Open Access Research Journal of
Science and Technology
Journals home page: https://oarjst.com/
ISSN: 2782-9960 (Online)

OARJ OPEN ACCESS RESEARCH JOURNALS

(Review Article)

Utilizing white rot fungi for effective environmental pollution management

Ali A Alsudani *

Environmental Research and Pollution Prevention Unit, College of Science, University of Al-Qadisiyah, Iraq.

Open Access Research Journal of Science and Technology, 2025, 13(02), 116-121

Publication history: Received on 08 February 2025; revised on 25 March 2025; accepted on 27 March 2025

Article DOI: https://doi.org/10.53022/oarjst.2025.13.2.0053

Abstract

The physiology, biochemistry, molecular biology, and ecology of white rot fungi must be understood to effectively manage environmental contamination, large companies produce pollutants that end up in the soil and water, which have negative effects on the environment and the economy. It is crucial to develop safe technology for the removal of contaminants. Some ligninolytic enzymes that efficiently degrade macromolecular pollutants and xenobiotics have been studied at the protein and DNA levels in the white rot fungus. Some enzymes linked to biodegradation appear to have both bacterial and fungal heritage, according to research. This review discusses the advantages and disadvantages of using white rot fungi to clean up contaminated substrates and emphasizes their potential in biodegradation research.

Keywords: Contamination; White rot fungi; Environmental Pollution Management; Biodegradation; Bioremediation

1. Introduction

Global pollution is a major environmental threat and still calls for an efficient and sustainable technique to manage it. Biodegradation is one of the important processes; it is a depolluting phenomenon that enables pollutants to metabolize by microorganisms through biological oxidation processes. Today, the number of microorganisms used in biodegradation processes is limited, with obvious limitations [1]. Among the potential organisms, many are undesirable, although they are capable of using many recalcitrant substances as sources of carbon. The feasibility of exploiting these organisms varies based on specific circumstances and the type of industrial contaminant residue. The large living cells of white-rot fungi possess a peculiar combination of properties and this enables them to function as excellent agents of biological oxidation for the breakdown of industrial contaminant residues. White rot fungi, such as those of the genus Phanerochaete, can utilize an extremely wide variety of recalcitrant organic compounds as sources of carbon and produce powerful ligninolytic extracellular enzymes into the outside culture medium [2,3].

The properties arising from the physical nature and extracellular fibrillar structure of these powerful ligninases confer advantages in using them as agents for the breakdown of recalcitrant pollutants, which are referred to as biological oxidations. Through these biological and enzyme systems, white rot fungi can release and transport substrate molecules within the extra-fungal compartment for further degradation by the numerous identical microorganisms that usually increase massively in number in such environmental conditions. Since antiquity, the vast importance of the Basidiomycetes as wood-destroyers has, of course, been recognized, and there exist many references to mechanisms such as these among the technologically and biotechnologically oriented tomes of mycology [4,5]. This review was, however, prepared in circumstances where the potential value of these properties in the breakdown of non-wood or so-termed xenobiotic pollutants had been recognized by only a few specialist groups.

2. Characteristics and Mechanisms Action of White Rot Fungus

Wood rotting is mostly caused by soft-bodied fungi called white rot fungi, which are members of the basidiomycete group. They may be able to decompose wood and other complex organic substances that other basidiomycetes,

---

* Corresponding author: Ali A Alsudani

ascomycetes, or fungi that cause brown rot which decomposes wood cannot use because of a special combination of biological and ecological traits. Oxaline is a characteristic of the white rot fungus genus; this fungus has the typical ecology of other rot fungi. White rot fungi are important agents of wood biodegradation that are capable of decomposing the wood polymers cellulose, hemicelluloses, and lignin. Lignin is degraded due to certain enzymes of low redox potential, especially heme peroxidases, and their reaction with hydrogen peroxide [6].

Lignin peroxidases and manganese-independent peroxidases are responsible for the Fenton reaction that initiates lignin degradation and for the degradation of various environmental pollutants. Some heme proteins, which are more abundantly produced in some species than lignin peroxidases, are particularly useful in breaking down resistant substances. One example of such an enzyme is the dye-decolorizing peroxidase. Because white rot fungi can also break down cellulose and cellobiose, they and their enzymes are crucial to the carbon cycle in ecosystems. In comparison with basidiomycete brown rot fungi, the oxidative attack by white rot fungi is of a much broader range, although this aspect is still less investigated for ascomycete brown rot decay [7,8]. White rot fungal breakdown of plant litter, such as wood, leaves, and grasses, is linked to the fungal's ecological importance. While some fungal species can decompose wood, white rot fungi are more prevalent when it comes to consuming lignin-rich plant litter. A substantial part of the white rot basidiomycetes being wood decay fungi has been used to perform the white rot process. Because of the ecological aspects that have been investigated, the basidiomycete white rot wood degradation fungi are particularly relevant for biotechnological applications. Environmental conditions, wood properties, and species features also determine the decay patterns. For example, wood-permeable gray rot occurs under particular environmental conditions when white rot basidiomycetes are abundant in polluted water. It has more restricted use for biotechnology purposes. Because white rot wood decay fungi are selective systems and show mutagenicity, white rot decay has been dealt with more than biological functions of the decay [9-11].

3. Applications of White Rot Fungus in Environmental Contamination Management

The white rot fungus has a complex structure and is resistant to injury. The rate of microbial perturbation and the half-life of pollutant components is slower, and accumulation does not break down. Based on its high-volume protein production in natural ecology, its ability to adapt to high concentrations of nutrients and maintain high concentrations of white rot fungi and their lipase activities make it an effective and environmentally friendly way to reduce the occupational hazards of biotransformation in livestock and their environment. The white rot fungus performs decolorization, degeneration, and other processes, especially the ability to degrade chlorophyll, which has shown good prospects in testing and application [12,13]. Biodegradation refers to the direct transformation of toxic substances into non-toxic substances, the loss of toxic effects, and the ability of organisms to fully participate in biodegradation and to reduce the degree of pollution, thus contributing to the desired management, treatment, and recovery of the environment. Biodegradation is therefore of great significance in the ecology of the environment and the improvement of environmental quality. Soil and water are the primary bioremediation environments, and a large group of scientists have been employed to study the integration and application of biodegradation to assess the recovery of soil and water resources. White rot fungus has been utilized for the depletion of toxic substances in recent years. By causing fungal mycelium and fungal spores, the compound with invasive effects has a strong ability to break down organic chemicals. Since its invention, white rot fungus has been utilized in the management and removal of environmental waste [14].

3.1. Biodegradation of Pollutants

The white rot fungus is an important organism in the field of environmental biotechnology due to its ability to mineralize a variety of xenobiotic pollutants. It degrades not only phenolic compounds and textile dyes but also industrial waste and some xenobiotic chemicals. The biochemical pathway of oxidative degradation of pollutants has been developed up to a certain degree; a complex network of enzyme systems participates in the multistep pathway. The action of lignin peroxidases, manganese peroxidases, and laccases, secreted by the lignin-degrading white rot fungi, results in the formation of free -OH radicals while cleavage of C-C and C-O bonds continues [15,16]. The use of white rot fungi for the reduction of the concentration of pollutants in the environment is an alternative treatment method to the conventional ones, which most frequently employ harsh chemical and physical treatments. However, the efficiency of this method is strongly influenced by the environment and by the pollutants to be removed. Biodegradation working rates and the extent of methyl tert-butyl ether (MTB) and halogenated contaminants depend on the environmental conditions in each case. Factors influencing the rate of biodegradation include in situ resting time, water saturation, temperature, stirring, period of fungi inoculation, pH, and the use of some carbon or nitrogen sources. It has been reported that ex-situ treatment of solid waste covered by soil influences the white rot fungi bioremediation success. Some case studies show that this technology, sometimes in combination with other technologies, allows restoration of contaminated soil. It can be concluded that white rot fungi, in combination with some other technologies, are a good tool to be included in heavy environmental restoration of highly semi-developed habitats [17,18].

3.2. Bioremediation of Soil Contamination

Biological treatments can restore the natural structure and function of living matter in the soil, and consequently reduce the contamination of soil and water. The bioremediation of polluted soil aims to restore the original ecosystems from an ecological viewpoint. From an environmental point of view, it aims to remove the pollutant and recover the affected part to make it available for agricultural, urban, or industrial purposes such as forestry. Bioremediation is any process that uses biological characteristics to neutralize pollutants and contaminants in the environment. White rot fungi not only degrade complex materials but also reduce the concentration of these materials by producing oxidative enzymes. Many researchers have studied the effectiveness of white rot fungi in bioremediation or the treatment of contaminated soils by either solid-state fermentation or the decontamination of drainage or effluents [6].

The feasibility of biological treatments in the recovery of polluted land has been widely demonstrated. Over the last decades, the effectiveness of biological treatments in the remediation of soils has been evaluated, especially their capacity to decrease the concentration of soil pollutants. The pollutants most often biomodified correspond to heavy metals and those that belong to semi volatile compounds secondarily, being many times substances with high persistence and toxicity. Fungal treatment with white rot fungi has given optimal results in the removal or decrease of these heavy metals in soils of different origins [4]. The treatments with white rot fungi have been carried out or assessed with the treatment of soils with effluents contaminated with hydrocarbons, obtaining results in the elimination of pollutants together with the recovery of the original soils or the treated land. Bioremediation is an attractive technology because of its potential for low cost, safety, and benefits for the ecology of the system when it is compared with chemical or mechanical technologies for the environment [19,20].

Many factors must be taken into account to establish the effectiveness of applying white rot fungi on a large scale, and these are related to the development of the treatment and the economic and environmental viability. Despite the promising results obtained in soil treatments with white rot fungi in the laboratory, the extrapolation of these results to major applications has certain constraints such as the variation in the results according to the treatment design, the part of the fungus inoculated, the variation in reagents and substrates used, etc. Moreover, the chronic toxicity of the fungi and the administration route preclude the application for labeling and in vivo purposes. However, the fungal treatments could help in the degradation of the toxins present in the treated effluents used [21].Techniques involving the treatment of soils or soil washed with effluent by white rot fungi that reach the ecological standards before the saprobe applications should also be estimated. Alternatively, the spores or the mycelia of the strains could be used as fungal insecticides to control the xylophagous pests in the field. The calculation of the recovery of conditions of the treated soils and their comparison with non-treated soils should be evaluated before applying any fungal treatment [22,23].

3.3. Bioremediation of Water Contamination

Pollution of surface and underground water has hazardous consequences for the environment and associated ecosystems and can also impact human and animal health. Pharmaceuticals are increasingly causing environmental contamination via the accumulation of metabolites in water bodies, contributing to growing interest in the use of the fungus responsible for white rot decay for their removal [24]. Even very small amounts of some drugs, like hormonal substances, have biologically negative effects. Every year in industrialized countries, tens of thousands of tonnes of industrial effluents and organic solvents are flushed into water. Delayed or negative effects of biologically active substances from medicine and industry are not yet known or fully recognized. The need of industry and drinking water companies to remove these substances from water supplies efficiently and economically has, therefore, increasingly become the focus of attention. Water treatment using white rot fungi appears technologically mature and holds promise for the future because such solutions are not only able to remove pollutants that are already known but also any toxic metabolites or new environmental threats that may appear in the future [25,26].

The ability of white rot fungi to remove metals and chemical pollutants from natural water bodies has already been demonstrated in geographically distinct sites. Water pollution affects the decomposition of organic matter. Organic pollution is correlated with nutrient pollution. Ligninolytic white rot fungi can grow successfully in nutrient-poor and degraded or nutrient-rich productive ecosystems. In aquatic systems contaminated with toxic substances, the slow growth of white rot fungus may be due to other reasons: white rot fungus may need a longer time to induce its enzyme activities, or it may compete with an adapted community of other decomposers [18]. The nutritional status of a polluted aquatic system appears to be extremely variable: it can be a source of nitrogen and phosphorus, which can, for example, stimulate the growth of white rot fungi if the other conditions are optimal. The decomposition of dissolved organic matter is tightly coupled with the acquisition of nitrogen and other nutrients being deficient in carbon for decomposers. Besides their ability to modify the ecological quality of water bodies, white rot fungi can thus be used to test and help manage the capacity for pollutants to be reused and detoxified in the environment [27,28]. Many harmful substances in water bodies today are not biodegradable due to their chemical structures. The costs and other environmental problems of such steady-state chemical substances are so high that the case for disposal rather than treatment has to some extent been made by contemporary engineers and regulators. The cost of biological treatment of industrial discharges feeding into water bodies can, though, be lower than that of release prevention or post-production treatment of the same chemicals. [29]. Furthermore, even the smallest residual toxicity after release can have an impact on the environment, and late consequences are likely to become apparent at a time when it is too late to carry out proper controls. Sharing water treatment techniques among several companies or entities and getting rid of many different pollutants will decrease both the cost and the potential long-term danger to humans, animals, plants, or ecosystems. Environmental pollutants can also be disposed of by water treatment. Resuspended contaminated solids may contribute significantly to the pollution of marine sediment environments. In all these cases, distributed biological treatment using white rot fungi will help get rid of the problem. More research is needed on the capacity of aquatic ecosystems to assimilate quickly back a high rate of pollutants emanating from a single source [30,31].

4. Challenges and Future Directions

The use of white rot fungus for the bioremediation of contaminated land and water is an appropriate technique for removing a wide range of pollutants. However, there are numerous constraints. One of the main challenges is incorporating the management of fungal activity within the wider environmental management scenario, as this group of organisms, like all fungal species, is extremely responsive to the wider ecosystem in which they grow. Based on contemporary knowledge of fungal physiological behavior, scaling up to large systems seems highly problematic. There are significant technological constraints that make it difficult to take laboratory findings to the field and environmental management. We lack an understanding of species ecology. One of the most significant problems is the 'black-box' effect arising from an inadequate understanding of the complex and often interactive nature of ecology, i.e., we are unable to predict ecosystem responses from the introduction of these organisms in most instances [32]. It is impossible to accurately research the benefits of these organisms without viewing ecological data as a longitudinal tool. To date, there have been almost no studies of the way that pollutants drive and sustain food web dynamics, especially those linked to pollution transformations. There are some future directions for research, which are wide-ranging and involve significant innovations at the cutting edge of biotechnology. The scale of genetic construction of fungi is vast and sophisticated and will require collaboration with scientists working in other fields such as material sciences, biochemistry, ecology and biology, physics, and engineering. We propose a series of future directions involving the use of genetically modified fungi and including the commercialization of contaminants containing volatile organic compounds, other forms of pollutants, large-scale applications in polluted areas, and also community-based approaches to building eco-sanitation systems. Researchers funded as part of research consortia together with industrial sponsors and key policymakers need to work together to formulate and drive forward research programs beyond these, we propose, will be the most productive and effective way forward [33-35].

5. Conclusion

White rot fungus is the main source of lignin-degrading enzymes, which are implicated in the degradation of many toxic organic pollutants. White rot fungi were mainly used for capability evaluations in biodegradation or bioremediation of complex persistent organic pollutants. The white rot fungus has shown an effective role in the degradation of various pollutants and contaminants. Bioremediation and other features of the white rot fungus are a strong useful and sustainable alternative in the cleanup of long-term neglected pollutants worldwide. However, some issues like the application and stability of the white rot fungus should be considered carefully. Interdisciplinary integration and application of the white rot fungus in-site bioremediation have promising potential and sustainable value. There is much yet to be discovered and understood about the ecology of wood-rotting Basidiomycetes and some great challenges remain for research groups who want to improve the practical applicability of these fascinating organisms as remediation agents. In the future, multidisciplinary studies and research approaches, in particular, can combine the knowledge of the microbial ecology of wood-rotting Basidiomycetes, environmental and industrial microbiology, enzyme protein structure biological degradation, and the science of engineering as interface areas of environmental science, ecology, microbiology, and environmental science development and application. There will be approaches that may offer not only fundamental insights about biological decay processes in the environment but also a real alternative between industry and management practices currently available to achieve or strengthen disposal and management strategies of other toxins.

References

[1] Mishra S, Lin Z, Pang S, Zhang W, Bhatt P, Chen S. Recent advanced technologies for the characterization of xenobiotic-degrading microorganisms and microbial communities. Frontiers in Bioengineering and Biotechnology. 2021 Feb 10;9:632059.

[2] Zhuo R, Fan F. A comprehensive insight into the application of white rot fungi and their lignocellulolytic enzymes in the removal of organic pollutants. Science of the Total Environment. 2021 Jul 15;778:146132.

[3] Latif W, Ciniglia C, Iovinella M, Shafiq M, Papa S. Role of white rot fungi in industrial wastewater treatment: a review. Applied Sciences. 2023 Jul 18;13(14):8318.

[4] Kathiravan A, Gnanadoss JJ. White-rot fungi-mediated bioremediation as a sustainable method for xenobiotic degradation. Environmental and experimental biology. 2021 Oct 17;19(3):103-19.

[5] Kumar V, Pallavi P, Sen SK, Raut S. Harnessing the potential of white rot fungi and ligninolytic enzymes for efficient textile dye degradation: A comprehensive review. Water Environment Research. 2024 Jan;96(1):e10959.

[6] Suryadi H, Judono JJ, Putri MR, Eclessia AD, Ulhaq JM, Agustina DN, Sumiati T. Biodelignification of lignocellulose using ligninolytic enzymes from white-rot fungi. Heliyon. 2022 Feb 1;8(2).

[7] Del Cerro C, Erickson E, Dong T, Wong AR, Eder EK, Purvine SO, Mitchell HD, Weitz KK, Markillie LM, Burnet MC, Hoyt DW. Intracellular pathways for lignin catabolism in white-rot fungi. Proceedings of the National Academy of Sciences. 2021 Mar 2;118(9):e2017381118.

[8] Marinovíc M, Di Falco M, Aguilar Pontes MV, Gorzsás A, Tsang A, de Vries RP, Mäkelä MR, Hildén K. Comparative analysis of enzyme production patterns of lignocellulose degradation of two white rot fungi: *Obba rivulosa* and *Gelatoporia subvermispora*. Biomolecules. 2022 Jul 22;12(8):1017.

[9] Algora Gallardo C, Baldrian P, López-Mondéjar R. Litter-inhabiting fungi show high level of specialization towards biopolymers composing plant and fungal biomass. Biology and Fertility of Soils. 2021 Jan;57(1):77-88.

[10] Lodge DJ, Van Beusekom AE, González G, Sánchez-Julia M, Stankavich S. Disturbance reduces fungal white-rot litter mat cover in a wet subtropical forest. Ecosphere. 2022 Feb;13(2):e3936.

[11] Haq IU, Hillmann B, Moran M, Willard S, Knights D, Fixen KR, Schilling JS. Bacterial communities associated with wood rot fungi that use distinct decomposition mechanisms. ISME communications. 2022 Dec;2(1):26.

[12] Rajhans G, Sen SK, Barik A, Raut S. Ligninolytic enzyme system of white-rot fungi: a natural approach to bioremediation and detoxification of azo dyes in textile wastewater. Environ Eng Manag J. 2020 Nov 1;19:1983-2002.

[13] Pozdnyakova N, Dubrovskaya E, Schlosser D, Kuznetsova S, Sigida E, Grinev V, Golubev S, Kryuchkova E, Varese GC, Turkovskaya O. Widespread ability of ligninolytic fungi to degrade hazardous organic pollutants as the basis for the self-purification ability of natural ecosystems and for mycoremediation technologies. Applied Sciences. 2022 Feb 18;12(4):2164.

[14] Sharma KR, Naruka A, Raja M, Sharma RK. White rot fungus mediated removal of mercury from wastewater. Water Environment Research. 2022 Jul;94(7):e10769.

[15] Grelska A, Noszczyńska M. White rot fungi can be a promising tool for removal of bisphenol A, bisphenol S, and nonylphenol from wastewater. Environmental Science and Pollution Research. 2020 Nov;27(32):39958-76.

[16] Chen L, Zhang X, Zhang M, Zhu Y, Zhuo R. Removal of heavy-metal pollutants by white rot fungi: Mechanisms, achievements, and perspectives. Journal of cleaner production. 2022 Jun 20;354:131681.

[17] Chmelová D, Legerská B, Kunstová J, Ondrejovič M, Miertuš S. The production of laccases by white-rot fungi under solid-state fermentation conditions. World Journal of Microbiology and Biotechnology. 2022 Feb;38(2):21.

[18] Chen S, Zhu M, Guo X, Yang B, Zhuo R. Coupling of Fenton reaction and white rot fungi for the degradation of organic pollutants. Ecotoxicology and Environmental Safety. 2023 Apr 1;254:114697.

[19] Bumpus JA. White rot fungi and their potential use in soil bioremediation processes. Soil biochemistry. 2021 May 30:65-100.

[20] Beltrán-Flores E, Pla-Ferriol M, Martínez-Alonso M, Gaju N, Blánquez P, Sarrà M. Fungal bioremediation of agricultural wastewater in a long-term treatment: biomass stabilization by immobilization strategy. Journal of hazardous materials. 2022 Oct 5;439:129614.

[21] Alsukaibi AK. Various approaches for the detoxification of toxic dyes in wastewater. Processes. 2022 Oct;10(10):1968.

[22] Kapoor RT, Danish M, Singh RS, Rafatullah M, HPS AK. Exploiting microbial biomass in treating azo dyes contaminated wastewater: Mechanism of degradation and factors affecting microbial efficiency. Journal of Water Process Engineering. 2021 Oct 1;43:102255.

[23] Bhatt P, Pandey SC, Joshi S, Chaudhary P, Pathak VM, Huang Y, Wu X, Zhou Z, Chen S. Nanobioremediation: A sustainable approach for the removal of toxic pollutants from the environment. Journal of Hazardous Materials. 2022 Apr 5;427:128033.

[24] Gworek B, Kijeńska M, Wrzosek J, Graniewska M. Pharmaceuticals in the soil and plant environment: a review. Water, Air, & Soil Pollution. 2021 Apr;232(4):145.

[25] Mejías C, Martín J, Santos JL, Aparicio I, Alonso E. Occurrence of pharmaceuticals and their metabolites in sewage sludge and soil: A review on their distribution and environmental risk assessment. Trends in Environmental Analytical Chemistry. 2021 Jun 1;30:e00125.

[26] Vaudin P, Augé C, Just N, Mhaouty-Kodja S, Mortaud S, Pillon D. When pharmaceutical drugs become environmental pollutants: Potential neural effects and underlying mechanisms. Environmental Research. 2022 Apr 1;205:112495.

[27] Sharma KR, Giri R, Sharma RK. Lead, cadmium and nickel removal efficiency of white-rot fungus Phlebia brevispora. Letters in Applied Microbiology. 2020 Dec 1;71(6):637-44.

[28] Kaur J, Singh AP, Singh AP, Kaur R. White-rot fungus: an updated review. International Journal of Pharmaceutics and Drug Analysis. 2021 Sep;9(3):202-17.

[29] Rathi BS, Kumar PS, Vo DV. Critical review on hazardous pollutants in water environment: Occurrence, monitoring, fate, removal technologies and risk assessment. Science of The Total Environment. 2021 Nov 25;797:149134.

[30] González C, Wu Y, Zuleta-Correa A, Jaramillo G, Vasco-Correa J. Biomass to value-added products using microbial consortia with white-rot fungi. Bioresource Technology Reports. 2021 Dec 1;16:100831.

[31] Benitez SF, Sadañoski MA, Velázquez JE, Zapata PD, Fonseca MI. Comparative study of single cultures and a consortium of white rot fungi for polychlorinated biphenyls treatment. Journal of Applied Microbiology. 2021 Oct 1;131(4):1775-86.

[32] Pecková V, Legerská B, Chmelová D, Horník M, Ondrejovič M. Comparison of efficiency for monoazo dye removal by different species of white-rot fungi. International Journal of Environmental Science and Technology. 2021 Jan;18:21-32.

[33] Madgett AS, Yates K, Webster L, McKenzie C, Moffat CF. The concentration and biomagnification of trace metals and metalloids across four trophic levels in a marine food web. Marine pollution bulletin. 2021 Dec 1;173:112929.

[34] Alsudani AA, Al-Awsi GR. Role of the Housefly as a Biological Vector for Bacteria and Fungi at Some Slaughterhouses. Pakistan journal of biological sciences: PJBS. 2022 Jan;25(4):353-7.

[35] Córdoba-Tovar L, Marrugo-Negrete J, Barón PR, Díez S. Drivers of biomagnification of Hg, As and Se in aquatic food webs: a review. Environmental Research. 2022 Mar 1;204:112226.