

POTENTIAL OF MARINE FUNGI AS BIOREMEDIATION OF HAZARDOUS POLLUTANTS

Tioko Arzeti Sinambela

Aquatic Products Technology Study Program, Faculty of Fisheries and Marine Sciences Bogor Agricultural Institute

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Corresponding Author:

Tioko Arzeti Sinambela

Email:

tiokoarzeti@apss.ipb.ac.id

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ABSTRACT

*The potential of marine fungi in the bioremediation of dangerous pollutants such as heavy metals, textile industry waste, and polycyclic aromatic hydrocarbons (PAHs). Marine fungi, known to have a high adaptive capacity in extreme environmental conditions, offer an effective and environmentally friendly solution to address contamination in marine and coastal habitats. Through bioleaching and biosorption processes, marine fungi are able to adsorb and accumulate heavy metals, reducing toxicity and pollutant concentrations. Species such as *Cerrena unicolor* and *Aspergillus niger* show effectiveness in degrading synthetic dyes and PAHs, breaking down complex compounds into simpler and less toxic ones. This discussion provides insight into the use of marine fungi as potential bioremediation agents, supporting the development of environmental remediation methods that are sustainable and less invasive than traditional methods. This review contributes to further understanding to optimize the use of fungi in environmental bioremediation applications, while providing a significant contribution to the environmental science of sustainable marine resource management*

INTRODUCTION

Population growth, the development of industrialization, and increasing urbanization have negative impacts on the environment (Marzan et al., 2017). This increase in industrial activity has brought many technological and economic advances, but has also left a significant negative footprint on the environment. Increased industrial activities such as the textile industry, electroplating, leather tanning, paint manufacturing, printing and refining have become one of the main sources of pollutants contributing to the water ecosystem (Jeyakumar et al., 2023). Hydrocarbon and heavy metal pollution are the two most persistent and dangerous types of contamination, originating from various industrial sources such as waste disposal, oil leaks and mining processes. These pollutants not only pose health risks to humans but also harm aquatic life and the ecosystem as a whole.

In facing this environmental problem, the use of marine fungi as bioremediation agents appears as a promising solution because of their ability to degrade pollutants naturally and effectively. Marine fungi have potential as a source of enzymes for the environment and industry. Some of the

enzymes produced by marine fungi include hydrolytic enzymes, oxidative enzymes, alginateliase, amylase, cellulase, chitinase, glucosidase, inulinase, keratinase, lignilase, lipase, nuclease, phytase, protease, xylanase (Santos et al., 2015). According to research by Dell' Anno et al., (2021), marine fungi have the ability to adsorb and metabolize heavy metals, making them potential candidates in environmentally friendly bioremediation technology.

Marine fungi, in particular, have been recognized as having great potential in bioremediation due to their unique adaptation to harsh environmental conditions and their ability to produce enzymes that can break down a wide range of pollutants. Fungi such as *Aspergillus*, *Penicillium* and *Fusarium* have been researched for their efficient ability to degrade hydrocarbons and heavy metals, making them ideal candidates for bioremediation applications in contaminated marine and coastal habitats.

The approach of using marine fungi not only addresses the pollution problem but also offers a more sustainable and less invasive method compared to traditional physicochemical methods. Through this biological approach, the possibility of improving environmental conditions without causing additional negative impacts can be realized. Therefore, further exploration of the potential of marine fungi in bioremediation paves the way for the discovery of more effective and environmentally friendly environmental remediation methods. This study aims to explore the potential of marine fungi in the context of bioremediation, offering new insights and sustainable solutions to heavy metal pollution.

METHODOLOGY

This study is a comprehensive literature review focusing on the bioactive compounds derived from marine fungi and their potential applications in bioremediation. The primary sources of data were three main databases: ScienceDirect, PubMed, and Google Scholar. The search strategy employed keywords such as 'marine fungi', 'bioactive compounds', and 'bioremediation'. Relevant articles were identified and reviewed to extract data on the types of compounds produced by marine fungi and their biological activities related to pollutant degradation.

In the initial phase, the selection criteria included peer-reviewed articles, reviews, and book chapters published in the last two decades. Studies were prioritized based on their relevance to marine fungi's role in bioremediation of heavy metals, textile industry waste, and polycyclic aromatic hydrocarbons (PAHs). The articles were further screened for detailed experimental methodologies, statistical analyses, and the robustness of the findings.

The second phase involved categorizing the identified bioactive compounds and their specific roles in bioremediation processes. This included examining the enzymatic activities of marine fungi, such as the production of hydrolytic and oxidative enzymes, and their efficacy in degrading pollutants. The data extracted were tabulated to provide a clear comparison of the bioremediation potential of different marine fungal species.

Lastly, the review also focused on the molecular mechanisms and kinetics of the enzymes involved in the bioremediation process. Field studies were analyzed to understand the practical applications and effectiveness of marine fungi in real-world contaminated sites. This multi-step approach ensured a thorough and detailed understanding of the potential of marine fungi as bioremediation agents.

Bioremediation Potential of Marine Fungi

The bioremediation potential of marine fungi in addressing environmental pollution has received significant attention in recent years, demonstrating unique advantages due to their adaptation to extreme conditions in the marine environment. The diversity of marine fungi is closely related to biological, physical and chemical factors including the availability of substrates for colonization, substrate properties, water temperature, pH and salinity (Jones & Pang, 2012). Marine fungi have proven effective in degrading polycyclic aromatic hydrocarbons (PAHs) and other hydrocarbon compounds, which are often found in oil spills, by breaking down complex organic compounds into simpler compounds that can be more easily broken down by other microorganisms or be less toxic. In addition, some species of marine fungi have the ability to adsorb and accumulate heavy metals from their environment, and through bioleaching and biosorption processes, these fungi can reduce the concentration of heavy metals in the environment, thereby reducing biological toxicity and associated health risks. Marine fungi have the potential to produce secondary metabolites, biosurfactants, new enzymes, polysaccharides and polyunsaturated fatty acids which can play a role in the bioremediation of hydrocarbons and heavy metals. Research conducted by Thatoi et al., (2013) shows the enormous potential of marine fungi to be developed as medicinal ingredients, enzymes, biodiesel, biopesticides and bioremediation. Marine fungi can tolerate high concentrations of heavy metals such as lead and copper (Gazem & Nazaret, 2013). Marine fungi also produce various enzymes such as laccase, peroxidase, and lipase which play an important role in the biodegradation process and facilitate the breakdown of organic pollutants, including plastics and pesticides. Thanks to their adaptations to survive conditions with high osmotic pressure, temperature variations, and the presence of salt, marine fungi tend to be more resilient and effective in challenging environmental conditions, which are often found in contaminated sites. In contrast to physicochemical methods for remediation that often use hazardous chemicals and can have additional environmental impacts, marine fungi offer a more environmentally friendly approach that does not involve toxic chemicals and usually has a lower ecological impact. Additionally, marine fungi can work together with other microorganisms such as bacteria in a process called microbial consortia, increasing the efficiency of bioremediation because different types of microorganisms can target different pollutants simultaneously. Fungi can survive and live in various types of habitats, such as soil, freshwater environments and seawater environments. The diversity of habitats and the ability to secrete many enzymes means that fungi have potential as agents for bioremediation at various sites (Desmukh et al., 2016). With their adaptative and biochemical capabilities, marine fungi represent an invaluable resource for bioremediation technologies, and further research exploring the molecular mechanisms and kinetics of the enzymes involved, as well as field studies to test their efficacy in contaminated sites, will help optimize the use of deep-sea fungi large scale bioremediation applications.

Table 1. Bioremediation Potential of Marine Fungi against Various Pollutants.

| Marine Fungi | Pollutan | Activity | References |
|---|-------------|--|----------------------------------|
| <i>Aspergillus niger</i> and <i>Trichoderma</i> sp. | Heavy metal | Use of marine fungi as bioremediation agents for marine sediments contaminated with heavy metals. Marine fungi, such as <i>Aspergillus niger</i> and <i>Trichoderma</i> sp., are used because of their ability to be effective in bioleaching—the process of mobilizing heavy metals from sediments, thereby reducing the concentration and toxicity of these metals in the environment. | (Dell’Anno <i>et al.</i> , 2022) |

| | | | |
|--|--|---|--------------------------------------|
| <i>Cerrena unicolor</i> | Textile industry waste, such as synthetic dyes | The use of marine fungi, especially <i>Cerrena unicolor</i> MTCC 5159, is focused as an effective bioremediation agent in decolorizing various synthetic dyes as well as a more environmentally friendly alternative to conventional chemical bleaching methods and the laccase enzyme produced by this fungus shows high activity and good thermal stability and tolerance to heavy metals. | (D'Souza-Ticlo <i>et al.</i> , 2009) |
| <i>Penicillium citrinum</i> , <i>Acremonium sclerotigenum</i> , <i>Aspergillus polyporicola</i> , <i>Aspergillus versicolor</i> , <i>Fusarium equiseti</i> , <i>Fusarium sp.</i> , <i>Aspergillus sydowii</i> , <i>Aspergillus sp.</i> , <i>Aspergillus flavus</i> , <i>Aspergillus sydowii</i> . | Polycyclic aromatic hydrocarbons (PAHs) | These fungi use a degradation strategy that involves the enzymatic breakdown of PAHs into less toxic metabolites, which can then be further broken down by other microorganisms in the environment. This process not only reduces the concentration of harmful PAHs but also reduces the risk of toxicity from degradation by-products, as proven in toxicity tests using <i>Vigna radiata</i> , where no increased toxicity was found under conditions treated with this fungus. | (Barnes <i>et al.</i> , 2023) |
| <i>Penicillium polonicum</i> <i>Penicillium chrysogenum</i> <i>Penicillium cyclopium</i> | Crude oil pollution | The marine fungi isolated in this study are capable of using crude oil as a primary carbon source and producing biosurfactants that increase hydrocarbon solubility, facilitating more efficient oil degradation in bioremediation processes. | (Maamar <i>et al.</i> , 2020) |

Dell'Anno *et al.*, (2022) in their research explained that the ability of marine fungi to bioremediate heavy metals is an important topic in environmental studies, especially to overcome pollution in marine sediments. Marine fungi such as *Aspergillus niger* and *Trichoderma sp.* have the unique ability to lower the pH of their environment. This occurs through the production of organic acids produced during metabolic processes. This decrease in pH is very important because it makes heavy metals more soluble, thus facilitating the process of transporting metals out of the sediment matrix. During growth and metabolism, marine fungi produce various organic acids, such as citric and oxalic acids. These acids function as chelating agents that can bind to metal ions in sediment. When these acids bind to metals, they form soluble complexes, which facilitate the removal of metals from sediments. Fungi have highly effective bioleaching capabilities, meaning they can change the chemical state of heavy metals so that they are easier to take up or transport. In the studies reviewed, fungi were shown to be more effective than bacteria in mobilizing heavy metals such as Zn, Cd, and As from sediments. The acidic environment produced by the bioleaching process can often inhibit other organisms, but the marine fungi used in this study demonstrated a strong ability to grow and function in such acidic conditions. This allows them to survive and continue to be active in conditions that would inhibit other microorganisms. Although fungi are very effective in bioremediation as sole agents, they can also be used in conjunction with bacteria to improve bioremediation results. This combination of microbes can optimize the benefits of each, exploiting the bioleaching capabilities of fungi and the adaptation of bacteria to different conditions to achieve more efficient decontamination. In the research carried out, the addition of fungi to contaminated sediments not only succeeded in increasing the solubilization of heavy metals significantly but was also the only treatment that was effective in dissolving metal fractions that were previously considered immobile. This shows the potential of fungi to address some of the biggest challenges in sediment bioremediation.

Research conducted by D'Souza-Ticlo *et al.*, (2009) described the unique abilities of the *Cerrena unicolor* MTCC 5159 fungus isolated from rotting mangrove wood. This fungus has been shown to be able to produce very high amounts of the laccase enzyme, around 23,700 units per liter, when grown in a medium that has a low nitrogen content and half strength seawater. Laccase is an enzyme that breaks down lignin and various complex aromatic compounds, making it very useful

for cleaning organic waste and dyes from industry. *Cerrena unicolor* is able to remove color from several types of synthetic dyes, including Congo Red, Methylene Blue, Trypan Blue, and Aniline Blue. This shows its potential in cleaning textile industry waste which often contains toxic dyes that are difficult to remove with ordinary methods. In addition, the laccase produced by this fungus succeeded in reducing the lignin content in sugarcane fiber by 36% in 24 hours, demonstrating its ability in the biobleaching process. Biobleaching is a whitening process that is more environmentally friendly compared to chemical bleaching, because it reduces the use of harmful chemicals. Laccase from *Cerrena unicolor* also shows excellent stability in high temperatures and is not affected by heavy metal concentrations up to 1 millimole, including lead (Pb), iron (Fe), nickel (Ni), lithium (Li), cobalt (Co), and cadmium (Cd). This stability and durability is critical for their use in heavily contaminated locations, where environmental conditions are often extreme. This enzyme works most effectively at pH 3 and a temperature of 70°C, and is most stable at pH 9, which provides flexibility for the use of laccase in various industrial and bioremediation process conditions.

This research conducted by Barnes et al., 2023 explored the use of fungi isolated from the marine environment for bioremediation of PAHs. PAHs are significant pollutants due to their carcinogenic and mutagenic properties and their persistent presence in the environment due to their difficulty in degradation due to their hydrophobic nature. His research used ten different fungal isolates tested for their ability to degrade PAHs in crude oil. These fungal isolates included *Fusarium* and *Penicillium* species that had been identified through ITS sequence analysis and examined using GC-MS analysis to determine their PAHs degradation potential. The main focus was on isolates NIOSN-T4 (*Fusarium equiseti*) and NIOSN-T5 (*Fusarium* sp.), which showed a reduction in total PAHs of 98.6% and 92.9%, respectively. In particular, *Fusarium equiseti* (NIOSN-T4) was highly effective in degrading low and high molecular weight PAHs, achieving almost complete removal of phenanthrene, pyrene, benzo anthracene, and indeni pyrene. Research also shows that *Penicillium citrinum* (NIOSN-M126) has a special ability to remove 100% of high molecular weight PAHs from crude oil mixtures. In addition, *Aspergillus* sp. (NIOSN-SK56S32) is effective in degrading fluorene and phenanthrene with an efficiency of more than 85%. One important aspect of the research he conducted was a toxicity test using *Vigna radiata* (mung bean) seeds to assess the safety of metabolites produced by the degradation process. showed that there was no significant increase in toxicity, indicating that the degradation products not only reduced PAH concentrations but were also relatively harmless to the environment. Overall, the results of this study provide strong evidence that fungi isolated from the marine environment can be an effective and environmentally friendly tool for the bioremediation of hydrocarbon contaminated sites, with potential application on a larger scale in the future. This shows the importance of exploring underutilized biological resources in bioremediation technologies to address serious hydrocarbon pollution challenges.

Research conducted by Maamar et al., (2020) in the Port of Oran, Algeria, revealed the significant capacity of marine fungi in the bioremediation of crude oil pollution, using 84 isolates of filamentous fungi successfully isolated from seawater samples. Further analysis showed that 12 of these isolates were capable of using crude oil as the sole carbon source. In particular, four isolates of *Penicillium polonicum* AMF16, *Penicillium chrysogenum* AMF47, as well as two isolates of *Penicillium cyclopium* (AMF40 and AMF74) not only utilized crude oil but also demonstrated effective biosurfactant production. Biosurfactants produced by these fungi play a crucial role in the bioremediation process by increasing the solubility of hydrocarbons, making it easier for other microorganisms to access and degrade these contaminants. This research also carried out degradation tests using the indicator 2,6-dichlorophenol indophenol (DCPIP), where a decrease in DCPIP concentration indicates effective degradation activity by the fungus. The results showed that these isolates were not only able to survive in conditions rich in crude oil but also actively degrade it. This unique ability marks these fungal isolates as potential candidates for bioremediation applications in addressing oil pollution in the marine environment. This study is

important because it provides new insights into the use of marine microorganisms for the restoration of contaminated ecosystems, offering a more sustainable and environmentally friendly solution than conventional methods that are often less efficient and expensive.

CONCLUSION

Marine fungi have great potential in the bioremediation process to treat various types of dangerous pollutants such as heavy metals, textile industry waste, and polycyclic aromatic hydrocarbons (PAHs). Through bioleaching and biosorption mechanisms, marine fungi are effective in adsorbing and accumulating heavy metals from the environment, while reducing their concentration and toxicity. Additionally, species such as *Cerrena unicolor* have been shown to be effective in decolorizing synthetic dyes from textile industry waste, offering a more environmentally friendly alternative to traditional chemical bleaching methods.

Marine fungi also show significant capacity in degrading PAHs, which are often found in oil spills, by decomposing complex organic compounds into simpler compounds that are less toxic. This effectiveness not only reduces harmful PAH concentrations but also reduces the risk of toxicity from degradation byproducts.

The adaptation of marine fungi to harsh environmental conditions, such as high osmotic pressure, temperature variations, and the presence of salt, allows them to grow and function effectively in challenging conditions, which are often found in contaminated sites. With the capacity to secrete many enzymes that support pollutant degradation, marine fungi offer an innovative, efficient and environmentally friendly bioremediation approach. With this in mind, marine fungi have the potential to play an important role in the development of bioremediation technology which aims to restore contaminated ecosystems and reduce the environmental impact of various industrial and natural pollutants.

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