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Scientific Article

Use of vegetable oils to improve the resistance of wood to attack by xylophagous termites

Uso de óleos vegetais para melhoria da resistência da madeira ao ataque de térmitas xilófagas

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ABSTRACT - There are various compounds to increase the natural resistance of wood, but they can be harmful to humans, domestic animals and the environment. Natural products are therefore being researched to ensure the sustainability of the environment, human health and reduce the use of traditional products. The objective of this research was to evaluate the efficiency of andiroba (*Carapa guianenses*), copaiba (*Copaifera* spp.) and jatropha (*Jatropha curcas*) oils in the biological resistance of *Pinus elliottii* wood to arboreal termites (*Nasutitermes corniger*). The andiroba and copaiba oils came from communities in the municipality of Santarém, Pará, and the jatropha oil from Fazenda Tamanduá, in the municipality of Santa Terezinha, Paraíba. They were used pure and enriched with sublimated iodine (1, 3, and 5% concentration). The effects of volatilization and leaching on the efficiency of the solutions against *Nasutitermes corniger* were evaluated. The lowest mass losses and damages were for wood impregnated with copaiba oil, both pure and enriched with iodine. The samples subjected to leaching showed the greatest damage (score = 9.33). Termite mortality was 100% at the end of the assay for all the treatments tested. Copaiba oil can be an environmentally friendly alternative to protect wood, especially wood in direct contact with humans and domestic animals and exposed to environments where *Nasutitermes corniger* is likely to attack, as it has the lowest mass losses (7.51-6.14%). However, it is not exposed to situations that could cause leaching.

Keywords: Natural products. Wood protection. Soil termites.

RESUMO - Há vários compostos para aumentar a resistência natural da madeira, porém eles podem ser nocivos a humanos, animais domésticos e ao meio ambiente. Assim, produtos naturais estão sendo pesquisados, para garantir a sustentabilidade do meio ambiente, a saúde humana, e diminuir a utilização de produtos tradicionais. O objetivo desta pesquisa foi avaliar a eficiência dos óleos de andiroba (*Carapa guianenses*), copaíba (*Copaifera* spp.) e pinhão manso (*Jatropha curcas*) na resistência biológica da madeira de *Pinus elliottii* a térmitas arborícolas (*Nasutitermes corniger*). Os óleos de andiroba e copaíba foram oriundos de comunidades do município de Santarém, Pará, e o óleo de pinhão-manso da Fazenda Tamanduá, município de Santa Terezinha, Paraíba. Eles foram utilizados puros e enriquecidos com iodo sublimado (1, 3, e 5% de concentração). Foram avaliados os efeitos da volatilização e lixiviação na eficiência das soluções contra *Nasutitermes corniger*. As menores perdas de massa e desgaste foram para a madeira impregnada com o óleo de copaíba, tanto puro, como enriquecido com Iodo. Os maiores desgastes foram para as amostras submetidas à lixiviação (nota = 9,33). A mortalidade das térmitas foi 100% ao término do ensaio para todos os tratamentos testados. O óleo de copaíba pode ser uma alternativa ambientalmente amigável proteger a madeira, em especial aquelas a terem contato direto com humanos e animais domésticos, e quando expostas a ambientes com probabilidade de ataques por *Nasutitermes corniger*, por terem as menores perdas de massa (7.51-6.14%). Porém não exposta a situações quem possam causar lixiviação.

Palavras-chave: Produtos naturais. Proteção da madeira. Térmitas de solo.

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INTRODUCTION

The incorporation of chemical products is essential to protect wood with low natural durability, to prevent damage and accidents (BRODA, 2020). These products extend the service life of wooden structures and contribute to the conservation of forest resources. However, environmental and health restrictions have led to limited use for wood protection, making research and development of products containing natural, non-toxic and ecologically sustainable ingredients essential (BROCCO et al., 2020; BESSIKE et al., 2023).

Some studies have shown the effectiveness of natural oils and extractives in protecting wood. Such as candeia oil and its by-products (TEIXEIRA et al., 2015), neem oil and castor oil (FATIMA; AHMED; HASSAN, 2021), extractives from the heartwood of teak (BROCCO et al., 2020), essential oils from Cerrado plants (MEDEIROS et al., 2016) and extracts from sawmill residues of Amazonian forest species (ALMEIDA, 2023). The use of natural products guarantees environmental sustainability, human health safety and reduces dependence on traditional products containing toxic compounds in their formulations (TEIXEIRA et al., 2015; MEDEIROS et al., 2016; ALMEIDA, 2023).

Andiroba, copaiba and jatropha oils are used as insecticides, fungicides and molluscicides and are an alternative to conventional products (OLIVEIRA; SANTANA; ANTIGO, 2013). Studies involving vegetable oils in wood protection have shown promising results, especially those containing iodine in their composition (SOUSA et al., 2020). Iodine oxidizes and polymerizes quickly, creating an elastic film when exposed to air. This characteristic contributes to the durability and stability of the impregnated wood, reducing the effects caused by exposure to the sun, rain, humidity and temperature variations. In addition, the film provides a barrier against deteriorating organisms such as fungi and insects, preserving the integrity of the wood (TOMAK et al., 2011, SOUSA et al., 2020).

In order to study the potential of natural substances with promising prospects for improving the durability of wood, the aim was to evaluate the efficiency of andiroba, copaiba and jatropha oils in the biological resistance of *Pinus elliottii* wood to arboreal termites (*Nasutitermes corniger*).

MATERIALS AND METHODS

Obtaining vegetable oils

The andiroba (*Carapa guianenses*) and copaiba (*Copaifera* spp.) oil came from communities in the municipality of Santarém - Pará, Brazil (latitude 2 24'52" S and longitude 54 42'36" W), a region with an average annual rainfall of 1,920 mm, with a predominantly hot and humid climate, characteristic of tropical forests.

The Jatropha oil (*Jatropha curcas*) was supplied by Fazenda Tamanduá, located in Santa Terezinha - Paraíba, Brazil (latitude 7 5'19" S and longitude 37 27'23" W), where the semi-arid climate prevails, with average annual rainfall of 800 mm.

Obtaining wood and preparing samples

The *Pinus elliottii* wood was obtained in the form of 10 × 10 × 300 cm beams (width × thickness × length), from plantations aged 21 years, located in the Pindobas Agroindustrial Complex, municipality of Venda Nova do Imigrante, Espírito Santo, Brazil (latitude 20°20’04” S and longitude 41°08”05” W). The beams were unfolded to take samples from the adult wood in the appropriate dimensions for the biological test, measuring 2.54 × 2.54 × 0.64 cm (longitudinal × radial × tangential).

The samples obtained were selected by discarding those with defects (knots, resin pockets and cracks). They were sanded to obtain a uniform surface and identified according to the treatment to be used in the biological test. Before impregnating the wood, the samples were dried in an oven at 103 ± 2 °C until they reached a constant mass. This procedure was adopted to obtain the masses, volumes (displacement in mercury) and determine the anhydrous density of the samples, as cited by Sousa et al. (2020).

Preparation and impregnation of oils in wood

The cold immersion method was used to impregnate the wood, in which the samples were immersed in pure oils enriched with iodine at concentrations of 1%, 3% and 5%, until they reached a retention of 50 - 70 kg m^{-3}. These retentions were stipulated on the basis of Paes et al. (2010; 2011). To this end, the masses of the samples, after impregnation, were obtained to determine the retention (kg m^{-3}) of the oils in the wood. After being impregnated, they were subjected to three situations (1 - leached, 2 - volatilized, and 3 - normal).

The volatilization test used the methodology of the American Wood Protection Association - AWPA E 10-22 (2022a), in which the samples were immersed in distilled water for two hours, followed by exposure in a forced circulation oven at 48.9 ± 1.1ºC for 334 hours.

For the leaching test, the methodology described by Freitas (1970) was used, which consists of submitting the samples for 150 hours in a container in which water circulates in and out, set at 400 mL min^{-1}, which is measured three times a day with a measuring cylinder. After this procedure, the samples were conditioned for 15 days (temperature 25 ± 2 ºC and 65 ± 5% relative humidity - RH). After being impregnated and subjected to volatilization or leaching, the biological test was carried out on tree and soil termites (*Nasuitermes corniger* Motsch.). For the normal situation, the impregnated samples had their surfaces cleaned with absorbent paper and set up for the test. The treatments used are listed in Table 1.

Table 1. Description of the treatments used in *Pinus elliottii* samples subjected to *Nasutitermes corniger* termites.

Treatment	Treatment description
1	Control (non-impregnated wood)
2	Pure Andiroba
3	Andiroba enriched with 1% iodine
4	Andiroba enriched with 3% Iodine
5	Andiroba enriched with 5% iodine
6	Pure Copaiba
7	Copaiba enriched with 1% iodine
8	Copaiba enriched with 3% Iodine
9	Copaiba enriched with 5% iodine
10	Pure Jatropha
11	Jatropha enriched with 1% iodine
12	Jatropha enriched with 3% Iodine
13	Jatropha enriched with 5% iodine

No-choice feeding test to soil termites

The samples subjected to the situations mentioned above (leached, volatilized and normal) were put to the no-choice feeding test with the termite (*Nasutitermes corniger*), in accordance with AWPA E1-22 (2022b). To this end, a termite colony was collected near the municipality of Jerônimo Monteiro, Espírito Santo, Brazil (latitude 20º 47' 22" S and longitude 41º 23' 42" W). To capture the termites, the colony was placed in a 250 L asbestos cement box, with a layer of moist sand of approximately 10 cm, containing three layers of moistened corrugated cardboard, as described by Brocco et al. (2020), Figure 1A.

The experiment was set up using 600 mL transparent glass flasks filled with 200 g of sand sterilized in an oven at 103 ± 2ºC, whose humidity was corrected according to its water retention capacity, and 36 mL of distilled water was added. A sample was added to each flask, measuring 2.54 × 2.54 × 0.64 cm (longitudinal × radial × tangential), and 1 ± 0.05 g of termite, which corresponded to ≈ 400 individuals, in the proportion of 80% workers and 20% soldiers, the proportion existing in the colony (Figure 1B). The flasks were closed slightly to allow for aeration (Figure 1C). Five replicates were used for each treatment and situation.

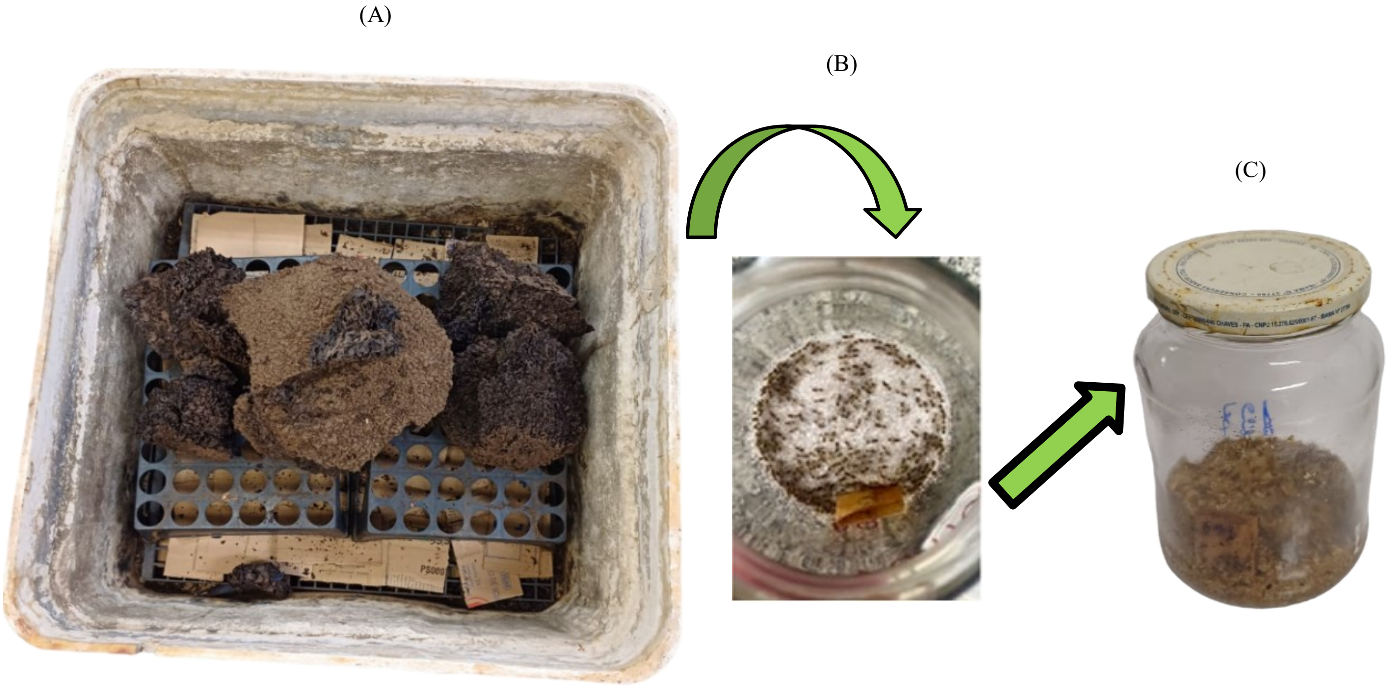


Figure 1. Termite colony used (A), termites and *Pinus elliottii* samples in the flask (B) and flask slightly closed for the test (C).

The test was kept in an air-conditioned room (27 ± 2 °C and 65 ± 5% RH) for 28 days, after which the efficiency of the oils was evaluated according to the damage (score) of the samples, termite mortality (%) (AWPA E1-22, 2022b), Table 2, and mass loss (%), corrected for operational loss (BROCCO et al., 2020).

Table 2. Evaluation of wood damage and mortality of *Nasutitermes corniger* termites.

Damage type	Visual score ratting
Healthy, allowing superficial scarifications	10
Light attack	9
Moderate attack with penetration	7
Intense attack	4
Failure, with the specimens breaking	0
Mortality	(%)
Low	0 - 33
Moderate	34 - 66
High	67 - 99
Total	100

Source: Modified from AWPA E1-22 (2022b).

Statistical analysis

The assay used a completely randomized design with a factorial arrangement (13 × 3), evaluating the effects of treatments (13 levels) and situation (three levels), for a total of 39 treatments. Each with five repetitions. Before carrying out the analysis of variance, the normality of the data (Lilliefors test) and the homogeneity of the variances (Cochran test) were checked.

The values of mass loss (%) were transformed into $arcsin\frac{\sqrt{Mass\ loss}}{100}$ and those of damage (score) into $\sqrt{Score+0.5}$. These transformations, suggested by Steel, Torrie and Dickey (1996), were necessary to ensure homogeneity of variance. The Scott-Knott test ($p < 0.05$) was used to analyze and evaluate the tests for the factors and interactions found to be significant by the F test ($p < 0.05$).

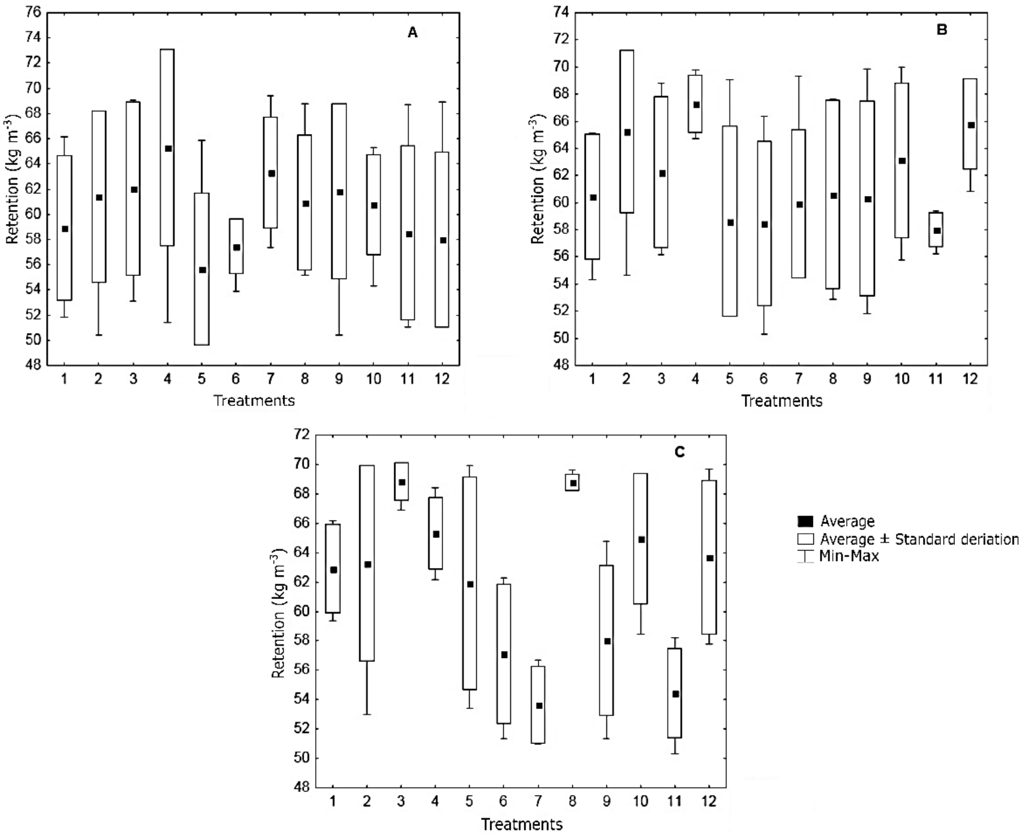
RESULTS AND DISCUSSION

Density and retention of oils in *Pinus elliottii* wood

It was found that the *Pinus elliottii* wood used in the experiment has a density of 0.552 g cm^{-3}, standard deviation of 0.09 g cm^{-3}, which classifies it as medium density according to the *Comisión Panamericana de Normas Técnicas* - COPANT (1974).

As density is a property resulting from the interaction between the chemical and anatomical composition of wood, it is assumed that differences in cell dimensions and the amount of chemical components cause variations in this characteristic. Density tends to increase with age, explained by an increase in cell wall thickness and a decrease in cell width. This can positively influence the retention of liquids in the wood, as well as consumption by termites and other insects. Melo et al. (2013) found an average of 0.332 to 0.364 g cm^{-3} for the density of *Pinus elliottii* for trees aged 9 and 14 years, respectively. This value was 36% lower than that obtained in this study for *Pinus elliottii* wood at approximately 21 years of age. Edaphoclimatic factors (soil type, relief, nutrition, cultural treatments, temperature and rainfall) also influence wood density (JATI; BARBOSA; FEARNSIDE, 2019).

The averages of the oils retained in the wood, the standard deviations and the maximum and minimum values are shown in Figure 2. The average retention achieved was 61.69 kg m^{-3}, in accordance with the stipulated (50 - 70 kg m^{-3}), with a maximum difference between them of 10.43 kg m^{-3}.



Treatment 1: pure andiroba oil; Treatment 2: andiroba oil with 1% I_2; Treatment 3: andiroba oil with 3% I_2; Treatment 4: andiroba oil with 5% I_2; Treatment 5: pure copaiba oil; Treatment 6: copaiba oil with 1% I_2; Treatment 7: copaiba oil with 3% I_2; Treatment 8: copaiba oil with 5% I_2; Treatment 9: pure jatropha oil; Treatment 10: jatropha oil with 1% I_2; Treatment 11: jatropha oil with 3% I_2; Treatment 12: jatropha oil with 5% I_2. Leached situation (A), volatilized (B), normal (C).

Figure 2. Retention (kg m^{-3}) of the oils in the samples submitted to the test, for the situations evaluated.

The wood quickly absorbed the oils (andiroba, copaiba and jatropha), and the samples remained in contact with the solutions for 5-15 seconds of immersion. It was observed that some samples required more time than others to absorb the established amount of product. This is explained by the anatomical differences in the material, the density of the samples and the permeability of the wood (since it is a heterogeneous material). In the test, it was possible to see that the lowest average retention was found in treatment 7 (normal situation) and the highest in treatments 3 and 8 (normal situation), Figure 2.

The anatomical structure of coniferous wood is relatively simple when compared to hardwoods. They are basically made up of 5 to 10% ray cells and 90 to 95% axial tracheids (GONZAGA, 2006). This anatomical constitution makes it easier to penetrate and retain the product in the wood. Thus, the anatomical constitution has a direct effect on the amount of product that the wood absorbs. The anatomy of the wood is of fundamental importance for a better understanding of treatability, contributing to the indication of an appropriate preservative treatment (LOPES et al, 2017).

For wood impregnation, permeability must also be taken into account, since lower penetration is probably related to higher density, which hinders the flow of fluids in the wood (LOPES et al., 2017), due to the smaller opening of the scores, which will require a greater effort to overcome the surface tension of the fluid and facilitate diffusibility in the wood. Thus, greater density also results in greater difficulty in drying and impregnation with preservative solutions, which is explained by the smaller volume of empty spaces (AUGUSTINA et al., 2023).

There are woods with similar densities, but with different degrees of impregnation, which is explained by the differences in anatomy between species and also by the blockages to the passage of fluids between tracheids (aspirated points - conifers) or the formation of tyloses in the vessels (hardwoods).

Soil termite no-choice feeding test

The analysis of variance of the mass loss data showed significant results by the F test, only for the treatments; and for damage, for treatments and situations. Termite mortality was 100% for all cases. It can be seen that the mass loss of the control (9.48%) differed from that of treatments 6; 7; 8; 9 and 10, and was similar to that of the treatments with andiroba oil (2; 3; 4 and 5) and also treatments 11; 12 and 13 (jatropha oil enriched with 1; 3 and 5%), respectively (Table 3).

Table 3. Comparison between means of mass loss and damage for each treatment and situation for the *Nasutitermes corniger* termite.

Treatment	Mass Loss (%)	Damage (Score)
1 - Control (non-impregnated wood)	9.48 a	9.23 b
2 - pure andiroba oil	8.74 a	9.48 b
3 - andiroba oil with 1% I_2	8.62 a	9.25 b
4 - andiroba oil with 3% I_2	8.93 a	9.19 b
5 - andiroba oil with 5% I_2	8.49 a	9.51 b
6 - pure copaiba oil	6.76 b	9.89 a
7 - copaiba oil with 1% I_2	7.51 b	9.84 a
8 - copaiba oil with 3% I_2	6.83 b	9.77 a
9 - copaiba oil with 5% I_2	6.14 b	9.84 a
10 - pure jatropha oil	6.62 b	9.52 b
11 - jatropha oil with 1% I_2	7.78 a	9.36 b
12 - jatropha oil with 3% I_2	8.18 a	9.59 a
13 - jatropha oil with 5% I_2	8.15 a	9.66 a
Situation	**Damage (Score)**	
1 - Leached	9.33 c	
2 - Volatilized	9.54 b	
3 - Normal	9.76 a	

Averages followed by the same letter for each characteristic evaluated do not differ (Scott-Knott, $p > 0.05$).

Although treatment 9 has the lowest absolute mass loss value, it did not differ from treatments 6; 7; 8; and 10 (pure copaiba oils or enriched with 1 and 3% I_2), and pure jatropha oil, respectively.

With regard to damage, it was generally observed that *Pinus elliottii* wood was only slightly attacked by termites, with superficial scarring visible. The average scores given to the impregnated wood were close to those of the control sample (non-impregnated), Table 3. This may have been caused by the subjectivity of the assessments and visual scoring ratting, as classified in AWPA E1-22 (2022b). Regarding the situations, it is noted that the leached situation was the most worn.

Among the wood impregnated with jatropha oil (Treatments 10, 11, 12 and 13), mass losses were lower than the control (Table 3), only for the pure oil (Treatment 10), which was the most efficient. Higher concentrations of iodine affected the efficiency of the oil and may have interacted negatively with its components.

The attack by termites in all situations was classified as healthy (Table 2), with only superficial scarring and scores above 9.0 in all cases. Copaiba oil is composed of diterpenoids, secondary metabolites commonly found in some plants, which promote defense against pests and diseases (URASAKI et al., 2020, NINKUU et al., 2021). Lepage, Salis and Guedes (2017) state that termites of the genus *Nasutitermes* consume less wood that contains a certain amount of terpenes and terpenoids.

Copaiba oil was found to have potential against the termites tested, with the lowest average mass losses being observed in the samples treated with this oil. It is thus efficient and has the ability to repel these wood-boring insects.

An average score of 9.23 was observed for treatment 1 (non-impregnated wood - control), but this value did not differ from wood treated with andiroba oil (treatments 2; 3; 4 and 5), and was not different from that obtained by treatments 10 and 11, which correspond to impregnations with pure and 1% enriched jatropha oil.

Lower damage was observed for treatments 6; 7; 8; 9, samples impregnated with copaiba oil (pure, 1; 3 and 5% I_2). It should be noted that the lowest mass losses were also found for these treatments. These results did not differ from treatments 12 and 13. The samples subjected to the leachate test were the most consumed by the termites.

Observations were made daily in the flasks with the termites and, in some treatments, no attack on the treated wood was observed. The termites were found to be far away from the samples. This may be due to the volatile substances they exude, such as terpenes and terpenoids, which repel these insects (ALMEIDA, 2023). Kang et al. (2005) explained that mass losses can also be due to volatilization and leaching of lighter fractions of the solutions. This may have occurred mainly due to the leaching of some compounds (terpenes and terpenoids), which diffuse into the damp sand in the flasks.

When testing the efficiency of candeia oil in improving the resistance of kapok wood to the *Nasutitermes corniger* termite, Paes et al. (2010) found that the retentions of 10.61 kg m^{-3} (no-choice feeding test) and 38.35 kg m^{-3} (choice feeding test) inhibited the attack of *Nasutitermes corniger* termites, and the retentions of 16.73 kg m^{-3} (no-choice feeding test) and 58.22 kg m^{-3} (choice feeding test) prevented the attack on the treated wood. The protective effect of candeia oil, at the retention rate used, was similar to that obtained by Paes et al. (2010) for the no-choice feeding test.

For the efficiency of neem and castor oil in improving the resistance of kapok wood to *Nasutitermes corniger*, in a choice feeding test, Paes et al. (2011) found that neem oil, like that of andiroba, was not efficient in protecting the wood, and volatilized wood was the one with the lowest mass loss, in relation to normal and leached wood. Pure neem and castor oils and solutions prepared with these ingredients showed some termite repellency effect, although it was not long-lasting.

In terms of mortality, it was noted that none of the treatments had live termites at the end of the assay (28 days), with 100% mortality. On the twentieth day of testing, all the termites were dead. It is worth mentioning that in some flasks the termites made tunnels in the sand, which shows the vigor of the insects used in the test.

The efficacy of andiroba and copaiba oils in protecting wood against termites has not been mentioned in the literature, and this research is pioneering. Some vegetable oils have already been used for this purpose, such as; jatropha, castor, neem and candeia and their by-products (PAES et al., 2010; TEIXEIRA et al., 2015; BESSIKE et al., 2023). As *Pinus elliottii* wood (control) showed some resistance (9.48% mass loss, in relation to copaiba with 5% I2, 6.14%) to *Nasutitermes corniger*, as it has compounds such as terpenes and terpenoids (resin components), Lepage, Salis and Guedes (2017). It is advisable to use hardwood, such as kapok, in order to better detect the effectiveness of copaiba oil against termites of this genus.

Because it is a renewable natural resource, wood has established itself as a common material for various sectors of society. However, certain chemical characteristics particular to wood make it vulnerable to damage and deterioration caused by various organisms. Environmental and health restrictions have limited the use of various products used to protect wood, making alternatives containing natural, less toxic and ecologically sustainable ingredients essential. One approach that is increasingly being explored for this purpose is the use of natural oils and extractives as alternatives for wood protection, as highlighted by Brocco et al. (2020) and Sousa et al. (2020).

Thus, the use of natural oils as termite protection agents in the wood treatment industry plays a crucial role in the research and development of new products that are important for the wood sector. However, the benefits of some products are not fully realized, as has been observed in practice. It was found that copaiba and jatropha oils have distinct characteristics and can be used to impregnate wood to be used in direct contact with humans, providing effective protection with low toxicity, which is a positive factor for the furniture industry.

Therefore, some oils and plant extracts may require the addition of chemicals that are not harmful to human health or the environment in order to improve their effectiveness. Iodine is a good option in this case, as it has bactericidal, fungicidal and insecticidal action (COSTA; GONÇALEZ; VALE, 2003), and low toxicity to humans and the environment (SOME et al., 2016), associated with low solubility in water (SONG et al., 2013). This is very interesting for the industry, as the active ingredient will remain when exposed to environmental action. Thus, oils that resist the effects of leaching and volatilization may be suitable for impregnating wood that will be exposed to more drastic environmental conditions, while those that persist less in wood may be suitable for use in protected environments, such as furniture, floors and partitions.

CONCLUSIONS

The lowest mass losses and damages were for wood treated with copaiba oil, both pure and enriched with iodine. The samples subjected to leaching showed the greatest damage. Termite mortality was 100% at the end of the assay, including the control.

The research indicated that vegetable oils, such as those derived from andiroba, copaiba and jatropha, have biocidal properties against arboreal or soil termites

(*Nasutitermes corniger*), in addition to being used in various industrial applications.

Impregnating wood with copaiba oil, either pure or enriched with iodine, could be a viable and environmentally friendly alternative for protecting wood used in direct contact with humans. However, the use of copaiba oil to protect wood that will be exposed to external environments is not recommended due to the leaching of its components and loss of effectiveness.

Although the laboratory test showed the effectiveness of copaiba oil, field or service tests are needed to draw better conclusions about its effectiveness, which require more time and higher costs.

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