EFFECT OF PRESERVATIVE TREATMENTS ON RETENTION AND STRENGTH PROPERTIES OF *OXYTENANTHERA ABYSSINICA, OLDEANIA ALPINA*, AND *BAMBUSA VULGARIS*

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Abstract
Oxytenanthera abyssinica, Oldeania alpina, and Bambusa vulgaris bamboo were treated with Boric-borax acid, Tanalith E3463 and Crude Lake salt using pressure and soaking impregnation methods. Comparisons were made in the preservative retention, compression strength and static bending strength between preservative-treated and untreated individual and across the bamboo species. The preservative retention varied across the bamboo species, with *O. alpina* retaining 15.7% more preservative, followed by *B. vulgaris* and *O. abyssinica*. The pressure-impregnated samples retained 16.4% more preservatives than the soaked samples across all the species. Across all the bamboo species, the mean compression strength increased with increasing preservative concentrations of Boric-borax and Crude Lake salt. The modulus of rupture of treated bamboo decreased with all the preservatives across all the species.

Keywords*: Bamboo; Boric Borax; Crude Lake Salt; Preservation; Strength Properties; Tanalith*

INTRODUCTION

The excessive utilization of wood that has resulted in the continuous depletion of forest resources and, consequently, various environmental challenges has been strongly criticised. There is a growing need to find alternatives to wood, and bamboo has attracted global attention. Bamboo is fast-growing as it attains maturity within three to five years. It has excellent regenerative ability and strength properties that are comparable to wood – indicating its potential for numerous applications, including furniture and construction. Bamboo is a vast resource, covering 37 million ha worldwide, with 2.8 million ha in Africa (Lobovikov *et al*. 2007). With the most extensive bamboo stock, Asia has the highest number of species and has enhanced bamboo development with technological advances, while Africa's bamboo development potential remains untapped. In East Africa, bamboo utilization and research are still in their infancy, drawing lessons from Asia, with the help of the International Bamboo and Rattan Organization.

Bamboo is a complex material by its biological nature, and the existence of diverse species of varying properties further complicates its utilization (Vorontsova *et al*. 2016). It is vital to understand the properties of individual bamboo species to enhance their utilization. Bamboo material properties result from variations in bamboo species anatomy and how bamboo as a material reacts under load. Bamboo properties vary with species, age, geographic location, and environmental conditions (Darwis *et al*. 2020; Kyakula, 2008; Rini et al. 2023; Trujillo & Lopez, 2020). Knowledge of properties alone could be insufficient for utilization since bamboo is highly biodegradable and is usually treated with preservatives to increase its service life. Most scholars have focused on the properties of bamboo species grown in Asia (Darwis *et al.* 2020; Huang *et al*. 2015; Rini *et al.* 2023; Siam *et al*. 2019; Zakikhani *et al*. 2017). Studies focused on bamboo in Africa have investigated the properties before preservation rather than the effect of the preservatives on those properties (Hankun *et al.* 2019; Mbuge, 2000; Mugisa, 2021). Although such property tests provide a guide pointer to the strength of bamboo, they do not evaluate more subtle effects, such as variations in the effect of preservatives on the bamboo or interactions between different preservative chemicals and components of bamboo, which could contribute to strength and service life of treated bamboo.

Preservative chemicals contain active compounds that could react with bamboo components to form compounds which either increase or reduce the strength properties of bamboo. Therefore, a direct extrapolation from the properties of untreated to treated bamboo species might not be possible. Previous studies have shown varying effects of preservative treatments on the properties of bamboo due to different species, preservative chemicals and treatment methods employed. Gauss *et al*. (2019), Handana *et al*. (2020), and Prinindya & Ardhyananta, (2014), reported an increase in mechanical properties of *Dendrocalamus asper* when treated with borax solution (disodium octaborate tetrahydrate). Wahab *et al*. (2015) reported a reduction in the strength properties of *Bambusa vulgaris* when treated with ammonium-copper-quaternary, copper-chrome-arsenic and borax-boric acid (BBA). A review study by Sánchez Vivas *et al.* (2019) noted that whereas post-harvest treatments are crucial in utilization, they also influence the mechanical properties of bamboo.

Bamboo preservation in Uganda involves using several methods and chemicals, including smoking, leaching, and treatment with BBA, CCA and crude lake salt (CLS) (Mwanja *et al*. 2023). For a preservative treatment to increase the service life of bamboo, it should have high penetration, retention and permanent fixation into the bamboo tissues without reducing the strength of the treated bamboo (Liese & Kumar, 2003). This study investigates variations in the preservative retention and strength properties of treated and untreated bamboo grown in Uganda to understand the role of preservative treatments on the material properties.

MATERIAL AND METHODS

Sample collection and preparation

Four-year-old bamboo culms of *Oxytenanthera abyssinica*, *Oldeania alpina* and *Bambusa vulgaris* from Metu, Kifu and Echuya forests respectively in Uganda were selected and marked. The culms were harvested at approximately 20 cm above ground level. Each culm was subdivided into three equal lengths corresponding to the basal, middle, and top sections (ISO 22157-1: 2004). For this study, the middle and basal sections were used because their thickness allowed the cutting of samples of the required sizes. The sections were marked and transported to the National Forestry Resources Research Institute. Samples were cut from the bamboo culms to specifications for each test. All specimens were placed in a conditioning room at 20 ºC and a relative humidity of 65 % for four weeks before the preservation process.

Sample preservation

Preservatives

Three preservatives i.e., Borax and boric acid (BBA), Tanalith E3463 (Tan E), and Crude Lake salt (CLS) were used at two varied concentrations each. Borax and boric acid were mixed in a ratio of 1.5:1, respectively, to form BBA. BBA was diluted with water as a solvent to mimic concentrations used by bamboo artisans of 2 and 6%. These concentrations also fall in the 2 to

20% range, as reported in other studies using BBA to preserve both bamboo and wood (Mwanja *et al*. 2023; Setiyowati & Mappaturi, 2020). Tanalith E3463 (Copper carbonate, 2-aminoethanol, Ethoxylated amine), a commercial product in the form of aqueous copper solutions, is widely used to protect wood for outdoor use. In this study, concentrations of 2 and 3% were used similar to what has been used for wood. Crude lake salt is traditionally used by bamboo artisans to treat bamboo (Mwanja *et al*. 2023; Zuraida & Larasati, 2015). Crude lake salt is a highly alkaline substance that contains a large amount of Na+, Cl, CO3, SO4, and HCO3 ions, with smaller amounts of K+, Mg2+, Ca2+, Br, and F ions. It is mined and extracted from Lake Katwe, a closed saline crater located on the northern side of Lake Edward, within the East African Rift Valley system in western Uganda (Kasedde et al., 2014). This salt is easily accessible in most local markets and is frequently used by artisans. This study used grade 3 crude lake salt diluted with water as a solvent to make 2 and 6% concentrations.

Impregnation methods

Soaking and pressure treatment were the two impregnation processes applied in this study. These were selected because they were Uganda's most commonly used bamboo preservation techniques (Mwanja *et al*. 2023). A drum was fabricated by cutting a 200-litre drum into half horizontally. The bamboo samples were soaked in the drum with the preservative solution for seven days with a weight placed on top to ensure they did not float. Vacuum-pressure impregnation was performed following Wahab et al. (2006). An initial vacuum of -600mmHg (8 bar) was applied for 30 min to expel air from the bamboo. The preservative solution was let into the cylinder, and using a compressor, a pressure of 5 bar was applied for 2 hours to force the preservative solution into the bamboo. A final vacuum of -600 mmHg (8 bar) for 30 minutes was introduced to remove the excess preservative solution. After preservation, the preservative retention was calculated, and the samples were conditioned to 12% moisture content before carrying out the strength tests.

Parameters measured and calculated

Thickness, culm diameter and internode length were measured to aid with describing the species in the study. Samples for calculation of density were prepared with dimensions of 25 mm * 25 mm * wall thickness and dried to constant mass at 103^0C oven-dry temperature before being weighed on a precision scale. Density was determined following Eq 1.

$$\text{Density (kg / m}^3) = {}^{m}/_{V} * 10^6 \qquad (1)$$

Where: m = oven-dry mass;
V = oven-dry volume

For determination of preservative retention, samples of 50 mm * 25 mm * wall thickness were used. Preservative retention was determined following Eq 2.

$$R = {}^{GC}/_{V} * 10 \qquad (2)$$

Where: *R* is Preservative retention;
G is T2 - T1 (gram), T2 and T1 is the sample weight after and before preservation respectively;
C is preservative concentration in %;
V is volume of sample in cm^3.

After preservation, before property tests, bamboo specimens were conditioned at 20°C and 60% RH for six weeks. Strength properties tests were carried out following ISO 22157.

Strength properties

Compression strength, Modulus of rupture and Modulus of elasticity were determined using a universal testing machine. The Compression strength specimen's dimensions length were twice the culm's external diameter. For MOR and MOE test specimen's dimension were 4 mm in depth, 10 mm in width and 200 mm in length, a three-point bending test with a span of 150 mm, as reported by Topaloglu, (2019) was applied. MOR, MOE, and CS tests were carried out according to ISO 22157 standard with modified specimen dimensions.

Data analysis

Analysis of variance (ANOVA) in Minitab version 12 was used to test differences in the mean retention and strength properties among the three bamboo species. For all the tests post hoc testing using Dunnett test for comparisons to the control samples was done. All tests were done at 5% level of significance.

RESULTS

Physical properties

Table 1 gives a summary description of the three bamboo species in this study. The density was highest for *O. abyssinica* (863 kg/m^3), followed by *B. vulgaris* (644 kg/m^3) and *O. alpina* (458 kg/m^3). The diameter was highest for *O. alpina*, followed by *B. vulgaris* and *O. abyssinica.* The ANOVA showed that the mean density was significantly different at 5% across bamboo species ($F_{2,\ 149}$ = 334.59, P ≤ 0.000). The internode length was highest for *O. alpina*, followed by *O. abyssinica* and *B. vulgaris*. Some of the culms of *O. abyssinica* were solid while the other species were completely hollow.

Table 1: *Description of the sampled bamboo species according to density, diameter, thickness and internode length*

Species	Density (kg/m^3)	Diameter (cm)	Internode length (cm)	Thickness (mm)
O. abyssinica	863.08^a (78.02)	3.8 (0.7)	33.2 (7.4)	6 - Solid
B. vulgaris	644.94^b (63.97)	4.8 (0.9)	23.9 (5.8)	8 - 9
O. alpina	458.16^c (89.8)	5.4 (0.4)	33.2 (9.1)	8 – 10

Means with different letters are significantly different; Standard deviations are shown in parentheses.

Preservative retention

In this study, the preservative retention varied from 4.6 – 20.6 kg/m^3 across the bamboo species, preservative and method of impregnation (Table 2). The pressure-impregnated samples retained more preservatives (12.8 kg/m^3) than the soaked samples (10.7 kg/m^3). *O. alpina* retained more preservatives (12.7 kg/m^3), followed by *B. vulgaris* (11.9 kg/m^3) and *O. abyssinica* (10.7 kg/m^3). 6% BBA was the most retained preservative (11.9 kg/m^3), followed by 3% Tan E (15.9 kg/m^3), 6% CLS (14.4 kg/m^3), 2% Tan E (10.6 kg/m^3), 2% CLS (7.2 kg/m^3) and 2% BBA (5.8 kg/m^3).

Table 2*: Preservative retention across the bamboo species*

TP	Conc (%)	MI	Preservative Retention *(kg/m^3)*		
			B. vulgaris	***O. alpina***	***O. abyssinica***
BBA	2	P	5.5 (1.1)	6.0 (1.2)	5.2 (0.5)
		S	4.9 (0.9)	5.4 (1.2)	4.6 (0.6)
	6	P	19.1 (2.2)	20.6 (1.8)	18.3 (1.1)
		S	16.0 (2.5)	15.9 (2.3)	13.7 (1.7)
CLS	2	P	13.1 (1.5)	13.3 (2.4)	10.5 (1.5)
		S	9.5 (1.5)	10.2 (3.0)	9.3 (1.5)
	6	P	18.8 (1.8)	18.8 (3.4)	14.7 (1.9)
		S	16.1 (2.2)	16.3 (2.1)	12.7(1.4)
Tan E	2	P	7.7 (1.0)	9.5 (1.4)	7.1 (1.9)
		S	6.9 (1.4)	8.4 (1.8)	6.4 (1.7)
	3	P	19.4 (2.2)	18.5 (2.6)	15.9 (2.0)
		S	11.9 (1.8)	15.4 (2.0)	12.9 (3.5)

Standard deviations are shown in parenthesis; TP (Preservatives); MI (Method of impregnation); P (Pressure), S (Soaking); Means are for 40 test samples.

Compression strength

Table 3 shows the treated and untreated bamboo samples' mean compression strength (CS). The CS increased across all three preservatives across the three bamboo species. For the untreated samples, *O. abyssinica* had the highest CS (81.1 N/mm^2), followed by *B. vulgaris* (59.5 N/mm^2) and *O. alpina* (54.4 N/mm^2).

Table 3*: Compression strength of the treated and untreated bamboo samples*

TP	Conc (%)	MI	Compression Strength, (N/mm^2)		
			O. abyssinica	***B. vulgaris***	***O. alpina***
Untreated			81.1^a (11.4)	59.5^a (11.9)	54.4^a (12.4)
BBA	2	P	83.8 (11.2)	62.2 (11.4)	52.8^a (21.4)
		S	82.3^a (11.8)	61.8^a (11.1)	51.8 (11.4)
	6	P	85.9 (18.4)	62.9 (14.3)	58.3 (13.8)
		S	84.7 (10.8)	60.4^a (12.1)	57.1 (15.7)
Tan E	2	P	81.7^a (12.3)	58.9^a (11.7)	55.6^a (12.5)
		S	78.6 (21.3)	57.6 (18.9)	55.2^a (21.7)
	3	P	82.1^a (21.0)	59.7^a (15.9)	55.5^a (20.9)
		S	79.2^a (16.9)	59.1^a (13.8)	55.6^a (14.9)
CLS	2	P	83.6 (10.9)	62.6 (14.7)	57.9^a (12.9)
		S	82.3^a (12.5)	60.5^a (12.0)	55.9 (20.9)
	6	P	84.7 (20.9)	62.1 (15.9)	58.6 (12.9)
		S	82.9 (17.5)	61.6^a (18.1)	57.2 (14.3)

Means with the letter a in each column are not significantly different from the control. Standard deviations are shown in parenthesis; TP (Preservative); MI (Method of impregnation); P (pressure), S (Soaking)

Generally, there was an increase in the CS of the treated samples. The ANOVA showed that the mean CS was significantly different at 5% across bamboo species ($F_{2,\ 798}$ = 3.55, P ≤ 0.029), preservatives ($F_{6,\ 798}$ = 16.52, P ≤ 0.000) and method of impregnation ($F_{1,\ 798}$ = 10.26, P ≤ 0.001). The two factor ($F_{20,\ 798}$ = 190.25, P ≤ 0.000) and three factor ($F_{12,\ 798}$ = 110.33, P ≤ 0.000) interactions were significant at 5%.

Modulus of elasticity

The MOE of treated bamboo samples was higher than that of the untreated samples both within and across all the species (Table 4). Among the untreated samples, *O. abyssinica* samples registered the highest MOE (9367.4 N/mm^2), followed by *B vulgaris* (5328.2 N/mm^2) and *O alpina* (3580.2 N/mm^2).

Table 4: *Modulus of Elasticity of treated and untreated bamboo samples*

TP	Conc (%)	MI	MOE, (N/mm^2)		
			O. abyssinica	***B. vulgaris***	***O. alpina***
Untreated		Control	9367.4^a (1283.8)	5328.2^a (1255.4)	3580.2^a (1089.2)
BBA	2	P	9539.6 (1869.4)	5340.1 (1177.8)	3429.3 (1178.3)
		S	9395.3^a (1396.1)	5320.0^a (1464.0)	3323.1 (903.0)
	6	P	9628.5 (2483.5)	5386.2 (1392.5)	3532.6^a (959.7)
		S	9503.9 (2480.4)	5360.3^a (1480.0)	3532.1^a (1069.8)
Tan E	2	P	9455.1^a (1631.1)	5363.5 (1588.6)	3656.0^a (1071.8)
		S	9400.1^a (1639.5)	5367.4^a (1683.8)	3601.0^a (1457.3)
	3	P	9539.6	5375.1^a	3652.5^a

			(1596.1)	(1850.1)	(1585.4)
		S	9455.1^a (1431.1)	5385.3^a (1678.4)	3640.8^a (1388.2)
CLS	2	P	9248.5^a (2601.9)	5352.9^a (1680)	3615.9^a (890.4)
		S	9156.2 (2112.1)	5339.2 (1380.4)	3666.6^a (960.0)
	6	P	9403.5^a (2210.8)	5369.9 ^{a} (1277.5)	3619.4^a (1155.4)
		S	9375.1^a (1978.4)	5208.0^a (1562.3)	3595.7^a (1301.3)

Means with the letter a in the superscript in each column are not significantly different from the control. Standard deviations are shown in parenthesis; TP (Preservative); MI (Method of impregnation); P (pressure), S (Soaking)

There was an increase in MOE of the treated bamboo samples. The ANOVA showed that the mean MOE was significantly different across species ($F_{2,\ 798}$ = 5.79, P ≤ 0.003), preservatives $F_{6,\ 798}$ = 3.09, P ≤ 0.005) and method of impregnation $F_{1,\ 798}$ = 5.30 P ≤ 0.022). The two factor ($F_{20,\ 798}$ = 2906.3, P ≤ 0.000) and three factor ($F_{12,\ 798}$ = 863.02, P ≤ 0.000) interactions were significant at 5%.

Modulus of rupture

The MOR of untreated bamboo samples was lower than that of the treated samples both within and across all the species (Table 5). Among the untreated samples, *O. abyssinica* bamboo demonstrated the highest MOR, 60.8 N/mm^{2,} followed by *B. vulgaris,* 43.3 N/mm^2 and *O. alpina,* the lowest value of 35.9 N/mm^2.

Table 5*: Modulus of Rupture of treated and untreated bamboo samples*

TP	Conc %	MI	MOR, (N/mm^2)		
			O. abyssinica	***B. vulgaris***	***O. alpina***
Untreated		Control	60.8^a (12.6)	43.3^a (16.5)	35.9^a (12.2)
BBA	2	P	59.1^a (15.9)	37.5^a (12.2)	32.5^a (12.7)
		S	59.5^a (21.6)	34.3 (20.7)	32.7^a (19.8)
	6	P	58.2^a (12.0)	36.8^a (14.6)	40.8^a (17.6)
		S	58.4^a (14.7)	35.9^a (12.1)	32.8^a (13.5)
Tan E	2	P	60.6^a (12.4)	40.1^a (18.8)	34.2^a (13.2)
		S	60.2^a (11.9)	38.9^a (12.4)	34.5^a (13.7)
	3	P	59.4^a (20.6)	39.4^a (12.2)	37.1^a (13.5)
		S	60.9^a (12.2)	39.3^a (12.1)	34.7^a (12.9)
CLS	2	P	58.3^a (17.9)	36.5^a (12.8)	32.6^a (14.5)
		S	60.2^a (11.9)	30.6 (15.6)	31.8^a (16.6)
	6	P	59.2^a (13.1)	35.4^a (12.5)	32.6^a (13.6)
		S	57.9 (23.3)	35.6^a (11.9)	32.7^a (14.8)

Means with the letter a in the superscript in each column are not significantly different from the control. Standard deviations are shown in parenthesis; TP (Preservative); MI (Method of impregnation); P (pressure), S (Soaking)

The analysis of variance showed that MOR was significantly influenced by the preservative ($F_{6,\ 798}$ = 48.24, P ≤ = 0.000), method of impregnation ($F_{1,\ 798}$ = 6.40, P ≤ 0.012) and bamboo species ($F_{2,\ 798}$ = 5.40, P ≤ 0.005). The two factor ($F_{20,\ 798}$ = 875.1, P ≤ 0.000) and three factor ($F_{12,\ 798}$ = 535.86, P ≤ 0.000) interactions were significant.

DISCUSSION

Several studies have highlighted the effect of preservatives on the properties of bamboo. In this study, results showed both increasing and decreasing effects of preservatives on the strength properties of bamboo. A precursor for all effects of preservation is the retention of the preservative in bamboo. The retention values presented in this study meet the requirement values of at least 4 and 6 kg/m^3 of active ingredient as recommended by American Wood Preservers' Association (AWPA) Caldeira, (2010) and the code of practice of preservation of bamboo and cane respectively (Indian Starndard BIS 1902, 2006).

Preservative retention varied across the bamboo species. The variation could be attributed to the density variation among the bamboo species. Density highly influences treatability and consequently affects preservative retention (Ozdemir *et al*. 2015; Tarmian *et al*. 2020). Species with lower density have more voids in their cells which absorb more preservatives. The preservative retention is also a result of the permeability of bamboo species. More permeable species retain more preservatives than the less permeable species (Hansmann *et al*. 2002; Keskin, 2017).

The anatomical structure of bamboo influences permeability. Different bamboo species have variations in their anatomical structure based on geographic location and species makeup (Darwis *et al*. 2020; Ogunsanwo *et al*. 2015; Rini *et al*. 2023; Zakikhani *et al*. 2017). Bamboo cells are organised in the longitudinal direction. These influence the longitudinal flow of liquids with no ray cells to enhance radial flow (Huang *et al*. 2015; Nkeuwa *et al*. 2022; Xu *et al*. 2018). This also influences how much preservative will flow into the bamboo, contributing to the variation in the retention among the bamboo species.

The method of impregnation influences the preservative retention of bamboo. The pressure method ensures more retention levels and deeper penetration compared to the soaking treatment (Anthony & Lebow, 2015; Gauss *et al*. 2020; Kim *et al*. 2011; Rabbi *et al*. 2015). The pressure process increases the flow rate of the preservative into the bamboo, while the soaking method utilizes only diffusion as the process with which the preservative moves into the bamboo cell wall and in the lumens (Tarmian *et al*. 2020).

The chemical composition of the water-based preservatives could influence the variation in strength properties. The influence can also result from a reaction between the preservative and the chemical components of bamboo (Sánchez Vivas *et al*. 2019). Studies involving boron compounds and sodium chloride indicate that a reaction between these compounds and wood is purely physical and not chemical (Lesar *et al*. 2009). This could imply that there is no reaction between the preservatives used in this study (BBA and CLS) and the chemical components of the bamboo. Therefore, the increase in strength could result from the salt crystals from the preservatives depositing in the bamboo cell wall structure and bearing the extra load compared to the untreated samples.

These results are in agreement with other studies, such as Yusof et al. (2023) reported an increase in strength properties of *Gigantochloa scortechinii, Gigantochloa levis, Dendrocalamus asper,* and *B. vulgaris* bamboo when treated with 5% boric acid. Other bamboo species, such as *D asper,* have also been reported to increase compression strength when treated with borax and disodium octaborate tetrahydrate (Gauss *et al*. 2019; Handana *et al*. 2020). The strength properties of *G. scortechinii,* when treated with copper chrome boron, boron and BBA solutions, were reported to increase (Baharuddin *et al*. 2022; Daud *et al*. 2018). The CLS used in this study is unrefined sodium chloride, which positively influenced the bamboo species' CS. Kapidani, (2015) reported increased CS of silver fir wood when treated with pure sodium chloride. Similarly, other preservatives, such as Tan E at 2 and 2.8%, have been reported to increase yellow pine wood's strength properties, such as MOR and MOE (Yildiz *et al*. 2004).

However, other studies have reported decreased strength properties of bamboo when treated with water-based preservatives (Fattah *et al*. 2014; Wahab *et al*. 2015). The reduction in strength properties could result from hydrolytic reactions between the water-based preservatives and the cellulose in the bamboo cell wall reducing the degrees of polymerization in the bamboo. The reduction can also be attributed to the fixation of the preservative components in the bamboo cell wall, which happens through oxidation(Yusof *et al*. 2023; Simsek *et al*. 2010; Toker *et al*. 2009; Winandy, 1993).

Other factors that might lead to reduced bamboo strength after preservation include the possibility of increased equilibrium moisture content due to the hygroscopic nature of salts in some preservatives(Lesar *et al*. 2009). As these salts absorb water from the surrounding environment, the bamboo's moisture content increases, lowering strength properties. Other studies argue that some properties are not in any way affected by preservative treatment; for example, compression parallel to the grain is solely an axial property, and reduction in the cellulose chain due to acid dehydration has no great effect on the strength (Colakoglu *et al*. 2003).

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were made from the study.

The preservative retention varied with the different preservatives, methods of impregnation and bamboo species. The retention increased with the concentration levels of the preservative. The retention decreased with an increase in the density of the species. Due to the variations in preservative retention, it is recommended that species are sorted and preserved separately to ensure uniform penetration and retention of preservatives.

The different preservative treatments varied in their influence on the strength properties of bamboo. The compressive strength (CS) of bamboo increased when treated with borax-boric acid (BBA) and crude lake salt (CLS), but was not affected by Tan E treatment. On the other hand, the modulus of rupture (MOR) decreased with all of the preservatives. Therefore, when using preserved bamboo, it is recommended to account for variations in strength when calculating loads for bamboo structures.

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DECLARATION OF COMPETING INTERESTS

The authors declare no potential conflicts of interests

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