability of naturally durable timbers, coupled with their high costs, has resulted in immense application of wood preservatives formulated with toxic substances and designed to inhibit the activities of biodegraders (Eaton and Hale 1993), and increase resistance of non-durable woods against physico-chemical agents of wood damage (Singh 2010). Several wood preservatives introduced onto the market have not gained acceptance either because of their low efficacy and corrosiveness (Murphy 1990), or leakage and toxicity (Anon 2002). There are three inorganic types, each having its peculiar problems. These are: water-borne salts (e.g. chromate copper arsenate [CCA] and other alternatives) (FAO 1986; Anon 2002), oil-borne types (e.g. creosote and coal tar) and organic solvent types with biocides including Pentachlorophenol [PCP] and tri-*n*-butyltin oxide [TBTO] dissolved in non-volatile, non-polar organic or volatile solvents, which are the commonest and leave wood paintable (Eaton and Hale 1993; Desch and Dinwoodie 1996). Currently, extracts from organic sources including durable timbers (e.g. *Erythrophluem suaveolens* (Guill. & Perr.) Brenan (potrodom), *Azadirachta indica* A. Juss (neem) have been proven efficacious in the extension of the service-lives of treated non-durable timbers (Onuorah 2000; Swathi et al.

Published online: 12 July 2012

2004; Antwi-Boasiako and Abubakari 2008; Antwi-Boasiako and Damoah 2010).

CCA is effective, economical and commonly used but banned in several countries due to its toxicity (Anon 2002). Its non-preserving chromium component is a chemical fixing agent (Hopey 1998). Together with arsenic in the CCA formulation, these constituents have generated environmental impacts and health risks including diffuse capillary leak and cardiomyopathy resulting in shock, lung and skin cancers, hepatic necrosis, increased frequency of abortions, congenital malformations and other health implications (Anon 2009). Recently, CCA-treated wood is phased out for residential uses due to the potential health risks associated with leaching of the arsenic-laced preservatives (Fu et al. 2008). Although considered leach-resistant, small amounts of its components are lost during the service lives of a number of treated products (Murphy and Dickinson 1990; Lebow 1996; Stevanovic-Janezic et al. 2005). Thus, CCA efficacy requires a balance between having the components soluble enough to be effective against target organisms throughout the service-life of a wood product, and also having low enough solubility to resist leaching (Lebow 1996; Hingston et al. 2001). Creosote is also widely used for treatment and waterproofing of wood for commercial purposes since it is characterized by low water solubility. However, it is miscible with most hydrocarbon solvents (Swartz et al. 1995; Vilholth 1999; Anon 2004, 2005). It is applied by pressure to wood products primarily poles, foundation and marine piles, railroad ties and bulkheads, which become very resistant to mechanical wear (Anon 2011), and as a fungicide, insecticide, miticide and sporicide (Klyosov and Klesov 2007). Three types (1, 2 and 3), based on their physical properties such as liquidity or viscosity, exist (Betts 1991; Anon 1997). Currently, a low toxicity alternative, pigmented emulsified creosote (PEC) or Cleansote is developed (Safer Solutions 2011). The organic solvent type formulations include the commonly used non-leach resistant or non-fixed PCP. Its gravitational migration to the ground line region of poles provides a preservative reservoir, which is slowly depleted to the environment (Lamar and Dietrich 1990). Consequently, these types usually contain additives (e.g. waxes, oils and resins), which improve the water repellency of treated wood (Desch and Dinwoodie 1996). Although several extracts have been proven efficient against bio-degraders, their leach-resistance has never been examined. *E. suaveolens* extracts have been tested efficacious against three coleopteran pests (*Acanthoscelides obtectus, Prostephanus truncates* and *Sitophilus oryzae)*, termites and decay-fungi (Niber et al. 2009; Onuorah 2000; Antwi-Boasiako and Damoah 2010). Onuorah (2000) experimented with extract dosages between 8.009 and 96.11 kg/m^3 and established that between 48.056 and 96.11 kg/m^3 were effective in suppressing fungal attack. This means the unused bulky residues could be leached into the environment. Furthermore, *A. indica* bitter seed and leaf extracts are ideal insecticides against many pestiferous species, leaving beneficial insects and mammals unharmed. Its bio-active compounds include triterpenoids, phenolic compounds carotenoids, steroids and ketones. Tetranortriterpenoid azadirachtin is relatively abundant in the kernels and has much biological activity on various insects. It has received most attention as a pesticide because azadirachtin is a mixture of seven isomeric compounds (azadirachtin-A to -G). Azadirachtin-A has the highest quantity, while E is the most effective insect growth regulator (Verkerk and Wright 1993).

Extraction of any of these substances into media such as liquid (i.e., leaching) is a very important feature of preservative-treatment for wood in service. Hopey (1998) reported that about 20–50 % of CCA can seep out of wood when it is improperly applied, which causes their imperfect "fixing". This implies that the amount of chemicals leached into the environment may increase over time. Therefore, in ensuring their long term efficacy against target organisms, it is imperative that the leaching potential of all kinds of chemicals employed as wood preservatives is well established so as to alleviate their health and environmental impacts. This is against the backdrop that some chemicals including polycyclic aromatic hydrocarbons (PAHs) contained in greasy creosote, despite its efficacy and range of uses, have also shown acute and chronic toxicity to marine and land animals (Brooks 2000; Ozretich et al. 2000). Hence, creosote, for instance, is no longer regarded as universally acceptable for timber treatment due to the presence of minute amounts of highly toxic dioxins during its manufacture and handling. For CCA, the hazards associated with arsenic and chromium are more acute prior to impregnation, as fixation results in the formation of insoluble complexes in wood (Eaton and Hale 1993). These constituents have all generated apprehensions over possible health risks through leakage (Chou et al. 2007). While considering the hazards associated with conventional preservatives due to their potential leakage, the wood preservative-treatment industry has currently been promoting chemicals from organic sources to supplant the former. Information on the leaching potential of many of the organic preservatives is non-existent. However, their fullest utilization could be achievable if their leaching characteristics are also ascertained alongside the conventional types since leakages reduce the potency and long-term efficacy of wood preservatives and create environmental concerns amid their potential risks to aquatic and other life forms. This study sought to examine the leachability and termite resistance of CCA-, creosote- and two durable hardwood (i.e., *E. suaveolens* and *A. indica*) extract-treated *Ceiba pentandra* (L.) Gaertn. stakes in the field.

Materials and methods

Preparation of preservatives for impregnation of stakes

Azadirachta indica seeds and *E. suaveolens* bark were collected from the Kwame Nkrumah University of Science & Technology (KNUST), Kumasi-Ghana, in the semi-deciduous forest zone. They were cut into smaller pieces, air-dried to 12 % MC and milled with a Marlex electric mill into powder (40–60 mesh, i.e., particle size of 250–425 μm). Equal weight (3,000 g) of each powder was added to distilled water (1:10), stirred for 60 min. and allowed to settle for 48 h to ensure efficient removal of the extracts. The contents were decanted and sieved through 1 mm mesh. Each liquid extract was centrifuged (1,800×*g* for 60 min.) and the supernatant extract decanted from its precipitate. Concentration of each liquid was determined (i.e., dry powdered sample [g] in equal volume of distilled water [ml]) and standardized at 2 %. Besides, 2 % CCA was prepared, while creosote was employed at the manufacturer's specification [density = 0.920–0.970 (kg/m^3) at 20 °C; viscosity = approx. 5.0 centistokes at 40 °C (Anon 2004)]. *C. pentandra* stakes (500 × 50 × 25 mm) were sampled (from 35 to 120 growth rings from pith) from four matured, healthy round beams (2 m long × 1.5 m wide) harvested 50 cm above diameter at breast height (i.e., 1.3 m from the soil level) from the Juaso Forest District in the same forest zone. The stakes were air-dried to 12 % MC. Ten replicates, fully submerged in each prepared extract or conventional preservative (10,000 ml), were pressure-impregnated (at 124 °C and 1.2 bar for 3 h). The volume of each preservative chemical absorbed by their respective replicates was then determined. Ten other untreated replicate stakes (500 × 50 × 25 mm) served as controls. All stakes were conditioned at 25 °C and 65 % RH until equilibrium moisture content (EMC) of 12 % was reached.

Leachability of chemicals from treated *C. pentandra* stakes

Seventy replicates of each of the treated stakes with the various chemicals (i.e., CCA, creosote, *E. suaveolens* and *A. indica* extracts) were subjected to laboratory leaching conditions in four different glass troughs (20 l) filled with distilled water (10 l), which completely covered the stakes. Ten replicates were taken out of the respective troughs every 48 h and the water changed each time until 336 h (i.e., at 48, 96, 144, 192, 240, 288 and 336 h). Ten treated non-leached replicates served as controls (i.e., 0 h leaching). All the stakes were conditioned (at 25 °C and 65 % RH) and then air-dried until they achieved 12 % EMC.

Initial mass and hardness determination of *C. pentandra* stakes before field exposure

Mass and hardness properties of all the air-dried stakes were determined prior to the field or graveyard test to examine the effect of leaching of chemicals on the susceptibility of the treated stakes to bio-deterioration. The masses of all the stakes (i.e., untreated control, treated non-leached and treated leached) were taken. MCs of another set of three of each of these stakes were determined at a pre-set oven temperature of 105 ± 2 °C. Corrected oven-dry masses of their respective replicates were determined from their means, and were taken as initial masses of the stakes before impregnation and field exposure (Antwi-Boasiako and Damoah 2010). The hardness of each stake was also determined with wood density meter (Pilodyn 6 J [Proceq SA]) (Brunner and Grüsser 2006). The depth of penetration of its pin in each stake (i.e., 0 mm = very hard; 40 mm = very soft) was taken as its initial hardness.

Determination of durability of *C. pentandra* stakes using the graveyard test

Decay resistance of the leached stakes and the controls was determined at the Durability Test Site (200 m × 150 m) of the Department of Wood Science & Technology at the Faculty of Renewable Natural Resources (FRNR) Demonstration Farm of KNUST, which is dominantly colonized by subterranean termites. Stakes were inserted one-third their lengths in the ground and 50 cm from one another using Completely Randomized Design [CRD] (Plate 1). Regular inspection of stakes was made every 4 months for the assessment of deteriorating features. The level of termite activity, fungal rot and other damages to the stakes were determined using visual durability ratings provided by EN 252 classification (Anon 1989): 0 = no sign of attack, 1 = slight attack, 2 = moderate attack, 3 = severe attack and 4 = failure. After 5 years of field exposure, the stakes were brushed off of all debris and conditioned at 25 °C and 65 % RH for 120 days. The stakes were air-dried until to 12 % MC and re-subjected to hardness test to assess their extent of softness. The final hardness for each stake was determined and its hardness loss (%) calculated as:

$$\text{Hardness loss } (\%) = \frac{\text{Initial hardness} - \text{Final hardness}}{\text{Initial hardness}} \times 100$$

The stakes were oven-dried at 105 ± 2 °C and the mass of each stake monitored until it attained a constant mass, which was taken as its final mass. The mean masses for replicate stakes were determined and their percentage mass losses calculated according to Yamamoto and Momohara (2002) as:

Plate 1 *C. pentandra* stakes randomly inserted in the field at the FRNR demonstration farm at KNUST [NB: Termite-infested dead stump arrowed]

$$\text{Mass loss (\%)} = \frac{\text{Initial or corrected oven} - \text{dry mass} - \text{Final oven} - \text{dry mass}}{\text{Initial or corrected oven} - \text{dry mass}} \times 100$$

Results

Retention of preservatives in *C. pentandra* stakes

Fig. 1 shows that *E. suaveolens* extract was retained most in treated *C. pentandra* replicates followed by CCA then *A. indica* seed extracts, which are all water-borne. However, the lowest retention was reported for stakes treated with the oil-borne creosote. Differences in the level of retention for the organic and inorganic preservative-treated stakes are significant ($p < 0.05$).

Resistance of leached *C. pentandra* stakes to bio-deterioration

Visual durability rating

The non-treated controls recorded the maximum visual durability rating of 4 (i.e., were most attacked and degraded) as well as the treated stakes exposed to 336 h of leaching. However, some few stakes treated with CCA and creosote recorded a rating of 3 (Fig. 2). The non-leached control stakes (i.e., 0 h of leaching) performed best in the field and resisted termite attack most (i.e., rating = 1) except for those treated with *A. indica* (i.e., 3). Although visual durability rating trend was not consistent, there was the general tendency for it to increase, as the treated stakes were soaked longer. CCA-treated stakes had the lowest rating followed by those by *E. suaveolens*, creosote and *A. indica*. For treated stakes exposed to the longest leaching period (i.e., 336 h), those impregnated with CCA performed better and resisted more degradation (rating = 3) than those treated with other chemicals (rating = 4).

Hardness loss

The degree of hardness loss was lowest for the treated non-leached controls (i.e. 0 h leaching) for all the preservative chemicals. Hardness loss for the chemically treated stakes ranks in the increasing order of: CCA < Creosote < *E. suaveolens* < *A. indica*. For the leached stakes, the trend for hardness loss for each chemical was a bit inconsistent. Yet, after field exposure, stakes exposed to the longest leaching periods were the softest, especially for *A. indica*-treated stakes soaked for 288 and 336 h. *E. suaveolens*-treated stakes became also softer than those treated with the two conventional preservatives (Fig. 3; Table 1).

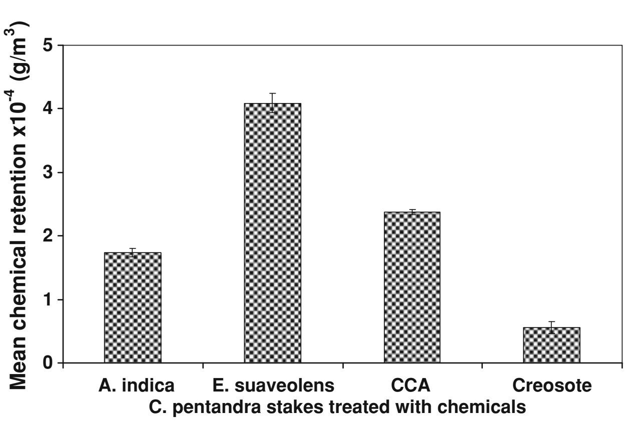

Fig. 1 Chemical retention for *C. pentandra* treated stakes. *Bars* ± SE ($n = 10$)

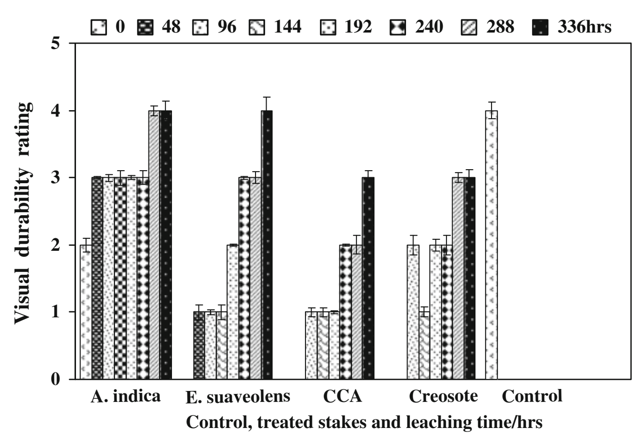

Fig. 2 Visual durability ratings for *C. pentandra* treated stakes under different leaching periods. *Bars* ± SE ($n = 10$)

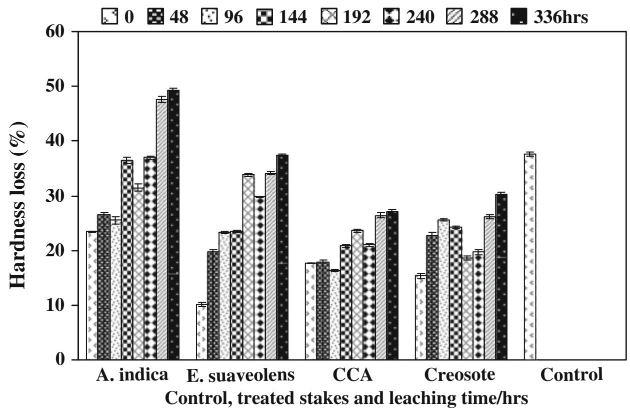

Fig. 3 Hardness losses for *C. pentandra* treated stakes under different leaching periods. *Bars* ± SE ($n = 10$)

Mass loss of stakes

Generally, mass loss for all the stakes ranks as: CCA < Creosote < *E. suaveolens* < *A. indica* < Untreated control. Mass losses for the non-leached treated stakes (i.e., 0 h) performed better than all those subjected to leaching (Fig. 4; Table 1). The mass loss trend for the leached stakes is also in the following increasing order of the chemicals used in the treatment: CCA < *E. suaveolens* < Creosote < *A. indica*. Their mass losses were consistently related with increasing periods of leaching. For stakes exposed to 336 h, the resistance to degradation by CCA-treated stakes was greater than by those treated with creosote, *E. suaveolens* and *A. indica*.

Discussion

Retention of extracts by *C. pentandra* stakes

Preservative-treated wood is an economical, durable building material and a likely choice for construction projects in National Parks and other public lands. It is expected that chemicals for treatment do not pose a threat to people or the environment. Thus, to avoid leakages of the toxic types, Lebow (1996) stressed on efficient treating factors such as good preservative formulation, processing techniques, preservative retention and post-treatment conditioning factors. An efficient chemical retention is a pre-requisite in preventing chemical leaching. Retention of the less viscous, water-borne preservative chemicals (i.e., *E. suaveolens* bark and *A. indica* seed extracts and CCA) depends on their high absorption and good bonding capacities to the cell walls of the stakes than the greasy creosote. For effective retention, chromium acts as a chemical fixing agent of CCA chemicals in wood by binding them to cellulose and lignin through chemical complexes (Hopey 1998; Anon 2010). The greatest retention of *E. suaveolens* extract could signify its fixation into the stakes and the likely reaction between its chemical constituents and those of wood. Unlike the water-borne types, the viscous nature of creosote made its impregnation into the wood cells much difficult. Thus, it could be stressed that variation in retention for the four preservatives could not only be attributed to their chemical composition but also other factors including their viscosity,

Table 1 Hardness and mass losses of *C. pentandra* stakes under different leaching periods

Leaching times (h)	Treatment with preservative chemical and control				
	A. indica extract	*E. suaveolens* extract	CCA	Creosote	Control
Hardness loss (%)					
0	23.49 ± 0.11	49.24 ± 0.35	17.67 ± 0.01	15.35 ± 0.40	37.60 ± 0.31
48	26.50 ± 0.49	19.71 ± 0.41	17.91 ± 0.26	22.81 ± 0.43	
96	25.50 ± 0.58	23.30 ± 0.20	16.35 ± 0.19	25.53 ± 0.20	
144	36.50 ± 0.49	23.50 ± 0.22	20.81 ± 0.30	24.23 ± 0.23	
192	31.50 ± 0.60	33.80 ± 0.26	23.65 ± 0.25	18.61 ± 0.31	
240	37.01 ± 0.29	29.90 ± 0.11	21.01 ± 0.32	19.67 ± 0.43	
288	47.59 ± 0.63	34.10 ± 0.29	26.41 ± 0.41	26.11 ± 0.37	
336	49.24 ± 0.35	37.41 ± 0.21	27.00 ± 0.43	30.23 ± 0.51	
Mass loss (%)					
0	23.68 ± 1.31	14.74 ± 0.41	12.79 ± 0.52	16.33 ± 0.81	93.91 ± 7.12
48	47.90 ± 1.28	16.92 ± 1.22	13.51 ± 0.70	17.99 ± 0.72	
96	50.36 ± 2.22	28.44 ± 0.28	12.84 ± 0.53	21.40 ± 0.69	
144	51.88 ± 0.32	29.70 ± 0.84	15.13 ± 0.81	22.58 ± 0.44	
192	54.22 ± 1.23	30.54 ± 0.73	17.08 ± 0.39	24.78 ± 0.40	
240	57.32 ± 0.97	30.74 ± 1.32	17.86 ± 1.04	26.51 ± 0.79	
288	61.62 ± 1.45	34.58 ± 1.32	19.93 ± 0.78	30.38 ± 0.75	
336	75.44 ± 1.52	38.97 ± 1.41	21.31 ± 1.31	33.17 ± 0.91	

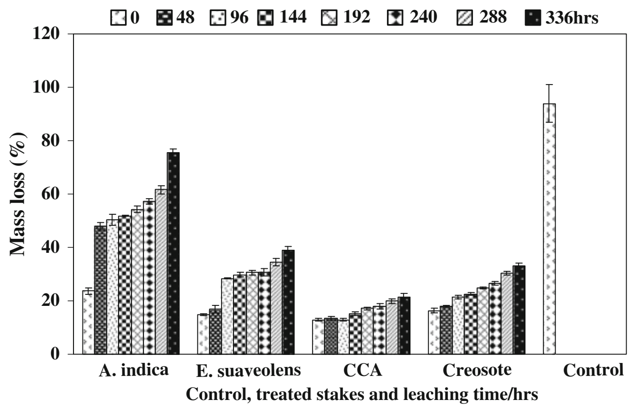

Fig. 4 Mass losses for treated stakes under different leaching periods Science of the Total Environment *Bars* ± SE ($n = 10$)

which also influences their leachability. Dawson-Andoh et al. (2002) asserted that losses of all CCA type C components from two Appalachian hardwoods and southern pine depended on the plant species, solvent system used in pre-extraction of the secondary metabolites and particularly the retention levels of the chemicals. Thus, the retention gradient for the preservatives (i.e., *E. suaveolens* > CCA > *A. indica* > creosote) could affect their leaching potential. However, Lebow (1996) observed that besides the influence of chemical retention, which is an important aspect of wood preservation, leaching in wood increased through exposure to water flow, water-soluble organic acids and low pH. The retention level of effective preservative varies with the intended use of the product. The varying environments to which wood is exposed (such as in harsh conditions) is important, as it affects greatly its susceptibility to degradation. It is therefore imperative that chemicals should be well retained in less durable woods and those employed in harsh conditions.

Durability assessment of leached *C. pentandra* stakes

Visual durability rating

This rating evaluated the degree of attack of the non-durable timber by bio-degraders including termites (Anon 1989), which are predominantly of the subterranean types at the test-site (Antwi-Boasiako 2004). The ranking depended on the efficacy and leach-resistance of the preservatives. As a result, CCA- and creosote-treated leached and non-leached stakes showed little signs of attack and had the lowest ratings. The results are unsurprising: creosote contains tar acids (e.g. phenols), which kill fungi, insects and other wood-destroying organisms (Sullivan and Krieger 2001). It is permanent in wood, has 'heavy' oils, which protect it against moisture and make it fairly repellent, reduce leaching (Ibach 1999) as well as damage by solar radiations (Anon 2004). Consequently, pressure-injected creosote does not easily exude out of wood to any appreciable extent in land use, and also for properly treated pilings and timbers in the marine environment. Since chromium is primarily a chemical fixing agent and enables CCA to resist leaching of its constituents in wood (Lebow 1996; Hopey 1998), it was expected that its copper would protect *C. pentandra* stakes against decay-fungi and bacteria, and the arsenic against the termites in the field. The fixing activity of chromium contributed to reduce the leaching rate for CCA-treated stakes during the initial periods of soaking, which was depicted by their lower visual durability ratings than for those of creosote except when the stakes were soaked for longer periods, especially at the 336 h. Hickin (1975), Hopey (1998), Cooper et al. (1997) and Cooper et al. (2001) made similar observations when treated samples from different wood species were exposed to wet environments. Nevertheless, stakes treated with the water-borne extracts performed poorer in the field and had greater ratings than CCA even though *E. suaveolens* bark extract was retained in the stakes more than CCA. Similar to the observations made by Antwi-Boasiako and Damoah (2010), *E. suaveolens* extract gave better protection than that of *A. indica*. Thus, visual durability ratings for the leached *A. indica* extract-treated stakes exhibited the greater tendency to increase than those of *E. suaveolens* when they were soaked for a long time before the field test.

Hardness loss

Wood hardness is inversely related to damage intensity by termites (Bultman et al. 1978). *C. pentandra* has light weight with low density and strength characteristics (Oteng-Amoako 2006; Anon 2008). The untreated controls were therefore heavily attacked and recorded the greatest hardness losses. Stakes treated with the inorganic preservatives were least attacked and did not lose much hardness (Bultman et al 1978). Wegner et al. (1989) reported that application of water-borne preservatives influences wood hardness since it soaks its cells, removes components of the lumina and interstitial materials (e.g. extractives) and causes cell disintegration and eventual loss of hardness. Although organic acids are effective in extracting CCA components from wood, an experiment conducted on poles in service by Cooper et al. (2001) also showed that natural water samples resulted in higher leaching of all components of CCA than by distilled water. However, longer exposure of the treated stakes to water removed several of the CCA components to increase their susceptibility to hardness loss and degradation. Small hardness losses for the CCA- and creosote-treated stakes did not show any relationship with the period of leaching alone but also to conditions external to the laboratory tests. Thus, their exposure to higher temperatures of the dry tropical harmattan weather (from November to March), which alternates with the wet season (April to July as well as September and October) over the five-year period, might contribute to affect their rigidity (Hickin 1975). Significant differences ($p < 0.05$) between the hardness losses for the non-leached treated samples (i.e., 0 h) emphasize the comparative effectiveness of the efficacy of the extracts with the inorganic preservatives (i.e., between *E. suaveolens* extract and CCA as well as *A. indica* extract and creosote). However, continuous soaking made *A. indica* and *E. suaveolens* treated stakes lose much hardness and became softer than those treated with inorganic preservatives. Differences in hardness losses for the treated stakes from 240 to 336 h of leaching show that, to some extent, the chemicals are all leachable. Hopey (1998) confirmed that: "Even CCA slightly leaches out of wood despite its fixing agent".

Mass loss

Mass loss assessment also revealed that the wood-degrading organisms removed the greater amount of materials from the untreated controls than the treated. This is not unexpected. Oteng-Amoako (2006) established that *C. pentandra* is non-durable, while an anonymous author (2008) also described its natural durability as low. Once again, the non-leached extract-treated stakes lost more masses than their inorganic-treated counterparts. Since *E. suaveolens* bark has proven more efficient than *A. indica* (Niber et al 2009; Antwi-Boasiako and Damoah 2010), *A. indica* treated replicates lost greater masses. The degree of protection achieved by wood preservative depends on its effective chemicals (Ibach 1999). CCA and creosote, known to be efficient wood preservatives (FAO 1986; Lebow 1996), could impart more improved protection to the stakes than the plant extracts. However, CCA imparted more resistance to the stakes than the water-repelling creosote. Generally, mass losses exhibited by both the conventional preservatives and the extracts showed a great relationship with the leaching periods. Stakes exposed to prolonged leaching lost greater masses in the field than those leached for shorter times. This could be that the protection levels of chemicals for the stakes soaked longer reduced more than those exposed to shorter times of leaching. Controversy, however, exists for the leaching performance of inorganic preservatives such as CCA. Lebow (1996) and Hingston et al. (2001) reported that they are most widely used and favoured for lumber treatment because they are inexpensive, leave wood in a dry, paintable surface, and particularly bind to wood and make it relatively leach resistant through complex chemical reactions. However, Murphy and Dickinson (1990), Hopey (1998) and Fu et al. (2008) demonstrated that small amounts of copper, chromium and arsenic are lost during the service lives of several CCA-treated wood products. Dawson-Andoh et al. (2002) observed losses of all CCA Type C components from sapwoods of two Appalachian hardwoods, yellow-poplar, red oak, and southern pine, while Stevanovic-Janezic et al. (2005) reported immense CCA leaching of arsenic component from oak, red maple, beech, aspen, basswood and yellow poplar. Shalat et al. (2006) indicated that CCA has been the subject of an EPA evaluation under provisions of the Federal Insecticide, Fungicide, and Rodenticide Act, including Scientific Review Panels and a risk assessment for residential settings and its potential exposure to children in playgrounds and home decks. They reported that the arsenic can be released into soil over time by rainfall through prolonged diffusion to wood surface from the chemical imbedded in its interior, and the soil around CCA-treated wood primarily in the form of As(V) for new wood, and both As(V) and As(III) for aged wood and stressed these are the most toxic arsenic forms to man. Thus, prolonged soaking of CCA-treated stakes indicates that CCA might consistently lose some of its components, hence, their susceptibility to bio-deterioration. Brooks (1996) also observed the release of creosote components from treated wood to surface water and detected elevated PAH levels in sediments 1.8–3.0 m downstream from wooden components of bridges. Swartz et al. (1995), Vilholth (1999) and Anon (2004) described creosote as having low water solubility. This explains the slight but consistent loss of its components, which led to small reduction in performance of the treated stakes. Similarly, chemicals from the water-borne extracts of *E. suaveolens* and *A. indica* leached most with time. Leaching of chemicals from the conventional preservatives and the extracts is a threat to the environment. Lebow (1996) reported speciation and mobility of leached components whose environmental fate need proper investigation and the assessment of the risk:benefit ratio of using treated wood as a construction material. Extracts from organic sources are now commonly employed to treat wood (Onuorah 2000). Their active ingredients need thorough analysis so as to establish fully their non-fixed chemicals and ecological impacts. These would require appropriate commercial water-repellents for above-ground applications so as to minimize wetting and subsequent leaching of their components (Taylor and Cooper 2003), or by applying common exterior coatings to timber (Lebow 2001). Leaching under laboratory conditions does not often demonstrate the entire chemical discharges that occur in service conditions, which are difficult to control. However, this information is most applicable as a useful indicator since it closely simulates leaching of chemicals from treated wood in service. Widespread use of wood preservative chemicals has found a number of them leach out to contaminate water, soil, plants and animals to the extent that small dosages often cause ecological risks and raise health concerns. It is therefore imperative that chemical treatment should be aimed at markedly reducing leachate content from treated wood products. It is commended this could be accomplished by the normal or secondary treatment with water repellents including borate complex widely used in timber preservation (Baysal et al. 2006), ammonium and other effective complexes or following impregnation.

Conclusions

Erythrophleum suaveolens and *A. indica* extracts were effective in protecting *C. pentandra* from degradation. Leaching of the chemicals influenced the susceptibility of the treated stakes to bio-deterioration. All the preservatives lost some chemicals, especially the extracts, as their treated stakes were exposed to longer leaching times. Accordingly, this resulted in decreased resistance of the leached stakes to bio-degradation for all the durability parameters examined. However, components of the inorganic preservatives, which leached steadily less than the extracts, showed more consistent mass losses of their treated stakes than those of the extracts. Extracts from the very durable timbers would therefore be more effective indoors than for outdoor applications or in wet conditions. When treated wood for construction is in contact with water, the potential exists for the toxic preservatives to leach from it. To increase the wood preservative-chemical resource base, the leaching potential of extracts from extensive organic sources would need thorough investigation so as to prove their efficacy and establish their health anxieties and environmental impacts. The mechanical restriction of access of water into wood by impregnating it with water repellent preservative-chemical complexes to limit the ingress of water and leachate content after treatment is therefore significant.

Acknowledgments We sincerely acknowledge the assistance from Staff of the Department of Wood Science & Technology Graveyard Test Demonstration Plot at the Faculty of Renewable Natural Resources Research Farm [KNUST, Kumasi-Ghana]. We also thank Miss Agnes Ankomah Danso (Biometrician, Crops Research Institute [CRI] of the Council for Scientific and Industrial Research [CSIR], Kumasi) for the statistical guidance.

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