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EFFICIENCY OF TRADITIONAL SHOU SUGI BAN WOOD PROTECTION TECHNIQUE IN ASSOCIATION WITH VEGETABLE OILS AGAINST ROTTING FUNGI ACTION ON PINUS WOOD[1]

EFICÁCIA DA TÉCNICA TRADICIONAL DE PROTEÇÃO DE MADEIRAS SHOU SUGI BAN, ASSOCIADA A ÓLEOS VEGETAIS, CONTRA À AÇÃO DE FUNGOS APODRECEDORES NA MADEIRA DE PINUS[1]

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ABSTRACT - The use of low-durability wood species encouraged the development of new methods focused on protecting wood from decay processes. Thus, the aim of the current study is to assess resistance-aggregation efficiency in *Pinus* sp. wood subjected to the action of fungi *Trametes versicolor* and *Rhodonia placenta*, as well as to the Japanese heat-treatment method called Shou sugi ban, in association with the incorporation of two oils. The experiment was performed based on the ASTM D – 2017 standard (1994). The herein adopted wood treatments comprised natural wood, charred wood, natural wood treated with linseed oil, charred wood treated with linseed oil, natural wood treated with Crude Tall Oil (CTO) and charred wood treated with CTO. There was resistance aggregation against the action of fungi *T. versicolor* and *R. placenta* in wood treated under all assessed conditions, although at different efficiency levels. Increased inhibition of xylophagous fungi action on charred Pinus sp. wood was observed when both linseed oil and CTO were incorporated to it. Based on the current findings, natural *Pinus* sp. wood is not resistant or perishable to these xylophages, but treated under the tested conditions were classified as resistant to *T. versicolor* and as moderately resistant to R. placenta.

Keywords: Wood-rotting fungi; Preservation; Heat treatment.

RESUMO - A utilização de espécies madeireiras com baixa durabilidade tem motivado o desenvolvimento de novos métodos para a proteção da madeira contra a deterioração. Diante desse contexto, esse trabalho teve como objetivo avaliar a eficiência da agregação de resistência na madeira de *Pinus* sp. à ação dos fungos *Trametes versicolor* e *Rhodonia placenta*, quando tratada pelo método japonês denominado Shou sugi ban, associado à incorporação de dois óleos vegetais. O experimento foi montado seguindo as recomendações da norma ASTM D – 2017 (1994) que enquadra a madeira em classes de resistência, em função da perda de massa proporcionada pela ação dos fungos. Os tratamentos na madeira foram: Madeira natural; Madeira carbonizada; Madeira natural com óleo de linhaça; Madeira carbonizada com óleo de linhaça; Madeira natural com Crude Tall Oil (CTO); Madeira carbonizada com CTO. Observou-se que ocorreu agregação de resistência frente à ação dos fungos *T. versicolor* e *R. placenta*, na madeira tratada em todas as condições avaliadas, porém com eficiências distintas. A inibição da ação de fungos xilófagos na madeira de *Pinus* sp. carbonizada, foi amplificada quando ocorreu a incorporação tanto do óleo de linhaça quanto o CTO. Conclui-se que a madeira natural de *Pinus* sp. é não resistente ou perecível a esses xilófagos, mas quando tratada nas condições testadas neste trabalho, foram classificadas como resistentes ao fungo *T. versicolor* e moderadamente resistente ao fungo *R. placenta*.

Palavras-chave: Deterioração da madeira; Preservação; Tratamento térmico.

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1 INTRODUCTION

The use of native wood species and the application of increasingly strict legislation about the use of chemical products have encouraged the development of new methods to protect wood from decay processes.

Thus, thermal modification processes applied to wood is currently seen as alternative technique to add biological resistance to this material (Trevisan et al. 2014, Modes et al. 2017). The application of this process to wood adds desirable features to it, such as reducing equilibrium moisture content, as well as improving dimensional stability and biological durability, without using chemical products (Sandberg et al. 2017).

Therefore, the thermal modification process comprises heat application to wood at temperatures lower than those capable of degrading its key chemical components, mainly hemicelluloses, which are the components mostly sensitive to heat action. On the other hand, high temperatures can have negative effects on wood, such as internal structure degradation, which, consequently, can lead to undesirable mechanical resistance loss (Brito et al. 2006).

Accordingly, the traditional Japanese wood preservation technique, the so-called Shou sugi ban, comprises wood charring by only applying specific heat at high temperatures to the external part of it in order to create a "protective layer" against xylophagous organisms and to help improving wood durability (Ebner et al. 2019). According to Kymäläinen et al. (2023), the charring process creates a superficial carbonaceous residue that protects the underlying unchanged wood. According to the aforementioned authors, this carbon layer works as coating-like natural protection form against adverse climate, moisture and deterioration-related effects on wood.

Besides the heat treatment, the aforementioned Japanese technique also recommends the superficial application (via brush) of a vegetable oil to further increase the wood's biological resistance. According to Soytürk et al. (2023), linseed oil is adopted in this case, but it can be replaced by other oil types. Thus, such a replacement is also the source of uncertainties about the efficiency of biological resistance aggregation to wood; therefore, it is the target of investigations. An alternative lies on Crude Tall Oil (CTO), which is a byproduct of resinous conifer pulp processing in the Kratf cellulose industry – this is an alternative compound to be used in this context. The use of this residual industrial oil should be encouraged and investigated in order to generate new products and to help increasing sustainability in cellulose production processes. Thus, CTO has the potential to protect wood from fungi-associated deterioration (Dias and Barreiros 2017a; Dias and Barreiros 2017b), therefore, it can be tested for such a purpose.

In light of the foregoing, the aim of the current study was to assess the effectiveness of the Shou Sugi Ban method, in association with linseed oil and CTO incorporation, in increasing *Pinus* sp. wood resistance to xylophagous fungi *R. placenta* and *T. versicolor*, under laboratory conditions.

2 MATERIALS AND METHODS

The experiment was conducted at the Forest Institute of Federal Rural University of Rio de Janeiro. Pinus wood boards were commercially acquired.

Wood deriving from these boards - which were cut with circular saw and, subsequently, with band saw - was used to produce the analyzed samples. The specimens were manufactured with the following dimensions: 3 cm x 2.5 cm x 1 cm (ASTM D-2017, standard 1994). This process was used to produce 240 specimens for laboratory tests conducted with two xylophagous fungal species.

The adopted experimental arrangement comprised six treatments with twenty repetitions for each fungal species and wood treatment condition (Table 1). Specimens were treated based on the Japanese method called Shou Sugi Ban. Initially, a torch was used to char the samples, based on Kymäläinen et al. (2023). Subsequently, a brush was used to apply linseed oil and Crude Tall Oil (CTO) to them. Oil brushing was carried out three times; new applications were performed after superficial oil absorption by the samples.

Table 1. *Pinus* wood nomenclature and treatment condition.

Tabela 1. Nomenclatura e condição de tratamento da madeira de pinus.

Nomenclature	Treatment condition
T1	Natural wood (Witness)
T2	Charred wood
T3	Natural wood treated with linseed oil
T4	Charred wood treated with linseed oil
T5	Natural Wood treated with CTO
T6	Charred Wood treated with CTO

Treated specimens remained 21 days under climate condition adjusted to 60 % relative humidity and temperature of 22 ºC, until constant weight was observed during consecutive measurements. Specimens subjected to this condition reached equilibrium moisture content compatible to the environment (approximately 13 %) and had their weight measured in four-digit analytical scale.

The test conducted with xylophagous fungi used 600 ml vials filled with 118 g of soil presenting pH 6,2 and 27 % water retention capacity. In total, 51 ml of distilled water and two *Pinus* veneers (3 cm x 3,5 cm), which worked as substrate for fungal growth, were added to each vial. The aforementioned vials were sterilized in autoclave at 120 ºC ± 1 ºC, for 30 minutes, when they got ready to receive pure fungal cultures of *R. placenta* and *T. versicolor*. These two fungi account for causing brown and white rot, respectively. Fungal manipulation and inoculation were carried out in laminar flow hood to avoid contamination.

The stage at which the *Pinus* veneers were fully colonized by the investigated fungi was monitored to check specimens' resistance to fungal action. In order to do so, sterilized and treated specimens were placed in vials, under veneers colonized by fungi.

The experiment was kept under acclimated conditions (28 ºC ± 2 °C and 75 % ± 5 % relative humidity) for 4 months. After this time was over, samples underwent the cleaning process based on using a soft-bristle brush to remove the entire fungal structure colonizing their outer surface.

Properly cleaned specimens were acclimated under the same humidity and temperature conditions adopted in the first acclimation procedure, and they remained like that until reaching constant weight. Then, specimens' mass was recorded again to calculate the difference between the final value and the one recorded before they were subjected to xylophagous fungi action.

Finally, samples' mass loss was classified based on parameters described in the ASTM D-2017 standard (1994) in order to assess treatments' efficiency against brown and white rot fungi development (Table 2).

Table 2. Wood resistance classification based on mass loss due to deterioration caused by xylophagous fungi - ASTM D - 2017 (1994).

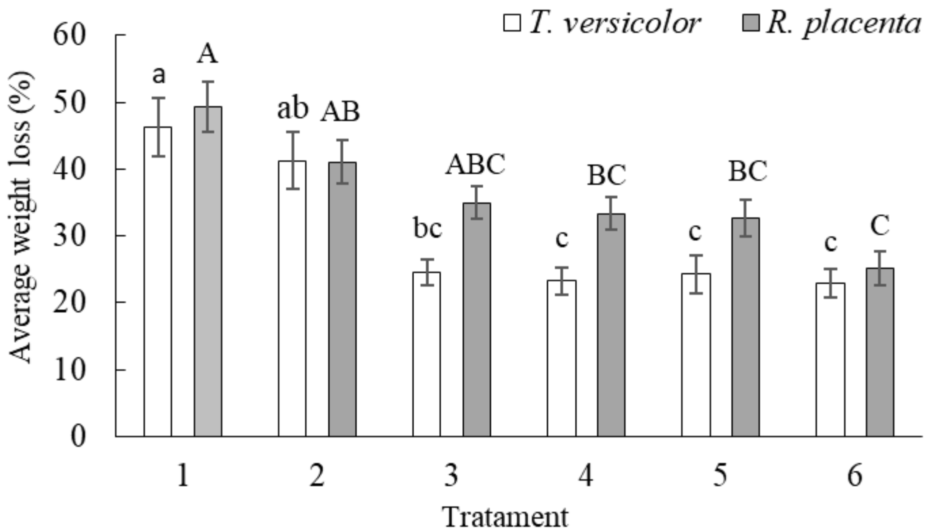
Tabela 2. Classificação da resistência da madeira, frente à perda de massa em função da deterioração proporcionadas por fungos xilófagos ASTM D – 2017 (1994).

Class of Resistance	Average Weight Loss (%)
Highly resistant	0-10
Resistant	11-24
Moderately resistant	25-44
Not resistant or perishable	45 or above

Statistical analysis was carried out in BioEstat software, version 5.0 (Ayres et al. 2007). Data normality was checked through Lillefors test, at 5 % significance level. Kruskal-Wallis test was applied after the recorded values did not show normal distribution. Average ranks were compared to each other through Dunn test. Both tests were carried out at 5 % significance level. The herein adopted statistical procedures were suggested by (Ayres et al. 2007).

3 RESULTS AND DISCUSSION

The mass loss observed for superficially charred Pinus sp. specimens incorporated with oils increased their resistance to the action of fungi *T. versicolor* and *R. placenta*, in comparison to that of natural wood, although at different efficiency levels (Figure 1).



Different letters, between bars, express statistically significant differences (Dunn at 5% significance level) through lowercase for fungus *T. versicolor* and uppercase for *R. placenta*.

Letras diferentes, entre barras, expressam diferenças estatisticamente significativas (Dunn ao nível de significância de 5%) por meio de minúsculas para o fungo *T. versicolor* e maiúsculas para *R. placenta*.

Figure 1. Mean mass loss rate recorded for natural Pinus wood (T1) only treated with external charring (T2), linseed oil (T3) or CTO (T4), as well as with charring / linseed oil (T5) or charring / CTO (T6), subjected to the action of fungi *T. versicolor* and *R. placenta* for four months, under laboratory conditions.

Figura 1. Perda de massa percentual média da madeira de pinus natural (T1), tratada somente com fogo externamente (T2), somente com óleo de linhaça (T3), somente com CTO (T4), com fogo/óleo de linhaça (T5) e com fogo/CTO (T6), submetida à ação dos fungos *T. versicolor* e *R. placenta*, por quatro meses em condições de laboratório.

Only the superficial charring was enough to make the wood moderately resistant to deterioration caused by fungus *T. versicolor* (Table 3). However, no statistically significant difference in mass loss was observed between charred and natural wood specimens (Figure 1). On the other hand, natural and charred wood treated with linseed oil and CTO recorded mass loss significantly lower than that of the witness wood (Figure 1). It is worth highlighting that samples subjected to these treatments were classified as resistant to the action of fungus *T. versicolor* (Table 3).

Table 3: Resistance classes of natural (T1) and externally charred (T2) *Pinus* wood, only treated with linseed oil (T3) or CTO (T4), as well as wood treated with charring / linseed oil application (T5) and charring / CTO application (T6), subjected to the action of fungus *T. versicolor* for four months, under laboratory conditions.

Tabela 3. Classes de resistência da madeira de pinus natural (T1), carbonizada externamente (T2), somente com óleo de linhaça (T3), somente com CTO (T4), carbonizada/óleo de linhaça (T5) e carbonizada/CTO (T6), submetida à ação do fungo *T. versicolor*, por quatro meses em condições de laboratório.

Tratament	Average Weight Loss (%)	Class of Resistance
Natural wood (Witness)	46.28	Not resistant or perishable
Charred wood	41.25	Moderately resistant
Natural wood treated with linseed oil	24.56	Resistent
Charred wood treated with linseed oil	23.29	Resistent
Natural Wood treated with CTO	24.30	Resistent
Charred Wood treated with CTO	22.94	Resistent

All the applied treatments made the assessed wood moderately resistant to deterioration caused by *R. placenta* (Table 4). Although these treatments were effective, they were less efficient in promoting wood resistance to deterioration caused by *T. Versicolor*. Therefore, statistical differences in mass loss were not observed between specimens only treated with charring and linseed oil application (experimental conditions 2 and 3, respectively), and natural wood (Figure 1). However, it is worth emphasizing that wood treated with charring / CTO - treatment 6 - recorded mass loss significantly lower than that observed for charred and natural woods - treatments 1 and 2 (Figure 1). These findings indicate that wood external charring is capable of increasing wood resistance class from perishable to moderately resistant to the action of fungus *R. placenta*. Moreover, resistance improvement has significantly increased when CTO application to the wood was synergistically associated with the heat treatment.

Table 4. Resistance class of natural (T1) and externally charred (T2) *Pinus* wood only treated with linseed oil (T3) and CTO (T4), as well as wood treated with charring / linseed oil (T5) and with charring / CTO (T6) subjected to the action of fungus *R. Placenta* for four months, under laboratory conditions.

Tabela 4. Classes de resistência da madeira de pinus natural (T1), carbonizada externamente (T2), somente com óleo de linhaça (T3), somente com CTO (T4), carbonizada/óleo de linhaça (T5) e carbonizada/CTO (T6), submetida à ação do fungo *R. placenta*, por quatro meses em condições de laboratório.

Tratament	**Average Weight Loss (%)**	**Class of Resistance**
Natural wood (Witness)	49.26	Not resistant or perishable
Charred wood	41.06	Moderately resistant
Natural wood treated with linseed oil	34.99	Moderately resistant
Charred wood treated with linseed oil	33.33	Moderately resistant
Natural Wood treated with CTO	32.72	Moderately resistant
Charred Wood treated with CTO	25.22	Moderately resistant

Part of this resistance improvement may have been promoted by chemical changes in the wood due to heat treatment application through surface charring. Accordingly, Kymäläinen et al. (2023) explained that wood's outer layer charring can decrease nutrient availability for fungi and insects; therefore, this procedure can help reducing wood likely deterioration.

Moreover, Kymäläinen et al. (2022) investigated surface charring application to *Piceaabies* (L.) H. Karste and *Betula pendula* Roth wood based on the direct flame impingement and heated iron surface-contact methods. They concluded that both techniques reduced the mass loss caused by brown- and white-rot fungi in comparison to untreated specimens. This result corroborates the current findings. However, according to Kymäläinen et al. (2022), wood charring performed through the heated iron-contact method was more effective in protecting the wood. According to them, this method resulted in smoother wood showing lesser porosity and cracks than the flame charring, which was the method adopted in the current investigation. The aforementioned authors also advocate that common wood's smoother and less porous surface can hinder fungal colonization and limit fungal growth on wood's thermally modified surface.

Soytürk et al. (2023) have tested the use of linseed oil in association with surface charring on *Pinus taeda* L and *Eucalyptus bosistoana* F. Muell wood specimens. Based on their findings, this treatment had synergistic effects against the action of white- and brown-rot fungi, as those observed in the current study. However, the aforementioned authors have emphasized that durability assignments based on weight loss rates observed for the treated samples have pointed out that the treated wood did not reach the "very durable" classification. This factor was also highlighted in the current findings, since charred *Pinus* sp. specimens treated with CTO or linseed oil were not classified as highly resistant to any of the tested conditions, based on criteria set in the ASTM D – 2017 (1994) standard.

However, the application of vegetable oils in separate, or in association with external wood charring, as shown in the current study, is a viable alternative to help protecting wood against deterioration caused by fungi, since several scientific studies have highlighted the effectiveness of using these compounds for such a purpose (Dias and Barreiros 2017a; Dias and Barreiros 2017b; Hassan et al. 2021; Soytürk et al. 2023).

Dias and Barreiros (2017b) investigated CTO's efficiency in increasing *Pinus elliotti* and *Eucalyptus grandis* wood's resistance to the action of fungus *T. versicolor*. According to them, this treatment enabled turning these woods from non-resistant in their natural condition to moderately resistant after treatment application. These findings support those observed in the current study, according to which, non-charred *Pinus* sp. wood treated with CTO was classified as resistant to the action of the same fungal species used in the study by the aforementioned authors (Table 3). However, it is worth pointing out that wood charring application in separate enabled classifying specimens as moderately resistant to fungal action. Nevertheless, wood charring, in association with CTO application, enhanced this effect and made specimens resistant to *T. versicolor*.

Wood resistance provided by the synergistic use of CTO and heat treatment was more subtle in the test conducted with *R. placenta* than in the one conducted with *T. versicolor*, since all samples were classified as moderately resistant to fungal action, regardless of the adopted treatment condition (Table 4). However, the mass loss observed for wood treated with charring and CTO application was significantly lower than that observed for wood specimens only subjected to charring. On the other hand, the fact that this outcome was not observed for charred wood treated with linseed oil suggests that CTO synergistically applied with charring is more efficient in promoting wood resistance to *R. placenta* than linseed oil application in association with the aforementioned heat treatment (Figure 1).

It is important highlighting that there are reports differing from the results in the presented study, although they are few in number. Vivian et al. (2020) tested the efficiency of CTO application in separate to increase *Araucaria angustifólia*, *Pinus taeda* and *Eucalyptus viminalis* wood resistance to the action of brown-rot fungi *T. versicolor* and *Gloeophyllum trabeum*. According to them, this procedure did not promote significant mass loss reduction or enabled resistance classification different from that of the control wood.

Furthermore, Hasburgh et al. (2021) tested the influence of external wood charring on 28 commercially available wood species treated with this technique. According to them, the effectiveness of this treatment in increasing wood resistance to the action of fungi *G. trabeum* and *T. versicolor* was inconclusive, since there was no evidence that wood charring promoted significant protection against the action of these fungi.

Although Hasburgh et al. (2021) reported these findings, they emphasized that besides providing an aesthetically attractive finishing, the charring process has promoted some wood protection against fungal action. With respect these findings, which differ from the ones presented in the current study, it is worth taking into consideration that the protocol type adopted for wood charring purposes has significant influence on the process to aggregate wood resistance to fungi, as reported by Kymäläinen et al. (2022); therefore, it could be an explanation for these divergences.

However, given these divergent reports, it is possible saying that the wood treatments assessed in the present research also aimed at establishing the synergistic effect of oil applications with wood surface charring to help increasing specimens' resistance to xylophagous fungi. On the other hand, Hasburgh et al. (2021) assessed commercially charred wood, without oil application, and Vivian *et al.* (2020) tested non-charred wood treated with CTO. Temiz et al. (2008) reported that CTO application in separate did not promote significant wood protection against the action of xylophagous fungi, whereas its application in association with boric acid was considered highly efficient for this purpose.

Therefore, CTO is seen as promising product to protect wood against deterioration processes (Dias and Barreiros 2017a, Dias and Barreiros 2017b). However, results in the present study reinforce the conclusion by Temiz et al. (2008), according to whom, it is necessary using CTO in association with another wood treatment method, such as the herein adopted one, namely: external wood charring based on the Shou sugi ban method. This association enabled observing the most promising outcomes in terms of increasing *Pinus* sp. wood resistance to xylophagous fungi under laboratory conditions.

Therefore, it is necessary testing the effectiveness of these results under the different field conditions wood will be actually subjected to. Accordingly, it is relevant highlighting the gap in scientific information, since the efficiency of external wood charring in association with CTO application to promote wood resistance to deterioration processes is yet to be investigated under field conditions. This investigation becomes relevant, since the environmental and ecological features wood is exposed to in the field promote the interaction of biotic and abiotic agents in the form of synergies and antagonisms that are extremely hard, if not impossible, to reproduce under laboratory conditions (Lepage and Salis, 2015).

4 CONCLUSIONS

Pinus sp. treatment based on the Shou sugi ban technique, in association with linseed oil and CTO (Crude tall oil) application, promoted wood resistance to the action of fungi *Trametes versicolor* and *Rhodonia placenta* under laboratory conditions. Furthermore, external wood-charring application, itself, is a method capable of inhibiting the action of fungi *Trametes versicolor* and *Rhodonia placenta*. However, its application in association with the incorporation of the herein tested oils has increased wood resistance to the investigated fungi.

Natural *Pinus* sp. wood is not resistant or perishable to the action of fungi tested in the current study. However, this wood became moderately resistant to *Rhodonia placenta* after treatment application under all tested conditions. Charred wood was moderately resistant to the action of *Trametes versicolor*, as well as resistant to it after charring application in association with CTO or linseed oil incorporation.

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6 AUTHORSHIP CONTRIBUTIONS

Henrique Trevisan: Supervision, Project administration, Writing – review & editing; Nathália Augusto dos Santos: Investigation, Writing – original draft, Methodology; Vinicius José Fernandes: Supervision, Writing – review & editing.

7 CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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