

Original Article

Potential of lignocellulosic materials (wood and bark) from *Ateleia glazioviana* and *Hovenia dulcis* as a natural wood preservative

Potencial de materiais lignocelulósicos (madeira e casca) de *Hovenia dulcis* e *Ateleia glazioviana* como um preservativo natural de madeiras

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Abstract

The lignocellulosic materials of some plant species are rich in chemical compounds that can serve as a source of natural and environmentally less aggressive biocides for treating wood. The aim of this study was to verify the potential of the lignocellulosic materials (wood and bark) of *Ateleia glazioviana* and *Hovenia dulcis* as a natural wood preservative. The extracts were prepared by heating the materials to 100 °C at a concentration of 10%. The wood samples were treated in a laboratory autoclave using the empty cell method. Control samples (untreated) and samples treated with chromated copper borate - CCB (2.5%) were used as a comparison. The accelerated rot test in the laboratory was carried out using a sample of the colony of the white rot fungus, *Trametes versicolor*. Mass loss, solubility in 1% NaOH, scanning electron spectroscopy (SEM) and attenuated total reflection infrared spectroscopy (ATR-FTIR) were evaluated. A rotting field test was also carried out in a forest fragment for 180 days and the mass loss, apparent specific mass, ATR-FTIR, and dynamic bending of the wood samples were evaluated. In laboratory tests, natural extractive solutions from the bark and wood of *Hovenia dulcis* and only from the bark of *Ateleia glazioviana* have fungitoxic potential against the white rot fungus, when compared to material without preservative impregnations. The resistance of the wood in the field to rot did not obtain significant results with the application of the natural preservatives, and future studies will need to increase the concentration of the extracts in an attempt to improve their performance as natural biocides.

Keywords: environment-friendly wood preservatives, wood protection, *Trametes versicolor*, decay resistance, field test.

Resumo

Os materiais lignocelulósicos de algumas espécies vegetais são ricos em compostos químicos que podem servir como fonte de biocidas naturais e ambientalmente menos agressivos para o tratamento da madeira. O objetivo deste estudo foi verificar o potencial dos materiais lignocelulósicos (madeira e casca) de *Ateleia glazioviana* e *Hovenia dulcis* como preservante natural da madeira. Os extratos foram preparados com o aquecimento em temperatura dos materiais a 100 °C com concentração de 10%. As amostras de madeira foram tratadas em uma autoclave de laboratório por meio do método de célula vazia, em forma de comparação foram utilizadas as amostras controle (sem tratamento) e tratadas com borato de cobre cromatado - CCB (2,5%). O teste de apodrecimento acelerado em laboratório foi realizado com uma amostra da colônia do fungo de podridão branca, *Trametes versicolor*. Foram avaliadas a perda de massa, a solubilidade em NaOH 1%, a espectroscopia eletrônica de varredura (SEM) e a espectroscopia infravermelha de reflexão total atenuada (ATR-FTIR). Também foi realizado o teste de campo de apodrecimento em fragmento florestal por 180 dias e avaliadas a perda de massa, a massa específica aparente, a ATR-FTIR e a flexão dinâmica das amostras de madeira. Em testes laboratoriais, as soluções extrativas naturais da casca e da madeira de *Hovenia dulcis* e somente da casca de *Ateleia glazioviana* têm potencial fungitóxico contra o fungo da podridão branca, quando comparadas a um material não impregnado com solução preservativa. A resistência da madeira no campo em apodrecimento não obteve resultados significativos com a impregnação dos biocidas naturais, sendo necessário em estudos futuros o aumento da concentração dos extratos na tentativa de melhorar seu desempenho como biocidas.

Palavras-chave: preservativos naturais de madeiras, proteção da madeira, *Trametes versicolor*, resistência ao apodrecimento, campo de apodrecimento.

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1. Introduction

The wood is a material much appreciated by the wood industries and final consumers, for presenting desirable physical, mechanical and aesthetic characteristics, besides being versatile in its applications in houses, furniture, toys, poles, fences and floors. However, all wood is susceptible to the attack of xylophagous organisms and, depending on the environmental conditions, it will suffer a greater or lesser deterioration.

In Brazilian industries, conventional treatments are still widely used. The wood needs to be treated for its application in rural buildings, power poles, sheds for agricultural machinery and implements. The durability of the wood is improved by adding chemicals, such as chromated copper arsenate - CCA and chromated copper borate - CCB, which are metallic salts impregnated in wood under vacuum and pressure, and although very efficient in what they propose, they are toxic to the environment and other living beings, in addition to the difficulty in disposing of the impregnated wood.

In order to extend the outdoor life of wood other methods are also tested, such as heat treatment (Herrera et al., 2018), chemical modification (Wei et al., 2013), impregnation of water repellents (Lesar et al., 2011), or covering the wood with coatings (Nguyen et al., 2018). To increase the durability of wood coatings, different types of photostabilisers have been incorporated, such as organic ultraviolet - UV absorbers (Grüneberger et al., 2015), hindered amine light stabilisers (Schaller et al., 2009) antioxidants and inorganic metal oxide nanoparticles (Shen et al., 2018).

Considering the environmental and health concerns of living beings, the application of alternative agents for wood protection based on natural compounds of plant origin has been gaining more and more interest from science (Broda, 2020). The example of tannins, found in abundance in the bark, leaves and seeds of plants, responsible for offering protection to plants against light and various biological threats, mainly insects and fungi (Shirmohammadli et al., 2018; Koopmann et al., 2020). Researchers found that wood impregnated with 5%, 10% or 20% aqueous tannin solution showed higher resistance to white rot and brown rot fungi (Tascioglu et al., 2013) and against termites (Yamaguchi et al., 2002). The use of tannin-based biocides is proposed by Silveira et al. (2017) and Silva et al. (2017) as they are sustainable natural products and provide protection and gains in wood life.

Plant species are rich in chemical compounds that can serve as a source of natural and environmentally less aggressive biocides. The potential use of these species has been pointed out by Silva et al. (2018), when extracting bioactives from leaves of *Nectandra grandiflora*; Xie et al. (2017) tested the antifungal activity of extracts obtained from leaves and shoots of *Origanum vulgare*, *Cymbopogon citratus*, *Thymus vulgaris*, *Pelargonium graveolens*, *Cinnamomum zeylanicum* and *Eugenia caryophyllata* against white and brown rot fungi. The potentials of *Jatropha curcas* seed oil and in combination with leaf extracts of *Cymbopogon citratus*, *Ocimum basilicum*, and *Eucalyptus globulus* as wood preservatives against *Macrotermes*

bellicosus termites was accessed by Bessike et al. (2023). The salicylic acid, tea tree oil, and cinnamon oil was natural additives investigated by Bardage et al. (2014) against blue stain and mold growth on wood. Tchinda et al. (2018) evaluated the effect of extractives of heartwood of five tropical wood species harvested in Cameroon on the growth inhibition of white rot and brown rot fungi.

The species used in this research are large trees, which can reach over 25m in height and 50cm in diameter. *Ateleia glazioviana* Baill. (Fabaceae) naturally occurring in southern and southeastern Brazil, Argentina and Paraguay (Gorski, 2021) and *Hovenia dulcis* Thunb. (Rhamnaceae), endemic in China, Japan and Korea and outside its area of occurrence is found in spontaneous state or cultivated in southeast Asia, northern Argentina, Paraguay and southern Brazil (Carvalho, 1994). The species were chosen because of literature reports of toxic potential to living organisms. Talgatti et al. (2020) show the fungitoxic potential of extracts from the wood, bark and leaves of *H. dulcis* and *A. glazioviana* against xylophagous organisms. The *A. glazioviana* trees are palatable and considered toxic to cattle and sheep (Lunkes et al., 2021; Da Rocha et al., 2022). The active principle of the plant are the isoflavones, and its action is described as ichthyotoxic, that is, it causes the disorganization of the membranes in the red blood cells, which will result in cellular hemolysis (Ortega et al., 1986). On the other hand, *H. dulcis* causes intoxication by ripe fruits, resulting in necrosis and vacuolar degeneration of hepatocytes accompanied by congestion in animals (Cardoso et al., 2015).

The aim of this study was to verify the potential of lignocellulosic materials (wood and bark) from *Ateleia glazioviana* and *Hovenia dulcis* as a natural wood preservative.

2. Material and Methods

2.1. Species, origin, collection and production of extractive solutions

The *Hovenia dulcis* and *Ateleia glazioviana* trees came from experimental plantations (29°65' S and 53°91' W) of the Department of Agricultural Diagnosis and Research - DDPA, located in the city of Santa Maria, in the state of Rio Grande do Sul, Brazil. Five trees of each species were cut and the first three-meter-long logs were selected and debarked. The wood was split into discs to facilitate processing. The bark and wood, herein called lignocellulosic material, were reduced to chips using a guillotine, then dried at room temperature for 15 days to obtain the natural extractive solutions. The region's climate, according to the Köppen-Geiger classification, is of the Cfa type, characterized as humid subtropical, with an average annual temperature of 19 °C and annual rainfall of 1,838 mm (Alvarez et al., 2013).

After air drying, 200 grams of wood and bark from each species were placed separately in Becker glasses with 2 liters of distilled water, and boiled at 100 °C until 10% concentration, using a hot plate. The material was sieved to filter the natural extractive solutions, which

remained in a climatic chamber (24 °C and 60% humidity) until being used.

2.2. Wood treatment and decay resistance in laboratory tests

A total of 20 *Eucalyptus grandis* wood specimens were made with dimensions of 2.54 cm x 2.00 cm x 1.00 cm (longitudinal x radial x tangential), according to the American Wood Protection Association - AWP A E10-16 (AWPA, 2016a). Subsequently, 10 specimens with each of the extracts: *H. dulcis* (bark and wood), *A. glazioviana* (bark and wood) were treated in a laboratory autoclave by the empty cell method, which initially consists of applying a back pressure for 15 minutes and then transferring the preservative product to the inside of the autoclave to apply a pressure of 8 bar for one hour.

This method was also used in the control experiment (untreated samples) and samples treated with chromated copper borate preservative – CCB solution (2.5%), totaling 60 specimens. CCB was used as the preservative solution, in which the proportions of the components of this solution were based on the Brazilian Standard - NBR 9480, Brazilian Association of Technical Standards - ABNT (2009) for preserved wood fence posts: 2,5% by weight of potassium dichromate, boric acid, copper sulphate, acetic acid and water. The materials with and without treatment were dried in oven at 103 ± 2 °C, until reaching constant mass. The volume and mass of each sample were determined as AWP A E10-16 (AWPA, 2016a) and the values used to calculate the wood mass loss.

We used the xylophagous fungus *Trametes versicolor*, the species that causes white rot, from the collection of the Forest Products Laboratory (LPF) of the Brazilian Forest Service (SFB) in Brasilia, Federal District, Brazil. The laboratory accelerated decay tests and evaluations were performed according to AWP A E10-16 (AWPA, 2016a) in the Forest Products Laboratory of the Federal University of Santa Maria - UFSM (29°42' S and 53°48' W). The test was kept in an acclimatized room under conditions of 28 ± 2 °C and 75 ± 5% relative humidity, for 12 weeks.

After the accelerated decaying test period, the parameters mass loss and solubility in 1% sodium hydroxide (NaOH) were evaluated. The detailed investigation of the fungal attack on the wood specimens was carried out by scanning electron microscopy (SEM) and by attenuated total reflectance infrared spectroscopy (ATR-IR).

The mass loss was obtained considering the initial dry mass and the final dry mass of the specimens, and the values were compared to those established according to AWP A E30-16 (AWPA, 2016b) and the wood resistance class to xylophagous fungi can be predicted (Table 1).

The solubility test in 1% NaOH determines the content of low molecular weight polysaccharides of a wood, i.e., the polyenes and eventual degraded cellulose chains. Its determination was conducted based on NBR 7990, ABNT (2010), in which 2 grams of the samples already reduced into sawdust were used and 100 mL of 1% NaOH solution was added, and then they were forwarded to the water bath, at approximately 100°C, for 1 hour, being shaken rapidly with a glass rod in the times of 10, 15 and

Table 1. Classes of wood resistance to xylophagous fungi, according to AWP A E30 (AWPA, 2016b).

Resistance classes	Mass loss (%)	Residual mass (%)
Very resistant	0-10	90-100
Resistant	11-24	76-89
Moderate resistance	25-44	56-75
Non-resistant	≥ 45	≤ 55

25 minutes after the beginning. After this period, the material was transferred to a vacuum filtration system, where the samples were washed first with hot distilled water, with 50 mL of 10% acetic acid, and again with hot distilled water, filtering the sample. The resulting filter paper was transferred to a crucible and dried in an oven at 103 ± 2 °C until constant mass was reached. This procedure was performed in triplicate for greater reliability of the data. To obtain the final wood solubility, Equation 1 was used.

$$S = \left[\frac{(A - B)}{A} \right] \times 100 \quad (1)$$

Where: A is dry weight of the specimen before extraction (g); B is dry weight of the specimen after extraction (g).

The transversal images of the specimens after fungus attack were acquired with a scanning electron microscope of the brand TESCAN, VEGA3 equipment. For the infrared spectroscopy analysis (ATR-IR) the specimens were reduced to small sticks, homogenized and milled in a knife mill (Willey type) and classified in vibrating sieves, being used the material retained in the 60 mesh sieve. In the spectrophotometer Nicolet Nexus 470, 32 scans were performed in transmittance with resolution of 4 cm⁻¹ and readings between 4000 and 700 cm⁻¹. For each test, the lamp of the equipment was aligned and the background spectra were collected.

2.3. Wood treatment and decay resistance in fields tests

The specimens for the decaying test in field conditions were prepared from the random sampling of six trees of *Eucalyptus grandis* with 20 years of age, avoiding individuals in bordering, twisted stem and with presence of bifurcation. Using a chainsaw, the first and second logs of each tree, approximately 3 m in length, were removed. After this process, with a band saw, planer, circular saw and top cutter, the central plank was made, from which the specimens were made in the dimensions 2.5 cm x 5.0 cm x 50.0 cm (thickness x width x length), according to Becker (1972).

The samples were treated with the extracts in a laboratory autoclave by means of the empty cell method, with controls (untreated samples) and samples treated with CCB solution being used.

After treatment the specimens were installed in a recovered forest fragment, located at the Silviculture and Forest Nursery Laboratory (29°42'S and 53°48'W), of the Federal University of Santa Maria, in the city of Santa Maria, Rio Grande do Sul, Brazil, in three randomized

blocks containing in each block, six rows, being randomly allocated 10 specimens of each treatment per block. The blocks and their rows were spaced 50 and 25 cm apart, respectively. The specimens were partially buried, approximately 15 cm, being equidistant 5 cm from each other where they remained exposed for 180 days.

After the field test period, the characteristics of mass loss, apparent specific mass and dynamic bending were evaluated. The detailed investigation of fungal attack on the wood specimens was performed by attenuated total reflectance infrared spectroscopy.

The mass loss was obtained considering the initial dry mass and the final dry mass of the specimens, and then the values were compared to those established according to AWPA E30-16 (AWPA, 2016b). The apparent specific mass at 12% humidity was determined based on NBR 7190, ABNT (2022).

The mechanical dynamic bending test in a Charpy pendulum followed the standard Association Francaise de Normalization - NF B51009 - AFN (1942). When the pendulum is released, the impact with the specimen occurs, obtaining the absorbed work (W) in Joule, on the graduated scale of the machine. The data obtained in the dynamic bending test were converted from Joule to kg m using the relation 1 joule = 0.101972 kg m. The coefficient of resilience (K) and the dynamic quota (DQ) were estimated using Equations 2 and 3, respectively. Additionally, the wood resistance and dynamic bending (f_{bw}) was measured according to NBR 7190, ABNT (2022), using Equation 4.

$$K = W / b \cdot \left(\frac{10}{h^{16}} \right) \quad (2)$$

$$DQ = K / \rho_{ap}^2 \quad (3)$$

$$f_{bw} = (1000 \cdot W) / b \cdot h \quad (4)$$

Where: K is coefficient of resilience (MPa.m); W is work absorbed to rupture the specimen in Joules; b and h are cross-sectional dimensions of the specimen in cm; DQ is dynamic quota; ρ_{ap} is bulk density (g cm^{-3}); f_{bw} is impact strength in KJ/m^2 .

2.4. Statistical analysis

The data was evaluated using the Genes statistical software (Cruz, 2001), which checked the normality of the errors and the homogeneity of the variances, respectively, Bartlett and Shapiro-Wilk. In the accelerated decaying test, a 4 x 1 factorial design (four treatments: wood and bark extracts, control and CCB) and a fungus (*Trametes versicolor*) were used for each of the two species evaluated (*Hovenia dulcis* and *Ateleia glazioviana*). Where there was significant interaction between the factors, the means were compared by the t-test ($p < 0.05$). Where there was no significant interaction, the means of each factor were evaluated by the Tukey test ($p < 0.05$). In the field decay test the experimental model was applied in randomized blocks, with Tukey test ($p < 0.05$).

3. Results and Discussion

3.1. Decay resistance test

3.1.1. Resistance to *Trametes versicolor*

After exposure to the white rot fungus *Trametes versicolor*, the samples of *Eucalyptus grandis* wood treated with CCB solution show the lowest value of mass loss, but statistically showed no difference from those treated with the natural extractive solutions of *Hovenia dulcis* (bark and wood) and of *Ateleia glazioviana* bark (Table 2). The worst performance (78.70% of mass loss), occurred in the samples without any treatment, followed by the treatment with the natural extractive solutions of *Ateleia glazioviana* wood, both classified as non-resistant.

The extracts of the bark and wood of *Hovenia dulcis* and the bark of *Ateleia glazioviana* presented an average reduction in mass loss in the order of 56.07%, and for the wood treated with CCB a reduction of 65.56%, officiating that the treatments with these natural extracts have shown a performance very similar to that offered by the conventional treatment of CCB. Corroborating, Vivian et al. (2014), in a study on the biological resistance of *Eucalyptus grandis* and *E. cloeziana* wood treated CCA against the action of the fungus *Trametes versicolor*, verified a reduction in mass loss of 35.17% and 82.31% compared to the control wood. Therefore, three of the extracts studied here are within the range of protection already mentioned in other researches.

Table 2. Average values of mass loss, decay classification and solubility in 1% NaOH of *Eucalyptus grandis* woods after the application of treatments and submitted to the action of the fungus *Trametes versicolor* in laboratory tests.

Sample	Mass loss (%)	Resistance class	Solubility in 1% NaOH
Control	78.70a	NR	32.15a
CCB	27.10c	MR	18.50b
<i>H. dulcis</i> bark	48.30bc	MR	21.11ab
<i>H. dulcis</i> wood	43.90bc	MR	26.70ab
<i>A. glazioviana</i> bark	40.20bc	MR	16.33b
<i>A. glazioviana</i> wood	50.90b	NR	18.93b

Means followed by the same letter in the row do not differ (T test, $p > 0.05$). NR: Non-resistant; MR: Moderate resistance, according AWPA E30 (AWPA, 2016b).

Promising results were obtained by Brocco et al. (2017), in protecting wood against the white and brown rot fungi in their research with natural extractives from teak wood (*Tectona grandis*). Bardage et al. (2014) investigated the effect of salicylic acid, tea tree oil, and cinnamon oil as natural additives, which performed well in both the blue stain and mold tests. The authors associate the success of natural preservatives with the modification of the fungal membrane properties of xylophagous organisms.

The observed mass loss behavior may be associated with the characteristics of the wood anatomical elements presented in the scanning electron microscopy images of

Figure 1. Visually, the wood anatomy was less affected in the treatments with lower mass loss. In the CCB samples (2A) the anatomical elements are intact and the fungus action is not very perceptible. The extracts of *Hovenia dulcis* (wood and bark) (Figure 1D) and of *Ateleia glazioviana* bark (Figure 1E) conferred protection to the point that the damage was hardly perceptible, in comparison with the samples treated with extract of *A. glazioviana* wood (Figure 1F) and untreated (Figure 1B), which showed the worst performance where it is not possible to distinguish the wood structure due to the evident degradation. In this image, there is evidence of branched hyphae of the fungus.

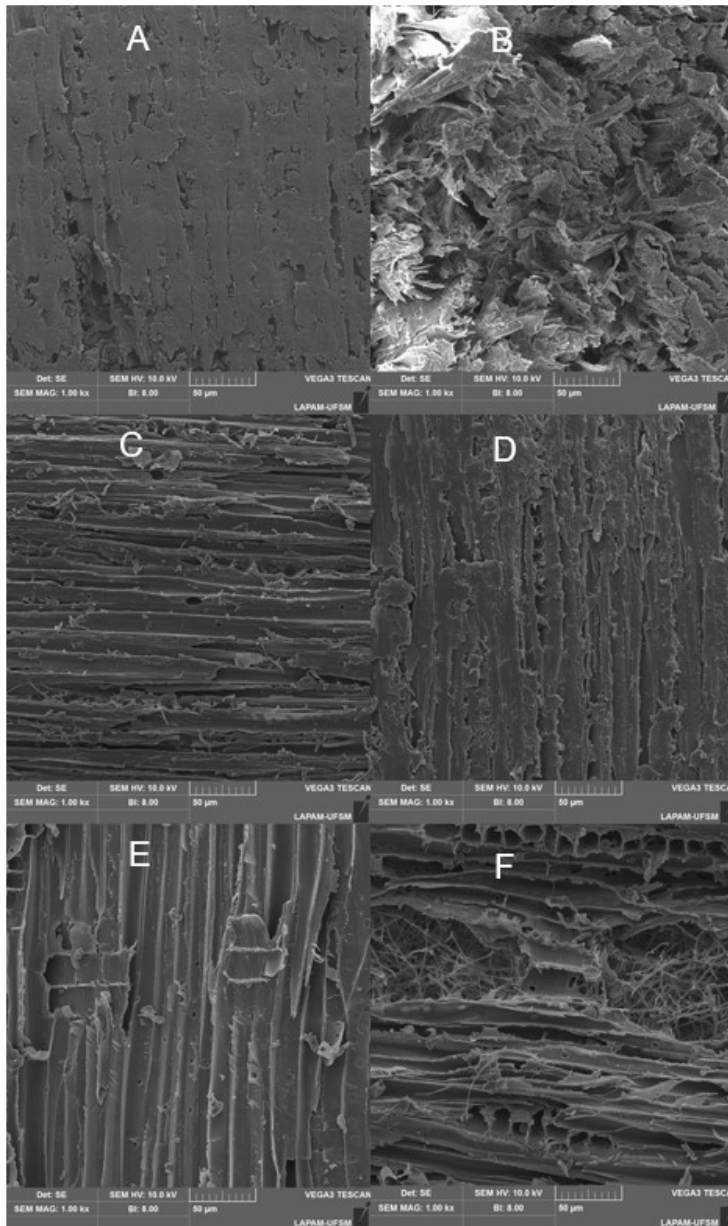


Figure 1. Surface of wood treated with CCB (A), untreated wood - control (B), wood treated with the natural extractive solutions of *Hovenia dulcis* bark (C), wood treated with the natural extractive solutions of *Hovenia dulcis* wood (D), wood treated with the natural extractive solutions of *Ateleia glazioviana* bark (E) and wood treated with the natural extractive solutions of *Ateleia glazioviana* wood (F).

According to Archer and Lebow (2006), the rotting fungi have as one of their main characteristics the ability of the hyphae to branch through the three-dimensional structure of the wood. Blanchette et al. (1994) comment that lignocellulosic materials degraded by white-rot fungi acquire a whitish appearance and break easily in the direction of the fibers. The analysis of the near infrared spectroscopy helps even more in understanding the action of these fungi on wood.

As for solubility in 1% NaOH, the control sample (untreated sample) was the most soluble when compared to the others, followed by those treated with wood extracts and *Hovenia dulcis* bark. The wood treated with CCB solution and extracts of the wood and bark of *Ateleia glazioviana* obtained the best performances, with no statistical difference among them. The results for the control sample indicate that the cellulose and hemicellulose polymers were broken into smaller molecules by *T. versicolor*, making the wood more soluble.

Associated to the data of solubility in 1% NaOH, the untreated woods and those treated with extracts of bark and wood of *H. dulcis*, show greater degradation of holocellulose and reduction of the values of total extractives. Pettersen (1984) reports that the holocellulose degradation is closely linked to the solubility contents in 1% NaOH and to the total extractive contents. The first parameter indicates the formation of free radicals soluble in alkali and the second the final phase of the degradation process of such compounds, where the presence of simple sugars from their total degradation can be found.

The increase in solubility values in 1% NaOH is closely linked to the increase of soluble materials in the solution, such as low molecular weight carbohydrates, basically composed of polyenes and degraded cellulose. Indicating the degree of degradation by fungi, heat, light and oxidation, according to the technical standard of the Technical Association of the Pulp and Paper Industry – (TAPPI, 2012).

Figure 2 shows the spectra for the *Eucalyptus grandis* wood of the different treatments in the wave range of 1800 to 800 cm^{-1} , where the main variations in the chemical compounds in the wood are found (Cademartori et al., 2013). The band located at 1510 cm^{-1} is associated with the C=C bonds present in the aromatic rings and according to Costa et al. (2011), can be studied to evaluate the intensity of lignin. In the frequency interval from 1161 to 898 cm^{-1} the wood treated with CCB showed the greatest reduction in absorbance values. The peak at 1161 cm^{-1} refers to C-O-C vibration in cellulose and hemicellulose and 898 cm^{-1} to C-H deformation in cellulose (Zhang et al., 2015).

It is possible to observe the reduction in the absorption values of *E. grandis* samples exposed to the fungus *Trametes versicolor* in accelerated decaying test, the reduction of constituents is indicated according to each reference band, being the wood treated with CCB the one that presented the greatest reduction in the presented intervals. Furthermore, it can be visually inferred that the treatments with extracts of *H. dulcis* (wood and bark) and *A. glazioviana* (wood) presented very similar behaviours, corroborating the data of mass loss of the samples.

The peaks presented in Figure 2, corresponding to the chemical compounds of the wood, corroborate the literature that states that these fungi degrade all the structural constituents of the biomass, being able to act selectively

and start by the degradation of the hemicelluloses and the lignin or remove the lignin and the structural carbohydrates at a similar rate, resulting in a homogeneous deterioration of the cell wall, as observed by Pandey and Nagveni (2007).

Under the conditions in which the laboratory test was conducted, it can be inferred that the separation of lignocellulosic materials from the *Hovenia dulcis* species is not necessary, as this would save time and cost in the preparation of the preservative solution.

3.2. Wood resistance in fields tests

The mass loss did not differ between the treatments with extracts, being in absolute values closer to the ones verified for the samples without treatment (control), than those treated with CCB. The measured values of apparent specific mass after the treatment with extracts and CCB, did not present statistical difference, possibly because it is the same species in evaluation *Eucalyptus grandis*. However, in absolute terms for the wood treated with the CCB solution, there was a slight increase in the apparent specific gravity, 0.5456 $\text{g}\cdot\text{cm}^{-3}$. In this treatment the mass loss was negligible in comparison with the others (Table 3).

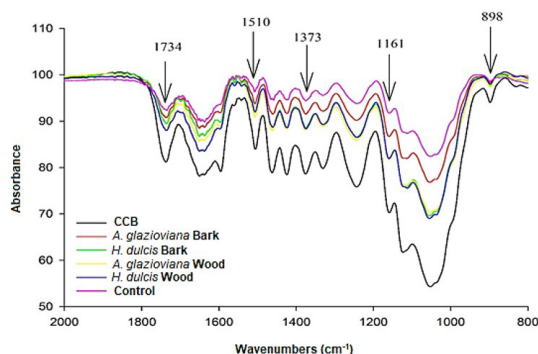


Figure 2. Absorption spectra by spectroscopy in the infrared region (ATR-FTIR) for the species of *Eucalyptus grandis* treated with the different natural extractive solutions, CCB solution and untreated, exposed to the fungus *Trametes versicolor*.

Table 3. Average values of mass loss and apparent specific mass of *Eucalyptus grandis* wood treated with the different natural extractive solutions, CCB solution and untreated, exposed to forest environment.

Sample	Mass Loss (%)	Apparent specific mass ($\text{g}\cdot\text{cm}^{-3}$)
Control	2.04a	0.4969a
CCB	0.21b	0.5456a
<i>H. dulcis</i> bark	1.82ab	0.4657a
<i>H. dulcis</i> wood	1.50ab	0.4657a
<i>A. glazioviana</i> bark	1.89ab	0.4783a
<i>A. glazioviana</i> wood	1.70ab	0.4852a

Average followed by the same letter in the row does not differ (T test, $p > 0.05$).

In this situation, the values of mass loss are in the range of 2.04% for the control and 0.21% for the CCB, lower than those found in the laboratory. It is important to mention that the decomposition of biological materials is related to a series of factors, such as climatic conditions, composition of the decomposer community, affinity with the substrate and the characteristics of the exposed material. Swift et al. (1979) emphasize that these elements when correlated close the deterioration cycle, and it is also necessary to consider the effect of sunlight on wood, which generates a variation of temperature and in the tensions created by humidifying and drying, becoming contributors to the process.

Analyzing the decaying field with wood of *Quercus petraea* and *Larix decidua*, Jacobs et al. (2019) reported over a three-year period the influence of more than 77 fungal genera on wood rot, especially white and soft rot, in addition to the species in question and the environmental conditions of the site.

Results of the impact strength (fbw), work absorbed (W), coefficient of resilience (K), and dynamic quota (DQ) of *E. grandis* wood in the different treatments after exposure to forest field environment are shown in Table 4. The results show that in none of the evaluations the treatments showed significant differences. This can be explained by the low exposure time, 180 days, and by the fact that it is the same species of wood. It is also worth mentioning that the loss in mass in general was below 2%, which may have caused few changes in the analyzed mechanical properties.

For correlation between the moisture content of wood and its mechanical strength, *E. grandis* in dry, acclimatized and saturated conditions, Pertuzzatti et al. (2017) did not observe significant difference in the work absorbed (mean W 1.60 kgm). Stangerlin et al. (2009), for *E. saligna* and *E. botrioides* wood, obtained an absorbed work value (W) of 4.1 kgm for both species, which was higher than in this study (W in the range 0.86 to 1.55 kgm). In turn, Stangerlin et al. (2008) for three species of *Eucalyptus* found for the coefficient of resilience (K) a maximum value of 0.32988 kgm.cm⁻² and a minimum value of 0.05047 kgm.cm⁻², respectively. The wood in the different treatments were, on average, within this range even after exposure to the forest environment for 180 days.

A wood, as state by Beltrame et al. (2010), to be considered resilient, i.e., highly resistant to impact, the dynamic quota value must be greater than 1.2, which is

the material's ability to withstand impact. Considering this study, it can be stated that after exposure to the forest environment, only the wood treated with CCB and with the extract of the wood of *A. glazioviana* are defined as resilient and, therefore, the other samples tested in this study should not be used in places subject to shock loads.

In Figure 3, it is observed the wave peaks from 1800 to 800cm⁻¹ for the samples of the treatments of the present study. The main variation occurred between 1161 and 898cm⁻¹, where the samples treated with CCB and with the extracts of wood and bark of *H. dulcis* and wood of *A. glazioviana*, present very similar peaks. This reports that the aforementioned treatments have very similar behaviour in the field compared to the CCB treatment and that the samples exposed to field conditions do not present considerable leaching of preservatives, indicating that in the studied materials, there are chemical compounds able to remain in the wood and repel xylophagous.

In the spectroscopic analysis of Figure 3, the samples treated with CCB and with extracts of *H. dulcis* wood and bark and *A. glazioviana* wood, present very similar peaks. This highlights the similar behavior between the preservatives in field conditions, and that the samples in the external environment do not present great leaching of the products, equating the natural extracts to the commercial

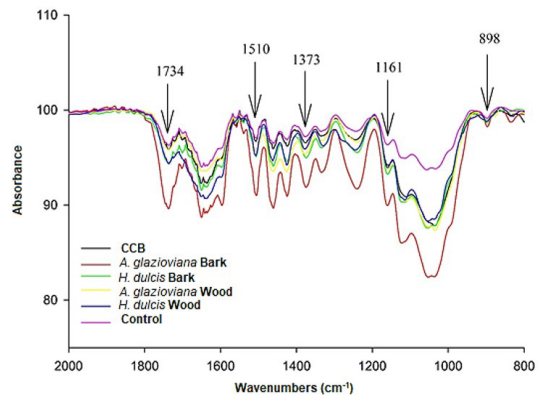


Figure 3. Absorption spectra by spectroscopy in the infrared region (ATR-FTIR) for the *Eucalyptus grandis* wood treated with the different natural extractive solutions, CCB solution and untreated, exposed to the forest environment.

Table 4. Mean values of impact strength (Fbw), work absorbed (W), coefficient of resilience (K), and dynamic quota (DQ) for *Eucalyptus grandis* wood treated with the different natural extractive solutions, CCB solution and untreated, exposed to forest environment.

Sample	Fbw (kJ.m ⁻²)	W (kgm)	K (kgf.cm ⁻²)	DQ
Control	24.91a	1.03a	0.33a	1.15a
CCB	37.22a	1.55a	0.50a	1.31a
<i>H. dulcis</i> bark	20.86a	0.86a	0.28a	1.08a
<i>H. dulcis</i> wood	20.94a	0.87a	0.28a	1.07a
<i>A. glazioviana</i> bark	22.84a	0.94a	0.30a	1.04a
<i>A. glazioviana</i> wood	26.29a	1.07a	0.35a	1.21a

Means followed by the same letter in the row do not differ (T test, p > 0.05).

CCB. The absorbance peaks are similar to those found in the materials degraded in the laboratory, and are linked to the degradation of hemicelluloses and wood extractives.

4. Conclusions

The natural extractive solutions of lignocellulosic materials (wood and bark) from *Hoveia dulcis* and from *Ateleia glazoviana* bark show preservative potential in wood impregnation under laboratory conditions, showing similar or very close results to those obtained with the commercial CCB solution (2.5%). It is not recommended the use of the wood extracts of *A. glazoviana* in the wood protection against the white rot fungus. To potentiate the results, it is stimulated to study the increase of the concentration of the extracts in an attempt to improve their performance as natural wood preservatives.

When the wood was treated with the biocides and taken to field conditions there was no protection against soil organisms. It is possible that this performance is due to the short time of exposure. It is recommended, in this case, to combine the increase of the extracts concentration and a longer exposure time of the treated wood to the environment.

This study is an initial proposal using lignocellulosic materials that can be easily found as wood processing waste, therefore, further studies should be conducted to determine the ecotoxicity and efficacy of these extractives in order to fulfill all the requirements of a natural wood preservative.

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