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ICWEP2022

https://icwep.uitm.edu.my/index.php
International Conference on Wood and Eco-Products 2022
Best Western Hotel iCity, Shah Alam, Selangor, Malaysia 15-16 Nov 2022
Organiser: Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Shah Alam
Malaysia & Research Nexus UiTM,, Office of Deputy Vice-Chancellor (Research & Innovation)

E-B Environment - Behaviour Proceedings Journal

e-IPH e-International Publishing House Ltd., United Kingdom

A Review on Natural Extractives as Protective Agent against Decay on Wood and Bamboo Products

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Abstract
This study examined plant extracts from leaves, bark, bole, roots, flowers, and fruits. Plant metabolites and derivatives inhibit brown, white, and soft rot, which decomposes wood and bamboo. The metabolites and derivatives found in plant extracts serve as a protective measure against the biodeterioration of wood and bamboo. The effectiveness of the plant depends on the toxicity of its extract. Plant extracts contain volatile compounds with antifungal properties. Mineral salts such as aluminium and copper sulphates, as well as MUF, impede the process of alcohol evaporation. Plant extract is a more effective and environmentally friendly treatment for bamboo and wood.

Keywords: Plant extracts; Decay fungi; Wood; Bamboo

DOI: https://doi.org/10.21834/e-bpj.v9iSI17.5968

1.0 Introduction

Wood and bamboo are sustainable materials with the most significant carbon sequestration pool globally. Carbon makes up about 50% of the dry mass of trees, and when wood from those trees is used in wood products, the carbon is stored in the trees and wood products for the product's life. Wood and bamboo are prone to deterioration due to attacks by decaying fungi (Brischke & Alfredsen, 2020) causing structural losses of cellulose, hemicellulose, and lignin. Meanwhile, mold is superficial, affecting only the aesthetic appearance of wood (Hu et al., 2020). Despite containing a highly integrated matrix of cellulose, hemicellulose and, lignin, which provides outstanding strength features, wood is also prone to deterioration by bio-agents, mainly insects, marine borers and, fungi. Wood contains sugars and free starch that serve as food for bio-agents to live. The cellulose content of wood is about 40-50%, hemicellulose content is about 20-30%, and lignin content is 25-35%. Besides using wood as a breeding place, wood also contains water for survival. Bamboo is one of the world's oldest building materials used by humankind. Due to advances in manufacturing technologies and increasing market demand, bamboo has been used extensively for household goods and structural applications. Bamboo has been utilized in structural components for bridges, skyscraper scaffoldings, water transportation, floors, ceilings, roofs, windows, and walls. Bamboo contains 40%-50% cellulose (Schmidt et al., 2013), 22-27% hemicellulose, and 25-30% lignin, which varies among species. Due to a high content of starch, sugar, and protein, bamboo is highly susceptible to bio-deteriorating agents such as fungi and powder-post beetles. Bamboo has a small amount of wax, resin, and tannin, which leads to low durability. Thus, treatment is needed (Tomak et al., 2013). The use of inorganic biocides such as copper chromium arsenic (CCA) and boron is banned. Therefore, new ways of protecting wood against biodegradation are necessary. Researchers are searching for alternative compounds and wood protection methods with few to no harmful ecological and human health consequences. Various essential oils, oil-based formulations, plant extracts, organic acids, and eco-friendly chemical-based preservatives are currently in the stage of development. Preservatives based on plant extracts have a lot of promise because only bio-agents targeted were affected by their toxicity and are entirely harmless for humans. This review aims to understand the research status in wood and bamboo protection using plant extract. The essential findings on the type of plant extract, the problem, and

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the future of wood and bamboo protection are presented. The toxicity of currently used preservatives has led to the urgency of finding novel green approaches in treating wood and bamboo products.

The literature was based on the Scopus database. The keywords used in the advanced search were bamboo green treatment or wood protection, which resulted in 214 articles, reviews, and book chapters from 1981 until 2022. Specific topics in wood, fungi, plant extract, chemical compounds, wood protection, wood preservation, decay, and protective coating were found in the literature search. The principle of wood preservation against biodegradation lies in the toxicity of those preservatives. Bamboo, a potential substitute for wood, has the same problem. The standard preservation of wood using toxic materials is no longer acceptable because it has a lot of negative drawbacks. Thus, an alternative of non-toxic materials for bamboo preservation is necessary. Most conventional preservatives can cause environmental pollution, and some can be detrimental to human health. Chromated Copper Arsenate (CCA) is currently used to preserve wood and bamboo. Owing to its toxicity to the environment and humans, CCA oxidation makes it much easier to leach out and contaminate the ecosystem. Hence, it was banned and prohibited in many countries. Similar forms of creosote copper chrome boron (CCB), ammonium chloride, metal salts, and borate compounds are still being used. Therefore, less hazardous alternatives are in demand.

2.0 Deteriorating Fungi

The main types of decaying fungi are soft rot, brown rot, white rot, and dry rot, which refers to the macroscopic and microscopic deterioration of wood structure, as shown in Table 1. Since lignin is an intricate compound to break down, most studies have been done on white rotters and their enzymatic activities. In white rot fungi systems, laccase, lignin peroxidase, versatile peroxidase, and manganese peroxidase are the main lignin-degrading enzymes (Manavalan et al., 2015). They use strong hydrolytic and oxidative enzymes, which slowly break down the cellulose as the lignin is mineralized, leaving white-colored cellulose residues (Riley et al., 2014). Meanwhile, the water-conducting deterioration causes dry rot, which is a type of brown rot (Res, 2021). Dry rot degrades on cellulose and hemicellulose, and other fungi and bacteria frequently accompany them.

Table 1. Soft rot, brown rot, white rot and dry rot decay mechanisms

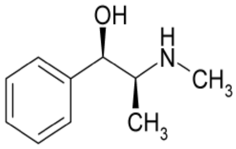
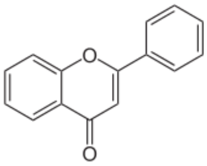
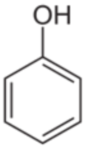
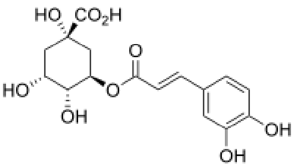
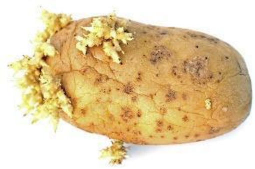
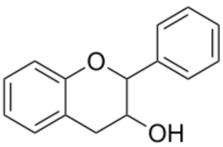
Fungi	Degradation on
Soft rot (ascomycetes)	Hemicelluloses, cellulose
	Lignin degradation is less extensive
Brown rot (basidiomycetes)	Hemicellulose, cellulose
	Leaving lignin rich residue
	Preferably conifers
White rot (basidiomycetes)	Complete lignin degradation
	Hemicellulose, cellulose
	Preferably deciduous tree
Dry rot	Cellulose, hemicellulose

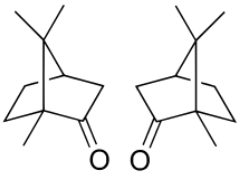
2.1 Plant Metabolites

It was reported that plants produce metabolites. Plant secondary metabolites protect themselves against attacks by selected bio-deteriorating agents. Phenols, flavonoids, tannins, terpenoids, and alkaloids are among the major categories of natural components produced by plants. Phenolic acids contain a phenolic ring and an organic carboxylic acid. Generally, polyphenols like tannins, stilbenes, and flavonoids are contained in some wood species, which protects the wood from biodeterioration and is naturally durable (Res, 2021). Polyphenols contain antioxidant and anti-inflammatory properties and have been documented in several studies in reducing cell aging, oxidative stress, and degenerative illnesses of the plant (Mojzer et al., 2016). Tannins are bio-based compounds that are capable of inhibiting wood-decaying fungi. Bioactive compound composition varies depending on the type of wood, its age, part of wood taken, seasons of harvesting, storage condition, and duration. It's critical to pick the suitable solvent to get the most bioactive chemicals out of the plant sample and their extract's yield. Bioactive compounds are found mainly in the leaves of the tree rather than the tree bark since tree bark is not readily obtainable (Adedeji et al., 2017).

Table 2. Plant secondary metabolites and their source examples

Secondary metabolites	Chemical structure	Plant source example	References

Alkaloid		 Gabon Hazel bark	Stone et al. (2021)
Flavonoid		 Tangerine peels	Barbero-López (2020)
Phenol		 Banana peels	Barbero-López (2020)
Chlorogenic acid		 Coffee beans	Martínez et al. (2017)
		 Potato tuber	Sneha et al. (2020)
Tannins		 Neem leaves	Adebawo et al. (2018)

Linalool		 Sour orange leaf	Wood et al. (2019)
D-camphor		 Camphor	Ka et al. (2020)

2.2 Plant extracts as preservatives

Compounds in plant extract include extractives, tannins, propolis, flavonoids, essential oils, organic acids, and alcohol compounds, which are contained in leaves, bark, wood, roots, and fruits. These extracts have shown their anti-fungal, anti-bacterial, and anti-termite properties, and their vast potential as wood and bamboo treatment has been highlighted.

2.3 Cinnamomum camphor (Camphor)

Zhang et al., (2020) revealed that methanol xylem extracts of camphor inhibited *Gleophyllum trabeum* (*G. trabeum*) effectively on their aerobic respiration because the lower level of pressure changes and respiratory were observed for *G. trabeum* in methanol extract treatment. Meanwhile, *Coriolus versicolor* (*C. versicolor*) aerobic respiration was inhibited more by camphor xylem chloroform extracts because of differences in pressure, and the same concentration was applied in both treatments. Both extracts significantly reduced the fungal respiration in wood deterioration. The cellulase activity of *G. trabeum* was strongly inhibited by extracts of camphor xylem ethyl acetate. The cellulose activity is the main functional enzyme that decays wood for *G. trabeum* (Karim et al., 2022).

Karim et al. (2020) reported that *Dendrocalamus asper* (*buluh betong*) treated with camphor and lemongrass extract fixed with 10% melamine urea formaldehyde (MUF) are safe preservatives for bamboo and wood, thus substitutes the usage of CCA and boron which are toxic. Compared to bamboo without skin, bamboo with skin had a lower mold visual rating after being treated with camphor and lemongrass extracts. Nevertheless, more research is needed to validate these findings reported in the literature. The extractives from camphor leaves have potent anti-fungal substances, including D-camphor, α-terpineol, eucalyptol, 4-terpineol, and linalool, which are readily volatilized because of the alcohol content. 10% of MUF fixation of camphor extract improved the resistance to decay, particularly compared to camphor extract alone. When treated with CEMUF (camphor extract + MUF), a decrease in mass loss of 5-6% has been shown due to deterioration by white rot (*P. chrysosporium*) and brown rot (*G. trabeum*). Meanwhile, for both white rotter and brown rotter, bamboo treated with camphor extract, CE showed a significant mass loss of 16.57% and 16.22% respectively (Xu et al., 2013).

2.4 Azadirachta indica (Neem)

At 75 mL and 100 mL concentrations, *Triplchiton scleroxylon* wood treated with neem seed oil gave the wood resistance to *Pleurotus ostreatus (P. ostreatus*) and *Sclerotium rolfsii* (*S.rolfsii*)and the treated wood blocks exposed to *S.rolfsii* (brown rotter) is more virulent compared to the *P. ostreatus* (white rotter) in terms of rate of attack. The resistance towards the wood-degrading fungi is due to the presence of alkaloids, flavonoids, tannins, terpenoids, steroids, and saponins based on the phytochemical analysis done by the author. The findings also revealed that greater oil concentrations contain more phytochemicals, conferred resistance to fungal degradation on the wood blocks. *Azadirachta indica* leaf extract has the highest anti-fungal activity, ranging from 78% to 100%, compared to the other six plant extracts obtained from the Toba Region. The high anti-fungal activity might be attributed to anti-fungal characteristics found in the extract's active components as a phytochemical analysis. Meisyara et al. (2019) revealed that the chemical component in the extract from A. indica leaf that contains flavonoids, saponins, steroids, and tannins was higher when compared to other extracts. A. indica seed oil has shown their ability as bio-based preservatives as they can successfully inhibit the wood deteriorating fungi growth. Methanol extracts of *T. diversifolia, C. odorata, S. bracteosa,* and *A. indica* leaf showed fungi inhibition properties up to 100% against selected wood-deteriorating fungi species, suggesting that it could be investigated further as a wood preservative agent. Termite exposure was used to assess the effectiveness of *Bambusa vulgaris* treated with neem extract for three weeks, and there was no sign that bamboo samples had been degraded or eaten up (Boateng, 2019).

2.5 Gabon Hazel

Stone et al. (2021) revealed the effects of *Coula edulis* (*C. edulis*) bark extracts were shown in growth inhibition studies on white and brown rot fungi, namely *Trametes versicolor (T.versicolor), Pycnoporus sanguineus (P. sanguineus), Rhodonia placenta* and *Coniophora puteana (C. puteana)* with brown roots being more sensitive than white rots in mycelium growth as they grow slower. *C. edulis* bark extracts seem more fungistatic than fungicidal. All extracts were able to completely suppress the growth of *C. puteana* and *R. placenta* (brown rot fungi) at 1000 mg/L, but only partially inhibited the growth of *T. versicolor* and *P. sanguineus* (white rot fungi). All extracts only cause a minor inhibition of fungi growth at 500 mg/L, regardless of the fungi strain examined. The phytochemical screening conducted by the same author also detected polyphenols, alkaloids, saponins, and flavonoids in extraction solvent of acetone, ethanol, and water except in dichloromethane. These group components in the literature were known as promising anti-fungal, antioxidant, termiticidal, anti-microbial, and anti-bacterial (Stone, 2021; Barbero-López, 2020; Martínez et al. 2017; Sneha et al. 2020). The effects of the extracts show a different character towards brown rot and white rot, which might be owing to differences in the processes involved in wood polymer breakdown.

3.0 Coffee beans

A thin covering surrounding the coffee bean is called a silver skin and will be separated from the beans during roasting. The coffee industry considers coffee silver skin as a waste product that is subsequently utilized as fuel or fertilizer. (Bessada et al., 2018). Silver skin extracts were shown to inhibit all of the wood-decaying fungi studied at the highest concentrations, but not to the same degree as the commercial copper-based wood preservatives even though their extracts were rich with chlorogenic acid and phenolic derivatives-which have anti-fungal properties (Barbero-López et al., 2020). Regarding ecotoxicity, coffee silver skin extract content is much lower than that of commercial wood preservatives, which had almost no mass loss. Chlorogenic acid and caffeine have been found to suppress fungi (Zhang et al., 2020 and Xu et al., 2013); thus, this information shall not be disregarded as their derivatives might be useful as wood preservation against wood deteriorating fungi. Martínez et al. (2017) discovered that chlorogenic acids could suppress the growth of mycelial and germination of spores in phytopathogenic fungi at 15 µg/µL. The anti-fungal properties of ground coffee were revealed not only due to the presence of caffeine but also due to the alkaloid's synergistic reactivity and cinnamates found in the residues. The hydroxycinnamates in the coffee samples were mainly chlorogenic acid (caffeoylquinic acids) and ferulic acid derivatives, as well as p-hydroxycinnamic acid and caffeine derivatives. These two chemical groups indicate a cooperative relationship with the microbes and, thus, contribute to the decay resistance. Kwaśniewska-Sip al. (2018) discovered that pine wood vacuum-treated with varying amounts of caffeine can inhibit fungal growth of *C. puteana, Rhodonia (Poria) placenta, G. trabeum,* and *Trametes versicolor*. The concentration of caffeine solution is raised to fivefold (10 mgmL−1) to protect wood against decay fungi successfully. This finding was supported by Šimůnková et al. (2021) where 2% of aqueous caffeine solution enhanced the wood resistance against brown rot fungi.

4.0 Vegetable origin household waste

Barbero-López et al. (2020) studied the potential of household wastes of vegetable origin as wood preservative formulas. Waste hot water extracts include banana, tangerine, watermelon, and onion peels. The natural compounds from the wastes were extracted and tested against wood-decaying fungi to see their anti-fungal properties. Their effects differ substantially based on the fungi species used including *G. trabeum, R. placenta,* and *T.versicolor*. Banana peel extract was the most effective in inhibiting fungi growth among all vegetable household waste studied since it was the only one that induced more than 50% inhibition in all of the selected fungi. Banana peel ash and powder were effective in inhibiting *Aspergillus niger* as it contains phenols, terpenoids, and carbohydrates in aqueous extracts, while the powdered form contains saponins. Fungal resistance might be due to the large quantities of phenolics in banana peels, which are recognized as antimicrobials (Vu et al., 2017). Ferulic acid, cinnamic acid, gallic acid, ellagic acid, rutin, myricetin, and o-coumaric acid were detected using high-performance liquid chromatography (HPLC) to evaluate the flavonoid and phenolic metabolites in banana peel extracts. Wood from chinaberry tree treated with banana peel methanol extracts (Musa paradisiaca) was found to have anti-fungal properties as they inhibit the mycelial growth of *Rhizoctonia solani* up to 68.88% and *Fusarium culmorum* reached 94.07% with an amount of 8.47 mg/100g and also bactericide towards *Agrobacterium tumefaciens* (Said et al., 2019). Contradicting to Saleem and Saeed (2019), when comparing methanol, ethyl acetate, and ethanol as solvents for extracting anti-bacterial fractions from discarded peels, distilled water was shown to be the best choice against the microscopic filamentous fungi, yeasts, and bacteria. The different methods of extract preparation may also contribute to the variation.

Tangerine peel extract was also shown to be an effective inhibitor of wood-decaying fungi, suppressing the growth of *G. trabeum*, and *T. versicolor* by 50% but only 10% for *R. placenta* (Barbero-López et al., 2020). The essential oil of tangerine has potent antioxidant, anti-fungal, and anti-bacterial properties. Tangerine peels contain citric acid, which is a beneficial chemical for protecting wood against deterioration by *R. placenta*. When exposed to tangerine peel extract, this fungal species developed only 10% growth inhibition lower than the control, which might be owing to the reduced concentration of citric acid in the extract or its other elements, such as carbohydrates found in the peels (Apraj & Pandita, 2014).

5.0 Conclusion and Recommendations

Natural extractives have the potential to be used as wood and bamboo preservatives as they have a wide range of anti-fungal, antimicrobial, anti-bacterial, and anti-termite properties. Phenolic and organic acid compounds in plant extract inhibit fungal growth in wood and bamboo. These anti-fungal compounds, including D-camphor, eucalyptol, α-terpineol, linalool, and 4-terineol, are alcohol which is easily volatilized. Therefore, it is critical to solve the volatilization issue by fixing the natural compounds with mineral salts and other potential bridging agents such as silane. The compatibility between the hydrophobic and the hydrophilic nature of those compounds needs to be solved. From 214 pieces of literature, only 23 articles reported the use of plant extract as wood and bamboo treatment substances. Therefore, research is needed to determine plant extract's efficacy and toxicity because toxicity is the main reason plant extract is used for wood and bamboo protection. Screening on extracts from abundantly found plants, including camphor, lemongrass, cinnamon, chili, star anise, neem, and bamboo vinegar, should be done to protect wood and bamboo products against decay and molds by fungi, termites, beetles, and marine bores. Potential extract after screening can be commercialized, but the only limitation is the availability of the resources. The viable and cost-effective treatment method is another critical area to be explored. Furthermore, several modification approaches are needed to enhance the efficacy of biocides against biodeteriorating agents and minimize biocide leaching in outdoor applications. Apart from steel, concrete, and wood as structural building materials, bamboo is also used. Treatment is needed to enhance the durability of bamboo as a structural material. Treatment with plant extract is an alternative green approach instead of the conventional method of using boron and CCA. The efficacy of plant extract extends the life of wood and bamboo products. The extended life of products ensures that carbon is kept longer in those product, where carbon is not emitted. In this way, the circular economy is practiced.

Acknowledgments

The first author would like to thank the University Teknologi MARA for financing her sabbatical research at Forest Research Institute Malaysia (FRIM).

Paper Contribution to Related Field of Study

This review provides possible new research in green treatment as an alternative to toxic preservative treatment in the wood and bamboo industries. Toxic preservatives containing boron and copper chromium arsenic are used in wood-based industries today, and new green treatment is needed and crucial.

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