Scientific Electronic Archives
Issue ID: Sci. Elec. Arch. Vol. 17 (5)
Sept/Oct 2024
DOI: http://dx.doi.org/10.36560/17520241965
Article link: https://sea.ufr.edu.br/SEA/article/view/1965

ISSN 2316-9281

Durability of thermally modified *Eucalyptus* wood against marine borer attack

Corresponding author
Tarcila Rosa da Silva Lins
Universidade Federal do Paraná
tarcila.lins@hotmail.com

Thiago Cardoso Silva
Universidade Federal de Rondônia

Laura Caroline Traiano Rieth
Universidade Federal do Paraná

Pedro Henrique Gonzalez de Cademartori
Universidade Federal do Paraná

Ricardo Jorge Klitzke
Universidade Federal do Paraná

Márcio Pereira da Rocha
Universidade Federal do Paraná

Abstract. Wood is a prevalent material in marine construction, both for fixed and mobile structures. However, the impact of xylophagous organisms diminishes its longevity by compromising its physical and mechanical properties. This study aimed to assess the influence of genetic variation and thermal treatment on the durability of Eucalyptus spp. wood against marine borers. Thermal modification was conducted in a kiln at 200 ºC for 14 hours, encompassing heating, exposure to peak temperature, and cooling stages. Two hybrids of E. grandis x E. urophylla, an E. grandis clone and an E. urophylla clone were tested. The experiment took place in the municipality of Pontal do Paraná (Paraná State, Brazil), using EN 275 (1992) guidelines with appropriate adaptations, during six months (summer and autumn). The extent of wood damage was visually evaluated, and damage intensity was categorized. All wood samples, irrespective of genetic material or thermal treatment, experienced attacks ranging from severe to complete infestation. Hence, the utilization of these species and hybrids in marine environments, whether in their natural state or after thermal modification, is not advisable given their insufficient resistance against marine borers.
Keywords: marine xylophages, wood biodeterioration, wood preservation, thermo-treated wood.

Introduction

When in contact with seawater, wood can be attacked by xylophages known as marine borers, composed of mollusks and crustaceans. Mollusks have an elongated, worm-like body with two shells in the anterior region that are used to bore into the wood (Müller& Lana, 2004), while crustaceans are tiny and have a rigid body with segments and legs (Kollmann& Côté, 1968).

These organisms attack wood that is in contact with seawater, whether used for fixed or movable structures, and can cause visible or non-visible damage. The marine environment has extreme conditions for deterioration of wood, because besides being efficient in the process of wood degradation, marine borers are in continuous contact with water, causing constant leaching of the wood extractives or preservative products, which contributes to the decay of the material (Bongers& Uphill, 2019).

To increase the durability of wood against the action of biotic and abiotic agents, various treatments are effective, especially when it comes to fast-growing species such as those in the

Eucalyptus genus (Cantera et al., 2021; Brito et al., 2022). Usually, this treatment enhances wood's physical and mechanical properties, such as dimensional stability as well as resistance against biodeterioration, degradation and fire (Yang et al., 2021).

To prevent or mitigate the action of xylophages, different modification techniques have been tested to increase the durability of wood exposed to marine environments (Palantiet al., 2022; Lins et al., 2023), including coating with rubber with silica added, chemical modification, and surface singing. The methods of wood modification to enhance its durability can be classified into impregnation, chemical modification, and thermal modification (Dong et al., 2016). Among these techniques, thermal modification involves exposing wood to heat, resulting in improvements in various properties such as reducing the equilibrium moisture content, enhancing dimensional stability, and increasing durability against xylophage attack, without the addition of chemical components that can be environmentally harmful (Trevisan et al., 2014; Modes et al., 2017).

The literature on the biodeterioration and preservation of wood in marine environments in Brazil is scarce (Lins et al., 2022; Lins et al., 2023). Most of the literature comes from countries with temperate climates, while Brazil has a predominantly tropical climate, making it more challenging to conduct these studies, mainly due to the difference in water and ecosystem temperatures (Lins et al., 2022). An example of this is the EN 275 (1992), which is a European standard based on environmental conditions existing on that continent that suggests field visits with annual intervals during the first five years of the experiment's duration. In the study published by Lins et al. (2023), the authors stated that the experiment lasted for 13 months, but most of the test specimens were completely deteriorated within the first three months.In particular studies are scarce in Brazil involving testing thermally modified wood for marine use. However, there are studies that have assessed the resistance of treated materials against the action of other xylophages, such as fungi (Cantera et al., 2021) and termites (Brito et al., 2022), as well as outdoor decay (Vivian et al., 2022).

This circumstance underscores the need to explore the response of treated wood concerning its vulnerability in marine settings, particularly in Brazil. In this context, we examined the inherent resistance of *Eucalyptus spp*. wood from various genetic materials, both in its untreated state and following thermal modification, in relation to susceptibility to marine borer infestation.

Material and Methods

General information and characterization of the study area

The experiment was conducted in an area located in the high-energy euhaline sector of Paranaguá Bay and along the Guaraguaçu River, the main watercourse in the Municipality of Pontal do Paraná (state of Paraná), which originates in the Serra do Prata and flows into Cotinga Channel (Reis et al., 2015). The region is contiguous to the Atlantic Ocean and is characterized as coastal estuarine. The specific point of the experiment was located within the Marina Ponta do Poço (-25.548608 N; -48.387937 W). The salinity of this location was measured using a salinity refractometer (0-100 ppt), and salinity greater than 30 ppt was identified.

The experiment began in December 2019 and lasted for five months, covering the summer and autumn seasons. Table 1 describes the maximum and minimum temperatures, followed by the total average precipitation values for each season, obtained from data provided by SIMEPAR climate bulletins, concerning the summer of 2019-2020 and autumn of 2020 in the coastal region of Paraná.

Table 1. Climatic characteristics of the coastal region of Paraná, containing maximum and minimum temperatures and average precipitation in each season of the year studied.

Season	**Average Temperatures (ºC)**	**Average total precipitation (mm)**
Summer	20.6 – 29.9	321.7
Autumm	15.7 – 25.0	110.8

Source: SAMEPAR

Table 2. Bulk density values (12%) for each *Eucalyptus* genetic wood material before and after thermal modification.

Identification	Genetic material	Bulk density natural wood ($g.cm^{-3}$)	Bulk density treated wood ($g.cm^{-3}$)
1	*E. grandis x E. urophylla*	0.50 (1.81)	0.46 (4.95)
2	*E. grandis*	0.60 (3.36)	0.52 (4.37)
3	*E. grandis x E. urophylla*	0.50 (4.00)	0.61 (5.72)
4	*E. urophylla*	0.60 (2.27)	0.65 (2.00)

Wood thermal treatment

The genetic materials used were i) a clone of *E. grandis*; ii) a clone of *E. urophylla*; and iii) two hybrids of *E. grandis* x *E. urophylla*, all aged 10 years. The thermal treatment was conducted on air-dried boards until reaching approximately 20% moisture content, with dimensions of 650 mm x 120 mm x 28 mm (length x width x thickness).

The thermal modification was carried out in an electric Linn ElektroTherm kiln, model kk260. The entire process lasted 14 hours, with 3 hours and 20 minutes in the heating phase (at a rate of 1 ºC.min-1), 4 hours of exposure to a temperature of

200 ºC, and 6 hours and 40 minutes of cooling (at a rate of 0.5 ºC.min-1). Table 2 presents the bulk density of each genetic wood material before and after thermal modification.

Preparation of specimens and biodeterioration testing in the marine environment

After the boards were thermally treated, samples were prepared for the biodeterioration test in a marine environment. The initial dimensions of the specimens were 220 mm x 55 mm x 25 mm, containing four different genetic materials in their treated and untreated forms.

The experiment was conducted in accordance with the standard EN 275 (1992), with adaptations. PVC structures (850 mm x 600 mm) were fabricated to shelter the wood samples, as shown in Figure 1. All told, six structures were built, each containing eight test specimens, resulting in a total of 48.

After the structures were installed, visits were made every 30 days to monitor the decay of the wood. Samples were deemed inappropriate for marine use when they exhibited a high degree of damage. When they had suffered an advanced degree of attack, the specimens were removed and stored in a container holding 70% alcohol until evaluation. The assessment of biodeterioration of the samples was conducted according to the EN 275 (1992) (Table 3).

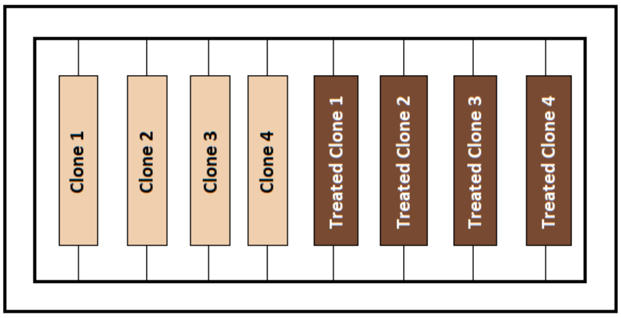

Figure 1. Structure containing the samples used in the biodeterioration test in marine environment in Pontal do Paraná-PR, Brazil.

Table 3. Visual classification of wood attacked by marine borers, according to EN 275 (1992).

Rating	Classification	Wood condition and appearance
1	No attack	No sign of attack
2	Light attack	Single or a few scattered tunnels covering not more than 15% of the specimen
3	Moderate attack	Tunnels covering not more than about 25% of the specimen
4	Severe attack	Tunnels covering between 25 and 50% of the specimen
5	Completely attacked	Tunnels covering more than 50% of the area of the specimen

Results and discussion

The results and discussion should be written Throughout the five months of exposure, all test specimens, regardless of treatment and genetic material, experienced attacks classified between severe and complete attack (Table 4). Approximately 73% of the samples deteriorated entirely on-site, detaching from the structures, which made their subsequent evaluation in the laboratory impossible.

Therefore, they were classified as completely attacked, receiving a rating of 5. According to the signs of marine borer attack (Figure 2), there was a significant loss of wood mass consumed by xylophages. All test specimens had the presence of xylophages and other encrusting organisms.

The damages identified were ranked from severe to completely attacked, making it impossible for the material to remain in service. While a few samples showed severe level of attack (Figures 2A and 2B), most of the specimens were classified as completely attacked (Figures 2C and 2D).

In a study of the outdoor decay of thermally modified wood, Carvalho et al. (2019) observed that thermal treatments reduced the mass loss of exposed *E. grandis* specimens, increasing the contributing resistance against xylophages. However, some authors have reported the low natural resistance of *E. urophylla* and *E. grandis* species to termite action (Medeiros Neto et al., 2022). Regarding hybrids, França et al. (2017) tested the natural resistance of *E. grandis* x *E. urophylla* to four species of decay fungi and subterranean termites. They found that the evaluated genetic materials had potential for external use, according to the resistance to these xylophages, especially the wood samples with higher density.

Table 4. Results of the visual assessment of the attack of marine borers on *Eucalyptus* spp. wooduntreated and thermally modified, according to EN 275 (1992).

Wood Treatment	Clone	Structures					
		I	II	III	IV	V	VI
Untreated	1	4	5	5	5	5	5
	2	5	5	5	5	5	5
	3	5	5	5	5	5	5
	4	5	5	5	5	5	5
Thermally Modified	1	5	4	5	5	5	5
	2	4	5	5	5	5	5
	3	4	5	5	5	5	5
	4	4	5	5	5	5	5

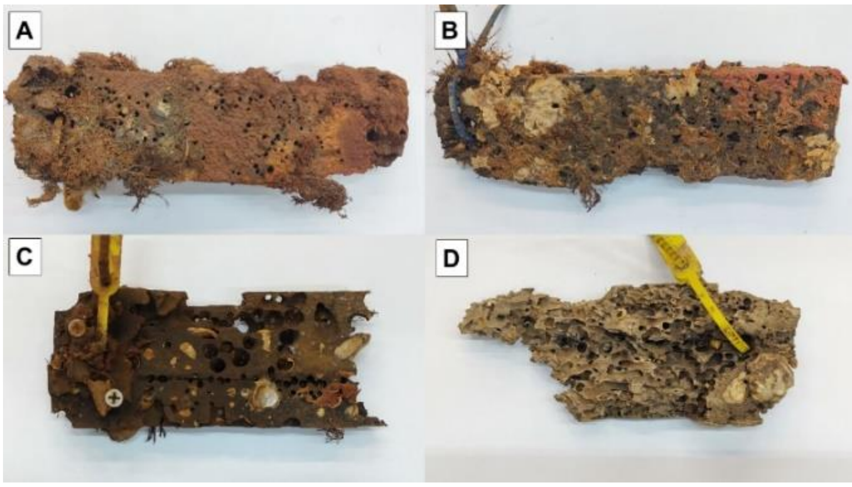

Figure 2. Specimens of *Eucalyptus* spp., untreated (B and D) and thermally modified (A and C) after six months of exposure in a marine environment in Pontal do Paraná-PR, Brazil.

Despite studies that have found good natural resistance of *E. urophylla*, *E. grandis*, and *E. urophylla* x *E. grandis* hybrids, the wood samples used in this study did not perform well, lacking natural resistance against marine borer attack. Thermal treatments can also be considered ineffective for the use of these clones in marine environments, since all samples showed significant loss of wood mass, impairing their physical and mechanical properties.

Although results from other studies have shown an increase in durability of wooden materials after thermal treatment, recommending their use in outdoor environments since they resist the action of biotic and abiotic agents (Modes et al., 2017), we found no studies related to marine environments in Brazilian climate conditions. Nevertheless, various studies have been conducted in countries with temperate climates (Janus et al., 2018). The low resistance of the wood, both natural and after treatment, may be related to the type of ecosystem and its conditions since marine environments are more hostile than terrestrial environments. Wood deterioration in the sea occurs in a more intense manner, given the constant contact with saltwater combined with the severe attack of marine borers (Roszaini&Salmiah, 2015).

Changes in the chemical components of wood after exposure to high temperatures may be one of the main factors in developing resistance against xylophages. Furthermore, extractives and other components produced by secondary metabolism can confer antibiotic and antifungal activities, also enhancing the natural resistance of wood (Moreira et al., 2016). On the other hand, constant contact with water culminates in the leaching of these compounds, as well as magnifying the solubility of the wood in water (Trugilhoet al., 2020), which impairs the resistance against the organisms that compromise the structural properties of wood.

Although thermal modification reduces the hygroscopicity of wood even when performed at milder temperatures, contact with moisture can cause the wood to lose this advantage (Melo et al., 2019). Therefore, the characteristics acquired after the treatment are not applicable to the marine environment, since the material will be in constant contact with water, contributing to its decay.

The use of high temperatures in thermal treatment has the disadvantage of causing damage such as degradation of the internal structure of the wood, causing loss of mechanical resistance (Trevisan et al., 2014). In a study to evaluate the resistance against the action of termites, Melo et al. (2019) stated that the use of a temperature of 200 ºC caused a reduction in the natural resistance of *Qualeaparaensis* wood. On the other hand, other authors have reported that treatments at high temperatures with longer exposure times are more efficient in increasing the durability of wood against fungi, for example, due to changes in its chemical structure (Lazarottoet al., 2016; Leão et al., 2018).

For temperate climates, several studies have investigated thermally modified wood to assess durability in marine environments. Janus et al. (2018) conducted laboratory experiments and found promising results. Nonetheless, the heat treatment was only the final part of the process, since the species analyzed were first subjected to a thermomechanical densification treatment. Westin et al. (2006) tested different types of techniques, including thermal modification, which did not present satisfactory results for this purpose.

Various techniques and products for modifying wood were tested by Lins et al (2023) involving the same parameters as our experiment. The authors stated that the treatments that showed the best performance, considering the percentage of deteriorated area, were waterproofing rubber (with and without the addition of silica). On the other hand, the specimens treated by paraffin impregnation, hot and cold bath with burnt oil and superficial burning using the shou sugi ban method, were considered inefficient for the purpose of extending the lifespan of the tested material in marine environments. This last method is perhaps the one that most resembles thermal modification, despite only charring the surface of the lumber, proving further evidence that methods of this kind are not suitable for use under the environmental conditions of this study.

Although some researchers have affirmed the effectiveness of thermal treatment in increasing the durability of wood against the action of xylophages, there is still no consensus, since other authors have reported opposite results (Westin et al., 2006; Janus et al., 2018). For the context of the present study, the damage suffered by treated wood was equivalent to that of natural wood, indicating that heat treatment is not appropriate for preserving *Eucalyptus spp.* wood against exposure to marine environments of any of the genetic materials tested. This reaffirms that thermal treatment alone is not a viable solution for enhancing wood durability in marine environments, highlighting the need for chemical additives for effective preservation.

Conclusion

E. urophylla, E. grandis, and E. urophylla x E. grandis woods are unsuitable for marine applications, whether in their natural state or after thermal modification. Furthermore, the utilization of different genetic materials did not significantly impact the outcomes, as all of the specimens exhibited similar behavior, characterized by severe attack levels (>25% of area attacked). Likewise, thermal modification at 200 °C did not enhance the durability of these genetic materials since the treated wood suffered comparable levels of attack as untreated wood.

Acknowledgment

We thanktheBrazilian agencies Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) - FinanceCode 001 for financing this study.

References

BONGERS F.; UPHILL, S. Performance of acetylated wood in aquatic applications. International Wood Products Journal, v. 10, n.3, p.95-101, 2019. DOI: https://doi.org/10.1080/20426445.2019.1621041

British Standard. EN 275: wood preservatives - determination of the protective effectiveness against marine borers. Bruxelas: European Committee for Standardization; 1992, 16 p.

BRITO, T. M.; FERREIRA, G.; MISSIA DA SILVA, J. G.; DE MENDONCA, A. R.; NETO, H. F.; PAES, J. B.; BATISTA, D. C. Resistance to biodeterioration of thermally modified Eucalyptus grandis and Tectona grandis short-rotation wood. Wood Material Science & Engineering, v.18, n.1, p.3-10, 2022. DOI:https://doi.org/10.1080/17480272.2022.2150985

CANTERA, L.; ALONSO, R.; LUPO, S.; BETTUCCI, L.; AMILIVIA, A.; MARTÍNEZ, J.; DIESTE, A. Decay resistance of thermally modified *Eucalyptus grandis* wood against wild strains of *Trametes versicolor* and *Pycnoporussanguineus*. Wood Material Science & Engineering, v.17, n.6, p.478-487, 2021. DOI: https://doi.org/10.1080/17480272.2021.1892185

CARVALHO, D.E.; JUIZO, C.G.F.; FRANÇA, M.C.; LOIOLA, P.L.; ROCHA, M.P. Effect of thermal modification in the natural resistance of Eucalyptus grandis and *Pinus taeda* woods. Revista Brasileira de Ciências Agrárias, v.14, n.1, p. 1-7, 2019. DOI: https://doi.org/10.5039/agraria.v14i1a5606

DONG,Y.; QIN, Y.; WANG, K.; YAN, Y.; ZAHNG, S.; LI, J.; ZAHNG, S. Assessment of the performance of furfurylated wood and acetylated wood: Comparison among four fast-growing wood species. Bioresources, v.11, n.2, p.3679-3690, 2016. DOI: https://doi.org/10.15376/biores.11.2.3679-3690

FRANÇA, F.J.N.; FRANÇA, T.S.F.A.; ARANGO, R.; WOODWARD, B.M.; VIDAURRE, G.B. Variation in Natural Durability of Seven *Eucalyptus grandis* x *Eucalyptus urophylla* Hybrid Clones. Forest Products Journal, v.67, n. 3/4, p.230-235, 2017.

JANUS, M.; CRAGG, S.; BRISCHKE, C.; MEYER-VELTRUP, L.; WEHSENER, J. Laboratory screening of thermo-mechanically densified and thermally modified timbers for resistance to the marine borer *Limnoriaquadripunctata*. European Journal of Wood and Wood Products, v. 76, p.393–396, 2018. DOI: https://doi.org/10.1007/s00107-017-1239-y

KOLLMANN F.F.P.& COTE W.A.J. Principles of Wood Science and Technology. 1.ed. Berlin: Springe; 1968.

LAZAROTTO, M.; CAVA, S.S.; BELTRAME, R.; GATTO, D.A.; MISSIO, A.L.; GOMES, L,G.; MATTOSO, T.R. Resistência biológica e colorimetria da madeira termorretificada de duas espécies de eucalipto. Revista Árvore, v.40, n.1, p.135-145, 2016. DOI: http://dx.doi.org/10.1590/0100-67622016000100015

LEÃO, R.M.; MOURA, A.S.; LUZ, S.M.; DEL MENEZZI, C.H.S.H. Caracterização e avaliação da resistência biológica da madeira sobre o ataque de fungos. Revista Interdisciplinar de Pesquisa em Engenharia – RIPE, v. 4, n. 2, p.1-16, 2018.

LINS, T.R.S.; SILVA, T.C.; ARAUJO, E.C.G.; ROCHA, M.P. Brocas marinhas e a biodeterioração da madeira no Brasil: uma revisão sistemática. Nativa, v.10, n.4, p. 495-505, 2022.
DOI: https://doi.org/10.31413/nativa.v10i4.14083

LINS, T.R.S.; SILVA, T.C.; RIETH, L.C.T.; MÜLLER, A.C.P.; LANA, P.C.; CADEMARTORI, P.H.G.; KLITZKE, R.J.; ROCHA, M.P. Evaluation of marine borers attack on treated wood in Southern Brazil. Holzforschung, v.77, n.4, p.1-10, 2023.
DOI: https://doi.org/10.1515/hf-2022-0164

MEDEIROS NETO, P.N.; PAES, J.B.; GONÇALVES, F.G.; LÓPEZ, Y.M.; BARAÚNA, E.E.P.; RIBEIRO, L.S. Relation of physicochemical characteristics on biological resistance of eucalypts woods to xylophagous termites. Journal of Building Engineering, v.52, n.15, p.1-8, 2022. DOI: https://doi.org/10.1016/j.jobe.2022.104462

MELO, R.R.; SILVA, A.G.M.F.; SABINO, M., STANGERLIN, D.M.; BATISTA, F.G.; SOUZA, M.J.C. Efeito do tratamento térmico sobre a resistência da madeira de cambará a cupins subterrâneos. Revista de CiênciasAgrárias, v.42, n.3, p. 786-791, 2019.
DOI: https://doi.org/10.19084/rca.17079

MODES, K.S.; SANTINI, E.J.; VIVIAN, M.A.; GARLET, A. Influência da termorretificação na resistência a degradação biológica das madeiras de Pinus taeda e *Eucalyptus grandis*. Ciência Florestal, v. 27, n.3, p.993–1002, 2017.
DOI: https://doi.org/10.5902/1980509828672

MOREIRA, E.L.; FAZION, H.; RIBEIRO, E.S. Variação dos teores de extrativos de três espécies florestais. Biodiversidade, v. 15, n.2, p. 163-172, 2016.

MÜLLER, A.C.P.; LANA, P.C. Manual de identificação de moluscos bivalves da família dos teredinídeos encontrados no litoral brasileiro. 1. ed. Curitiba: UFPR; 2004.

PALANTI, S.; STEFANI, F.; ANDRENACCI, M.; FAIMALI, M.; GUARNERI, I.; SIGOVINI, M.; TAGLIAPIETRA, D. BIOLOGICAL Resistance of Acetylated Radiata Pine, European Beech, and MDF against Marine Borers at Three Italian Sites after Five Years Immersion. Forests, v.13, n.5, p.1-6, 2022.
DOI: https://doi.org/10.3390/f13050636

REIS, C.S.; FRANÇA, H.T.S.; MOTYL, T.; CORDEIRO, T.S.; ROCHA, J.R.C. Avaliação da Atividade Antrópica no Rio Guaraguaçú (Pontal do Paraná, Paraná). Engenharia Sanitária Ambiental, v.20, n.3, p.389-394, 2015. DOI: https://doi.org/10.1590/S1413-1522015020000112471

ROSZAINI, K.; SALMIAH, U. Resistance of five timber species to marine borer attack. Journal of Tropical Forrest Science, v. 27, n.3, p. 400-412, 2015.
DOI: http://www.jstor.org/stable/43490298

SIMEPAR. Boletim climatológico. Available from: http://www.simepar.br/prognozweb/simepar/timeline/boletim_climatologico?page=2# Accessed in 13 May 2024.

TREVISAN, H.; LATORRACA, J.V.F.; SANTOS, A.L.P.; TEIXEIRA, J.G.; CARVALHO, A.G. Analysis of rigidity loss and deterioration from exposure in a decay test field of thermorectificated*Eucalyptus grandis* wood. Maderas, v.16, n.2, p.217-226, 2014.
DOI:https://doi.org/10.4067/S0718-21X2014005000017

TRUGILHO, P.F.; ASSIS, M.R.; LOUREIRO, B.A.; SIMETTI, R.; LIMA, L.V.L.; RODRIGUES, T.A.F.; MENDES, F.M. Efeito do material genético e tipo de solvente na quantificação de compostos solúveis da madeira em clones de *Eucalyptus*. Brazilian Journal of Animal and Environmental Research, v. 3, n. 2, p.785-792, 2020. DOI: https://doi.org/10.34188/bjaerv3n2-038

VIVIAN, M.A.; MENEGUSSI, M.; SOLDI, C.; MODES, K.S. Quality and efficiency of tannin and additives in the preservation of *Pinus taeda* wood against decay. Advances in Forestry Science, v. 9, n. 2, p. 1773-1780, 2022.
DOI: https://doi.org/10.34062/afs.v9i2.13255

WESTIN, M.; RAPP, A.; NILSSON, T. Field test of resistance of modified wood to marine borers, Wood Material Science and Engineering, v.1, n.1, p.34-38, 2006. DOI: https://doi.org/10.1080/17480270600686978

YANG, H.; GAO, M.; WANG, J.; MU, H.; QI, D. Fast Preparation of High-Performance Wood Materials Assisted by Ultrasonic and Vacuum Impregnation. Forests, v.12, n.5, p.1-12, 2021.
DOI: https://doi.org/10.3390/f12050567