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Scientific Article

Candeia oil efficiency in improving wood resistance to decay fungi

Eficiência do óleo de candeia para melhor a resistência da madeira a fungos apodrecedores

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ABSTRACT - World demand for wood products and the shortage of good quality lumber species are exerting pressure on native forests. This study aimed to evaluate the efficiency of *Eremanthus erythropappus* crude oil in improving the resistance of *Pinus taeda* wood to *Rhodonia* (≈*Postia*) *placenta*, *Gloeophyllum trabeum*, *Neolentinus lepideus* (brown rot) and *Pycnoporus sanguineus* (white rot) in accelerated laboratory decay tests. Test samples measured 1.90 × 1.90 × 1.90 cm. Oil was applied to wood surfaces using a brush to obtain nominal retentions of 15, 30, 45, and 60 kg of oil per m^3 of wood. After treatment, the samples reached average retentions of 16.25, 28.75, 41.50, and 53.75 kg m^{-3}, respectively, and were submitted to a soil block decay test (accelerated decay test) for 12 weeks. Increased oil retention caused a decline in the mass loss of *Pinus taeda* wood exposed to the fungi tested. A retention of 16.25 kg m^{-3} inhibited *Rhodonia placenta* degradation and prevented other xylophagous fungi attacks. The most severe decay occurred with *Rhodonia placenta* and the least with *Pycnoporus sanguineus*. Oil improved *Pinus taeda* resistance to the decay fungi, indicating that it is useful for treating wood in contact with domestic animals and humans, since it is not toxic to them.

Keywords: Biological assays. Natural products. Wood protection.

RESUMO - A demanda mundial por produtos madeireiros e a escassez de espécies de madeira de boa qualidade estão pressionando as florestas nativas. Esta pesquisa teve como objetivo avaliar a eficiência do óleo de candeia (*Eremanthus erythropappus*) bruto para melhorar a resistência da madeira de *Pinus taeda* aos fungos apodrecedores *Rhodonia (≈Postia) placenta*, *Gloeophyllum trabeum*, *Neolentinus lepideus* (podridão parda) e *Pycnoporus sanguineus* (podridão branca) em ensaios de apodrecimento acelerado em laboratório. As amostras tinham dimensões nominais de 1,90 × 1,90 × 1,90 cm. O óleo foi aplicado nas superfícies da madeira com pincel, visando obter retenções nominais de 15; 30; 45 e 60 kg de óleo por m^3 de madeira. As amostras após o tratamento atingiram retenções médias de 16,25; 28,75; 41,50; e 53,75 kg m^{-3}, e foram submetidas ao teste solo-bloco (apodrecimento acelerado) durante 12 semanas. O aumento da retenção de óleo provocou redução na perda de massa da madeira de *Pinus taeda* submetida aos fungos testados. Observou-se que a retenção de 16,25 kg m^{-3} foi capaz de inibir a degradação do fungo *Rhodonia (≈Postia)* e prevenir o ataque de outros fungos xilófagos. Os maiores danos foram observados para *Rhodonia (≈Postia)* e os menores danos para *Pycnoporus sanguineus*. O óleo conferiu maior resistência à madeira de *Pinus taeda* aos fungos testados, indicando ser útil para o tratamento de madeiras que ficarão em contato com animais domésticos e seres humanos, uma vez que não é toxico a tais organismos.

Palavras-chave: Ensaios biológicos. Produtos naturais. Proteção de madeira.

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INTRODUCTION

The wood of most *Pinus* and *Eucalyptus* species is susceptible to fungal decay, requiring chemical treatment to protect them from deterioration by indoor and outdoor exposure to xylophages (PAES et al., 2010; LOPES; PAES; BOBADILHA, 2018). To that end, bioactive chemicals are applied to increase lumber durability. However, the products used to improve resistance are toxic to humans and the environment (PAES et al., 2010; LOPES; PAES; BOBADILHA, 2018; ANDERSONE et al., 2022; PAKHRIN et al., 2022). They require careful disposal, and it is recommended that they be remediated by chemical or biological treatments (LOPES; STOKES; BOBADILHA, 2019; COSTA et al., 2022; EUFLOSINO et al., 2022).

Thus, there is increasing interest in renewable products and processes that are more benign to humans and the environment (BROCCO et al., 2020; SOUSA et al., 2020; PAES et al., 2021; GEORGES et al., 2022; PAKHRIN et al., 2022; SHINY et al., 2022). One option is to use candeia oil (*Eremanthus erythropappus*) or its byproducts to extend the life of indoor and outdoor wood (PAES et al., 2010; TEIXEIRA et al., 2015), or synthesized products, such as thymol (2-isopropyl-5-methylphenol), found in the essential oils of plants such as oregano, thyme, and rosemary-pepper (MARCHESE et al., 2016).

Candeia (*Eremanthus* sp.) is a species of the family Asteraceae, considered a forerunner in the rapid colonization of open fields, developing quickly and forming pure stands (SCOLFORO; OLIVEIRA; DAVIDE, 2012). It is an alternative to exotic crops, such as eucalyptus, previously established in the country because its traits enable good yields, generating employment and income for small and medium-sized farmers in the regions where the species is found (ARAÚJO et al., 2018).

Various candeia species develop in shallow low-fertile soil, topsoil, and predominantly in fields ranging in altitude between 900 and 1,700 m. The most economically important species are *Eremanthus incanus* (Less.), used for fence posts and exhibiting a lower oil content, and *Eremanthus erythropappus* (DC.) Macleish., with multiple applications (SCOLFORO et al., 2002). Their wood is used for fences and fence posts (SCOLFORO et al., 2002) and for producing essential oil. Candeia oil and its main component, alpha-Bisabolol, exhibit antichloristic, antimicrobial, antibacterial, antimitotic, dermatological, spasmodic, and anticancer activities (LIMA et al., 2013; LIMA FILHO et al., 2020).

Thus, candeia oil may have bioactive properties that improve resistance to wood-deteriorating organisms. Biological assays performed by Paes et al. (2010) demonstrated the efficiency of the oil in improving kapok (*Ceiba pentandra*) resistance to *Nasutitermes corniger* termites. Teixeira et al. (2015) demonstrated the efficiency of candeia oil byproducts in improving the decay resistance of *Pinus caribaea* to the decay fungi *Postia (≈ Rhodonia) placenta*, *Neolentinus lepideus* (brown rot), and *Trametes versicolor* (white rot).

Little research related to improving the resistance of wood impregnated with candeia oil against wood-deteriorating organisms has been conducted. This study aimed to assess the efficiency of candeia oil [*Eremanthus erythropappus* (DC.) Macleish.] in improving the resistance of *Pinus taeda* (loblolly pine) to decay fungi under laboratory conditions.

MATERIALS AND METHODS

Obtaining candeia crude oil, staging, and wood treatment

The oil used to treat the wood was donated by Citróleo Ltd. (Citróleo Group), located in Carrancas, Minas Gerais state, Brazil (21 º 29 '16 "S, 44 ° 38'34" W, altitude 1060 m), obtained from commercially viable forest stands.

Due to its low resistance to wood decay fungi, *Pinus taeda* was selected for testing, in the form of 3 cm-thick, 30 cm-wide and 2-m-long planks obtained from a store in Jerônimo Monteiro, Espírito Santo state, Brazil and transformed into test samples with dimensions suitable for biological testing.

To perform the accelerated decay test in the laboratory, the American Wood Protection Association soil block standard - AWPA E10-16 (2016) was used, with 10 repetitions, 1.9 cm cubes for each treatment (fungus and retention), and defect-free sapwood.

The samples were dried at 103 ± 2°C until constant mass. Anhydrous volumes were obtained by mercury immersion, as recommended by AWPA E10-16 (2016). Mass and volume were used to calculate candeia oil retention in wood and the mass loss caused by fungi.

In order to treat the wood with a preservative, we used a brush to apply oil on the sample surface, with greater application in the bottom-up direction. The amount of material used to impregnate each test sample ranged from 0.10 to 0.35 grams, representing 15 to 60 kg of oil per m^3 (kg m^{-3}) of wood. Retention was defined based on Paes et al. (2010) and Teixeira et al. (2015).

After treatment, the test sample surfaces were dried with a paper towel, and their retention was obtained by dividing the difference in specimen mass (before and after treatment) by the same initial volume. They were submitted to an accelerated decay test, in accordance with AWPA E10-16 (2016).

Chemical identification of candeia crude oil compounds

The compounds in the extracts were chemically identified in a gas chromatograph - mass spectrometer - GC-MS (QP2010 SE, Shimadzu, Japan). Samples were diluted in dichloromethane (Anidrol) before being injected into an SH-RTx-5MS column (Shimadzu, 5% phenyl-methylsiloxane, 30 m × 0.25 mm id, 0.25 µm) using an auto sampler (Shimadzu AOC–20i). Helium was used as the carrier gas at a 1.0 mL min^{-1} flow rate and linear velocity of 37.5 cm s^{-1}. In each analysis, the amount of injected sample was 1.0 µL (20 mg mL^{-1}), with a split ratio of 60:1.

The column temperature was initially set at 50 °C, heating at 10 °C min^{-1} to 80 °C, 180 ºC at 5 ºC min^{-1}, and 280 ºC at 15 ºC min^{-1}, where it remained for 5 min (SANTOS et al., 2017). The injector and ion source temperatures were maintained at 280 and 260 ºC, respectively. Mass spectra were recorded at 70 eV, ranging from m/z 40 to 650 amu. The compounds were identified in the Spectra NIST Mass Spectral Library database (version 2014).

Laboratory accelerated decay test

For the decay test, brown and white rot fungi were selected because they are known to degrade wood. The brown rot fungi were *Rhodonia placenta* [(Fr.) Niemelä, K.H. Larss. & Schigel], (previously *Postia placenta*), (Mad-698-R), *Gloeophyllum trabeum* [(Fr.) Mur.], (Mad-617) and *Neolentinus lepideus* [(Fr.) Redhead and Ginns], (Mad-534), and the white-rot fungus *Pycnoporus sanguineus* [(Fr.) Mur.), (FP 105 829-SP)]. All fungi were provided by the United States Department of Agriculture, Forest Service, Forest Products Laboratory, in Madison, WI, USA.

To assemble the test, soil was collected in the vicinity of the Department of Forest and Wood Sciences (DCFM), located in Jerônimo Monteiro, Espírito Santo state, Brazil. B horizon soil was sampled and its pH, moisture and water-holding capacity determined, in line with AWPA E10-16 (2016). The moisture content of the soil used as a substrate to fill the bottles (600 mL) was adjusted to 130% of its water-holding capacity.

The bottles were filled with 300g of soil, whose moisture content was adjusted by adding 101 mL of distilled water and two *Pinus taeda* feeders. They were autoclaved at 121°C, 103 kPa for 30 minutes. After cooling, the fungal cultures (≈ 0.5 x 0.5 cm) were inoculated in a laminar flow chamber to reduce the risk of contamination.

Once inoculated and with the fungal cultures well developed, the test specimens, sterilized under the same conditions previously described, were added at a rate of two samples (from different treatments) per bottle.

The assay was kept in a temperature-controlled room (27 ± 2°C and 65 ± 5% relative humidity), for 12 weeks, as described in AWPA E10-16 (2016). Bottles were prepared in a similar manner but not inoculated with fungi in order to determine the operating mass loss.

After the test, the samples were cleaned with a soft-bristle brush to remove the accumulated mycelium, the oven was kept at 103 ± 2°C for 48 hours and their mass determined.

Mass loss was calculated before and after the assay. However, mass loss is caused by many factors in addition to fungal degradation. As such, we used mass loss to correct operational data, as per AWPA E10-16 (2016). The correction produced more accurate values, ensuring that the mass loss observed in the samples was caused by wood decay fungus attacks, and not by other operational factors. AWPA E30-16 (2016) was used to assess the quality of wood decay resistance (Table 1).

Table 1. Wood resistance to xylophagous fungi, as per AWPA E30-16 (2016).

Resistance classes	Average mass loss (%)	Average residual mass (%)
Highly resistant	0 - 10	90 - 100
Resistant	11 - 24	76 - 89
Moderately resistant	25 - 44	56 - 75
Slightly resistant or non-resistant	≥ 45	≤ 55

Statistical analysis of results

To analyze the results of the fungi assay, we used a completely randomized design with a factorial arrangement (5 x 4). This design examined the effects of retention factors (five levels) and fungi (four levels), and the interaction between factors, with a total of 200 repetitions.

For statistical analysis, the data were transformed into arcsine [root (loss mass/100)], as described by Steel, Torrie and Dickey (1996), to allow homoscedasticity of variances. The F-test was used to assess significance ($p < 0.05$).

Graphs were constructed to investigate the relationship between average mass loss for candeia oil retention and the fungi *Rhodonia placenta*, *Neolentinus lepideus*, *Gloeophyllum trabeum*, and *Pycnoporus sanguineus*.

RESULTS AND DISCUSSION

Chemical composition of candeia oil

Six compounds (Table 2) were identified in crude candeia oil, with α-Bisabolol (oxides A plus B) having the highest percentage. Alpha-Bisabolol oxide B and A were also identified, in addition to Eremanthin and Costunolide (Figure 1). These values were similar to those found by Lima et al. (2013), Santos et al. (2016), and Santos et al. (2019), in candeia oil studies.

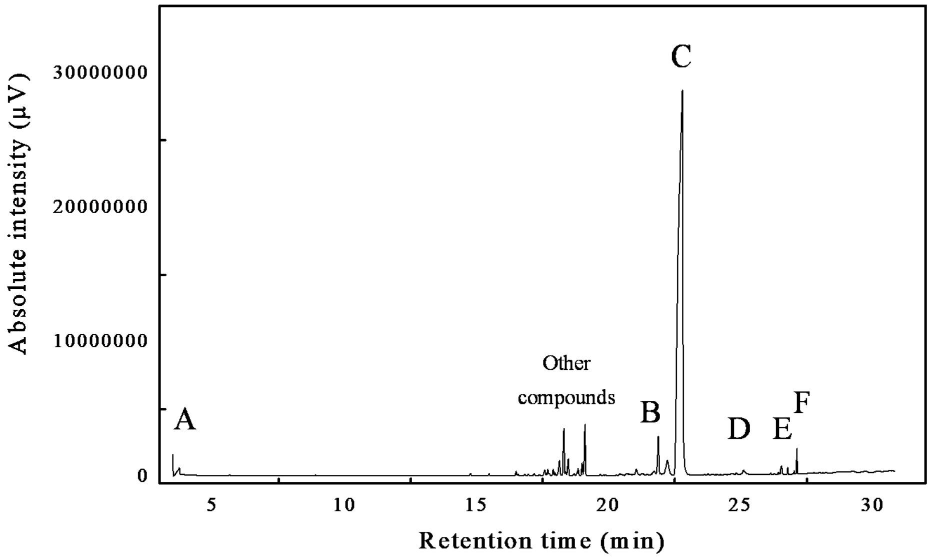
In addition to wood, candeia oil is also found in leaves, branches and inflorescences, with the highest proportion of α-Bisabolol in the branches (ALBERTTI et al., 2018). The results revealed that *E. erythropappus* oils are promising potential sources of antimicrobial and antioxidant compounds with good future practical applications for human health, as reported by Lima et al. (2013), Nakagawa et al. (2016), and Albertti et al. (2018).

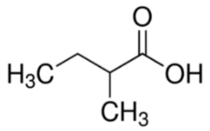
According to Albertti et al. (2018), candeia oil has wound healing and nociceptive properties. Sesquiterpene alcohol and (-)-α-Bisabolol are present at high concentrations, with the latter exhibiting antibacterial, anti-inflammatory, skin -smoothing and wound-healing properties. For *Zanthoxylum tingoassuiba* essential oil, where α-Bisabolol is one of the main compounds, Detoni et al. (2009) found that it exhibits antimicrobial activity against bacteria and dermatophyte fungi.

For extracts obtained with branch, leaf and root dichloromethane from candeia seedlings, Albertti et al. (2018) detected α-Bisabolol isomer [(-)-α-Bisabolol and (+)-α-Bisabolol] structures, with (-)-α-Bisabolol found in greater concentration in the roots of plant material collected in the nursery of the Universidade Federal de Lavras (Lavras, Minas Gerais, Brazil).

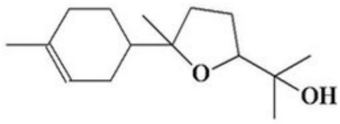
Table 2. Chemical compounds identified in candeia oil by gas chromatograph-mass spectrometry (CG-MS).

Compound identified	Retention time (min.)	Area (%)
Isovaleric acid	3.74	0.88
α-Bisabolol oxide B	21.88	2.25
α-Bisabolol	22.79	81.65
α-Bisabolol oxide A	25.11	0.63
Costunolide	26.26	0.02
Eremanthin	27.12	0.76
Other compounds	---	13.80

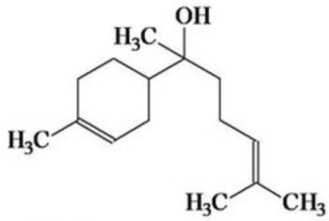




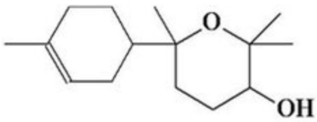
(A) Isovaleric acid *



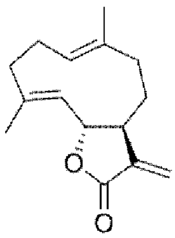
(B) α-Bisabolol oxide B**



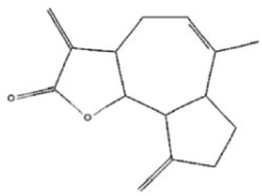
(C) α-Bisabolol**



(D) α-Bisabolol oxide A**



(E) Costunolide***



(F) Eramanthin ****

*(LIMA et al., 2013); **(DETONI et al., 2009); ***(KIM; CHOI, 2019); ****(DURAIPANDIYAN et al., 2012).

Figure 1. The spectrum was recorded in the *Eremanthus erythropappus* oil sample prepared in diluted dichloromethane and the chemical structure of the compounds.

Like α-Bisabolol, Costunolide also exhibits biological activities, such as anti-inflammatory, antiallergic, bone remodeling, neuroprotective, hair growth promoting, anticancer, and antidiabetic properties (KIM; CHOI, 2019; LIMA FILHO et al., 2020). Two sesquiterpenoid compounds (Costunolide and Eremanthin) isolated by Duraipandiyan et al. (2012) from *Costus speciosus* in hexane extract, showed the most effective antifungal activity, the former superior to the latter.

In the distillation of crude candeia oil to obtain α-bisabolol, Citróleo - Alpha Bisabolol Natural (Citróleo Group), located in Torrinha, São Paulo state, Brazil, manufactures two non-commercial byproducts (residues): candeia terpene - CT (lighter, top of column) and bisabolol resin - BR (heavier, bottom of reactor).

Teixeira et al. (2015) used CT, BR, and CT + BR (1:1, vol: vol), at concentrations of 5 and 50%, to treat *Pinus caribaea* wood (minimum retention of 16 kg m^{-3}), and observed that a concentration of 50% was efficient against xylophagous fungi [*Trametes versicolor* (white rot), *Postia* (currently called *Rhodonia*) *placenta* and *Neolentinus lepideus* (brown rot)]. The treated wood was classified as resistant and highly resistant, respectively, to the action of the fungi. This confirms that, in addition to α-Bisabolol, other products present in candeia oil (Table 2 and Figure 1), or generated during its distillation, have antifungal characteristics and can be used in wood treatment, corroborating Duraipandiyan et al. (2012).

Accelerated fungal decay

The average volume of test samples using mercury immersion was 5.82 cm^3, average dry mass 1.89 g, and average anhydrous density 0.32 g. cm^{-3}. The real retentions in kg of oil per cubic meters of wood (kg m^{-3}) were obtained near the proposed nominal retentions for conducting the tests. The values obtained are shown in Table 3.

For *Rhodonia placenta* (Table 3), retention was 16.25 kg m^{-3}, mass loss for treated *Pinus taeda* wood decreased by 29.27% compared to the control (untreated wood). This represents a 54.17% increase in resistance. Retention of 28.75 kg m^{-3} decreased mass loss by 28.63%, representing a 52.99% improvement in resistance. For 28.75 kg m^{-3} retention, mass loss declined by 46.67%, with an 86.38% improvement in wood resistance. Retention of 53.75 kg m^{-3} decreased mass loss by 52.09%, equivalent to a 96.41% improvement in resistance to the fungus tested.

Table 3. Average mass loss according to retention in the decay test.

Retention (kg m^{-3})	Average mass loss (%)				Average (%)
	Rhodonia placenta	*Neolentinus lepideus*	*Gloeophyllum trabeum*	*Polyporus sanguineus*	
0 (Control)	54.03 ± 5.41	39.52 ± 8.29	33.55 ± 15.25	10.94 ± 4.27	34.51 ± 17.91
16.25 ± 2.92*	24.76 ± 8.79	3.30 ± 1.36	0.83 ± 0.88	3.43 ± 0.90	8.08 ± 11.19
28.75 ± 3.01	25.40 ± 6.99	5.65 ± 4.36	1.59 ± 1.86	2.91 ± 1.15	8.89 ± 11.14
41.50 ± 2.95	7.36 ± 4.48	0.67 ± 1.03	1.49 ± 1.10	1.05 ± 1.49	2.64 ± 3.16
53.75 ± 3.83	1.94 ± 2.16	1.20 ± 1.54	1.75 ± 1.76	1.83 ± 1.94	1.68 ± 0.33

*Average ± standard deviation.

For *Neolentinus lepideus* (Table 3), retention of 16.25 kg m^{-3} decreased fungal attack by 36.22% when compared to the control, representing a 91.65% increase in wood resistance. Retention of 28.75 kg m^{-3} decreased degradation by 33.87% when compared to the control, with an 85.70% increase in resistance. For 41.50 kg m^{-3} retention, mass loss declined by 38.85%, representing a 98.30% improvement in resistance. Retention of 53.75 kg m^{-3} decreased degradation by 38.32%, that is, a 96.96% improvement in resistance.

The test with *Gloeophyllum trabeum* (Table 3) found 16.25 kg m^{-3} retention and a 32.72% decrease in mass loss for treated *Pinus taeda* wood compared to the control, representing a 97.53% increase in wood resistance. Retention of 28.75 kg m^{-3} decreased degradation by 31.96%, resulting in a 95.26% improvement in resistance. For 41.5 kg m^{-3} retention, mass loss declined by 32.06%, indicating an 95.56% improvement in resistance. Retention of 53.75 kg m^{-3} decreased mass loss by 31.80%, representing a 94.78% improvement in resistance.

For *Pycnoporus sanguineus* (Table 3), 16.25 kg m^{-3} retention decreased fungal attack by 7.51% compared to the control, representing a 68.65% increase in resistance. Retention of 28.75 kg m^{-3} decreased degradation by 8.03% compared to the control and increased resistance by 73.40%. For 41.50 kg m^{-3} retention, mass loss declined by 9.89%, improving resistance by 90.40%. Retention of 53.75 kg m^{-3} showed a 9.11% decrease in mass loss, improving resistance to the fungus by 83.27%.

The average values found for the fungi showed that 16.25 kg m^{-3} retention decreased the attack on treated wood by 26.43% when compared to the control, representing a 76.59% increase in resistance. Retention of 28.75 kg m^{-3} decreased degradation by 25.62% in relation to control, providing a 74.24% increase in resistance. For 41.5 kg m^{-3} retention, mass loss declined by 31.87%, improving wood resistance by 92.35%. Retention of 53.75 kg m^{-3} decreased mass loss by 32.83%, resulting in a 95.13% improvement in resistance. These results confirm the efficiency of candeia oil, its components, and byproducts as fungicidal agents, as reported by Lima et al. (2013), and Teixeira et al. (2015).

Given the values established by AWPA E30-16 (2016) and the deterioration caused by *Rhodonia placenta*, which resulted in a higher mass loss, retention of 41.50 ± 2.95 kg m^{-3} (average ± standard deviation) was sufficient to classify the *Pinus taeda* wood treated with candeia oil as highly resistant to fungi in a laboratory experiment. It should be noted that untreated *Pinus taeda* wood exhibited low natural durability, with a mass loss of 54.03 ± 5.41 kg m^{-3}, classified as not resistant to deterioration caused by the fungus (AWPA E30-16, 2016).

According to a study by Paes et al. (2010) with conehead termites, candeia oil (*Eremanthus erythropappus*) retention of 10.00 kg m^{-3} (no choice feeding test) and 37.21 kg m^{-3} (choice feeding test) was sufficient to improve kapok wood (*Ceiba pentandra*) resistance, inhibiting the attack of *Nasutitermes corniger* termites. Retention of 16.57 kg m^{-3} (no choice feeding test) and 58.22 kg m^{-3} (choice feeding test) using candeia oil repelled attacks on the wood tested, preventing access to the termite food source.

Analysis of variance for mass loss (%) caused by fungi at each retention is shown in Table 4. The effect of fungi, retentions, and fungi x retention interaction was significant (F test, $p < 0.01$).

Table 4. Analysis of variance for mass loss (%) caused by fungi at different retentions (kg m^{-3}). The data are transformed into arcsine [square root (loss of mass/100)].

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F (p-value)
Fungus	3	2.31	0.77	113.88**
Retention	4	6.39	1.60	236.61**
Fungus × Retention	12	1.40	0.12	17.25**
Error	180	1.21	0.67 x 10^{-2}	
Total	199	11.31	-------	-------

** Significant (F-test, $p < 0.01$).

Since retention values were quantitative, they were analyzed using scatter plots and correlation coefficients. The effects of fungus-induced mass loss decreases with increased candeia oil retention are shown in Figures 2, 3, 4 and 5. Figure 6 shows the effects of retention on the average mass loss for the different fungi tested, which are analyzed in Figure 7. The effects on average mass loss for the three fungi showed further wood deterioration.

Figure 2 shows the decrease in mass loss of *Pinus taeda* wood with a retention of 41.50 ± 2.95 kg m^{-3}. AWPA E30-16 (2016) classifies wood as highly resistant to attack by *Rhodonia placenta* for this retention. The wood was classified as moderately resistant for retentions of 16.25 ± 2.92 kg m^{-3} and 28.75 ± 3.01 kg m^{-3}. However, for the control (untreated wood), the fungus caused severe degradation, classifying the wood as non-resistant (AWPA E30-16 2016), (Table 2).

Figure 3 shows a decrease in the mass loss of *Pinus taeda* wood with a retention of 16.25 ± 2.92 kg m^{-3}. This wood is classified as highly resistant to *Neolentinuns lepideus* attack, AWPA E30-16 (2016), (Table 1).

Figure 4 shows a decline in the mass loss of *Pinus taeda* wood with a retention of 16.25 ± 2.92 kg m^{-3}, classifying it as highly resistant to *Gloeophyllum trabeum* attack, AWPA E30-16 (2016), (Table 1).

The assay with *Pycnoporus sanguineus* (Figure 5) showed low *Pinus taeda* wood deterioration when compared to the other fungi studied. The mass loss of this wood classified it as resistant to fungal attack, since the control showed a mass loss of less than 24%. However, there was a significant decline in mass loss with a retention of 16.25 ± 2.92 kg m^{-3}.

Figure 6 shows a decrease in mass loss of *Pinus taeda* wood with a retention of 16.25 ± 2.92 kg m^{-3}. With this retention, AWPA E30-16 (2016) classifies the timber as highly resistant to fungal deterioration since its mass loss was between 0 and 10%. Fungus-induced degradation in the control classified it as wood non-resistant to attack, AWPA E30-16 (2016), (Table 1). Figure 7 shows mass loss as a function of retention for the tested fungi, with the lowest effect for *Pycnoporus sanguineus*.

Biological assays performed by Paes et al. (2010) to evaluate the efficiency of candeia oil against *Nasutitermes corniger* termite species, when applied to kapok (*Ceiba pentandra*) wood, found that retentions between 10.61 and 16.73 kg m^{-3} (no choice feeding test) and 38.35 to 58.22 kg m^{-3} (choice feeding test), were sufficient to increase wood resistance, inhibiting termite attacks. With retentions over 16.73 kg m^{-3} (no choice feeding test) and 58.22 kg m^{-3} (choice feeding test), candeia oil prevented attacks on the wood tested, blocking termite access to the food source. The authors concluded that, depending on candeia oil efficiency against termites, retention of 10.61 kg m^{-3} would prevent termite attack in several structures.

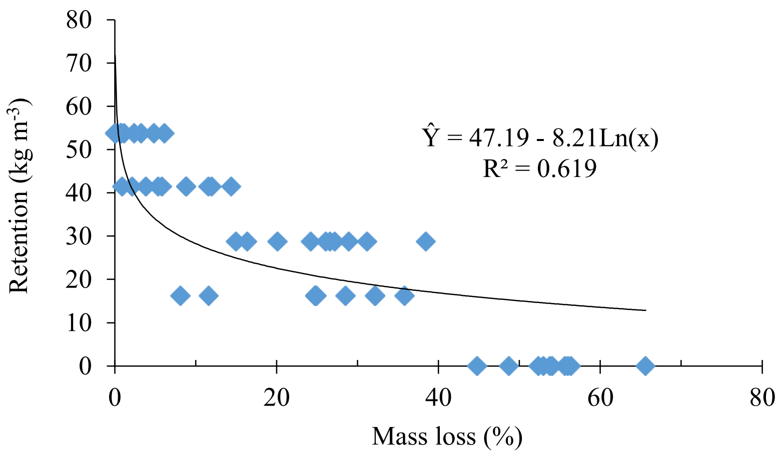


Figure 2. Mass loss as a function of retention for *Rhodonia placenta*.

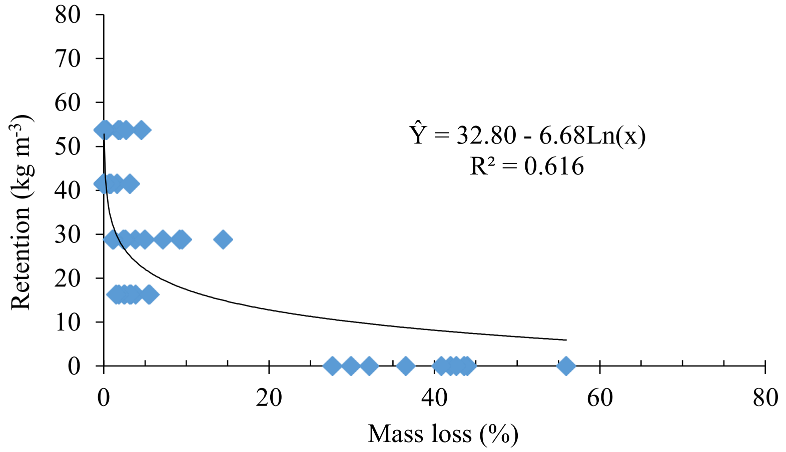


Figure 3. Mass loss as a function of retention for *Neolentinuns lepideus*.

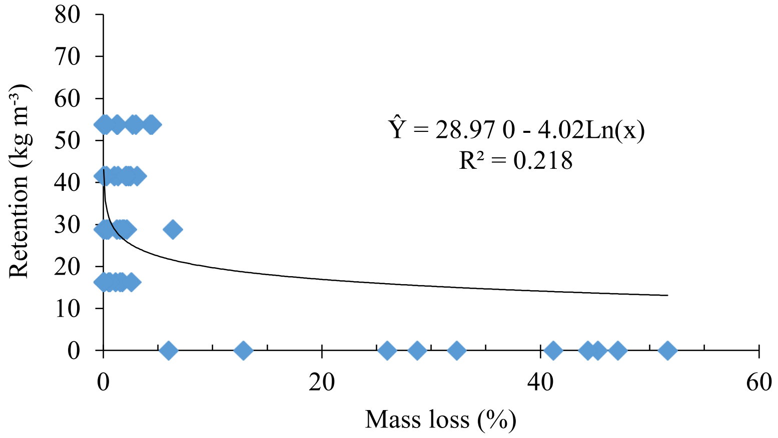


Figure 4. Mass loss as a function of retention for *Gloeophyllum trabeum*.

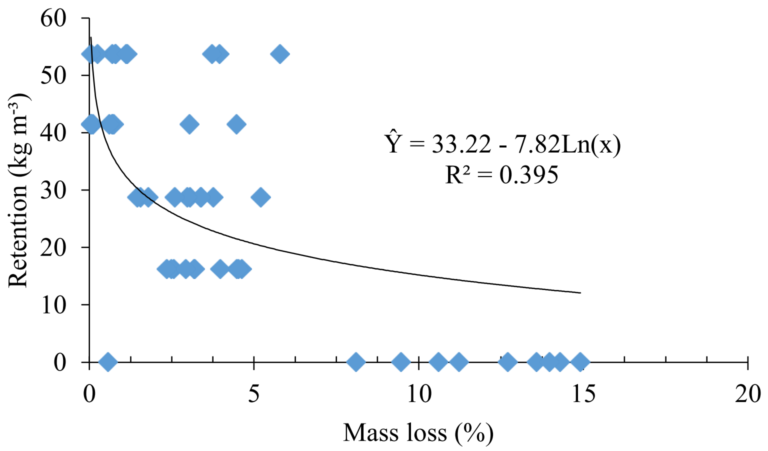


Figure 5. Mass loss as a function of retention for *Polyporus sanguineus*.

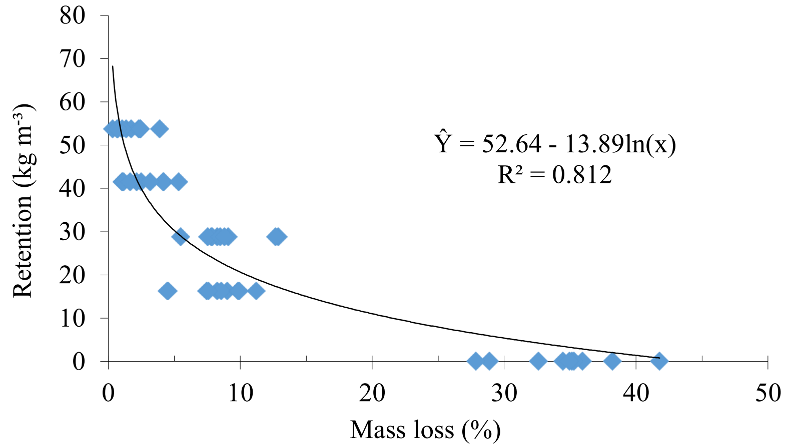


Figure 6. Mass loss as a function of retention for all tested fungi.

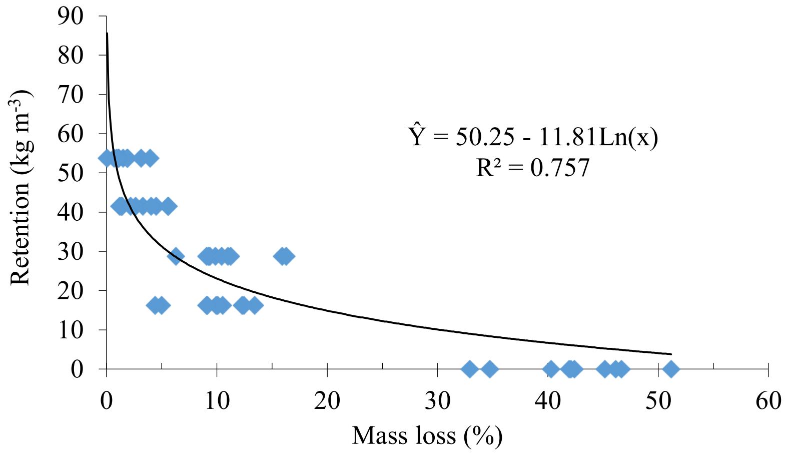


Figure 7. Mass loss in function of retentions for assayed fungi, less Polyporus sanguineus fungus effect.

Paes et al. (2010) found that candeia oil is impractical for use in rural buildings (fences and other structures) due to its high cost and other market alternatives. However, wood could be used in applications such as furniture, including built -in cabinets, shelves and closets. Products commonly used to treat wood are highly toxic. Candeia oil, however, can be used to preserve wood for use in household items such as furniture, due to its low toxicity to humans and minimal environmental impact.

In addition, its byproducts (TEIXEIRA et al., 2015), isolated components (LIMA et al., 2013), and the possibility of obtaining them through organic synthesis may make its cost more competitive and expand its use, as is the case with thymol and other compounds obtained from essential oils (MARCHESE et al., 2016). In addition, candeia oil can be combined with other molecules and chemical compounds to make it more accessible, which has been proposed for other products or byproducts of chemical processes, as reported by Pakhrin et al. (2022).

CONCLUSIONS

Candeia oil (*Eremanthus erythropappus*) increased the resistance of *Pinus teada* to the wood-destroying fungi tested. Increased candeia oil retention in wood reduced the mass loss caused by brown and white rot fungi. Retention of 16.25 kg m^{-3} prevented or inhibited fungus-induced degradation in *Pinus taeda*, obtaining a 26.43% decrease in attacks when compared to the control. This represented a 76.59% increase in *Pinus taeda* wood resistance. Among the fungi tested, *Rhodonia placenta* degraded *Pinus taeda* wood the most. Wood attacked by *Pycnoporus sanguineus* showed the least degradation, even in the control (untreated *Pinus taeda* wood). This study reinforces the need for further research to evaluate the effect of candeia oil on treated wood when exposed to real world conditions, such as accelerated aging and field tests with treated wood cuttings, at concentrations that provide the best results for the fungi tested.

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