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Original Article

Resistivity of ten Nigerian Guinea Savannah Timbers to *Lentinus sajor-caju, Sclerotium rolfsii*, and Subterranean Termites

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ABSTRACT

In this study, the resistivity of Ten Nigerian hardwood trees to fungi and subterranean termites was evaluated through visual and percentage weight loss using standard procedures in the Nigerian Guinea Savannah. The experimental samples were prepared from heartwood and sapwood portions of the species. Fungal decay resistance tests were conducted according to the ASTM D 2017-81 standard method using two fungi species, *Lentinus sajor-caju* (Fr.) Fries. (white rot fungi) and *Sclerotium rolfsii* (Curzi) C.C. Tu & Kimbr. (teleomorph) (brown rot fungi). The wood specimens were also exposed to subterranean termites to determine their weight loss due to attack. After exposure, the species were grouped into durability classes based on the weight loss due to resistance of the heartwood to the selected biodeteriorating agents. *Lannea welwitschii, Vitellaria paradoxa, Afzelia africana, Albizia zygia,* and *Syzygium guineense* were found to be resistant to both fungi. *Khaya ivorensis* and *Isoberlinia doka* were highly resistant to *S. rolfsii*, and *Vernonia colorata* was highly resistant to *L. sajor-caju. L. welwitschii* and *Irvingia gabonensis* were nonresistant to termite attack unlike their resistance to both fungi, but *Anogeissus leiocarpa* was highly resistant unlike its moderate resistance to the fungi. *K. ivorensis* and *I. doka* were highly resistant to all the biodeteriorating agents. *K. ivorensis* was ranked best, whereas *I. gabonensis* was ranked lowest, in terms of their resistance against decay. *K. ivorensis* showed the highest resistance against termite attack, whereas *L. welwitschii* and *I. gabonensis* were nonresistant to termite attack. In general, *K. ivorensis* exhibited the best natural durability against the selected biodeteriorating agents.

Keywords: Fungi, heartwood, sapwood, termites, tropical hardwood, weight loss

Introduction

No known wood is entirely immune to attack by biodeteriorating organisms. Wood durability is related to the end use conditions (Amusant et al., 2014) and is measured when the wood is in direct contact with soil and water, which are the optimum moisture and oxygen conditions required for the growth of microorganisms (Márquez, 2008). The service life of wood is generally limited because of its susceptibility to destruction by biological agents (Orozco, 2008). Each wood has its inherent resistance to attack by wood-destroying organisms even if it is extremely poor in resistance. However, some species have higher resistance than others (Hillis, 1987). To satisfactorily use a particular wood in construction, it is necessary to test its natural durability against deterioration (Haygreen & Bowyer, 1996). This is an important aspect to be considered when wood is to be used for outdoor constructions. Recently, the natural defense mechanisms of durable wood species are being exploited because of the negative impacts of conventional chemical treatments for timbers on human health and the environment. The natural durability of wood is related to the presence of heartwood, which contains more extractive compounds than sapwood, resulting in greater natural durability (Kirker et al., 2013). However, weight loss due to attack can be explained by the degradation of polysaccharides in the initial stages of decay and by the degradation of lignin in the later stages (Venäläinen et al., 2014).

The durability of wood has been classified into very durable, durable, moderately durable, nondurable, and perishable (ASTM, 1999; AWPA, 1999). Wood species belonging to the perishable class are not generally suitable for use in construction works and cannot withstand damp environment or last long when in contact with the ground. The natural resistance demonstrated by some species is the resultant effect of the presence of extractive compounds in the heartwood region. The relationship between durability and extractive compounds is primarily due to phenolic compounds (Syofuna et al. 2012). Although the heartwood of the majority of wood species exhibits excellent resistance to biodegradation, the resistance is sometimes diminished in the sapwood (Orozco,

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2008). The sapwood undergoes numerous changes, a part of which is the formation of extractive compounds that are transformed progressively into the heartwood. The presence of these extractive compounds in sufficient amounts prevents or minimizes the severity of attack by destructive organisms when the extractive compounds are toxic. However, the toxicity of these extractive compounds varies within and between species and in their chemical properties (Eaton & Hale, 1993).

Considerable research has been conducted on the resistance of wood against fungi and termites using different timbers. However, there is limited information on the natural durability of Nigerian Guinea Savannah species to fungi and subterranean termites. Although *Khaya ivorensis* (dry zone mahogany) was classified as susceptible to both brown and white rot fungi by Fortin and Poliquin (1976), Nzokou et al. (2005) classified it as resistant to brown rot fungi and nonresistant to white rot fungi. Although a few Nigerian timber species have been evaluated for their natural durability, further research is needed on more species to widen the database and increase the pool of timber resources to choose from when considering wood for utilization in construction. As deterioration is more rapid in warm, moist climates (Moya & Berrocal, 2015) as we have in Nigeria due to the high population of biodeteriorating agents than that in temperate climates (Mora et al., 2006; Rodrigues et al., 2010), the lack of knowledge about the natural durability of these species will further pose an obstacle to their utilization (Moya & Muñoz, 2010).

The primary objective of this study was to provide baseline information on the natural resistance of Ten wood species (common to the Nigerian Guinea Savannah) to the two fungi species based on an established and accepted protocol, the ASTM D-2017-81 (ASTM, 1999) test method for solid wood. Similarly, the wood samples were subjected to termite attack in a graveyard experiment according to ASTMD 1413-76 and ASTM D 3345-74 methods, because being resistant to fungi does not necessarily imply being resistant to termites. This was a preliminary study aimed at providing a basis for validation and for a more efficient utilization of these wood species.

Method

Materials

The wood materials used in this study included the heartwood and sapwood of 10 different tropical timber species common to the Nigerian Guinea Savannah, which were *Khaya ivorensis* (mahogany), *Irvingia gabonensis* (bush mango), *Albizia zygia (Ayunre), Anogeissus leiocarpa (Ayin), Afzelia africana* (Apadan), *Vitellaria paradoxa* (Emi), *Vernonia colorata* (Eriri), *Lannea welwitschii* (Opon), *Syzygium guineense* (Adere), and *Isoberlinia doka* (Babo). They were obtained from defect-free portion of the wood samples available in local wood mills in Ilorin, Kwara State. The two fungi species, viz., *Lentinus sajor-caju* (white rot fungi) and *Sclerotium rolfsii* (brown rot fungi), were supplied by the Pathology Department of the Forestry Research Institute of Nigeria, Ibadan.

Sample Preparation

Air-dried planks of 65 × 350 × 1000 mm were obtained from a sawmill in Ilorin, Kwara State, Nigeria. Wood samples for the study were collected from logs whose diameter ranged from 60 to 105 cm. All wood samples were collected from mature wood. Special care was taken to ensure that the species were accurately identified. The wood samples were first identified by the saw millers. The local identification was further substantiated by literature to obtain their corresponding scientific names. A total of 150 sapwood and heartwood samples each measuring 20 × 20 × 60 mm were cut from the planks for each species for each of the resistance test. The test samples were first dried to constant weight to obtain the initial weight before treatment.

Durability Assays

Termite bioassay

The 10 wood samples were exposed to subterranean termites for a duration of 12 weeks in a timber graveyard following the ASTMD 1413-76 method. Visual observations were made weekly. At the end of exposure period, the weight loss due to termite infestation was determined gravimetrically following the ASTM D 2017-81 method. Each specimen was examined and visually rated using the standard rating systems of ASTM D 3345-74 (Table 1).

Fungal Bioassay

The wood samples were also exposed to *Lentinus sajor-caju* (white rot fungi) and *Sclerotium rolfsii* (brown rot fungi) in a modified decay test. Each of a total of 50 specimens were exposed to *L. sajor-caju* and *S. rolfsii* at five replicates per species. Each of the wood specimens were dried to constant weight, steam-sterilized at 100°C, weighed, and then exposed to the fungi in a mod-

Table 1
Rating System for Visual Examination of Termite Damage in the Specimens According to ASTM D 3345-74

Rating	Severity of termite attack
10	Sound, surface nibbles permitted
9	Light attack
7	Moderate attack, penetration
4	Heavy attack
0	Failure

Table 2
Decay Resistance Expressed as Either Weight Loss or Residual Weight According to ASTM D 2017-81

Average weight loss (%)	Average residual weight (%)	Resistance class
0–10	90–100	Highly resistant
11–24	76–89	Resistant
25–44	56–75	Moderately resistant
≥45	≤55	Slightly resistant/nonresistant

ified soil-block test for 12 weeks at 27°C ± 2°C and 80% RH. After incubation, the surface fungi mycelia were removed, and the specimens were dried at 60°C. Weight losses were determined by comparing them with preexposed values. The average percentage weight loss was indicated by the resistance classes to specific test fungi, which ranged from highly resistant to slightly resistant or nonresistant according to the ASTM D- 2017-81 (ASTM, 1999) test method for solid wood as shown in Table 2.

$$\text{Percentage weight loss} = \frac{Initialweight - Finalweight}{Initialweight} \times 100$$

where initial weight is the weight before exposure, and final weight is the weight after exposure.

Table 3
Percentage Weight Loss due to White Rot and Brown Rot Fungal Attack

	Sapwood		Heartwood	
Species	White rot	Brown rot	White rot	Brown rot
L. welwitschii	16.95[ab]	10.51[c]	20.00[ab]	13.95[abc]
V. paradoxa	21.95[a]	31.92[a]	23.17[ab]	13.77[abc]
A. africana	19.80[a]	15.19[bc]	18.94[abc]	14.97[abc]
A. zygia	18.44[ab]	23.73[ab]	18.81[abc]	11.84[abc]
A. leiocarpa	15.32[ab]	15.83[bc]	24.16[ab]	24.87[a]
I. gabonensis	17.41[ab]	18.95[bc]	28.29[a]	21.31[ab]
K. ivorensis	18.04[a]	11.83[c]	6.82[c]	7.57[c]
V. colorata	2.60[c]	13.64[bc]	18.96[abc]	13.29[abc]
I. doka	9.09[c]	19.82[bc]	11.06[bc]	7.91[bc]
S. guineense	22.66[a]	19.03[bc]	13.99[bc]	10.73[bc]

Note. Means in columns with the same superscript were not significantly different ($p \leq .05$)

Table 4
Classification of the Heartwood of the Species Based on Their Weight Loss due to Fungal Attack

	Natural Durability Rating	
Species	*L. sajor-caju*	*S. rolfsii*
L. welwitschii	Resistant	Resistant
V. paradoxa	Resistant	Resistant
A. africana	Resistant	Resistant
A. zygia	Resistant	Resistant
A. leiocarpa	Moderately resistant	Moderately resistant
I. gabonensis	Moderately resistant	Resistant
K. ivorensis	Resistant	Highly resistant
V. colorata	Highly resistant	Resistant
I. doka	Resistant	Highly resistant
S. guineense	Resistant	Resistant

Data Analysis

All data were analyzed using one-way analysis of variance. Duncan's multiple range test ($p < 0.05$) was used to evaluate the differences among mass losses in the decay and termite resistance tests.

Results

Fungal Resistivity

The average weight losses of the wood specimens exposed to *L. sajor-caju* and *S. rolfsii* for 12 weeks are presented in Tables 3 & 4. There were significant influences of the species on the susceptibility to the two fungi. The sapwood of *V. colorata* was the most resistant (2.60%) to white rot fungi, followed by the heartwood of *K. ivorensis* (6.82%), whereas *I. gabonensis* showed the least resistance (28.29%) to *L. sajor-caju*. The heartwood of *K. ivorensis* showed the highest resistance (7.57%) against *S. rolfsii*. However, the opposite result was observed for *I. doka* as its heartwood was more resistant to *S. rolfsii*, ranking the second after *K. ivorensis*. The sapwood of *V. paradoxa* showed the least resistance to brown rot fungal attack with the highest average weight loss of 31.92%.

There were significant variations in the resistance of the species to the selected fungi species. Although significant variation was detected in the resistance of the species to *L. sajor-caju* (white rot fungi), the resistance values of the sapwood of *L. welwitschii*, *A. zygia*, *A. leiocarpa*, and *I. gabonensis* were statistically similar. *V. paradoxa*, *A. africana*, *K. ivorensis*, and *S. guineense* exhibited similar resistivity, whereas that of *V. colorata* and *I. doka* was not statistically different.

The resistance of the sapwood of six of the species to *S. rolfsii* (brown rot fungi) was statistically similar, except for *V. paradoxa* whose resistance differed significantly from that of other species. However, *L. welwitschii* and *K. ivorensis* had similar resistance to brown rot fungal attack (Table 4). The heartwood of *A. africana*, *A. zygia*, and *V. colorata* showed similar resistance to the two fungi. *I. doka* and *S. guineense* also showed similar weight loss due to the attack by both white rot and brown rot fungi. *I. gabonensis* had significant weight loss due to white rot fungal attack unlike other species (Table 4).

Based on the durability classification of solid wood as outlined in ASTM D 2017-81, the wood species were grouped into durability classes based on the resistance of the heartwood portion only to the selected biodeteriorating agents as shown in Table 4. *L. welwitschii*, *V. paradoxa*, *A. africana*, *A. zygia*, and *S. guineense* were resistant to both *L. sajor-caju* and *S. rolfsii. K. ivorensis* and *I. doka* were highly resistant to only *S. rolfsii*, whereas only *V. colorata* was highly resistant to *L. sajor-caju*. However, *A. leiocarpa* was moderately resistant to both fungi. The difference in the deterioration rates between the species may be due to the high concentration of phenolic extractive compounds present in the wood samples.

The findings of this study are similar to those of previous studies (Nzokou et al., 2005; Schultz & Nicholas, 1997). *K. ivorensis* (dry zone mahogany) was classified as susceptible to both brown rot and white rot fungi by Fortin and Poliquin (1976). However, Nzokou et al. (2005) classified it as resistant to brown rot fungi and nonresistant to white rot fungi. Conversely, in the present study, *K. ivorensis* was found to be highly resistant to brown rot fungi and resistant to white rot fungi. The resistance of *L. welwitschii*, *V. paradoxa*, *A. africana*, *A. zygia*, and *S. guineense* to both *L. sajor-caju* and *S. rolfsii* may be due to the high phenolic extractive content in the heartwood that contributed to wood protection.

Although both fungi species attacked all the wood species, the attack by white rot fungi appeared to be more intense. These findings were consistent with previous findings (Nzokou et al., 2005; Schultz & Nicholas, 1997). According to Nzokou et al. (2005), the high weight loss values obtained due to *L. sajor-caju* attack in all heartwood samples of the 10 species were attributed to the fact that hardwoods are more susceptible to white rot decay fungi than softwoods (Schultz & Nicholas, 1997). Due to this reason, white rot fungus is always included in the testing of the natural durability of hardwood species because it attacks all the wood components, whereas brown rot fungus preferably attacks the hemicellulose and cellulose components, leaving the lignin component undigested (Green & Highley, 1997).

Table 5
Weight Loss due to Termite Attack

Species	Sapwood	Heartwood
L. welwitschii	62.92[a]	100.00[a]
V. paradoxa	.61[c]	11.59[c]
A. africana	1.02[c]	28.05[bc]
A. zygia	.93[c]	13.93[c]
A. leiocarpa	1.33[c]	38.78[bc]
I. gabonensis	72.99[a]	94.59[a]
K. ivorensis	.33[c]	4.05[c]
V. colorata	1.36[c]	67.05[ab]
I. doka	.17[c]	5.28[c]
S. guineense	20.99[b]	63.03[ab]

Note. Means in columns with the same superscript were not significantly different ($p \leq .05$)

Table 6
Classification of the Wood Species Based on Their Weight Loss due to Fungal and Termite Attacks

Species	Termite resistivity: Visual rating	Termite resistivity: Resistance class
L. welwitschii	0	Nonresistant
V. paradoxa	9	Highly resistant
A. africana	7	Highly resistant
A. zygia	7	Highly resistant
A. leiocarpa	7	Highly resistant
I. gabonensis	0	Nonresistant
K. ivorensis	7	Highly resistant
V. colorata	7	Highly resistant
I. doka	7	Highly resistant
S. guineense	4	Resistant

Termite Resistivity

The average weight losses due to the termite infestation of wood species during the 12 weeks exposure period in the graveyard are shown in Table 5. In general, the h eartwood of *L. welwitschii* was completely destroyed by the subterranean termites with 100% weight loss. This was closely followed by *I. gabonensis* that was consumed severely with a weight loss of 94.59%. These two species had a visual rating of 0 termed as "failure" and were classified as perishable or nondurable (Table 6). *K. ivorensis* was the least consumed and lost only 4.05% of its weight, which was rated as moderate attack. However, *K. ivorensis* was visually rated 7, whereas *V. paradoxa* was rated 9, despite a weight loss of 11.59%. The high rating of *V. paradoxa* might be due to the hardness that is a function of density. The attack on the sapwood followed almost a similar pattern to that on the heartwood. Although *L. welwitschii* and *I. gabonensis* were severely attacked, in the case of sapwood, *I. gabonensis* was consumed (72.99%) more than *L. welwitschii* (62.92%), whereas *I. doka* was least attacked (0.17%).

Statistical differences were observed in the weight loss of both sapwood and heartwood of the species due to termite infestation. However, the sapwoods of *V. paradoxa*, *A. africana*, *A. zygia*, *A. leiocarpa*, *K. ivorensis*, *V. colorata*, and *I. doka* were consumed at the same rate. *L. welwitschii* and *I. gabonensis* were consumed at a similar rate, whereas *S. guineense* was moderately consumed different from other species. The rates of consumption of the heartwoods of *L. welwitschii* and *I. gabonensis*; *V. paradoxa*, *A. zygia*, *K. ivorensis*, and *I. doka*; *A. africana* and *A. leiocarpa*; and *V. colorata* and *S. guineense* were similar, respectively.

The result of the weight loss due to fungal and termite attack showed almost the same trend. The weight loss due to white rot fungal attack in *V. colorata* was considerably low and it was similar for *I. doka* and *K. ivorensis* heartwood infested by both white rot and brown rot fungi. It was observed that these species were similarly consumed less by termites (Table 5). This implies that the wood that is resistant to fungal attack may or may not be durable when subjected to attack by insects or marine borers (Panshin & de Zeeuw, 1980).

The wood species were grouped into resistance classes based on visual assessment according to the AWPA, 1999 rating system, as well as on their weight losses due to the attack by subterranean termites according to the ASTM D 2017-81 method (Table 2). *L. welwitschii* and *I. gabonensis* were nonresistant/perishable unlike their resistance to white rot and brown rot fungi, whereas *A. leiocarpa* was highly resistant unlike its moderate resistance to both white rot and brown rot fungi. However, *K. ivorensis* and *I. doka* were highly resistant to all the biodeteriorating agents (Tables 5 and 6).

Conclusions

The natural durability of the 10 Nigerian hardwoods was evaluated based on weight loss obtained from laboratory soil-block test and graveyard experiments. Our findings showed that the decay intensity on the tropical hardwood due to white rot fungal attack was more severe than that due to brown rot fungal attack. However, it was found that both fungi could decay the hardwoods. *K. ivorensis* was ranked best in terms of fungal resistivity, followed by *I. doka*, whereas *I. gabonensis* was ranked lowest in terms of resistance against decay. *K. ivorensis* showed the highest resistance against termite attack, followed by *I. doka*, whereas *L. welwitschii* and *I. gabonensis* were nonresistant to termite attack. In general, *K. ivorensis* exhibited the best natural durability against *L. sajou-caju*, *S. rolfsii*, and subterranean termites. Based on weight loss, *L. welwitschii*, *V. paradoxa*, *A. africana*, *A. zygia*, and *S. guineense* were classified as resistant to both *L. sajor-caju* and *S. rolfsii*, whereas *A. leiocarpa* was moderately resistant to both fungi species. Similarly, seven of the wood species were highly resistant to subterranean termite infestation, whereas *L. welwitschii and I. gabonensis* were nonresistant to termite attack. Further research is needed on the durability testing of Nigerian wood species for the appropriate management and utilization of Nigerian wood resources.

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References

- Amusant, N., Nigg, M., Thibaut, B., & Beauchene, J. (2014). Diversity of decay resistance strategies of durable tropical woods species: *Bocoa prouacencsis* Aublet, *Vouacapoua americana* Aublet, Inga alba (Sw.) Wild. *International Biodeterioration and Biodegradation, 94*, 103-108. [Crossref]
- ASTM (American Society for Testing Materials). (1999). Standard Method of Accelerated Laboratory Test of Natural Decay resistance of Woods. D 2017-81 (Reapproved 1994). Vol 04.10 on Wood. Annual Book of ASTM Standards. ASTM, West Conshohocken.
- American Wood Preservers' Association (AWPA). (1999). Standard E10-91. Standard method of testing wood preservatives by laboratory soil-block cultures. AWPA Book of Standards. Granbury, TX. pp: 375-385.
- American Wood Preservers' Association (AWPA) (1999). E1-97. Standard method for laboratory evaluation to determine resistance to subterranean termites. In: American Wood Preservers' Association, Woodstock, MD, pp. 282-285.
- Eaton, R. A., & Hale, M. D. C. (1993). Wood Decay, pests and protection. Chapman and Hall, University Printing house, Cambridge. pp. 546.
- Fortin, Y., & Poliquin, J. (1976). Natural Durability and Preservation of One Hundred Tropical African Woods. Ottawa International Development Centre, Ottawa.
- Green, F. III., & Highley, L. T. (1997). Mechanism of brown-rot decay: Paradigm or Paradox? *International Biodeterioration and Biodegradation, 39*(2-3), 113-124. [Crossref]
- Haygreen, J. G., & Bowyer, J. L. (1996). Forest Products and wood science. Third Edition. Iowa State University Press. pp.243-247.
- Hillis, W. (1987). Heatwood and tree exudates. Springer – Verlag. Berlin. pp. 268. [Crossref]
- Kirker, G. T., Blodgett, A. B., Arango, R. A., Lebow, P. K., Clausen, C. A. (2013). The role of extractives in naturally durable wood species. *International Biodeterioration and Biodegradation, 82*, 53-58. [Crossref]
- Márquez, A., Castro, F., Ramirez, E., Gómez, L., Toro, M. E., & Velásquez, J. (2008). Natural durability of hardwood species in contact with the ground. (Resistencia natural de la madera de especies forestales latifoliadas en contacto con el suelo). *Copérnico Revista Arbitrada Interdisciplinaria, 4*(8), 9-15.
- Mora, N., Encinas, O., Molina Y., & Vielma, J. (2006). Durability of treated wood with CCA and CCB exposed to Judibana and San Juan de Lagunillas soils, Merida, Venezuela. (Durabilidad de Maderas Tratadas con CCA y CCB en Suelos de Judibana y San Juan de Lagunillas. Estado Mérida, Venezuela). *Revista Forestal Latinoamericana, 39*, 17-37.
- Moya, R., & Berrocal, A. (2015). Evaluation Of Biodeterioration And The Dynamic Modulus Of Elasticity Of Wood In Ten Fast- Growing Tropical Species In Costa Rica Exposed To Field Testing. *Wood Research, 60*(3), 359-374.
- Moya, R., & Muñoz, F. (2010). Physical and mechanical properties of eight species from fast-growth plantation in Costa Rica. *Journal of Tropical Forest Science, 22*(3), 317-328.
- Nzokou, P., Wehner, K., & Kamdem, D. P. (2005). Natural durability of eight tropical hardwoods from Cameroon. *Journal of Tropical Forest Science, 17*(3), 416-427.
- Orozco, Y. C. (2008). Improving the Durability of Second Growth Timbers of Naturally Durable
- Species. Master of Science Thesis submitted to Department of Wood Science and Engineering Oregon State University. pp. 89.
- Panshin, A. J., & de Zeeuw, C. (1980). Text Book of Wood Technology. McGraw-Hill Book Company, New York, ISBN 0-07-048441-4, 720pp.
- Rodrigues, A. M., Theodoro, P. N., Eparvier, V., Basset, C., Silva, M. R., Beauchêne, J., Laila S., Espíndola, L. S., & Stien, D. (2010). Search for antifungal compounds from the wood of durable tropical trees. *Journal of Natural Products, 73*(10), 1706-1707. [Crossref]

- Syofuna, A., Banana, A. Y., & Nakabonge, G. (2012). Efficiency of natural wood extractives as wood preservatives against termite attack. *Maderas Ciencia y Tecnología, 14*(2), 155-163. [Crossref]
- Schultz, T., & Nicholas, D. D. (1997). Susceptibility of Angiosperm Sapwood to White Rot Fungal Colonization and Subsequent Degradation: A Hypothesis. International Research Group in Wood Preservation. Doc IRG/WP/97-10211.
- Venäläinen, M. H., Partanen, H., & Harju, A. (2014). The strength loss of Scots pine timber in an accelerated soil contact test. *International Biodeterioration and Biodegradation, 86*, 150-152. [Crossref]