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RESEARCH ARTICLE

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Resistance to Degradation of *Pinus* spp. Wood Treated with Two Industrial Residues: Burnt Oil and Soybean Oil

Resistencia a la degradación de la madera de *Pinus* spp. tratadas con dos residuos industriales: aceite quemado y aceite de soja

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Highlights

- Soybean and burnt oil represent alternatives for wood protection.
- The hot-cold bath treatment with soybean oil provided the highest protection to the wood.
- Treatments with burnt oil can be used to extend the lifespan of posts, pieces, and stakes.
- Brushing and immersion treatments in soybean oil are not recommended for wood treatment, as they do not provide protection against xylophagous agent attacks.

Abstract

The objective of this study was to evaluate the effectiveness of two industrial residues (soybean oil and burnt oil) as preservative products under three different treatments in increasing the resistance of pine wood to degradation by xylophagous agents. To this effect, 46.6 x 5.0 x 2.0 cm pine samples were subjected to immersion treatments for 24 hours in both oils; to brushing treatments with three layers applied in 1-hour intervals; and to hot-cold baths in both oils for 1 hour at temperatures of 90 to 100 °C, followed by immersion for 2 hours. After the treatments, all samples were air-dried for 48 hours. The treatments with

burnt oil and hot-cold baths with soybean oil were more efficient in protecting pine wood, which is why their use as preservative products is recommended.
Keywords: alternative products, biodeterioration, natural degradation.

Resumen
El objetivo de este estudio fue evaluar la efectividad de dos residuos industriales (aceite de soya y aceite quemado) como productos preservantes bajo tres tratamientos diferentes para aumentar la resistencia de la madera de pino a la degradación por agentes xilófagos. Con este fin, se sometieron muestras de pino de 46.6 x 5.0 x 2.0 cm a tratamientos de inmersión durante 24 horas en ambos aceites; a tratamientos con brocha, con tres capas aplicadas en intervalos de 1 hora; y a baños caliente-frío en ambos aceites durante 1 hora a temperaturas de 90 a 100 °C, seguidos de inmersión durante 2 horas. Después de los tratamientos, todas las muestras se secaron al aire durante 48 horas. Los tratamientos con aceite quemado y los baños caliente-frío con aceite de soya fueron más eficientes en la protección de la madera de pino, por lo que se recomienda su uso como productos preservantes.
Palabras clave: productos alternativos, biodeterioración, degradación natural.

INTRODUCTION

Wood is used for various purposes, as is the case of the furniture industry and various segments of the timber industry. However, according to Ritter (1990), even though it exhibits some resistance to biological deterioration, its properties are still compromised by the action of wood-degrading organisms. Fungi, termites, mold, bacteria, algae, and lichens are the main wood-degrading agents (Stirling *et al*., 2017).

According to Stangerlin *et al*. (2011), wood species with a greater resistance to degradation have greater acceptance in the market. However, according to Gallon *et al*. (2014), there is no specific wood species that can tolerate any environment or situation without showing some susceptibility to certain wood-degrading agents.

To address this challenge, the use of preservative products can increase the resistance of wood to the action of wood-degrading organisms, prolonging its useful life and preserving its properties (Lelis *et al*., 2001). According to Souza *et al*. (2016), preservative products are important for increasing the useful life of wood against the attack of degrading agents due to alterations in its chemical composition. Additionally, they confer a hygroscopic behavior to the wood, which prevents the development of degrading organisms (Lee *et al*., 2018).

Santini (1988) states that the useful life of wood can be extended through the application of physical or chemical treatments. These products are classified into two classes according to the solvent used: oil-soluble and water-soluble (Archer & Lebow, 2006). According to Gallon *et al*. (2014), wood preservative treatments are classified into two methods: industrial and household.

Vegetable oils have been used for years in wood treatment (Rapp & Sailer, 2001). According to Menz Holz (2012), vegetable oils such as canola, sunflower, and linseed are the most commonly used preservative products. Another oil widely used for treating wood is burnt oil, which, according to Olaniran *et al*. (2010) and

Ssemaganda *et al*. (2011), even though not recognized as a wood preservative product, stands out because it can enhance resistance to attacks by wood-degrading organisms. According to Mattos *et al*. (2013), burnt oil can increase the resistance of fence posts, fences, and small rural structures.

Among the techniques employed to increase the useful life of wood, Santini (1988) highlights that the hot-cold bath method consists of keeping the wood in a container with the preservative product at high temperatures, and then in oil at room temperature to enable the penetration of the preservative product into the wood. According to the same author, simple immersion consists of placing the wood in a container with the preservative products for a certain period. This is one of the main household methods for treating wood for small-sized pieces (Gallon *et al*., 2014). İlhan *et al*. (1978) emphasize that brush treatment consists of painting the wood with preservative products.

In light of the foregoing, this study aimed to evaluate the efficiency of two industrial residues as preservative products, under three different treatment methods, in enhancing the resistance of pine wood to degradation by wood-degrading agents.

METHODOLOGY

Site characterization and material preparation

This study was conducted in an experimental field at the Federal University of Sergipe, in the municipality of São Cristóvão (SE), located in the northeastern region of Brazil. The climate of the municipality is characterized as megathermic humid and sub-humid, with an average temperature of 25 °C throughout the year, an annual average rainfall of 1333.4 mm, and a rainy season between March and August. The soil types in the area include red-yellow podzolic, eutrophic and dystrophic alluvial, slightly humid gray podzol, and mangrove indiscriminate soils, with the presence of Atlantic Forest, capoeira, and hygrophilous vegetation (EMBRAPA, 1999).

The decay field was set up using pinewood stakes obtained from the Woodworking and Furniture Production Laboratory of the Department of Forest Sciences (DCF) at the Federal University of Sergipe (UFS). The pinewood samples, which were 15 years old and had a moisture content of 12%, were prepared through tangential cuts. 2.0 x 10.0 x 100 cm stakes (thickness, width, and length, respectively) were manufactured while following standards adapted from ASTM D143-94. The test specimens were then produced, measuring 46.6 cm in length, 5.0 cm in width, and 2.0 cm in thickness. Out of a total of 35 test specimens, 30 were subjected to preservative treatments using industrial waste, and five were reserved as a control group.

Wood preservative treatments

Two industrial types of waste were used as preservatives: residual soybean oil from restaurants, with a viscosity between 65 and 70 cp (centipoise); and used motor oil, with a SAE-10W viscosity. These materials were obtained from the Wood Technology and Machining Laboratory (DCF) of UFS.

The preservatives were applied using three distinct methods – note that, for the control group, five test specimens were not subjected to any preservative treatment:

1. *Immersion treatment.* Five stakes were submerged in motor oil and five in soybean oil, where they remained for 24 hours. After this period, they were air-dried for 48 hours.

2. *Brushing treatment.* Using industrial brushes, five stakes received three coats of motor oil, and another five received three coats of soybean oil, with intervals of 1 hour between applications. After the last coat, the stakes were left to dry for 48 hours, following an adaptation of the method by İlhan *et al*. (1976).

3. *Hot-cold bath treatment.* Five stakes were immersed in motor oil and another five in soybean oil at temperatures between 90 and 100 °C for 1 hour. During the process, rigorous care was taken to avoid the ignition of the oils, given their flammability. After heating, the test specimens were immersed in containers with the respective oils at room temperature, where they remained for 2 hours before being air-dried for 48 hours, following an adaptation of the method by Santini (1988).

After the 48-hour drying period, the test specimens were weighed on a Col-BN3000-CLN precision balance (in grams) and installed in the decay field. The samples were fixed in the soil at a depth of 30 cm, with 16.6 cm remaining above the ground. The evaluation took place between July and October 2023.

Deterioration and mass loss analysis

The degree of deterioration of the stakes was assessed through visual and tactile inspection by six evaluators after removing the test specimens from the rotting field, according to the method by Lepage (1970). During this assessment, the stakes were visually inspected and individually scored based on the percentage of preservation, as presented in Table 1.

Table 1. Classification of wood deterioration index, as suggested by Lepage (1970)

Health Condition	Grade	Preservation Index (%)
Healthy, no visible damage	0	100
Mild or superficial attack by fungi, termites, or wood borers	1	90
Evident but moderate attack by fungi, termites, or wood borers	2	70
Severe rot or internal termite attack	3	40
Severe deterioration with evident fibering	4	0

To analyze the mass loss variation, the specimens were weighed after the application of the products and again after they were removed from the decay field. They were then placed in a ventilated environment for six days to dry, and they were weighed again to assess the weight variation. The mass loss caused by wood-degrading agents was determined for each wood sample using Equation (1).

$$PM = (Mi - Mf) \qquad (1)$$

where: PM = Mi = initial mass (g); Mf = final mass (g).

Statistical analysis

The data obtained from this study were electronically processed and analyzed via the Sisvar statistical software (Ferreira, 2011), in accordance with the research objectives. The mass loss (g) was analyzed using a completely randomized design (CRD) in a 2 x 3 factorial arrangement, with the factors being the products (at two levels) and the treatments (at three levels). Additionally, the degradation percentages of the specimens were determined, and the assessment was based on the degradation indices per treatment. All the data were subjected to an analysis of variance (ANOVA), followed by mean comparisons using the Scott-Knott test, with a significance level of 5% probability of error.

RESULTS

Mass loss analysis

The results indicate a significant influence of the type of preservative and the different treatments on wood protection against mass loss. Therefore, it can be stated that the lower mass loss observed in the preservative treatments is influenced by the type of product used, the different types of treatments, and the combinations of these factors (Table 2).

Table 2. ANOVA for the variation in mass loss (g) of the test specimens regarding the preservative products

FV	DF	SS	MS	Pr>Fc
Residue	1	1168.88	1168.88	0.0000**
Treatment	5	1553.73	310.75	0.0002**
Residue x Treatment	1	1.17	1168.88	0.0000**
Error	24	997.75	1168.88	

***DF** = degrees of freedom; SS = sum of squares; MS = mean square; ** = significant at a 5% level of error probability.*

For the samples treated with soybean oil residue, the immersion and brushing methods and the control showed no statistically significant differences, with all pine stakes exhibiting the highest average mass loss values, indicating the ineffectiveness of these treatments. In contrast, the hot-cold bath treatment with soybean oil demonstrated greater efficiency in protecting the wood, showing no statistical difference from the treatments with used motor oil (Table 3).

Means followed by the same uppercase letter in the rows and the same lowercase letter in the columns do not differ from each other according to the Scott-Knott test (p<0.05).

As shown in Table 3, the used motor oil treatments also showed no statistical differences between each other, displaying the lowest variations in mass loss and providing greater protection against deteriorating agents, which supports the literature's recommended utilization of used motor oil for stakes, posts, and other wooden pieces intended for rural use (Owoyemi *et al*., 2020; Belchinskaya *et al*., 2021; Vani *et al*., 2022).

Table 3. Mass loss (g) of pine wood under three different treatments with two industrial residues

	Residues	
Treatments	**Soybean oil**	**Burnt oil**
Hot and Cold Bath	9.33 Aa	4.37 Aa
Immersion	18.45 Ab	1.63 Aa
Brushing	20.53 Ab	4.86 Aa
Control	21.23 Ab	
CV (%)	65.37	

Deterioration index

The immersion, brushing, and hot-cold bath treatments in burnt oil, as well as the hot-cold bath with soybean oil, significantly influenced the preservation index of the test specimens, with greater wood health observed in the samples subjected to these treatments (Figure 1).

Although there was no statistical difference between these preservative treatments, a decreasing trend was noted in the preservation index, starting from the hot-cold bath with burnt oil treatment (Figure 1).

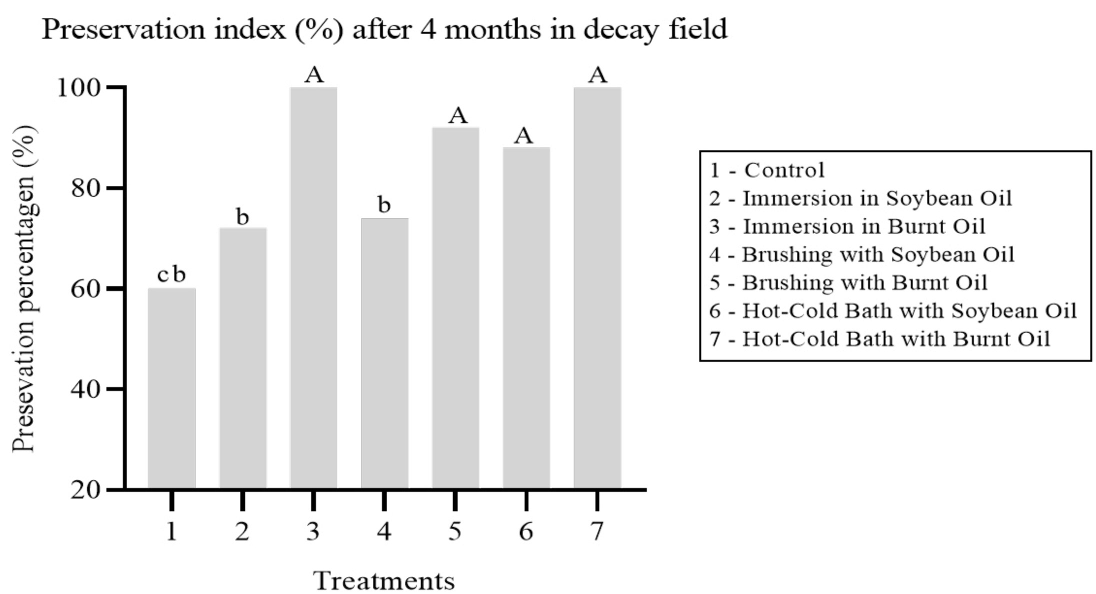

Figure 1. Preservation index of wood treated with two different industrial residues. Columns followed by the same uppercase or lowercase letter do not differ statistically from each other at a 5% probability level, according to Fisher's LSD test.

DISCUSSION

Mass loss analysis

Santini (1988) emphasizes that an effective wood preservative should exhibit high resistance to leaching, given that test specimens are subjected to adverse environmental conditions. In contrast to treatments involving brushing and immersion in soybean oil at room temperature, the hot-and-cold bath treatment, as presented in this analysis, demonstrated a significantly superior efficacy. Moreschi (2014) explains that the effectiveness of this treatment is due to the rapid contraction of heated air inside the wood, creating a vacuum that facilitates a deeper penetration of the preservative into the wood structure through absorption, a crucial phenomenon for enhancing the wood's resistance to degrading agents, as illustrated in Table 3.

The treatment of wood by immersion in vegetable oil at high temperatures has shown promising results (Zablonsky *et al*., 2017; Baar *et al*., 2021). Studies suggest that vegetable oils enhance the wood's resistance to xylophagous attacks more effectively than other preservation methods (Zablonsky *et al*., 2017; Bahmani & Schmidt, 2018; Sousa *et al*., 2019; Woźniak, 2022; Šimůnková *et al*., 2022).

Although not classified as a conventional preservative, the use of vegetable oil can be recommended for wood treatment in rural construction due to the significant resistance it imparts to pine wood in decay contexts (Mandraveli, 2023). Lee *et al*. (2018) observed that wood thermally treated with soybean oil is also suitable for flooring and external applications such as fences, garden furniture, and cladding, given its enhanced moisture resistance. However, it is important to note that, despite its high efficiency, the application of vegetable oil should be avoided in areas where the wood comes into direct contact with the soil. This, in order to prevent contamination.

The effectiveness of used oil can be attributed to its viscosity (SAE-10W), as demonstrated in studies by Souza *et al*. (2016). These studies investigated the penetration and retention capacity of oil with SAR 10 viscosity in *Trattinnickia rhoifolia* wood, confirming that this type of oil increases the wood's resistance to biological degradation due to its superior penetration capacity.

These findings are consistent with the results obtained by Souza *et al*. (2016), who found that used oil provided greater resistance to the biological decomposition of amescla wood. This protection was further confirmed by Gallon *et al*. (2014), who evaluated the deterioration resistance of Amazonian woods treated by simple immersion in used oil, attributing the efficacy of the treatment to its water-repellent properties. Eaton and Hale (1993) support this observation, noting that high moisture levels in wood promote the activity of xylophagous microorganisms, thereby compromising the physical properties of the wood.

Additionally, Mattos *et al*. (2013) concluded that, when comparing preservative treatments with CCB and used oil in eucalyptus wood, the latter exhibits a high capacity to retain more preservative, thereby increasing resistance and maintaining wood mass. Although not traditionally classified as a wood preservative, Ssemaganda *et al*. (2011) reported that used oil can provide protection against termite attacks. Nonetheless, as with the recommendations for soybean oil, in order to prevent contamination, the application of used oil should be avoided in areas where the wood comes into direct contact with the soil.

These results underscore the relevance of thermal and oil-based treatments in wood preservation, suggesting that, despite their limitations, these approaches offer effective and viable alternatives for protection against xylophagous agents, with significant practical implications for rural and external applications.

Preservation index

The results obtained for the wood preservation index, measured through a visual analysis followed by scoring (Figure 1), show that the treatments involving used oil and hot-cold baths with soybean oil are efficient due to their high penetration capacity, resulting in wood resistant to degradation. According to Kamdem *et al*. (2002) and Weiland & Guyonnet (2003), the durability of wood is related to the hydrophobic character, the production of extractives, and the modification of polymers related to the application of oils, providing greater resistance to the attack of xylophagous agents.

According to Moreschi (2014), a product's ability to penetrate and adhere to wood is directly linked to the depth of the sapwood, the anatomical directions, the vessels with tyloses, the resin canals, and the types of pits. For Temiz *et al*. (2008), a promising strategy to enhance the cell wall penetration and adhesion capacity of preservatives and consequently increase the effectiveness of treatments is the incorporation of additives. The treatment of wood using hot-cold bath cycles with soybean oil led to high preservation percentages. This approach presents itself as a viable alternative for the wood preservative industry, as it employs an underutilized industrial residue.

CONCLUSIONS

The use of burnt oil was effective in providing greater resistance to degradation in pine wood across different types of treatments. However, for soybean oil, the hot-cold bath treatment conferred greater resistance to attacks by wood-degrading agents. Treatments involving brushing and immersion in soybean oil are not recommended for use as wood preservative products, as they do not provide adequate protection.

CONFLICT OF INTEREST

The authors declare no conflict of interest**.**

AUTHOR CONTRIBUTIONS

All authors contributed equally to the discussion and commented on the drafts.

REFERENCES

American Society for Testing and Materials (ASTM) (2009). *ASTM F 88/F 88M: standard test method for seal strength of flexible barrier materials*. ASTM.

Archer, K., & Lebow, S. (2006). Wood preservation. In J. C. F. Walker (Ed.), *Primary Wood Processing: Principles and Practice* (pp. 297-338). Springer.

Baar, J., Brabec, M., Slávik, R., & Čermák, P. (2021). Effect of hemp oil impregnation and thermal modification on European beech wood properties. *European Journal of Wood and Wood Products, 79*(1), 161-175. https://doi.org/10.1007/s00107-020-01615-9

Bahmani, M., & Schmidt, O. (2018). Plant essential oils for environment-friendly protection of wood objects against fungi. *Maderas. Ciencia y Tecnología, 20*(3), 325-332. http://doi.org/10.4067/S0718-221X2018005003301

Belchinskaya, L., Zhuzhukin, K. V., Ishchenko, T., & Platonov, A. (2021). Impregnation of wood with waste engine oil to increase water-and bio-resistance. *Forests, 12*(12), 1762. https://doi.org/10.3390/f12121762

Eaton, R. A., & Hale, M. D. (1993). *Wood: decay, pests and protection*. Champman and Hail.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) (1999). Centro Nacional de Pesquisas de Solo: Sistema Brasileiro de Classificação de Solos. EMBRAPA.

Ferreira, D. F. (2011). Sisvar: A computerstatisticalanalysis system. *Ciência e Agrotecnologia, 35*, 1039-1042.

Gallon, R., Stangerlin, D. M., de Souza, A. P., Pariz, E., Gatto, D. A., Calegari, L., & de Melo, R. R. (2014). Resistência à deterioração de madeiras amazônicas tratadas por imersão simples em óleo queimado. *Nativa, 2*(1), 48-52. https://doi.org/10.31413/nativa.v2i1.1343

İlhan, R., Taskin, O., & Erten, P. (1976). Studies on the control of blue stain by using some chemicals. *Journal of the Turkish forest research inst*itute, (38).

Kamdem, D. P., Pizzi, A., & Jermannaud, A. (2002). Durability of heat-treated wood. *Holz als Roh- und Werkstoff, 60*, 1-6. https://doi.org/10.1007/s00107-001-0261-1

Lee, S. H., Ashaari, Z., Lum, W. C., Halip, J. A., Ang, A. F., Tan, L. P., Chin, K. L., & Tahir, P. M. (2018). Thermal treatment of wood using vegetable oils: A review. *Construction and Building Materials, 181*, 408-419. https://doi.org/10.1016/j.conbuildmat.2018.06.058

Lelis, A. T., Brazolin, S., Fernandes, J. L. G., Lopez, G. A. C., Monteiro, M. B. B., & Zenid, G. J. (2001). *Biodeterioração de madeiras em edificações*. Instituto de pesquisas tecnológicas.

Lepage, E. S. (1970). Método sugerido pela IUFRO para ensaios de campo com estacas de madeira. *Preservação de Madeiras, 1*(4), 205-216.

Mandraveli, E., Mitani, A., Terzopoulou, P., & Koutsianitis, D. (2024). Oil heat treatment of wood—A comprehensive analysis of physical, chemical, and mechanical modifications. *Materials, 17*(10), 2394. https://doi.org/10.3390/ma17102394

Mattos, B. D., Gatto, D. A., de Cademartori, P. H. G., Stangerlin, D. M., & Beltrame, R. (2013). Durabilidade a campo da madeira de três espécies de Eucalyptus tratadas por imersão simples. *Revista Brasileira de Ciências Agrárias, 8*(4), 648-655. https://doi.org/10.5039/agraria.v8i4a3050

Menz Holz. Catálogo [online]. (2012). Retrieved from: http://www.pletscherzaun.ch/menz/pdf/katalog_menzholz.pdf

Moreschi, J. (2014). *Biodegradação e preservação da madeira: fatores que afetam a qualidade do tratamento preservativo da madeira maciça*. UFPR.

Olaniran, S. O., Olufemi, B., & Oluyege, A. O. (2010). Absorption and effect of used engine oil as wood preservative. *ProLigno, 6*(3), 1-2.

Owoyemi, J. M., Eniabiire, O. M., Emmanuel, U. O., & Fuwape, J. A. (2020). Efficacy of commonly used wood preservatives against subterranean termites in Akungba-Akoko, Ondo State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment, 12*(1), 111-121.

Rapp, A. & Sailer M. (2001). *Use of vegetable oils for wood protection*. Cost Action E22.

Ritter, M. A. (1990). *Timber bridges: Design, construction, inspection, and maintenance*. Forest Service, United States Department of Agriculture. https://www.ltrc.lsu.edu/ltap/pdf/timber_bridges_design_construction_inspection_maintenance.pdf

Santini, E. J. (1988). *Biodeterioração e preservação da madeira*. CEPEF/FATEC.

Šimůnková, K., Hýsek, Š., Reinprecht, L., Šobotník, J., Lišková, T., & Pánek, M. (2022). Lavender oil as eco-friendly alternative to protect wood against termites without negative effect on wood properties. *Scientific Reports, 12*(1), 1909. https://doi.org/10.1038/s41598-022-05959-5

Sousa, S. F. D., Paes, J. B., Arantes, M. D. C., Lopes Junior, D. V., & Nicácio, M. A. (2019). Efficiency of vegetable oils in wood resistance to Cryptotermes brevis termites. *Floresta e Ambiente, 26*, e20170780. https://doi.org/10.1590/2179-8087.078017

Souza, R. de S., Stangerlin, d. M., Pariz, e. end de Melo, r. R. (2016). Efficiency of burnt oil as wood preservative submitted to field deterioration tests. *Nativa, 4*(3), 139-143. https://doi.org/10.31413/nativa.v4i3.3410

Ssemaganda, I. E., Mugabi, P., & Tumwebaze, S. B. (2011). Effectiveness of selected preservatives in protecting ugandan grown Eucalyptus grandis wood against termite attack. *Maderas. Ciencia y Tecnología, 13*(2), 135-142. https://doi.org/10.4067/s0718-221x2011000200001

Stangerlin, D. M., de Melo, R. R., Garlet, A., & Gatto, D. A. (2011). Durabilidade natural de painéis aglomerados confeccionados com *eucalyptusgrandis* e *bambusavulgaris*em ensaio de apodrecimento acelerado. *Ciência Rural, Santa Maria, 41*(8), 1369-1374. https://www.scielo.br/j/cr/a/J3pmcfg9rkmH49MpzSFjYzL/?format=pdf&lang=pt

Stirling, R., Sturrock, R. N., & Braybrooks, A. (2017). Fungal decay of western redcedar wood products–a review. *International Biodeterioration & Biodegradation, 125*, 105-115. https://doi.org/10.1016/j.ibiod.2017.09.001

Temiz, A., Alfredsen, G., Eikenes, M., & Terzıev, N. (2008). Decay resistance of wood treated with boric acid and tall oil derivates. *Bioresource Technology, 99*(7), 2102-2106. https://doi.org/10.1016/j.biortech.2007.08.052

Vani, C. N., Prajwal, S., Sundararaj, R., & Dhamodaran, T. K. (2022). Chemical preservatives in wood protection. In R. S Sundararaj (Ed.), *Science of Wood Degradation and its Protection* (pp. 559-587). Springer. https://doi.org/10.1007/978-981-16-8797-6_16

Weiland, J. J., & Guyonnet, R. (2003). Study of chemical modifications and fungi degradation of thermally modified wood using DRIFT spectroscopy. *Holz als Roh- und Werkstoff, 61*, 216-220. https://doi.org/10.1007/s00107-003-0364-y

Woźniak, M. (2022). Antifungal agents in wood protection—A review. *Molecules, 27*(19), 6392. https://doi.org/10.3390/molecules27196392

Zablonsky, K. M., Bonduelle, G. M., & Trianoski, R. (2017). Efeito do Tratamento Térmico com Óleo de Soja na Madeira de Pinus. *Floresta e Ambiente, 24*, e20150231. http://doi.org/10.1590/2179-8087.023115