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ANTIFUNGAL AND ANTITERMITIC POTENTIAL OF EXTRACTS OF INDUSTRIAL WOOD WASTE FROM CENTRAL AMAZON, BRAZIL

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ABSTRACT

Studies on wood durability have highlighted the use of new environmentally friendly substances. In this sense, research carried out with Amazonian forest species is extremely important for the discovery of new bioactive substances from durable wood and its residues. The aim of this study was to evaluate the antitermitic and antifungal potential of extracts obtained from industrial processing residues of wood species from Central Amazonia, Brazil. The sawdust of seven Amazonian wood species were collected to obtain extracts and quantify the extractive content. The extracts produced were tested for inhibition of fungal growth of *Rhodonia placenta* and *Trametes versicolor* and impregnated in low natural durability wood known as *Simarouba amara* (marupa) to verify the effect on wood natural durability against *Nasutitermes* sp. termites and *Gloeophyllum trabeum* fungus. *Simarouba amara* (marupa) wood was easily impregnated and showed satisfactory retention values. The species *Buchenavia* sp., *Dinizia excelsa* (red angelim), *Hymenolobium flavum* (angelim pedra) and *Manilkara elata* (maçaranduba) exhibited high contents of secondary metabolites. It was observed that the extracts of *Roupala montana* (louro faia) and *Hymenolobium flavum* (angelim pedra) exhibited the best performance in inhibiting fungal growth. In the accelerated decay test, marupa wood impregnated with *Buchenavia* sp. (tanimbuca) extract showed the lowest weight loss after exposure to the fungus *Gloeophyllum trabeum*. In the termite choice feeding test, wood impregnated with *Dinizia excelsa* (red angelim) and *Buchenavia* sp. (tanimbuca) extracts were most consumed and the extracts of *Roupala montana* (louro faia), *Cordia* sp., *Hymenolobium flavum* (angelim pedra) and *Manilkara elata* (maçaranduba) provided greater inhibition of termite attack. The combination of extracts must be tested in future studies to verify the synergistic effect, in addition to the chemical analyses of the selected extracts.

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INTRODUCTION

Wood-based materials are subject to deterioration by biotic agents under certain conditions. Among these, decay fungi, insects (Isoptera and Coleoptera) and marine borers can be highlighted. These organisms can attack the main components of the cell wall such as cellulose, hemicellulose and lignin (Martín and López 2023, Vivian *et al.* 2020). Therefore, the use of methods and products for the protection of low natural durability wood is essential to ensure rational use and useful life in service.

Wood preservation studies have increasingly highlighted the use of natural products such as oils, resins and extractives obtained from plant species (Brocco *et al*. 2020, Hassan *et al.* 2020, Barbero-López *et al.* 2021, Alade *et al.* 2022, Bi *et al.* 2022). Research carried out with Amazonian species is of paramount importance, as it contributes to the discovery of new bioactive substances and opens up possibilities for broader knowledge on the subject (Reis *et al.* 2017, Leonardi *et al.* 2019, Nobre Lamarão *et al.* 2023).

In this sense, Amazonian wood species stand out for presenting a variety of woods with high natural durability, provided, in part, by the secondary metabolites produced by these plants (Carneiro *et al.* 2009, Rodrigues *et al.* 2012, Gouveia *et al.* 2021). The production of tropical roundwood from the legal Amazon in Brazil is around 11 million m^3 per year (Caires *et al.* 2019, IBGE 2020). Highly durable wood exploited through forest management in the Amazon has a low volumetric yield during the conversion of logs into sawn wood (below 40% on average), generating a large amount of waste, which is most often burned and used as energy source (Romero *et al.* 2020).

Thus, the secondary metabolites of Amazonian woods, obtained mainly from wood processing residues from sustainable forest management, appear as an alternative for research on new products or substances with antioxidant, antifungal, antimicrobial and antibacterial activities (Imai *et al.* 2008, Barbosa *et al.* 2007).

Wood residues comprise most of the wood process, and those from species with high natural durability can contain chemical components that are highly toxic to wood destroying organisms. Secondary metabolites, commonly called extractives, are low molecular weight compounds, and include terpenes, oils, gums, tannins and dyes and are directly linked to the organoleptic properties of wood as well as the degree of resistance against xylophagous organisms (Xu *et al*. 2013, Arantes *et al.* 2011, Morrell 2018). In Amazonian species, wood extractive contents can vary widely, reaching contents of up to 18 % in some species (Lima *et al.* 2021).

In view of the above, in order to confirm the effectiveness of secondary metabolites obtained from Amazonian wood species, it is important to obtain these compounds from viable sources and in considerable quantities, in order to obtain significant results against xylophagous organisms, in a less destructive way to the environment and with high yield. Thus, this work aimed to evaluate the antitermitic and antifungal effect of extracts obtained from residues of industrial processing of wood species from Central Amazonia, Brazil.

MATERIAL AND METHODS

Collection and preparation of material

The residues used were obtained in the form of sawdust from the industrial processing of wood known as having moderate to high biological resistance, from two timber companies, WS Madeireira Ltda and Serraria Verbena, both located in the municipality of Itacoatiara, Amazonas, Brazil.

Sawdust was obtained from seven wood species, namely: angelim pedra (*Hymenolobium flavum* Kleinhoonte), red angelim (*Dinizia excelsa* Ducke), louro faia (*Roupala montana* Aubl.), louro pardo (*Cordia* sp. L.), maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach), tanimbuca (*Buchenavia* sp. Eichler), and red tauari (*Cariniana micrantha* Ducke). The material was transported to the Wood Technology Laboratory, located at the Center for Higher Studies of Itacoatiara - CESIT of the Amazonas State University - UEA, where it was classified in a 2 mm opening sieve. After sorting, they were air-dried, and later, the sawdust was stored in plastic bags.

Extractives quantification

Representative samples of the collected sawdust (500 g) were used to determine the extractive content in different solvents. The selected sawdust was classified in a set of sieves so as to pass through a 40 “mesh” sieve and be retained on a 60 “mesh” sieve. Test specimens consisting of 2 g of air-dried sawdust was subjected to hot water, ethanol and ethanol/hot water sequence (total). Extractions in how water were carried out in a boiling water bath for 3 h according to American Society for Testing and Materials, ASTM D1110-84 (2007). Ethanol solubility was determined in a soxhlet apparatus where the specimens were extracted in ethanol (95 %) for 6 h, according to ASTM D1107-96 (2005). To determine the total extractive content (ethanol/hot water sequence), the specimens were subjected to extraction in ethanol for 8 h in a soxhlet apparatus, followed by extraction in hot water for 1 h, following the recommendations of the ASTM D1105-96 (2005), with some adaptations.

Preparation of extracts and biological activity

To produce extract solutions for wood impregnation, only ethanol was used as a solvent. Cold extractions (maceration) were carried out with the sawdust of each species. The sawdust: solvent (ethanol) ratio for each species was 1:10 (weight: volume), that is, for each 100 g of sawdust, 1000 mL of ethanol was added. The sawdust remained in extraction for 48 h in an Erlenmeyer flask under orbital agitation. Filter paper and a Büchner funnel fitted to a Kitassato connected to a vacuum pump were used for filtering the extracts. Then, the extracts were concentrated in a rotary evaporator to recover the solvents and obtain the crude extract, that was oven dried (50 ºC) to a constant mass.

To verify the biological activity and inhibition potential against wood destroying organisms, the crude extracts of different species were diluted to concentrations of 1 %, 2 % and 4 % and tested in fungal inhibition tests in Petri dishes, containing malt agar culture medium (2 %: 1,5 %). Thus, using a micropipette, 300 µL of the solution of each extract and concentration were added in the center of each Petri dish. After evaporation of the solvent, a 5 mm fragment obtained from the growing edge of an active fungal culture of brown rot fungus *Rhodonia placenta* (Fr.) Niemelä, K.H.Larss. & Schigel (Mad-698-R, USDA Forest Service, Forest Products Laboratory, Madison, WI, USA) and white rot fungus *Trametes versicolor* (L.) Lloyd (Mad-697, USDA/FS/FPL) was added in the center of the Petri dish.

Petri dishes were incubated (25 °C; 70 % relative humidity - RH) and the measurements of the fungal growth zone was performed 3, 5 and 7 days after inoculation (Figure 1), using a 0,01 mm accuracy digital caliper, for both control treatment (without extract) and extracts tested. The measurements were carried out on the diameter of fungal colonies in two perpendicular directions and the percentage of fungal inhibition was calculated in relation to the growth area of the control samples (Equation 1).

$$I_{(\%)} = \left(\frac{M_C - M_E}{M_C} \right) x\ 100 \qquad (1)$$

I: Inhibition of fungal growth in %;

M_C: Mycelial growth area in control (mm^2);

M_E: Mycelial growth area in extracts tested (mm^2).

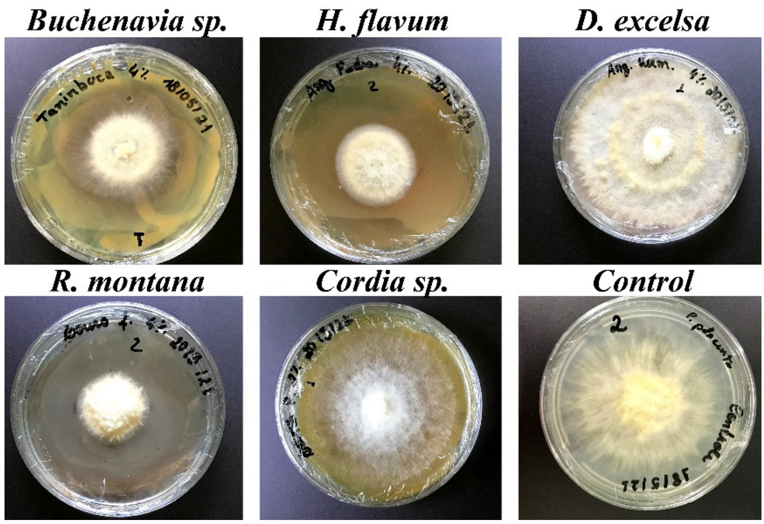

Figure 1: Visual aspect of fungal growth zones (*Rhodonia placenta* (Fr.)) according to some extracts tested at 4 % concentration during the inhibition tests in Petri dishes.

Impregnation of wood with extracts produced

According to the results obtained in the inhibition tests, the concentrations for the impregnation of the solutions in the wood were defined. For this purpose, new serial extractions (20/specie) were performed according to the procedures described above. Final dilutions with the crude extracts were made in ethanol for concentrations established by the inhibition test. Marupa (*Simarouba amara* Aubl.) was selected for extracts impregnation due to its light color and low natural durability. Samples with dimensions of 25 mm x 25 mm x 9 mm (termite test) and 19 mm x 19 mm x 19 mm (decay test) were oven dried at 50 °C, weighed and measured (height, length and width) with a digital caliper. Samples of marupa (*Simarouba amara* Aubl.) non-impregnated and impregnated with ethanol (96 %) were used as control samples.

Samples were impregnated following the American Wood Protection Association - AWPA E10-16 (2016) with some adaptations described by Brocco (2019). The samples were immersed in the extracts and subjected to vacuum (500 mmHg for 30 min), followed by 30 min at atmospheric pressure. After impregnation, the specimens were oven dried at 50 °C and weighed. The retention of the extracts was evaluated as based on oven dried weight of wood and obtained through the differences in the initial and final weight after treatment, where the results were obtained according to Equation 2.

$$R=\frac{W_2 - W_1}{V} \qquad (2)$$

R: Retention in kg/m^3;

W_1: Initial oven-dry weight before treatment;

W_2: Final oven-dry weight after treatment.

V: Volume in m^3

Decay and termite resistance tests

The accelerated decay test (soil block test) was carried out according to AWPA E-10 (2016), in laboratory conditions using only the brown rot fungus *Gloeophyllum trabeum* (Pers.) Murrill (Mad-617, USDA/FS/FPL), generally more aggressive than *Rhodonia placenta* (Fr.) and *Trametes versicolor* (L.) (Brocco *et al.* 2017, Kölle *et al.* 2021). When setting up the experiment, 500 mL glass bottles were filled with 250 g of soil and moistened to 130 % of the water holding capacity, by adding 100 mL of deionized water and two feeder strips marupa (*Simarouba amara* Aubl.). The bottles were sterilized in an autoclave at 103 kPa and 121 °C for 30 min.

After cooling the flasks, two fragments of each fungal culture were inoculated into feeder strips in contact with the soil. After the development of the fungus and its colonization, treated wood blocks were sterilized in an autoclave at 103 kPa and 121 °C for 30 min, and placed onto the feeder strips, two blocks per bottle. The test was kept in an acclimatized room (25 °C; 70 % - RH) for 12 weeks. After this period, Samples were removed, cleaned and oven dried to evaluate weight loss.

The termite resistance of marupa wood impregnated with the extracts was verified using choice feeding test, according to the procedures described by Paes *et al*. (2015) and Brocco *et al*. (2020), with some adaptations. Thus, samples with dimensions of 25 mm x 25 mm x 9 mm (R x T x L) were distributed according to a randomized block design in a box with a capacity of 50 L, containing a layer of sand of approximately 5 cm and moistened with distilled water at 18 ± 2 %. The wood samples were placed side by side on the sand layer and equally spaced in the center of the box.

The termite colony (*Nasutitermes* sp.) was placed in a grid supported by two ceramic blocks placed on the sand layer. The test remained in an acclimatized room for 28 days. At the end of the test, the samples were cleaned, oven dried and the weight loss (%) was evaluated. Each sample was examined and visually rated using the AWPA rating system The visual damage (rating) caused by the termites was evaluated (Table 1).

Table 1: Evaluation of visual damage of wood samples caused by termites.

Classification	Rating
Sound, surface nibbles permitted	10
Slight attack, up to 3 % of cross sectional area affected	9
Moderate attack, penetration, 10 %-30 % of cross sectional area affected	7
Very severe attack, 50 %-75 % of cross sectional area affected	4
Failure, rupture of test samples	0

Source - Adapted from AWPA E1-16 (2016).

Analysis and evaluation of results

The quantification of extractives, retention and fungal inhibition data were evaluated using descriptive statistics by using means and standard deviations. Five repetitions were used for each extract and concentration. A completely randomized design was used to verify the effect of extracts and concentration on the response variables obtained by the decay and termite resistance test. For the factors and interaction detected as significant by the F test ($p \leq 0,05$), the Tukey test ($p \leq 0,05$) was used.

RESULTS AND DISCUSSION

Extractives quantification

It was observed that the species that presented the highest values of soluble substances for all extractions were tanimbuca (*Buchenavia* sp. Eichler), red angelim (*Dinizia excelsa* Ducke), *Hymenolobium flavum* and maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach) (Figure 2). The species red tauari (*Cariniana micrantha* Ducke), louro faia (*Roupala montana* Aubl.) and louro pardo (*Cordia* sp. L.). showed the lowest values of extractive content.

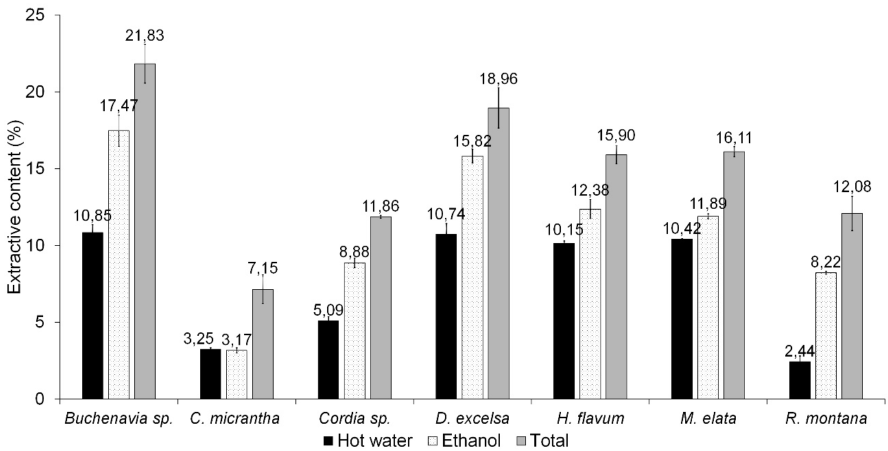

Figure 2: Extractives content in sawdust collected from different forest species according to solubility.

Ethanol extractive contents of tanimbuca (*Buchenavia* sp. Eichler) and red angelim (*Dinizia excelsa* Ducke) presented higher values than those found by Barbosa *et al*. (2007), where they obtained values of 8,2 % and 7,8 %, respectively. Lima *et al*. (2021) found similar values for total extractive content of red angelim (*Dinizia excelsa* Ducke), (18 %) and maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach) (12 %). The average contents of maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach) extractives in this work were higher than those observed by Araújo *et al*. (2014), who obtained lower results in hot water (6,78 %) and ethanol: water (8,19 %).

According to Lobão *et al*. (2011) angelim pedra (murarema) wood (*Hymenolobium petraeum* Ducke.) presents around 20 % of total extractive content, although Silva (2013) obtained 10 % of total extractives for the same specie. Some studies show that natural durable wood is a source to obtain extractives with biocidal activity (Kirker *et al.* 2013, Broda 2020, Vek *et al.* 2020). Although even in lower amounts, effective compounds can have great potential to inhibit wood destroying organisms (Niamké *et al*. 2021). In addition, in species that have secondary metabolites that influence their natural durability, the total extractives content may be positively correlated with the amount of such compounds (Lukmandaru and Takahashi 2009, Broda 2020).

The extractive contents in this work showed differences between the species and solvents used, showing higher values, in some cases, than those found by some of the aforementioned literature. In addition, in this research, recently sawn wood residues were used, indicating that such residues have a considerable amount of extractives and could be explored for other uses.

Biological activity and inhibition test

At the end of seven days of fungal growth, it was observed that the extract of louro faia (*Roupala montana* Aubl.) inhibited by approximately 80 % the growth of *Rhodonia placenta* (Fr.) and 90 % of *Trametes versicolor* (L.) in all tested concentrations. The angelim pedra (*Hymenolobium flavum* Kleinhoonte) extract also showed good inhibition, occurring mainly at concentrations of 2 % (64,60 %) and 4 % (83,10 %) for *Rhodonia placenta* (Fr.) and an almost complete inhibition (98 %) for *Trametes versicolor* (L.) louro pardo (*Cordia* sp. L.), red angelim (*Dinizia excelsa* Ducke) and maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach) extracts showed satisfactory inhibition, above 60 %, at concentrations of 2 % and 4 % for *Trametes versicolor* (L.), but the same was not observed for *Rhodonia placenta* (Fr.) (Table 2).

Table 2: Inhibition of fungal growth at the end of seven days, depending on the extract, concentration and fungus tested.

Extract	Fungal inhibition (%)					
	Trametes versicolor			*Rhodonia placenta*		
	Extract concentration			Extract concentration		
	1 %	2 %	4 %	1 %	2 %	4 %
Roupala montana	91,95 (0,79)	90,33 (1,40)	89 (2,76)	80,17 (1,99)	85,34 (1,68)	83,29 (1,94)
Hymenolobium flavum	96,68 (1,20)	98,05 (0)	98,05 (0)	31,08 (5,41)	64,60 (2,24)	83,10 (3,12)
Cordia sp.	71,89 (2,27)	72,65 (4,69)	84,41 (6,44)	0 (0)	18,01 (10,67)	31 (4,91)
Dinizia excelsa	31,79 (11,22)	63,58 (10,89)	74,40 (2,45)	0 (0)	0 (0)	0 (0)
Manilkara elata	30,18 (3,16)	73,30 (9,18)	71,35 (15,82)	0 (0)	0 (0)	20,92 (6,23)
Buchenavia sp.	21,16 (9,54)	29,86 (7,24)	69,04 (5,62)	0 (0)	40,81 (11,30)	44,65 (18,36)
Cariniana micrantha	68,14 (7,08)	69,40 (0,88)	58,43 (3,42)	0 (0)	0 (0)	23,76 (5,89)

Values in parentheses are standard deviations

Considering teakwood extract, a wood with recognized natural durability, several works with fungal inhibition tests in Petri dishes allowed evaluating its inhibitory effect for the analyzed fungi. According to Brocco *et al*. (2017) at a concentration of 2 % and 4 % the extract showed an inhibition rate of 86 % and 100 % for the fungus *Rhodonia placenta* (Fr.). Pinto (2020) found the teak extract caused 70 % of growth inhibition of *Rhodonia placenta* (Fr.). However, these results are lower than those found in the present study when compared with the extract of louro faia (*Roupala montana* Aubl.), which provided high inhibition even at the lowest concentration tested.

In general, for the minimum concentration tested, the louro faia (*Roupala montana* Aubl.) and angelim pedra (*Hymenolobium flavum* Kleinhoonte) extracts showed the best performance. The extract of red tauari (*Cariniana micrantha* Ducke)showed low inhibition to the fungi tested, in addition, due to the low solubility in the studied solvents, this extract was removed from the wood durability tests to fungi and termites.

The natural durability of wood against wood destroying organisms is attributed mainly to the quantity and type of extractives, especially those present in the heartwood. Thus, certain extracts obtained from naturally durable wood may not present satisfactory performance against wood destroying organisms (Feraydoni and Hosseinihashemi 2012). This highlights the importance of studying a broad spectrum of species and obtaining effective extracts at appropriate concentrations. Some studies have shown that in tropical species with recognized wood durability, specific compounds present in extractives, even in small quantities (less than 2%), play a key factor in the high natural durability (Thulasidas and Bhat 2007, Niamké *et al.* 2021).

Wood impregnation and extractive retention

Considering the results from inhibition test, 2 % and 4 % concentration was used for marupa (*Simarouba amara* Aubl.) wood impregnation and the extractive retention results are shown in Figure 3. It was observed that marupa (*Simarouba amara* Aubl.) retention varied, in the concentration of 2 % from 15 kg/m^3 to 25 kg/m^3 for the tested extracts. For 4 % concentration the values ranged from 25 kg/m^3 to 35 kg/m^3.

The retentions of extractives in the present study were higher than those presented by Barbosa *et al*. (2007), where marupa (*Simarouba amara* Aubl.) wood impregnated with extracts of four Amazonian species, including red angelim (*Dinizia excelsa* Ducke) and amarelinho (*Buchenavia parviflora* Ducke), obtained retentions ranging from 5 kg/m^3 to 7 kg/m^3. It is noteworthy that the highest concentration of extract used by the authors was 1 %, half of the lowest concentration used in the present study for wood impregnation.

When impregnated at 4 % concentration, teak extract provided retentions ranging from 21 kg/m^3 to 27 kg/m^3 in *Pinus* sp. (Brocco *et al.* 2017, Brocco *et al.* 2020). At concentrations of 8 % and 12 %, retention of extractives in treated wood can vary from 40 kg/m^3 to 100 kg/m^3 (Tascioglu *et al.* 2012, Brocco 2019). Comparing the aforementioned studies, marupa (*Simarouba amara* Aubl.) wood showed satisfactory retention according to the method tested for the impregnation of Amazonian wood extracts (Figure 3).

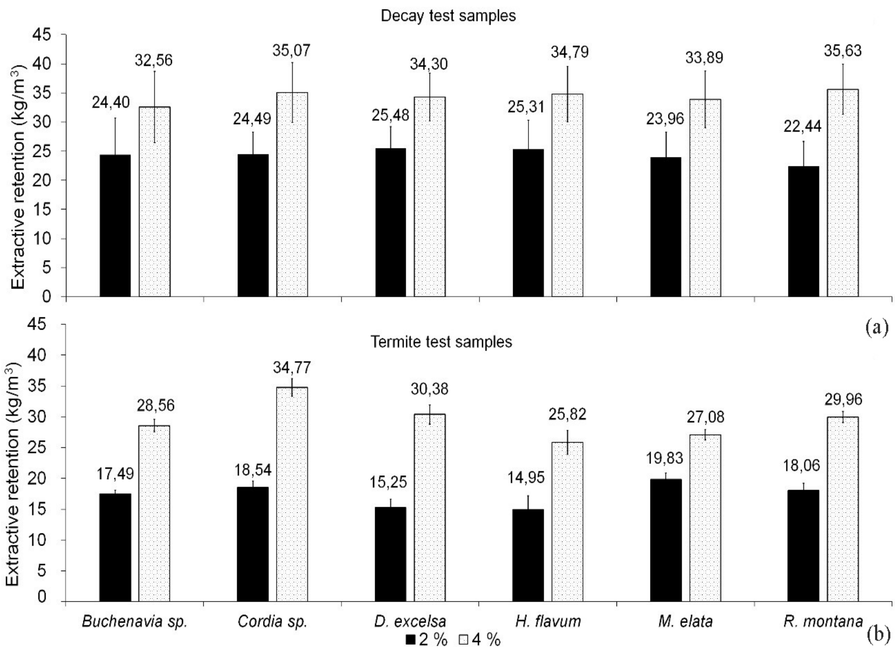

Figure 3: Extractive retention of marupa (*Simarouba amara* Aubl.) wood impregnated with extracts for decay (a) and termite test (b).

Decay and termite resistance tests

The analysis of variance indicated a significant difference between the extracts and concentrations tested during the evaluation of weight loss data. In general, for decay and termite resistance, the 4 % concentration promoted lower weight losses, differing significantly from the 2 % concentration. After 12 weeks of duration of decay test, it was observed that marupa (*Simarouba amara* Aubl.) wood treated with tanimbuca (*Buchenavia* sp. Eichler) extract obtained a lower weight loss in both concentrations tested, not differing statistically from maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach) extract, indicating that the extract showed some effectiveness in protecting the wood when subjected to *Gloeophyllum trabeum* (Pers.) attack, which had not been identified for *Rhodonia placenta* (Fr.) by the inhibition test (Table 3).

The extracts of louro faia (*Roupala montana* Aubl.) and angelim pedra (*Hymenolobium flavum* Kleinhoonte), which had obtained the best performance in the inhibition test against *Rhodonia placenta* (Fr.) and *Trametes versicolor* (L.), did not guarantee a good protection of wood against *Gloeophyllum trabeum* (Pers.) in the soil block test, since they obtained the highest weight loss values, statistically differing from the extracts mentioned previously. However, they obtained the best performance against termite attack, indicating that the compounds present in the extracts may act differently between the wood destroying organisms tested.

Table 3: Biological resistance of marupa (*Simarouba amara* Aubl.) wood treated with different extracts and concentrations, subjected to the action of decay fungus and termites.

Extracts	Decay resistance (*G. trabeum*)		Termite resistance			
	Weight loss (%)		Weight loss (%)		Visual damage (rating)	
	Concentration		Concentration			
	2 %	4 %	2 %	4 %	2 %	4 %
Buchenavia sp.	19,67 Ac (5,81)	14,00 Bc (7,93)	23,98 Aa (6,35)	16,31Ba (10,10)	6,40 Bb (0,89)	7,47Ab (0,87)
Cordia sp.	32,04 Aa (7,23)	24,41 Ba (2,73)	2,99 Ab (0,22)	3,17 Bb (0,34)	9,53 Ba (0,38)	9,67 Aa (0,00)
D. excelsa	28,00 Aab (3,66)	24,54 Bab (1,31)	32,79 Aa (14,06)	19,23 Ba (8,20)	5,40 Bi (1,14)	6,93 Ab (0,92)
H. flavum.	33,26 Aa (5,21)	24,66 Ba (6,67)	3,04 Ab (0,29)	2,93 Bb (0,59)	9,00 Ba (0,00)	9,53 Aa (0,30)
M. elata	25,16 Abc (4,34)	15,45 Bbc (2,55)	7,28 Ab (3,97)	3,24 Bb (0,13)	8,40 Ba (1,01)	9,67Aa (0)
R. montana	33,35 Aa (9,69)	31,38 Ba (4,97)	3,57 Ab (1,49)	3,00 Bb (0,13)	8,93 Ba (0,68)	8,53 Aa (0,30)
Control (ethanol)	34,35 (6,94)		30,78 (16,31)		6,13 (1,56)	
Control (non-impregnated)	31,05 (7,14)		27,21 (9,25)		6,93 (0,60)	

Means followed by the same letter, uppercase (lines, between concentration) or lowercase (column, among extracts), do not differ (Tukey, p > 0,05). Values in parentheses are standard deviation.

Carneiro *et al*. (2009) found 33 % average weight loss when marupa (*Simarouba amara* Aubl.) wood was submitted to different decay fungi while Stangerlin *et al*. (2013) and Vieira *et al*. (2020) found weight losses close to 50 %. Carneiro *et al*. (2009) also found that maçaranduba (*Manilkara huberi* (Ducke) A.Chev) and murarema (*Hymenolobium petraeum* Ducke.) obtained an average weight loss of approximately 2 % and 12 %, respectively, when subjected to decay fungi.

All wood extracts used in the present work were selected from species with recognized durability (Jesus *et al.* 1998, Carneiro *et al.* 2009, Costa *et al.* 2019, Gouveia *et al.* 2021). Therefore, it was possible to observe that marupa (*Simarouba amara* Aubl.) wood treated with durable wood extracts at present concentrations did not exhibit the high resistance index, evidencing the complexity of the fungal attack mechanism and that the wood natural durability depends on different classes of compounds and other factors besides the presence of extractives (Brocco *et al.* 2017, Brocco *et al.* 2020, Brischke and Alfredsen 2022).

The extract from woods with the highest extractive content, in general, showed a tendency towards lower weight loss to fungi. Wood with higher extractive content is more likely to have different classes and compounds that influence the wood natural durability (Yamamoto *et al.* 1998, Lukmandaru and Takahashi 2009, Stangerlin *et al.* 2013).

After 28 days, it was possible to obtain satisfactory test results when viewing the specimens before and after the termite attack (Figure 4). Regarding termite resistance, significant differences between the extracts and concentrations were also found. It was noted that marupa (*Simarouba amara* Aubl.) wood impregnated with angelim pedra (*Hymenolobium flavum* Kleinhoonte), louro pardo (*Cordia* sp. L.) and louro faia (*Roupala montana* Aubl.) extracts differed significantly from the other extracts for both concentrations tested and showed the lowest weight loss. Maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach) extract also showed similar performance to the previous ones at 4 % concentration.

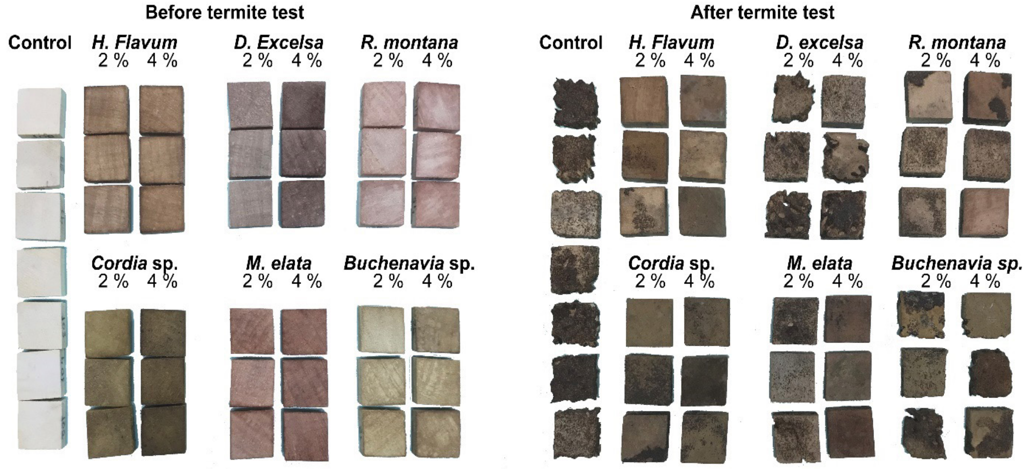

Figure 4: Visual appearance of marupa (*Simarouba amara* Aubl.) wood samples impregnated with different wood extracts before and after choice feeding test against *Nasutitermes* sp.

Our findings indicates that these extracts had a greater inhibition effect against termites than decay fungi. The highest weigh loss values were obtained for wood treated with red angelim (*Dinizia excelsa* Ducke) and tanimbuca (*Buchenavia* sp. Eichler) extracts, which means that its extracts were not efficient against the action of termites used in the present work, despite having provided some action when used at a concentration of 4 %.

Regarding visual damage ratings, the extracts of angelim pedra (*Hymenolobium flavum* Kleinhoonte), louro faia (*Roupala montana* Aubl.), louro pardo (*Cordia* sp. L.) and maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach), were the extracts that differed significantly and provided the best visual classification of damage caused by termite attack. Results found by Paes *et al*. (2007) corroborate with the present study, where the species *Cordia trichotoma* stood out as one of the most resistant species against termites in a choice feeding test against *Nasutitermes* sp., presenting weight loss below 3 % in the heartwood and visual rating of 9,8.

Using the heartwood of freijo (*Cordia goeldiana* Huber), maçaranduba (*Manilkara huberi* (Ducke) A.Chev) and red angelim (*Dinizia excelsa* Ducke), Pêgas (2007) observed that these woods obtained the lowest weight loss and maximum visual damage ratings (high resistance), values close to the present work, when subjected to the termite *Coptotermes gestroi*. Costa *et al*. (2019) found low wood weight loss for red angelim (*Dinizia excelsa* Ducke), murarema (*Hymenolobium petraeum* Ducke.) and maçaranduba (*Manilkara huberi* (Ducke) A.Chev) when attacked by *Nasutitermes octopilis* (Banks). According to the authors, the composition and high toxic concentrations of extractives is one of the main inhibition factors for termites, being important for the wood durability, as well as its density.

The samples Impregnated with extracts of tanimbuca (*Buchenavia* sp. Eichler), red angelim (*Dinizia excelsa* Ducke) and control (non-impregnated and etanol impregnated marupa (*Simarouba amara* Aubl.), received the lowest ratings and visually suffered more attack from termites, especially at a concentration of 2 %. The results of the present study are different from those obtained by Barbosa *et al*. (2007), where marupa (*Simarouba amara* Aubl.) wood was impregnated with red angelim (*Dinizia excelsa* Ducke) and amarelinho (*Buchenavia parviflora* Ducke) wood extracts and exhibited good resistance against *Nasutitermes* sp. attack in a choice feeding test. These differences may be related to the quantity and dimensions of the samples, variation in composition, concentration of extracts and extraction solvent, in addition to the behavior of the species of termites in use.

According to Pinheiro *et al*. (2017), more studies of this nature are important, since with colonies in the laboratory it is possible to explore the diversity of termite attacks in a more reliable, controlled and similar way to the field.

CONCLUSIONS

In general, it was possible to obtain significant amounts of extractives from the industrial processing residues of Amazonian woods. Marupa (*Simarouba amara* Aubl.) wood was easily impregnated with all extracts and showed satisfactory retention values for the tested concentrations. The extracts from louro faia (*Roupala montana* Aubl.) and angelim pedra (*Hymenolobium flavum* Kleinhoonte) guaranteed a high inhibition in the growth of the fungi tested, while the extracts of louro pardo (*Cordia* sp. L.), red angelim (*Dinizia excelsa* Ducke) and maçaranduba (*Manilkara elata* (Allemão ex Miq.) Monach) obtained satisfactory results.

The extracts from louro faia (*Roupala montana* Aubl.) and louro pardo (*Cordia* sp. L.) provided greater inhibition of termite attack for both tested concentrations, however, exhibited the lowest extractive content. In the accelerated decay test the extracts from tanimbuca (*Buchenavia* sp. Eichler) provided resistance to marupa wood. Future studies should test combination of extracts with best results, including more prolonged tests and chemical analyses. In addition, extracts from other species, combinations with other Amazonian bioproducts should be tested.

Authorship contributions

V. F. B.: Conceptualization, funding acquisition, writing – original draft, investigation. L. G. C.: Conceptualization, investigation, critical revision. M. C. M. C.: Data analysis, writing – review & editing. A. V. X. B.: Writing – review & editing. P. H. C. L.: Data acquisition and writing. R. C. A. C. C.: Data acquisition and writing.

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