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EFFICACY OF A COMBINED FUNGICIDE-INSECTICIDE IN ENHANCING THE BIOLOGICAL DURABILITY OF RAJUMAS WOOD (*Duabanga moluccana* Blume): LABORATORY AND FIELD EVALUATIONS

Efikasi Kombinasi Fungisida-Insectisida dalam Meningkatkan Ketahanan Biologis Kayu Rajumas (Duabanga moluccana Blume): Uji Laboratorium dan Uji Lapangan

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ABSTRACT

The decreasing availability of timber from natural forests has led to the use of rapidly growing types of wood as alternative materials in order to satisfy the needs of the wood-based industry. In West Nusa Tenggara Province one such fast-growing species is rajumas wood (*Duabanga moluccana* Blume). Nevertheless, this species has poor natural durability and is therefore vulnerable to attack by wood-decaying fungi and subterranean termites. The present study was carried out with the aim of assessing the effectiveness of wood preservation treatments involving a fungicide, an insecticide and a combined fungicide-insecticide in enhancing the durability of rajumas wood. The wood preservation was performed by means of the cold-soaking method and was then followed by laboratory tests using the wood-decaying fungus *Schizophyllum commune* and field exposure tests. The data were analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at a 95% confidence level. The laboratory results showed that the fungicide treatment provided the highest resistance to fungal attack and was not significantly different from the combined of fungicide-insecticide treatment. In the field test, the combined fungicide-insecticide treatment provided the best protection against subterranean termite attack, although its performance was not significantly different from that of the insecticide treatment. Overall, the combined fungicide-insecticide treatment demonstrated greater potential as an effective wood preservation method because it simultaneously protected the wood against both major groups of wood-destroying organisms, thereby extending the service life of rajumas wood.

Keywords: Biocide; Fungicide; Insecticide; Rajumas Wood; Subterranean Termites; Wood-Decaying Fungi

ABSTRAK

Menurunnya pasokan kayu dari hutan alam mendorong pemanfaatan jenis kayu cepat tumbuh sebagai bahan baku alternatif untuk memenuhi kebutuhan industri hasil hutan. Salah satu jenis kayu cepat tumbuh yang potensial di Provinsi Nusa Tenggara Barat adalah kayu rajumas (*Duabanga moluccana* Blume). Kayu ini memiliki kelas keawetan alami rendah sehingga rentan terhadap serangan jamur pelapuk dan rayap tanah. Penelitian ini bertujuan untuk mengevaluasi efektivitas pengawetan kayu rajumas menggunakan *fungicide, insecticide*, dan kombinasi *fungicide-insecticide* terhadap ketahanan kayu. Pengawetan dilakukan dengan metode perendaman dingin, kemudian ketahanan kayu diuji di laboratorium terhadap jamur pelapuk *Schizophyllum commune* serta uji lapangan. Data dianalisis menggunakan ANOVA dan uji DMRT pada taraf kepercayaan 95%. Hasil penelitian menunjukkan bahwa pada uji laboratorium, perlakuan *fungicide* memberikan ketahanan terbaik terhadap serangan jamur pelapuk dan tidak berbeda nyata dengan perlakuan kombinasi *fungicide-insecticide*. Pada pengujian lapangan, kombinasi *fungicide-insecticide* memberikan perlindungan terbaik terhadap serangan rayap tanah, meskipun tidak berbeda nyata dengan perlakuan *insecticide*. Secara keseluruhan, penggunaan kombinasi *fungicide-insecticide* berpotensi menjadi metode pengawetan yang lebih efektif karena mampu memberikan perlindungan terhadap dua kelompok organisme perusak kayu sekaligus sehingga dapat meningkatkan umur pakai kayu rajumas.

Kata kunci: Biosida; Fungisida; Insektisida; Rajumas; Jamur; Rayap

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A. INTRODUCTION

The demand for wood as a raw material for the forest products and construction industries continues to increase, while the availability of timber from natural forests is becoming increasingly limited (Arets *et al.* 2011). Consequently, alternative raw materials derived from forest plantations and fast-growing tree species are needed to ensure a sustainable wood supply (Brischke *et al.* 2023; Stewart *et al.* 2021). The utilization of fast-growing tree species has become one of the key strategies for supporting the sustainability of the forest products industry due to their high productivity, relatively short rotation period, and potential to reduce harvesting pressure on natural forests (Brischke *et al.* 2023). Rajumas (*Duabanga moluccana* Blume) is a species that is both fast-growing and promising and which occurs naturally in various parts of Indonesia, where it has for a long time been used by local communities for light construction, for making simple furniture and for a variety of household purposes (Martawijaya *et al.* 1989).

The relatively rapid growth rate and favorable physical characteristics of rajumas indicate its potential as an alternative raw material to meet the increasing demand of the forest products industry while reducing dependence on timber harvested from natural forests (Martawijaya *et al.* 1989; Anggoro *et al.* 2024). Nevertheless, the utilization of rajumas wood remains limited because information regarding its fundamental properties, natural durability, and wood quality improvement technologies is still scarce compared with that available for other commercially important timber species (Lestari 2020). Wood with low natural durability is generally more susceptible to deterioration caused by wood-decaying fungi and termites because it contains lower concentrations of protective extractive compounds than naturally durable wood species (Wibisono *et al*. 2018; Krisdianto *et al.* 2015; Herliyana *et al.* 2011). Wood-decaying fungi are capable of degrading the structural components of the wood cell wall through enzymatic activities, resulting in weight loss, structural deterioration, and a reduction in the mechanical properties of wood (Batista *et al.* 2022; Herliyana *et al.* 2011).

One of the wood-decaying fungi widely used as a standard test organism for evaluating wood durability in Indonesia is *Schizophyllum commune*, owing to its ability to degrade lignin, cellulose, and hemicellulose, as well as its capability to attack a wide range of tropical wood species (Herliyana *et al.* 2011). In addition to fungal decay, subterranean termites are among the most destructive biological agents affecting wood products, particularly in tropical regions characterized by high temperature and humidity. These pests destroy the wood biological structure and significantly reduce its service life (Brischke *et al.* 2023; Muslich & Rulliaty 2011). Attack by termites results in the formation of large hollows in the attacked wood, causing a reduction in wood density and quality, and therefore its useful properties (Brischke *et al.* 2023). One of the most effective ways to improve the biological durability of wood is its preservation with biocides (Lebow 2010).

Wood preservatives commonly contain fungicides, insecticides, or a combination of both, depending on the biological agents that threaten the wood during service (Kirker & Lebow 2021; Martín & López 2023). Fungicides are used to control wood-decaying fungi, whereas insecticides target wood-damaging insects, including termites (Khademibami & Bobadilha 2022). The use of these biocides is important because fungal decay and termite attack can reduce wood mass, structural integrity, and service life (Woźniak 2022; Suprapti *et al*. 2021). Combining a fungicide and an insecticide may provide broader protection against these two types of biological deterioration; however, its effectiveness needs to be evaluated because the performance of each active ingredient may vary according to the target organism.

The wood preservation process is influenced by many factors, among which the most important is the ability of wood to absorb and retain biocides in its volume, which is expressed in indicators such as absorption, retention, and penetration (Ayanleye *et al.* 2023; Brischke *et al.* 2023). High values of this indicator and uniform distribution of the biocide throughout the volume of the sample ensures the high protective performance of the wood preservation treatment, since the active ingredient penetrates deep into the cells where it is needed to protect the wood from pest attacks (Rajput *et al.* 2023; Brischke *et al.* 2023). Preservation of wood using the cold soaking method is one of the simplest and most accessible methods, but at the same time, it is effective in terms of retaining biocides in the wood volume of various types of rapidly growing trees (Anhar *et al.* 2024; Anggoro *et al.* 2024). The study of rajumas wood properties has mainly focused on its wettability properties (Lestari 2020; Dewi et al. 2023), coating adhesion (Umitasari et al. 2023), and preservation using the cold-soaking method (Anggoro *et al.* 2024). However, there is a lack of research on the study of the influence of different wood preservation methods on the biological durability of this wood species against fungi and termite attacks. Thus, the relevance of this research is justified.

To date, no study has comprehensively evaluated the effectiveness of combined fungicide-insecticide in enhancing the biological durability of rajumas wood through both laboratory decay tests using wood-decaying fungi and field exposure tests against subterranean termites. Such an approach is important because wood products under service conditions are commonly exposed to simultaneous or sequential attacks by multiple biodeteriorating organisms throughout their service life. Therefore, this study aimed to evaluate the effectiveness of fungicide, insecticide, and their combined biocide treatment in improving the biological durability of rajumas (*Duabanga moluccana* Blume) wood against *Schizophyllum commune* and subterranean termites through laboratory and field evaluations.

B. METHODS

Materials and Equipment

The primary material used in this study was rajumas wood (*Duabanga moluccana* Blume). The preservatives consisted of a commercial insecticide (BioCide Insecticide) and a commercial wood fungicide (BioCide Wood Fungicide), both supplied by Bioindustries, Indonesia. The insecticide contained permethrin as its active ingredient, with the product concentration expressed in g/L. The wood fungicide contained 2-(thiocyanomethylthio)benzothiazole at 10% (w/w), with the product concentration expressed as a mass fraction. Both products were diluted with water at a ratio of 1:100 and applied individually or in combination to the wood specimens. Their effectiveness was evaluated through laboratory decay resistance tests and field exposure tests against subterranean termites.

The equipment used included a table circular saw, sandpapers (grit sizes #100, #150, and #400), an analytical balance, an oven, a digital caliper, a moisture meter, a vernier caliper, permanent markers, soaking containers, a mechanical stirrer, beakers, Petri dishes, test bottles, a desiccator, an autoclave, an incubator, a laminar airflow cabinet, culture bottles, standard laboratory glassware, and other supporting laboratory equipment.

Sample Preparation

Test specimens were prepared from defect-free sapwood of rajumas. The wood samples were cut according to the dimensions specified for each testing method. All specimens were air-dried to reach equilibrium moisture content before being subjected to preservative treatment.

Preservative Treatment

Wood preservation was carried out using the cold-soaking method for 36 h, which was identified as the optimum soaking duration based on the study conducted by Anggoro *et al.* (2024). The specimen was divided into four treatment groups, which were as follows: untreated control (A), fungicide treatment (B), insecticide treatment (C), and a combined fungicide-insecticide treatment (D). After soaking, all specimens were air-dried under ambient conditions until reaching a stable moisture condition before the biological durability test.

Laboratory Decay Resistance Test

The decay resistance test was performed according to the Indonesian National Standard (SNI 01-7207-2006) using white-rot fungi Schizophyllum commune. Potato Dextrose Agar (PDA) was applied as a culture medium for growing fungus. The fungal isolate was incubated at 30 ± 2°C for 10 days until the whole surface of the PDA medium is fully colonized by the fungus.

A total of 20 wooden specimens with a dimension of 5 × 2.5 × 1.5 cm were prepared and randomly divided into four treatment groups, each of which consisted of 5 replicates, namely, untreated control, fungicide insecticide, and combined of fungicide-insecticide treatment. Prior to fungal exposure, all specimens were oven-dried at 103 ± 2°C to constant weight. The specimens were then placed individually in culture bottles containing PDA medium previously colonized by *S. commune* and tightly sealed to prevent contamination by other fungal species (Figure 1).



Figure 1. Laboratory decay resistance test using *Schizophyllum commune*

After a 12-week incubation period, the specimens were removed from the culture bottles, cleaned to remove adhering mycelia, and oven-dried again at 103 ± 2°C until constant weight was achieved. Decay resistance was evaluated based on the percentage of weight loss, calculated using the following equation:

$$WL = [(W1-W2)/ W1] \times 100$$

where WL is the percentage of weight loss (%), W1 the dry weight of the specimen before fungal exposure (g), and W2 is the dry weight of the specimen after fungal exposure (g)

The decay resistance of rajumas wood was subsequently classified into five durability classes according to SNI 01-7207-2006, as presented in Table 1.

Table 1. Durability classification of wood based on laboratory decay resistance

Durability class	Durability rating	Weight loss (%)
I	Very resistant	0
II	Resistant	1-5
III	Moderately resistant	5-10
IV	Non-resistant	10-30
V	Highly non-resistant	> 30

Field Test Against Subterranean Termites

The field test against subterranean termites was conducted using wood specimens measuring 45 × 2 × 2 cm. A total of 20 specimens were prepared, consisting of five specimens treated with a fungicide, five treated with a insecticide, five treated with a combined of fungicide-insecticide formulation, and five untreated control specimens. All specimens were labelled and conditioned under ambient laboratory conditions (29 ± 1.2°C and 85 ± 2.2% relative humidity) for 10 days. The specimens were subsequently oven-dried at 60 ± 1.5°C until they reached a moisture content of 12 ± 2%, after which the initial oven-dry weight (W_0) of each specimen was recorded. Each specimen was vertically buried to a depth of 30 cm in the soil using a randomized arrangement with a spacing of approximately 30 cm between specimens (Figure 2a). The field exposure test was conducted for 12 weeks under natural conditions to allow infestation by subterranean termites (Figure 2b).



(a) (b)

Figure 2. Field exposure test: (a) installation of wood specimens at the test site; (b) wood specimens after 12 weeks of field exposure

Following the field exposure period, the specimens were air-dried under sunlight and subsequently oven-dried at 60 ± 1.2°C until a constant weight was achieved. The specimens were then weighed to obtain the final weight (W_1). The resistance of rajumas wood to subterranean termite attack was evaluated using the field test method in accordance with ASTM D1758-06 (ASTM International 2007). The biological durability class of each treatment was determined based on the percentage weight loss and the corresponding classification criteria presented in Table 2.

The percentage of weight loss was calculated using the following equation:

$$P = [(B0 - Bt) / B0] \times 100$$

where P is the percentage of weight loss (%), B0 is the initial weight of the specimen (g), and Bt is the final weight of the specimen after field exposure (g).

For data interpretation, wood durability against subterranean termite attack was classified according to the weight-loss criteria adopted from ASTM D1758-06 (ASTM International 2007), as presented in Table 2.

Table 2. Durability classification of wood against subterranean termite attack based on weight loss

Class	Durability	Weight loss (%)
I	Very resistant	0-5
II	Resistant	6-15
III	Moderately resistant	16-30
IV	Non-resistant	31-50
V	Highly non-resistant	> 50

Data Analysis

The experiment was arranged in a completely randomized design (CRD) consisting of four preservative treatments. The experimental data were subjected to analysis of variance (ANOVA) to determine the effects of preservative treatments. When significant differences among treatments were detected, mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at a 95% confidence level. All statistical analyses were conducted using IBM SPSS Statistics version 25.

C. RESULTS AND DISCUSSION

Decay Resistance of Rajumas Wood Against Wood-Decaying Fungi

The decay resistance of rajumas wood was evaluated based on the percentage of weight loss after inoculation with *Schizophyllum commune*, as presented in Table 3, while the ANOVA results are shown in Table 4. Weight loss is the primary indicator of the degradation of wood cell wall components caused by the lignocellulolytic enzymatic activity of fungi. Lower weight loss values indicate higher resistance of wood to fungal decay attack (Goodell *et al.* 2020; Herliyana *et al.* 2011).

Table 3. Weight loss of rajumas wood after laboratory decay test (DMRT 5%)

Treatment	Weight before (g)	Weight after (g)	Weight loss (%)
C	5.24	4.32	17.55^{b}
F	5.44	5.16	5.11^{a}
I	5.40	4.46	17.45^{b}
FI	6.52	6.17	5.36^{a}

Notes: Means followed by different superscript letters indicate significant differences according to Duncan's Multiple Range Test (DMRT) at α = 0.05; C = control; F = fungicide; I = insecticide; FI = combined fungicide–insecticide treatment.

Table 4. ANOVA of weight loss after laboratory decay test

Source of variation	df	SS	MS	F value	Sig.
Treatment	3	652.79	217.60	9.37	0.005
Error	8	185.77	23.22		
Total	11	838.56			

According to the durability classification of SNI 01-7207-2006, untreated rajumas wood (C) exhibited a weight loss of 17.55%, indicating Class IV (non-resistant) against *S. commune*. The insecticide treatment (I) resulted in a similar weight loss of 17.45% and was also classified as Class IV (non-resistant), demonstrating that the insecticide treatment was ineffective in improving resistance against fungal decay.

In contrast, the fungicide treatment (F) produced a weight loss of 5.11%, while the combined fungicide-insecticide treatment (FI) resulted in a weight loss of 5.36%. Both treatments were classified as Class II (resistant). The improvement from Class IV in the untreated wood to Class II after fungicide application suggests that the fungicide treatment, either alone or in combination with an insecticide, greatly improved the biological durability of the wood against fungal attack.

The ANOVA results demonstrated that preservative treatment had a highly significant impact on the percentage of weight loss following exposure to *S. commune* ($F = 9.37$; $p = 0.005$). These results indicate that the preservative treatments

had a significant effect on the decay resistance of the wood. The DMRT grouping also displayed that the fungicide treatment and the combined fungicide–insecticide treatment were not significantly different from each other, but differed significantly from the control treatment and the insecticide treatment.

This means that the fungicide was the most effective preservative in preventing the growth of *S. commune*. Fungicides suppress mycelial development and lignocellulolytic enzyme activity, thereby reducing the degradation of lignin, cellulose, and hemicellulose (Broda 2020). On the other hand, the addition of insecticide to the combined treatment did not increase the efficiency of treating against fungal decay, but it also did not interfere with the ability of the fungicide to protect the wood. In contrast, the treatment with insecticide failed to provide protection against fungal decay as its mode of action is to control insects and not fungi (Goodell *et al.* 2020).

The low weight loss recorded for the fungicide-treated specimen was also explained by the preservative retention and penetration properties of rajumas wood. Anggoro *et al.* (2024) reported that rajumas wood species recorded better preservative retention and penetration values. Broda (2020) stated that the effectiveness of preservatives against fungal decay mainly depends on the level of active ingredients retained and penetrated into the wood.

Resistance of Rajumas Wood Against Subterranean Termites

The field exposure experiment was conducted to determine resistance of the test specimens against subterranean termites attack for a period of twelve weeks. The results of the percentages weight losses for samples exposed to subterranean termites are presented in Table 5. Similarly, the analysis of variance (ANOVA) results are given in Table 6. The weight loss of the samples was taken as an indication of wood consumption by subterranean termites and thus a measure of the biological durability of the treated wood.

Table 5. Weight loss of rajumas wood after field exposure to subterranean termites (DMRT 5%)

Treatment	Weight before (g)	Weight after (g)	Weight loss (%)
C	72.60	39.77	45.22^{c}
F	71.47	55.55	22.28^{b}
I	70.74	59.02	16.57^{a}
FI	65.79	55.14	16.19^{a}

Means followed by different superscript letters are significantly different according to Duncan's Multiple Range Test (DMRT) at α = 0.05.; *C = untreated control; F = fungicide; I = insecticide; FI = combined fungicide–insecticide treatment.*

Tabel 6. ANOVA for weight loss of rajumas wood after the field exposure test

Source of variation	df	SS	MS	F value	Sig.
Treatment	3	1648.97	549.66	2.73	0.078
Error	16	3221.43	201.34		
Total	19	4870.40			

The field exposure test showed that the preservative treatment affected the resistance of the rajumas wood to subterranean termite attack. Untreated specimens (C) had the highest value of weight loss (45.22%), thereby, rajumas wood has a low natural resistance to subterranean termites. Such weight loss suggests that the wood underwent excessive feeding by termites, which caused the drastic decrease in its weight coupled with the damage of its integrity. This implies that untreated wood is not suitable in areas with a high risk of termite attack unless it is treated using appropriate preservatives (Muslich & Rulliaty 2011).

Based on the durability classification adopted from ASTM D1758-06 (ASTM International 2007), the untreated wood was classified as Class IV (severe deterioration). The samples treated with a fungicide (F) were associated with 22.28% weight loss (Class III: moderate deterioration). However, the lowest weight loss values (16.57% and 16.19%) were recorded for the insecticide treatment (I) and the combination treatment (FI), respectively. Both were assigned to Class III (moderate deterioration). Nevertheless, treatment with either insecticide or combination conferred better protection against termite attack than the untreated one. All the preservative treatments decreased the weight loss values as compared to the control.

Generally, the lowest weight loss was recorded in FI and I treatments; they were not significantly different from each other based on the Duncan's Multiple Range Test. In contrast, the F treatment resulted in a significantly higher weight loss compared to the treatments containing an insecticide. This implies that treatment with a fungicide provides limited protection against subterranean termites. This may be because the fungicides do not kill or impact the insect physiology

in any way. However, insecticides inhibit the central nervous system of the termites, thereby, reducing feeding activity and increasing colony mortality (Hassan *et al.* 2019).

Even though Analysis of Variance (ANOVA) showed that the preservative treatment did not significantly affect the weight loss at 5% probability level ($p = 0.078$), the combined treatment resulted in the lowest weight loss among all the treatments and was not significantly different from the insecticide treatment. It appears that the presence of an active ingredient (insecticide) was the main reason for the resistance against subterranean termites, while the addition of a fungicide to an insecticide did not reduce or enhance the protection.

In spite of the non-significant difference between the combining insecticide and the combined treatment, the former has an added advantage of being effective against decay fungi. This is evident from the result of the laboratory decay test. Therefore, using a single preservative formulation to protect the wood from both the attack of subterranean termites and decay fungi can be considered for application in the outside environments and in the humid service classes (Broda 2020).

In general, the results of this study indicate that the effectiveness of the wood preservation treatment heavily relies on the compatibility between the active ingredients and the target organisms. The fungicide treatment was the most appropriate for the resistance to decay fungi. In contrast, insecticide-containing treatments offered better resistance to subterranean termites than the treatment with a fungicide alone. The combination treatment was effective against both subterranean termites and decay fungi. This study will facilitate the development of integrated treatment technologies to prolong the service life of fast-growing wood species to increase its utilization potential instead of relying on the harvest from the natural forests (Brischke *et al.* 2023).

D. CONLUSION

Biocide preservative treatment effectively improved the biological durability of rajumas (*Duabanga moluccana* Blume) wood against both wood-decaying fungi and subterranean termites. Under laboratory conditions, the fungicide treatment provided the greatest resistance to fungal decay and did not differ significantly from the combined fungicide-insecticide treatment. In the field exposure test, the combined fungicide-insecticide treatment exhibited the best performance against subterranean termite attack, although its effectiveness was statistically comparable to that of the insecticide treatment alone. Overall, the combined preservative treatment provides broader biological protection than single-component treatments and therefore represents a promising preservation strategy for extending the service life and enhancing the utilization potential of rajumas wood as an alternative fast-growing timber resource.

AUTHOR'S DECLARATION

The authors declare there is no conflict of interest for this article. We hereby confirm that all the Figures and Tables in the manuscript are ours. There is no animal studies, no human studies, and no potentially identified images or data are present in the manuscript.

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