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Exploring Local Plant-Based Antimicrobials for Conservation of Art and Cultural Objects in Indonesia: A Review

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Abstract

Indonesia possesses a rich collection of art and cultural objects made from both organic and inorganic materials, which are highly susceptible to biodeterioration, particularly in the warm and humid tropical climate. Microorganisms are one of the primary causes of deterioration, leading to structural degradation, aesthetic changes, and the loss of historical and cultural value. Therefore, effective conservation strategies are needed to control the growth of microorganisms in conservation. This study examines various local plants used in traditional conservation in Indonesia, analyzing their bioactive compounds, effectiveness, and antimicrobial activity through a literature review. This study reviews various local plants used in traditional conservation in Indonesia by integrating ethnobotanical and microbiological conservation data from scientific literature. The analysis focuses on identifying bioactive compounds, reported antimicrobial activity, and their relevance to cultural material conservation. Findings indicate that Indonesian plants such as lemongrass, tobacco, clove, and nutmeg contain bioactive compounds with proven antimicrobial properties against microorganisms such as eugenol, alkaloids, citral, geraniol, monoterpenes and flavonoids. Although traditional conservation practices have been applied for a long time and have shown effectiveness, some of these practices lack scientific validation and require further research. Plant-based materials also generally have lower efficacy than synthetic chemicals, necessitating enhancement strategies such as nanoparticle technology. Further studies are essential to identify the mechanisms of active compounds in inhibiting microbial growth on cultural heritage objects, their long-term effectiveness, and their impact on various types of cultural materials. This study highlights the potential of local plants as antimicrobial agents in conservation of art and cultural objects. Further research is needed to optimize their application in modern conservation practices.

Keywords: *antimicrobial agents, biodeterioration, art and cultural objects, traditional conservation*

1. Introduction

Indonesia is home to a vast and diverse collection of tangible art and cultural objects, including keris, shadow puppets, masks, paintings, statues, temples, and ancient manuscripts. These objects are crafted from a wide range of materials, including organic materials such as wood, bamboo, palm fruit leaves, paper, textiles, and leather, as well as inorganic materials such as stone and metal. They serve as invaluable sources of historical insight, reflecting the remarkable advancements of past civilizations and underscoring the need for their preservation.

Over time, the materials composing these objects undergo interactions with environmental factors, including physical, chemical, and biological influences, that trigger structural and compositional changes [1–5]. Previous studies have shown that such interactions can lead to material deterioration. For example, corrosion influenced by humidity or salt accumulation may cause the development of colored patinas on silver and bronze, as well as sweating, weeping, and blistering on iron [6–8]. Other inorganic materials, including stone and cement, are likewise vulnerable to deterioration under the influence of moisture, temperature, pH, sunlight, and pollutants, leading to forms of damage such as cracking, delamination, mineral

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dissolution, and salt deposition [6,9–13]. Organic materials, including wood, paper, textiles, and leather, are similarly susceptible to biodeterioration caused by microorganisms and insects, as well as to physical and chemical degradation driven by fluctuations in humidity, temperature, and light exposure, which can result in holes, stains, discoloration, warping, and embrittlement [3,10]. Among these factors, biological activity plays a significant role as it is closely interconnected with both physical and chemical processes, particularly microbial activity. It not only causes direct mechanical damage and discoloration but also produce acids and enzymes that alter the material's chemistry, leading to further degradation, often by exploiting or accelerating damage initiated by physical or chemical processes [3,10,12].

Microbial activity, including that of fungi, bacteria, algae, and lichens, poses a significant threat to the preservation of artistic and cultural heritage, particularly in tropical regions where warm and humid conditions provide an ideal environment for their growth [3,10]. Common fungi such as *Cladosporium, Penicillium, Trichoderma, Fusarium,* and *Phoma* damage inorganic materials through discoloration, dark spots, and mineral dissolutions [3,10,12–16], while others like *Aspergillus, Alternaria, Penicillium,* and *Chaetomium* degrade cellulose, collagen, and starch, often alongside bacteria such as *Bacillus, Pseudomonas, Streptomyces,* and *Cytophaga* [3,10]. Sulphur-oxidizing *Thiobacillus*, nitrifying *Nitrosomonas*, and heterotrophic *Flavobacterium* and *Pseudomonas* corrode and stain surfaces, while actinobacteria such as *Streptomyces* can precipitate calcium carbonate and alter surface colour [3,10]. Cyanobacteria and microalgae often act as primary colonizers, forming dark or colored patinas, such as those produced by *Micrococcus roseus*, which retain moisture and increase stress from temperature changes [3]. Lichens, such as *Protoblastenia, Verrucaria, Caloplaca, Aspicilia, Lecanora,* and *Xanthoria*, are highly aggressive on outdoor stone heritage, causing discoloration and weathering [7,8,10,11].

By colonizing a wide range of substrates and thriving under fluctuating environmental conditions, these organisms can both initiate and accelerate deterioration, often in synergy with other damaging factors. This capacity makes microorganisms one of the most influential agents in the long-term degradation of cultural heritage materials and a critical focus in conservation research.

Given the significant threat posed by microorganisms to cultural heritage materials, efforts to conserve and protect art and cultural objects have been practiced in Indonesia for centuries. Traditional conservation knowledge has long played a crucial role in safeguarding art and cultural objects, with local communities utilizing plant-based materials for protection against biodeterioration. Various natural substances have been employed for generations to safeguard these objects from microbial and insect-induced damage. For example, Javanese communities have used clove and tobacco extracts to clean and protect wooden structures from biological deterioration. Additionally, they have traditionally used larasetu (vetiver roots) to protect textiles from fungal infestations and insect attacks [12].

In modern conservation, synthetic chemicals such as fungicides are commonly used to control microbial growth on cultural objects. While these chemical treatments may provide immediate efficacy, they also pose long-term risks, including environmental contamination due to persistent chemical residues. Moreover, prolonged exposure to these substances may pose health hazards, particularly for conservators who handle them frequently [12]. Some studies have also indicated that the use of certain fungicides can lead to microbial resistance, creating new challenges in conservation.

Recognizing the threats posed by microbial deterioration in the preservation of cultural objects in tropical regions and the negative impact of synthetic chemicals, there is a growing need for alternative conservation approaches that are environmentally friendly, sustainable, and rooted in local wisdom. Although traditional conservation practices remain widely recognized and have demonstrated effectiveness, further scientific validation is needed to establish them as an indigenous Indonesian conservation technology based on research and empirical evidence. Therefore, this study aims to examine various local plants used in traditional conservation in Indonesia, analyze their bioactive compounds, effectiveness, and antimicrobial activity based on a literature review.

2. Methodology

This study employs a literature review approach to examine the antimicrobial potential of local plants in the conservation of cultural objects in Indonesia, integrating data from both ethnobotanical and microbiological perspectives. This method was chosen to identify and analyze previous research relevant to this topic systematically.

The literature utilized in this study consists of books and scholarly articles from journals and other relevant publications addressing the application of plant-based materials in heritage conservation and the antimicrobial properties of local plant species. Both printed and digital sources published from the early 21st century to the present (2001–2025) were reviewed. Digital searches for e-books, journal articles, and other scientific publications were conducted using platforms such as Google Scholar, ResearchGate, ScienceDirect, and SINTA (Science and Technology Index). Keywords used in the search process included "biocide," "essential oil," "preservation," "conservation," "cultural heritage," "biodeterioration," "biodeteriogen," "deterioration," and "conservation materials"—in both Indonesian and English, applied individually or in combination.

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3. Result and Discussion

3.1 Microorganisms as Biodeterioration Agents of Arti and Cultural Objects

One of the major biological factors contributing to the deterioration of cultural objects is microbial activity [3]. They can exploit heritage materials as nutrient sources, shelters, or habitats. Microbial-induced deterioration includes bioweathering of stones and minerals, biodeterioration of organic materials, and biocorrosion of metals. In general, deterioration caused by microorganisms (and other organisms) in both organic and inorganic materials is commonly referred to as biodeterioration. This damage can lead to irreversible changes and the loss of invaluable heritage value.

In the biodeterioration of inorganic materials, microorganisms involved include autotrophic and heterotrophic bacteria, fungi, algae, and lichens. Microbial deterioration of inorganic materials can be classified into physical, chemical, and aesthetic deterioration [3,10]. Physical deterioration occurs when microbial growth alters the structural integrity of the material. Chemical deterioration results from the release of microbial metabolites or other substances, such as acids, which degrade materials by increasing porosity, weakening the mineral matrix, dissolving minerals, forming biominerals, and inducing biocorrosion in metals and alloys. Aesthetic deterioration manifests as colored stains, patinas, and crust formations due to biofouling, the accumulation and proliferation of microorganisms on material surfaces, especially in humid environments.

Examples of microbial damage to inorganic materials include the formation of white or yellowish-white crusts caused by fungi from the genera *Paecilomyces, Cladosporium, Penicillium, Aspergillus,* and *Mucor* on the stone surfaces of Borobudur Temple and Pawon Temple [14,15]. Additionally, black biofilms and dark stains resulting from the growth of *Aspergillus, Penicillium,* and *Scopulariopsis* fungi have been reported on the stone surfaces of Mendut Temple [13]. Further microbial-induced deterioration includes stone exfoliation, pustule formation, and alveolarization, involving fungi such as *Penicillium, Paecilomyces, Mucor, Stachybotrys, Aspergillus,* and *Cladosporium* on Pawon Temple [15]. Additionally, fungal growth has been found on the oil layer of iron-based keris that have not undergone regular maintenance [17].

Biodeterioration of organic materials is primarily caused by heterotrophic microorganisms, particularly fungi [3]. Common organic materials used in the production of art and cultural objects in Indonesia include wood, bamboo, lontar leaves, dluwang, paper, textiles, and animal leather. These plant-based materials provide an excellent substrate for heterotrophic organisms such as fungi, bacteria, and Actinomycetes. The main components of these materials are cellulose, lignin, and hemicellulose [10]. Microorganisms produce extracellular enzymes capable of degrading cellulose and hemicellulose, leading to material deterioration. Additionally, plant-based materials contain simple sugars, starch, tannins, resins, and rubber, which influence microbial activity. Simple sugars and starch accelerate biodeterioration, while tannins and resins slow down microbial degradation.

Deterioration in plant-derived materials includes soft rot and staining [10]. Soft rot occurs where fungal growth in humid environments and contact with soil causes the material to soften and crack upon drying. Staining results from microbial pigment production, typically by fungi, or from the presence of dark-colored fungal hyphae. Common fungi responsible for the biodeterioration of artistic and cultural heritage objects include *Aspergillus, Aureobasidium, Fusarium, Penicillium,* and *Trichoderma*. Examples of microbial damage to plant-based materials include lichen growth, which causes white spots on the Majapahit Gate in Pati [18], as well as discoloration and fungal stains on lontar manuscript collections at Royal Surakarta [19].

Certain cultural heritage objects are also made from animal-derived materials, such as parchment, shadow puppets, wool, and silk textiles [10]. The primary component of these materials is protein. Microorganisms utilize proteins as an organic nitrogen source through the action of proteolytic enzymes, such as proteases and peptidases. Microbial degradation of protein-based materials can result in the loss of original material properties, making them brittle and rigid; deformation, which leads to physical distortion of the object; staining caused by microbial pigments or metabolic byproducts; and fading of inscriptions, such as those on parchment manuscripts. An example of microbial deterioration in animal-based heritage objects is fungal growth on shadow puppets in the Jakarta Puppet Museum [20].

Microbial deterioration progresses more rapidly when environmental conditions are favorable, such as high moisture availability, optimal pH levels, suitable climate conditions, nutrient availability, and material properties that support microbial colonization [3]. The extent of microbial deterioration varies depending on climatic conditions and exposure factors [21]. Therefore, each type of damage requires a specific analytical approach and appropriate mitigation strategies tailored to environmental conditions and material characteristics.

3.2 Plant-Based Traditional Conservation Practices

The significant risk of damage to art and cultural objects, such as keris, shadow puppets, masks, paintings, statues, temples, and ancient manuscripts, particularly due to microorganisms, necessitates conservation efforts to preserve these objects. According to the Indonesian Dictionary (KBBI), conservation refers to the systematic maintenance and protection of objects to prevent damage and destruction through preservation and safeguarding. In the context of preserving art and cultural objects, conservation involves a

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series of efforts aimed at ensuring their longevity [22].

Traditional conservation practices in Indonesia have been carried out for generations using simple materials and tools based on local wisdom and inherited knowledge. These practices have been studied through observations, interviews with cultural practitioners, and the analysis of ancient manuscripts containing traditional conservation knowledge [6,23]. Modern conservation based on direct observations and interviews has provided researchers with insights into the techniques, materials, and philosophies behind these traditional conservation methods. Typically, natural preservatives or cleaning agents are used to protect materials from deterioration and microbial damage [18]. One of the most commonly utilized natural materials in traditional conservation is locally available plants.

The use of plants in conservation can be seen in the "jamasan keris" tradition, a traditional method of maintaining keris. Keris is Indonesian daggers primarily made of iron, often with high cultural, historical, and spiritual significance. Keris are found in various regions, including Central Java, East Java, West Java, Madura, Bali, Sumatra, Sulawesi, and Kalimantan. The jamasan process consists of preparation, cleaning, acid treatment (mewarangi), and oiling. During the cleaning stage, various local plants are used, such as pace (noni fruit), lerak (soapberry), lime, sandalwood and teak wood powder, bilimbi, coconut water, and other materials like

Table 1. Traditional Conservation Practices for Inorganic Art and Cultural Objects

Objects	Conservant	Region of Use	Traditional Usage Steps	Reference
Keris	Coconut water	Java	Coconut water is used to soak the keris blade to issolve dirt and rust	[17]
	Palm sap	Java	Palm sap is used to soak the keris blade to dissolve dirt and rust.	[17]
	Pace fruit	Java	Pace fruit is crushed and mixed with coconut water to soak heavily rusted keris.	[17]
	Pineapple	Java	Pineapple is blended or grated and the juice is used to soak the rusted keris.	[17]
	Lime	Java	Lime is cut and rubbed on the surface of the keris blade.	[17]
	Soapberry (Lerak)	Java	Dried soapberry is boiled until soft or soaked and mashed in water. The solution is used to wash the keris.	[17]
	Rice bran	Java	Rice bran is rubbed on the keris blade.	[17]
	Teak sawdust	Java	Teak sawdust is rubbed on the keris blade.	[17]

Table 2. Traditional Conservation Practices for Organic Art and Cultural Objects

No	Objects	Conservant	Region of Use	Traditional Usage Steps	Reference
1	Palm leaf manuscript	Clove oil, roasted candlenut powder	Surakarta	A mixture of lemongrass oil and roasted candlenut powder is applied to the manuscript surface.	[19]
2	Traditional wooden house	Tobacco leaves, clove flowers, banana fronds	Kudus, Central Java	The mixture is soaked in water overnight and rubbed on the wood using a cloth or banana frond.	[1]
3	Batik and other textiles	Vetiver root and incense	Java	Dried vetiver root is placed in the wardrobe to repel mold and insects.	[14]
		Soapberry (Lerak)	Java	Dried soapberry is soaked in hot water, mashed, and left for 24 hours before straining. The solution is used to wash textiles.	[26]

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rice husk or husk ash [17].

Another example of traditional conservation is found in Sukawana Village, Bali, where the Sukawana D Inscription, a copper artifact from 1222, attributed to King Patih Kebo Parud, is cleaned using *Citrus aurantifolia* (key lime). The lime is rubbed onto the surface and then wiped with gauze to remove dirt and oxidation [24].

Traditional conservation is also widely applied to organic-based objects. In Kudus, Central Java, locals use clove, tobacco, and banana sheath extract to clean and protect traditional wooden houses from biological damage. The liquid is rubbed onto the wood using banana sheaths or cloth [1]. Additionally, Javanese communities use larasetu (vetiver roots) and incense to protect textiles from insect and fungal attacks [12].

Apart from oral traditions, traditional conservation knowledge is also documented in ancient manuscripts [23]. For instance, in Sidemen, Karangasem, Bali, an ancient lontar manuscript records the use of candlenut to enhance script clarity and preserve palm leaf manuscripts after writing. This manuscript has been passed down through generations within a local family. Summaries of various traditional conservation practices carried out by communities are presented in Tables 1 and 2.

3.3 Antimicrobial Activity of Local Plants in Indonesia

Although traditional conservation practices remain effective and widely recognized, further scientific support is needed to validate their efficacy and understand how active compounds in these plants function in the conservation of artworks and cultural heritage. Specifically, their role in inhibiting the growth of microorganisms that cause deterioration needs deeper exploration. A detailed study of the mechanisms of these active compounds could provide new insights into developing more eco-friendly and sustainable conservation methods. Additionally, scientific research can help identify potential interactions between active compounds and different cultural materials, ensuring their appropriate and targeted application. Through this approach, traditional conservation is not only preserved as cultural knowledge but also enhanced through systematic scientific studies.

Between 2009 and 2010, Borobudur Conservation Center conducted scientific validation of the jamasan keris practice through laboratory experiments and analysis, evaluating the effectiveness of natural materials in removing rust from keris blades [17]. The natural substances tested included coconut water, palm sap, noni fruit, tamarind, pineapple, and lime.

Ira Fatmawati from the Cultural Heritage Preservation Office of East Java conducted a series of experiments to test the effectiveness of lerak fruit and maja fruit in cleaning dirt and rust from metal collections at the Majapahit Museum in Trowulan, Mojokerto [25,26]. Her findings showed that lerak solution effectively removed tarnish from silver and bronze and partially cleaned rust from iron. Meanwhile, maja fruit was proven effective in reducing iron corrosion. However, antimicrobial testing of these fruits on cultural objects has not yet been conducted.

Riyanto from the Islamic University of Indonesia, in collaboration with the Borobudur Conservation Center, successfully tested the antifungal properties of lemongrass essential oil, as well as clove and nutmeg [8,11,27,28]. The study revealed that the essential oils from these three plants effectively inhibited fungal growth isolated from lichens found on Borobudur Temple stones. To enhance antifungal efficacy, the research team formulated the essential oils into nanoparticles by mixing silver nanoparticle powder ($AgNO_3$) with the essential oils. The results indicated that nanoparticle-formulated essential oils exhibited higher effectiveness in inhibiting fungal growth compared to direct application of the oils.

A summary of scientific findings validating the antimicrobial effectiveness of various plants on inorganic cultural objects is presented in Table 3.

Scientific testing has also been conducted to verify the effectiveness and antimicrobial activity of natural substances on organic art and cultural objects. Wood is one of the most commonly used organic materials in the creation of artistic and cultural artifacts in Indonesia. It contains cellulose, hemicellulose, and lignin, which are susceptible to degradation by heterotrophic microorganisms, particularly fungi [10]. The application of naturally derived antimicrobial agents can help reduce the deterioration of art and heritage objects.

A series of studies aimed at testing antifungal activity and identifying active compounds in clove and tobacco was carried out by the Borobudur Conservation Center between 2003 and 2006 [1]. The findings revealed that the active compounds in tobacco and clove are alkaloids and eugenol. The study also successfully demonstrated that tobacco and clove extracts exhibit antifungal properties on wood, providing scientific evidence supporting their use as protective and preservative agents for wooden materials. As a result, various institutions, including the Balai Pelestarian Peninggalan Purbakala (BP3) in multiple regions, have adopted tobacco and clove extracts for cleaning, maintenance, and preservation of wooden cultural heritage objects, with proven effectiveness.

Additionally, antifungal testing has been conducted on liquid smoke from coconut shells [2]. Liquid smoke contains acetic acid and phenolic compounds, which have been shown to inhibit the growth of Aspergillus sp., a fungus isolated from wooden collections at Kupang Museum.

A summary of scientific studies on the effectiveness and antimicrobial properties of organic cultural objects is presented in Table 4.

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Table 3. Chemical Content, Effectiveness Test, and Antimicrobial Test of Local Plants in Conserving Inorganic Art and Cultural Objects

No	Plant Name	Part Used	Active Compounds	Effectiveness Test	Antimicrobial Test	Reference
1	Coconut	Coconut water, palm sap	Electrolyte	Effective in cleaning rust from keris	ND (Not Described)	[17]
2	Pace	Fruit	Acid	Effective in cleaning rust from keris	ND	[17]
3	Tamarind	Fruit	Citric acid	Idem	ND	[17]
4	Pineapple	Young fruit	Citric acid	Idem	ND	[17]
5	Lime	Ripe fruit	Citric acid	Idem	ND	[17]
6	Soapberry (Lerak)	Fruit soaking water	Saponin, polyphenol, tannin	Effective in cleaning silver and bronze	ND	[26]
7	Bael (Aegle marmelos)	Fruit pulp	Marmelosin, essential oil, pectin, saponin, tannin, and 2-furocoumarins-psoralen	Effective as an iron cleaner	ND	[25]
8	Citronella	Citronella oil	Citronellal and geraniol	Effective in inhibiting mold and lichen growth on stone	Inhibits the growth of *Penicillium* sp. isolated from lichen on Borobudur temple stone	[8,11,29]
9	Clove	Essential oil	Eugenol	Idem	Inhibits the growth of fungi isolated from lichen on stone	[27]
10	Nutmeg	Essential oil	Monoterpenes, flavonoids, and alkaloids	Idem	Idem	[28]

Table 4. Chemical Content, Effectiveness Test, and Antimicrobial Test of Local Plants in Conserving Organic Art and Cultural Objects

No	Plant Name	Part Used	Active Compounds	Effectiveness Test	Antimicrobial Test	Reference
1	Tobacco	Leaf extract	Alkaloid (mainly nicotine)	Effective in inhibiting mold growth on wood	Inhibits the growth of *Hyalopus* sp. on wood	[1]
2	Clove	Flower extract	Eugenol (a phenolic compound)	Idem	Idem	[1]
3	Coconut	Coconut shell liquid smoke	Acetic acid and phenolic compounds	Effective in inhibiting mold growth on wood	Inhibits the growth of *Aspergillus* sp. isolated from wood collection at Kupang Museum	[2]

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3.4 The Potential of Local Plants as Antimicrobial Agents in Conservation

Biological control can be achieved using biocides, whether natural or synthetic chemicals. Although chemical agents have been widely applied and proven effective in controlling microbial growth, their use is being minimized due to their long-term negative impacts on preserved objects, the surrounding environment, and human health [1,12]. For instance, the chemical biocide AC 322, previously used for cleaning lichens on cultural heritage objects, was found to contain Arcopal compounds, which are hazardous, toxic, carcinogenic, and mutagenic, posing risks of cancer. To mitigate these risks, alternative approaches inspired by traditional conservation practices have been developed, including the use of natural plant-based substances that have been utilized by previous generations.

Although natural plant-based substances are safer, more sustainable, and environmentally friendly, they also have certain limitations that need to be addressed. For example, essential oils applied directly in the field tend to have high volatility, low solubility in water, and are easily degraded by heat, humidity, and oxygen, reducing their antimicrobial effectiveness [8,29]. To overcome these limitations, some researchers have successfully utilized nanotechnology to enhance the efficacy of essential oils. For instance, silver nanoparticles (AgNPs) combined with lemongrass, clove and nutmeg essential oil have been shown to improve lichen removal effectiveness [8,27,28]. Additionally, lemongrass essential oil formulated into a nanoemulsion has been proven to reduce volatility and increase absorptivity, thereby enhancing its efficiency in inhibiting lichen growth [29].

Many traditional conservation practices persist as community knowledge, despite the lack of scientific validation. While some investigations have been conducted to assess the effectiveness and antimicrobial activity of plant-derived natural substances in conserving artworks and cultural heritage, microbiological studies remain limited. Critical aspects such as the mechanisms of biological deterioration and how antimicrobial agents inhibit microbial growth on cultural objects have not been extensively explored. Therefore, research in this field remains open and essential, particularly given that microorganisms are one of the primary causes of deterioration in artistic and cultural heritage objects, especially in tropical climates.

4. Conclusion

This study highlights the potential of Indonesian local plants as antimicrobial agents in the conservation of art and cultural objects. Based on the literature review, various plants such as lemongrass, clove, tobacco, and nutmeg contain bioactive compounds such as eugenol, alkaloids, citral, geraniol, monoterpenes, and flavonoids, which have been proven to possess antimicrobial activity against biodeterioration-causing microorganisms. Although traditional conservation practices have long been applied with promising results, further scientific validation is needed to ensure their effectiveness and impact on various types of cultural materials.

This study also demonstrates that while natural plant-based materials are more environmentally friendly than synthetic biocides, their effectiveness is relatively lower. Therefore, enhancement strategies, such as the application of nanoparticle technology, are necessary to improve the stability and efficacy of active compounds. Further research is essential to understand the mechanisms of antimicrobial compounds from local plants in art and cultural heritage conservation, as well as to evaluate their long-term efficiency. By integrating scientific approaches, traditional conservation methods can be optimized as a sustainable solution for preserving Indonesia's art and cultural object.

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References

[1.] Cahyandaru N. Bahan Tradisional Tembakau dan Cengkeh sebagai Konservan BCB Kayu. J Konserv Cagar Budaya. 2008 Dec 2;2(1):8–12.

[2.] Habibi M, Puspitasari DE, Gunawan A, Yulianto H, Wahyudi W. Konservasi Cagar Budaya dengan Asap Cair. J Konserv Cagar Budaya. 2017 Jun 2;11(1):49–50.

[3.] Joseph E, editor. Microorganisms in the Deterioration and Preservation of Cultural Heritage. Cham: Springer International Publishing; 2021.

[4.] Munandar A. Kerusakan dan Pelapukan Material Bata. J Konserv Cagar Budaya. 2010 Dec 2;4(1):55–61.

[5.] Sutopo M, editor. Hasil Kajian 2014. Magelang: Balai Konservasi Borobudur; 2015.

[6.] Swastikawati A, Kusumawati H, Suryanto RK, Purnama YAH. Tanin Sebagai Inhibitor Korosi Artefak Besi Cagar Budaya. J Konserv Cagar Budaya. 2017 Jun 2;11(1):3–21.

[7.] Riyanto R, Jazuli MM, Sahroni I, Musawwa MM, Cahyandaru N, Wahyuni ET. A Simple Technique for the Corrosion Inhibition of Underwater Cannonball from a Shipwreck. Int J Technol. 2023 Jun 28;14(4):843.

[8.] Riyanto, Mulwandari M, Asysyafiiyah L, Sirajuddin MI, Cahyandaru N. Direct synthesis of lemongrass (*Cymbopogon citratus* L.) essential oil-silver nanoparticles (EO-AgNPs) as biopesticides and application for lichen inhibition on stones. Heliyon.

2022;8(6):1–11.
[9.] Swastikawati A, Ekarini FD, Wahyuni S. Efektivitas Edta Dalam Membersihkan Lapisan Kerak Pada Cagar Budaya Berbahan Batu. J Konserv Cagar Budaya. 2013;7(2):60–70.
[10.] Tiano P. Biodegradation of Cultural Heritage: Decay Mechanisms and Control Methods. In: ARIADNE 9 Work Historic Materials and Their Diagnostics [Internet]. 2009. Available from: http://www.arcchip.cz/w09/w09_tiano.pdf
[11.] Riyanto R, Untari DT, Cahyandaru N. Isolation and Application of the Lemongrass Essential Oil of *Cymbopogon nardus* L.as a Growth Inhibitor of Lichens on Stone Cultural Heritage. IOSR J Appl Chem. 2016;09(09):109–17.
[12.] Cahyandaru N, Wahyuni S, Purnama YAH. Indonesian Essential As Biocidesin Traditional-Based Artefact Consertvationstudy : A mini Review1. J Konserv Cagar Budaya. 2017 Jun 2;11(1):22–8.
[13.] Pangesti F, Octavia B, Cahyandaru N. Studi Keanekaragaman Kapang Pada Proses Biodeteriorasi Batuan Candi Mendut. J Konserv Cagar Budaya. 2022;16(1):23–38.
[14.] Munawati R, Octavia B, Cahyandaru N. Biodiversitas Kapang pada Proses Biodeteriorasi Batuan Candi Borobudur. J Konserv Cagar Budaya. 2021;15(2):1–17.
[15.] Indahsari PN, Octavia B, Cahyandaru N. Deteksi dan Identifikasi Kapang pada Proses Biodeteriorasi Batuan Candi Pawon. J Konserv Cagar Budaya. 2022 Dec 28;16(2):148–59.
[16.] Fauziyyah NA, Sari Putri DA. Isolasi Jamur dari Batuan Penutup Drainase Pada Sisi Selatan Lantai II Bidang H Candi Borobudur. J Konserv Cagar Budaya. 2016;10(2):40–4.
[17.] Swastikawati A, Suryanto RK, Purwoko AW. Metode Konservasi Tradisional (Penjamasan) Cagar Budaya Berbahan Logam Besi. Magelang: Balai Konservasi Borobudur; 2012. 1–91 p.
[18.] Astuti D, Cahyandaru N, Mujiharja. Konservasi Kayu Gapura Majapahit Di Kabupaten Pati. J Konserv Cagar Budaya. 2017;11(2):25–34.
[19.] Rachman YB. Palm leaf manuscripts from royal surakarta, Indonesia: deterioration phenomena and care practices. Restaurator. 2018;39(4):235–47.
[20.] Anjelia R. Upaya Konservasi Koleksi Wayang Kulit Purwa pada Museum Wayang Jakarta. UIN Syarif Hidayatullah; 2024.
[21.] Koestler RJ, Koestler V, Charola AE, Nieto-Fernandez FE, editors. Art, Biology, and Conservation: Biodeterioration of Works of Art. New York: The Metropolitan Museum of Art; 2003.
[22.] Ratnaningtyas YA, Dana IW, Purwanto TS. Konservasi Pusaka (Seni) Budaya Nusantara. Sleman: Lumintu Jaya Nagara; 2024.
[23.] Wahyuningsih I, Sularsih S, Yuanisa S, Aji DAP. Kajian Konservasi Tradisional Menurut Naskah Kuno. J Konserv Cagar Budaya. 2017;11(2):89–94.
[24.] Titasari CP, Zuraidah Z, Laksmi NKPA. Penggunaan Jeruk Nipis sebagai Salah Satu Upaya Konservasi Secara Tradisional pada Prasasti Sukawana D. J Konserv Cagar Budaya. 2014;8(1):12–6.
[25.] Fatmawati I. Efektivitas Buah Maja (*Aegle marmelos* (L.) Corr.) sebagai Bahan Pembersih Logam Besi. J Konserv Cagar Budaya. 2015;9(1):81–7.
[26.] Fatmawati I. Efektivitas Buah Lerak (*Sapindus rarak* De Candole) sebagai Bahan Pembersih Logam Perak, Perunggu, dan Besi. J Konserv Cagar Budaya. 2014;8(2):24–31.
[27.] Riyanto, Mulwandari M, Asysyafiiyah L, Sirajuddin MI, Cahyandaru N. Biopesticide Nanoformulations Based on Clove Essential Oil for the Growth Inhibition of Lichens. Biopestic Int. 2023 Dec;19(02):140–1.
[28.] Riyanto, Mulwandari M, Asysyafiiyah L, Sirajuddin MIM, Cahyandaru N. Synthesis of biopesticides using nutmeg essential oil (*Myristica fragrans* Houtt) and its application as a lichen growth inhibitor. J Biopestic. 2023;16(1):45–54.
[29.] Hanifah LD, Pradipta MF, Cahyandaru N. Optimasi Kondisi Proses Pembuatan Nanoemulsi Minyak Serai Wangi Dengan Metode Taguchi Sebagai Antijamur Pada Cagar Budaya. J Konserv Cagar Budaya. 2022;16(2):131–47.

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