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Evaluation of the Durability of *Petersianthus macrocarpus* (Essia) and Its Preservative Impregnated and Surface Finished Wood

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Abstract

In Ghana, there is high demand for the few naturally durable commercially utilized species (CUS), which are threatened with extinction. The promotion of the numerous lesser-utilized species (LUS) and lesser-known species (LKS) requires urgent and critical evaluation to augment the severely depleted CUS. Some timber species are naturally durable and can resist biodegradation due to their extractives and lignin. However, some LUS, such as *Petersianthus macrocarpus* (Essia), which are noted for their non-durability, could be impregnated with preservatives and/or surface finishes to enhance their durability. In this study, heartwood and sapwood of *P. macrocarpus* were used as the study wood, while *Ceiba pentandra* (Onyina) served as the control samples. The mean moisture content of samples (2 cm cubes) was heartwood (12.78%) < sapwood (13.18%) < Ceiba (13.46%). Samples (30 × 2 × 2 cm) were impregnated with CCA-B (45 g) of concentration using a full-cell method. Three surface finishes—varnish, shellac, and lacquer (200 ml)—were each diluted (mixed) with 300 ml of thinner for varnish and shellac, while turpentine was used for lacquer, to a viscosity measured using a 12 s/DIN cup 4 mm/20° (ASTM D1200 Ford), and applied using a bristle brush after the preservative treatment. The samples were buried at half their length at 25 cm intervals in a Completely Randomized Design (CRD) at the "graveyard". Thirty (30) samples for each treated and non-treated group of both timber species were used in this study. In addition, visual evaluations of the samples were conducted, focusing on the post-treatment weight and weight loss after 12 months of exposure at the "graveyard".

Keywords

Petersianthus macrocarpus, Impregnated, Graveyard, Full-Cell, Treatment, Durability

1. Introduction

Wood is admired for its beauty, durability, and strength. It is a natural, renewable structural material which is liable to attack by insects and other wood-degrading organisms at ground and/or above ground levels [1] [2]. A few tropical hardwood (scarlet star) species, such as *Entandrophragma cylindricum* (Sapele), *Entandrophragma angolensis* (Edinam), *Khaya grandifoliola* (Mahogany), *Terminalia superba* (Ofram), *Triplochiton scleroxylon* (Wawa), and *Melicia excelsa* (Odum), are noted to be durable and resistant to attack by bio-degraders, based on their extractives such as lignans, flavonoids, and terpene acid content [3]-[5].

As a result, there is high demand for and/or extinction of these few naturally durable and commercially utilised species (CUS) for the production of high-quality bridges, garden furniture, and other wood structural purposes [5] [6]. Consequently, the high demand for the few naturally durable timbers has also led to some timber industries being shut down or unable to function fully [3].

Durability of wood is its inherent ability to resist attack by bio-degraders such as insects, fungi, and marine borers [7]. Therefore, it is prudent to consider the durability of wood used for constructional purposes. In Ghana, LUS such as *Albizia ferruginea* (Awiemfosamina), *Cola gigantea* (Watapuo), *Petersianthus macrocarpus* (Essia), *Sterculia rhinopetala* (Wawabima), *Antiaris toxicaria* (kyenkyen), *Sterculia oblonga* (Ohaa), and Dahoma are not much exploited for the production of wood products because of their non-durability [8] [9]. LUS are rather exploited for purposes such as fuel wood, high-quality charcoal, food contact cookware, and wood products where high durability is not much required, such as crates [5] [8]. Therefore, to increase the exploitation, durability, and promote the use of LUS for furniture and other structural purposes, it is necessary for the LUS to be enhanced (treated) for use [8]. LUS could be treated with preservative and surface finish to enhance or increase its durability, dimensional stability, and usability in order to extend its service life [10]-[12].

According to Sreeja (2008) and Lahtela (2014), wood preservative chemical is used on wood either by pressure or non-pressure treatment methods [13] [14]. Preservatives are hazardous chemicals used to treat wood to prevent any form of attack by bio-degraders [14] [15].

Preservative-treated wood is much preferred and economical for the production of furniture and other wood items depending on the use parameters needed.

Thus, it reduces the cost of replacement and increases resistance to bio-degraders on treated wood compared to their untreated types [16] [17]. Preservatives are classified into three main categories: Oil-borne types (e.g., tar oil and creosote), Organic solvent types (e.g., synthetic pyrethroids and benzene hexachloride [BHC]), and Water-borne types (e.g., zinc chloride, boric acid and borax, Chromated Copper Arsenate [CCA], Ammoniacal Copper Zinc Arsenate [ACZA]) [4].

Based on the level of toxicity of some preservatives such as Chromated Copper Arsenate (CCA), some countries such as the UK, Germany, Japan, and Canada have banned their use [8] [13] [18]. Although preservatives should be toxic in order to impart resistance to bio-degraders such as wood borers, some preservatives are very dangerous to the health of users and contaminate food and the environment [15] [19].

Therefore, care should be taken in the selection and use of a wood preservative [20].

Hence, adequate knowledge of the durability of wood is of great importance to carpenters, engineers, and architects to enable the efficient use of a particular wood. *P. macrocarpus* is classified as moderately durable and a LUS which could be export-oriented from Ghana [3] [21]. However, it has not been adequately exported, utilized for furniture production, or used as a structural material in Ghana.

The traditional uses have been limited to the manufacture of high-quality charcoal, fuel wood, plywood, food, and contact cookware. Despite numerous studies on *P. macrocarpus*, information on the durability of CCA-B impregnated and surface-treated *P. macrocarpus* is scanty or scarce, to ensure sustainable management, exploitation, and utilization of the timber. This study is aimed at determining the durability of CCA-B impregnated and surface-treated *P. macrocarpus* by field assessment ("Graveyard test").

2. Materials and Methods

P. macrocarpus was selected for the durability test since it is one of the abundant and lesser-utilized species in Ghana [3], while *C. pentandra* (Onyina) was used as a control for the test [6]. Two stems (70 - 90 cm diameter, 45 - 50 years) each of *P. macrocarpus* and *C. pentandra* were felled and sawn across the bole at diameter at breast height (DBH) of 70 cm using a chain saw machine. The boles were numbered for easy identification and transported to Log and Lumber Limited, Ghana. The boles were quarter-sawn to prevent cupping using a vertical band mill and were transported to the Department of Wood Science and Technology Workshop at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.

The planks were air-dried for three months and further processed into heartwood and sapwood; 2 [radial] × 2 [tangential] × 30 cm [longitudinal] (BS 373, 1957) (**Figure 1(A)** and **Figure 1(B)**). *C. pentandra* was also sawn; 2 (radial) × 2 (tangential) x 30 cm (longitudinal), but not into heartwood and sapwood, due to the indistinguishable characteristics of its heartwood and sapwood (**Figure 1(C)**). Small clear defect-free samples (visually assessed) of heartwood and sapwood were selected for the study, but pieces with defects were rejected.

The two wood species were obtained from a concession of forest reserves within the boundaries of longitude 1˚15'E and 1˚23'W and latitude 6˚39'S and 6˚44'N (moist evergreen forest) at Sui in Nsawora near Sefwi Wiawso, Western Region [22].

Wood samples were tied in polythene sheets to avert moisture loss after initial weighing (Wt. 1) and oven-dried at 103˚C ± 2˚C to attain a constant weight. Orbital and disc sanders with 60 and 120 aluminium oxide sandpaper were respectively used to remove rough surfaces from the samples to achieve a smooth surface (Figure 2). A bristle brush and a clean rag were used to wipe off dust from the samples.

Figure 1. Samples of heartwood (A), sapwood (B), and control (C) stacked to air-dry.

Figure 2. Sanding of samples using a disc sander (D) and an orbital sander (E).

Samples were further impregnated with CCA-B (45 g) of concentration (40 g) at Busi and Stephenson Treatment Plant at Kaasi, Kumasi. Samples were air-dried in a polythene sheet after impregnation to allow for adequate fixation of preservative for two days. Weights of samples (Wt 2) after treatment were recorded. The samples were dispersedly arranged according to their species to air-dry for 5 days (Figure 3(F) & Figure 3(G)). Three surface finishes (varnish, shellac, and lacquer) were each applied to the set of CCA-B treated heartwood, sapwood, and control samples. Varnish and shellac (200 ml) were mixed with 300 ml of turpentine, and lacquer was mixed with thinner to a viscosity of 12 s/DIN cup 4 mm/20˚ using the Viscosity Cup Type FB.10 in accordance with ASTM D1200 (Ford).

Figure 3. Sapwood (F) and Heartwood (G) air-dried after CCA-B impregnation to air-dry.

The finishes were diluted (prepared) to the expected viscosity level at BOMPLEX Plywood Manufacturing Ltd at Ahinsan, Kumasi, Ghana (Figure 4(H)). The preservative-treated samples were placed horizontally on stickers, and each surface finish was applied liberally on each set of samples using a bristle brush (**Figure 4(I)**). The surface finish was applied on the set of samples in accordance with the manufacturers' recommendations and ASTM-D 3023: 1988 [23]-[25]. The samples were air-dried at room temperature for 2 hours. A second coat was applied, and samples were air-dried for two days to ensure equal adherence and adequately dry surfaces of the samples [25].

Figure 4. Sapwood (H) and Heartwood (I) air-dried after CCA-B impregnation.

Field (Graveyard) Test

The treated and non-treated samples were initially weighed (Wt 1) to the nearest 0.01 g of accuracy before the samples were sent to the field. The samples were randomly inserted vertically into the soil at half their length (15 cm) at an interval of 25 cm on a 50 m^2 test plot prone to termites for 12 months (**Figure 5**).

Periodic observations were made every three months to ascertain the rate of destruction and infections by bio-degraders and weathering. The samples were carefully exhumed after the field exposure of 12 months and all debris was wiped off with a bristle brush. The samples were air-dried to 12% - 14% mc and their final weights (Wt. 2) were recorded. One hundred and eighty (180) samples were used in this study. The percentage mass losses of each sample were calculated on air-dried weight instead of oven-dry weight using the formula in Equation (1).

$$\%\ \text{Weight loss} = \frac{\text{Wt1} - \text{F}}{\text{Wt1}} \times 100\% \tag{1}$$

Where Wt1 is the weight before field insertion (initial weight), F is the final weight after field insertion [12] [26]. The durability of samples was visually assessed on a four-point scale in accordance with EN 252:1957 (**Table 1**).

Figure 5. Samples inserted in soil of the test field.

Table 1. Visual rating codes for field (Graveyard) tests.

Classes (VR)	%Weight losses	Description of %Weight losses
1	0% - 5%	Slight attack (Durable)
2	6% - 10%	Moderately durable
3	11% - 40%	Severe decay (Non-durable)
4	41% - 100%	Total decay (Failure)

VR Visual rating. Source: Quartey (2009); [5]; [13].

3. Results

The mean percentage weight losses for heartwood treated with both the CCA-B and surface finish ranked in ascending order as: CCA-B and shellac treated heartwood (8.79%) < CCA-B and lacquer treated heartwood (9.11%) < CCA-B and varnish treated heartwood (9.38%) < non-treated heartwood (20.02%) (**Figure 6**). The sapwood treated with CCA-B and surface finish attained weight losses in ascending order as: CCA-B and varnish treated sapwood (11.36%) < CCA-B and shellac treated sapwood (14.28%) < CCA-B and lacquer treated sapwood (15.18%) < non-treated sapwood (21.88%) (**Figure 6**).

The percentage weight loss for sapwood treated with only CCA-B and sapwood samples treated with only the surface finish were also ranked respectively as: only CCA-B treated sapwood (24.96%) < only varnish treated sapwood (58.63%) < only shellac treated sapwood (61.48%) < only lacquer treated sapwood (61.77%) (**Figure 7**). The *C. pentandra* samples treated with both CCA-B and surface finish had their mean percentage weight loss ranked as: CCA-B and shellac treated *C. pentandra* (72.07%) < CCA-B and varnish treated *C. pentandra* (73.39%) < CCA-B and lacquer treated *C. pentandra* (74.66%).

The mean percentage weight loss for the non-treated heartwood, sapwood, and *C. pentandra* samples was ranked in increasing order as: non-treated heartwood (20.02%) < non-treated sapwood (21.88%) < non-treated *C. pentandra* (74.98%), respectively.

The termite destruction on heartwood treated and varnished (M), heartwood treated and shellacked (N), heartwood treated and lacquered (O), non-treated heartwood (P), sapwood treated and varnished (Q), sapwood treated and shellacked (R), sapwood treated and lacquered (S), non-treated sapwood (T), and *C. pentandra* (U) after 12 months of field (graveyard) test (**Figure 7(J)**, **Figure 7(K)** and **Figure 7(L)**). Mean percentage weight losses with their associated error bars for the treated and non-treated samples (**Figure 6**).

Legend: PMHV = heartwood treated and varnished, PMHS = heartwood treated and shellacked, PMHL = heartwood treated and lacquered, PMH = heartwood non-treated, PMSV = sapwood treated and varnished, PMSS = sapwood treated and shellacked, PMSL = sapwood treated and lacquered, PMS = sapwood non-treated, CPV = *C. pentandra* treated and varnished, CPS = *C. pentandra* treated and shellacked, CPL = *C. pentandra* treated and lacquered, CP = *C. pentandra* non-treated, OCCA = sapwood only preservative treated (CCA-B), OV = sapwood only varnished, OS = sapwood only shellacked, OL = sapwood only lacquered.

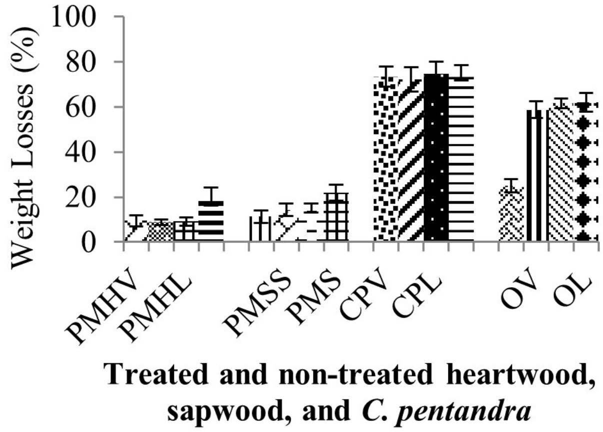

Figure 6. Weight Losses (%) of heartwood, sapwood, and control samples.

Figure 7. Termites' destruction on heartwood (J) sapwood (K), and control samples (L) after 12 months of field exposure (graveyard) test.

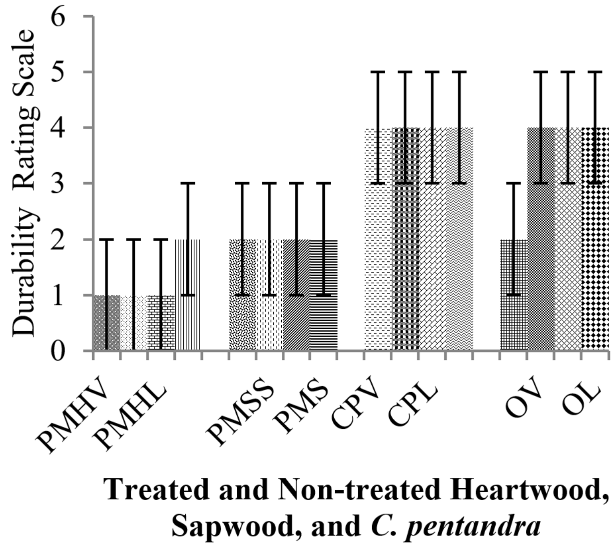

Figure 8. Visual rating of attack on heartwood, sapwood, and *C. pentandra*.

Table 2. ANOVA for durability tests of samples.

Source of variation	d.f	s.s	m.s	v.r	F pr.
Rep stratum	2	4.436	2.218	0.97	
Rep. Unit stratum Timber Species	1	5.558	5.558	2.43	0.150
Radial sections	2	10.629	5.314	2.33	0.150
Timber Species Radial	2	0.859	0.429	0.19	0.831
Residual	10	22.842	2.284		
Total	17	44.325			

4. Discussions

Durability test is expressed on the basis of mean percentage weight loss and visual rating of the treated and non-treated samples of the heartwood, sapwood, and *C. pentandra*. After 12 months of the durability test, *C. pentandra* had the highest mean weight losses, which ranged from 72.07% to 74.98%, and was therefore described as non-durable and was visually rated scale "3" (**Figure 8**). The higher the mean percentage weight losses and visual rating of attack on samples, the lower the durability and service life of the samples (EN 252 (2014)).

The treated heartwood exhibited the highest durability and was described as: Durable and was visually rated as "1" (**Figure 8**). However, the non-treated heartwood was described as: Moderately durable according to its mean percentage of weight losses and visual ratings (**Figure 8**). The destruction and loss of weight could be due to the absence of any form of treatment on the non-treated heartwood.

The treated and non-treated sapwood obtained higher mean percentage weight losses than the heartwood and was described as "Moderately durable" and given a visual rating of "2". The sapwood treated only with the preservative (CCA-B) was also described as moderately durable and rated "2" (**Figure 8**). The sapwood treated only with surface finishes was described as non-durable and rated as “3”. This could also be due to the absence of preservative treatment on them. There was a significant difference between the mean percentage weight losses (%WL) and the durability of heartwood and sapwood ($P < 0.05$) (**Table 2**).

Characteristically, the outcome between the heartwood and sapwood confirmed the fact that sapwood is more permeable (porous), which makes it easy for sorption and adsorption of moisture; hence, there is a higher loss in weight than in the heartwood. The differences between the mean percentage weight losses for the heartwood and the sapwood together with the *C. pentandra* samples could be attributed to variations in the proportions of the fibres, vessels, and rays of the wood cells.

According to Haygreen and Bowyer (1996) and Rowell (2005), wood fibres with thicker cell walls are common in denser woods [27] [28]. Such woods tend to contain a higher proportion of fibres, which contributes to greater durability. This is because their dense structure restricts gas diffusion, resulting in reduced oxygen availability that limits the growth and activity of wood-degrading organisms. Thus, heartwood and sapwood of *P. macrocarpus* have thicker fibres than in *C. pentandra*. Hence, the treated heartwood was durable, followed by the sapwood, whereas *C. pentandra* with less thick fibre was non-durable.

The preservative and surface treatment of the samples could also be attributed to the cause of the significant variation within the set of samples. Hence, preservative and surface treatment have increased the durability of heartwood and sapwood. This confirms the fact that both non-treated heartwood and sapwood had higher mean percentage weight losses than their treated counterparts.

The high rate of deterioration of *C. pentandra* samples could also be due to the high zone of termite activity at the site, since *C. pentandra* is very susceptible to termite attack and deterioration [29]. The durability rating shows that the treated heartwood is durable and its sapwood is moderately durable, but *C. pentandra* was non-durable within a moisture range of 12% - 15%. However, the sapwood mean percentage weight losses in this study were also consistent with those of Khaya ivorensis (Mahogany) [5]. It is therefore recommended that treated and surface-finished heartwood and sapwood of *P. macrocarpus* species be used for the manufacture of items at both ground and above-ground contact.

The preservatives and each of the three surface finishes could influence the durability of the wood and make the wood impermeable to biodegraders.

5. Conclusions

Mechanical and durability properties are major characteristics for the selection and demand of wood species in the manufacturing industries. This is in regard to the minimal or reduced cost of future maintenance and replacement of products. Hence, due to the declining quantities of traditional timbers, other available LUS timber species with comparable qualities, such as durability, strength, and beauty (including *P. macrocarpus*), could substitute for the endangered traditional timbers to ensure an adequate wood supply. Nonetheless, traditional timber species (*K. ivorensis*, *E. cy-*

lindricum, *P. elata*, and *M. excelsa*) are still in high demand in the manufacturing industries. To increase the use of LUS, adequate information regarding their strength and durability should be made available to manufacturing industries.

To meet the target of future demand for wood items, it behooves furniture manufacturing industries to step up efforts in the promotion and utilization of LUS. Therefore, to increase the utilization of LUS, information on a constant supply of LUS wood, their availability, strength, and durability properties could be made available to furniture manufacturing industries. Preservative treatment of LUS could improve their mechanical and durability properties, and they could be used as a substitute for the traditionally durable hardwoods.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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