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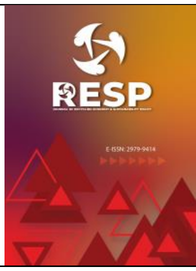

RESP

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Derleme Makalesi ● Review Article

Understanding interactions between toxic waste and fungi: breaking down toxic materials and restore ecosystems

Toksik atık ve mantarlar arasındaki etkileşimleri anlamak: toksik malzemeleri parçalamak ve ekosistemleri eski haline getirmek

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A N A H T A R K E L İ M E L E R

Mantarların yeryüzü için rolü
Zehirli maddeleri parçalama
Ekosistemleri iyileştirme
Zehirli atık
Mantar
Mikoremediasyon

ÖZ

Son on yılda ikincil kirliliğe veya kirlilikle başa çıkmak için aşırı maliyet üzerine önemli bir baskı uygulandı. Birçok çalışma, dünya kirliliğiyle başa çıkmak için uygun maliyetli yöntemleri keşfetmeye çalıştı. Doğada, herhangi bir ikincil kirlilik olmadan doğal olarak kirlilikle mücadelede hayati rol oynayabilecek birkaç tür vardır. Mikoremediasyon bu günlerde dikkat çekiyor, çünkü bu, mantarların değerli bir etki için bir şeyleri parçalama yeteneğini kullanma sürecidir. Sanayide biyoenerji, biyomalzemeler, biyokimyasallar ve biyogübre, biyoatık ve tarımsal ürün artıkları bu tür mantar ürünleri yardımıyla dönüştürülmektedir. Bu nedenle mantarlar her alanda daha fazla ilgi görmektedir. Çoğu mantarın birincil işi, dünyayı sürdürülebilir kılmaktadır. Bakteriler kadar mantarlar da dünya için önemlidir. Bu çalışma, mantarların farklı sektörlerdeki faydalarını incelemektedir. Ayrıca mantarların toksik maddelerle savaşmadaki rolünü de vurgulamaktadır. Bu çalışma aynı zamanda, mantarların biyoremediasyon aracı olarak potansiyelinin kullanılmasına yönelik daha fazla araştırma yapılmasını önermektedir.

K E Y W O R D S

Role of Fungi for earth
Breaking down toxic materials
Restore ecosystems
Toxic waste
Mushroom
Mycoremediation

A B S T R A C T

Significant pressure has been applied to the secondary pollution or over costing to deal with pollution over the past decade. Several studies have tried to explore cost-effective methods to deal with earth's pollution. There are several species in the nature which can play vital role to fight with pollution naturally without any secondary pollution. Mycoremediation is getting attention these days, because this is process of harnessing fungi's ability to break down things for a valuable effect. In industry, bioenergy, biomaterials, biochemicals, and bio-fertilizer are converted from bio-waste and agricultural crop residues with the help of such fungal products. This is the reason fungi is getting more attention in every field. The prime job of most fungi is to sustain the natural world. Along with bacteria, fungi are important for the earth. This study reviews the benefits of fungi in different sectors. It also highlights the role of fungi to fight with toxic materials. This study also recommends further research towards the exploitation of potential of fungi as bioremediation tool.

1. Introduction

Recently, environmental issues need green response because many practices which we apply have secondary pollution (M Akram, 2010; Muhammad Akram et al., 2022; Dan et al., 2020). In developing countries, environmental issues related to waste are being solved by different methods, sometimes they have secondary pollution (Gadd, 1994) and it creates several problems. A biological method is recommended to deal this issue. As several studies are looking to conversion from fossil to bio-based resources with the help of fungi

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because they are attractive vital biodegradable building blocks. In addition, fungi are useful for pollutant removal from the waste (Jones, Mautner, Luenco, Bismarck, & John, 2020). Fungi exposed a higher progression rate than bacteria during 150 year's succession (Wang et al., 2019). Easy ways for removing man-made contaminants from the environmental bodies by fungi have been discovered because they use their enzymatic power to degrade these unwanted chemicals (Akhtar & Mannan, 2020). They are also able to break down waste plastics (which persist in the environment for years) within few weeks (Zimmermann, 2021), and produce sustainable building materials (Ferrari et al., 2015). There should be new advanced study to understand fungal biology and diversity. Aspergillus tubingensis is one of the types, which is typically found in soil. Researchers continue to look at the broad ways fungi can probably redevelop soils and keep moisture in the ground (Buil, Renison, & Becerra, 2021). Recent study found that it can also thrive on the surface of plastics (Lange, 2010). In addition, species of indigenous fungal isolates: A. candidus, , A. clavatus A. iizukae, A. niger, A. ochraceus and A. westerdijkiae, were used for bioaccumulation (Vašinková, Dlabaja, & Kučová, 2021).

Mycoremediation is getting attention these days, because this is process of harnessing fungi's ability to break down things for a valuable effect. In industry, bioenergy, biomaterials, biochemicals, and bio-fertilizer are converted from bio-waste and agricultural crop residues with the help of such fungal products (M Akram, 2010; Muhammad Akram et al., 2022; Inam, Khan, Akram, Khan, Park, et al., 2019; Inam, Khan, Akram, Khan, & Yeom, 2019; Inam et al., 2021). Several projects around the globe are looking to manipulate fungi to break down toxic waste and other man-created contaminants in a lab. Those projects will work effectively in industries, since they feed on trash, they can detoxify global waste and convert it into usable and valuable materials that are non-extractive. This process offer a neat way out for closing the loop on unrecyclable plastic (Meyer et al., 2020). Increased mycological research efforts are needed to unlock this potential (Lange, 2010). This papers focus on fungi, its role of breaking down toxic materials such as waste which create problems to the environment and human. It is very expensive to deal with this problem but this study will review how and where fungi play its role for solving this issue.

2. Role of fungi for breaking down toxic materials

In the past few years, recent studies and new projects have highlighted a very old natural process and role of fungi for cleaning the environment. Some innovations in existing studies (M Akram, 2010; Muhammad Akram et al., 2022; Inam, Khan, Akram, Khan, Park, et al., 2019; Inam, Khan, Akram, Khan, & Yeom, 2019; Inam et al., 2021; Nairn, 2021) have demonstrated that fungus species can save planet so that there should be deep research. Chinese scientists from Kunming Institute of Botany, Chinese Academy of Sciences have found a fungus Aspergillus tubingensis on a rubbish dump in Islamabad, Pakistan. Study has documented that fungus can possibly help us to address the issues of non-biodegradable (Scientists Find Fungus with an Appetite for Plastic in Rubbish Tip, 2017). There are many types of fungi with useful properties (See table 1), which play vital role such as White-Rot Fungi, Marine Fungi, Extremophilic Fungi, Symbiotic Fungi with Plants and Bacteria, Bioremediation Potential of Fungi etc. There are so many more that we don't yet know about them but as human activities and deforestation have destroyed habitats. If this continues then we might never gain access to such species.

Table 1: Role of Fungi/mushroom

Fungi / Mushroom	Role	References
Pleurotus, Agaricus,	Keep antimutagenic or antigenotoxic power against cancer	(Gameiro, 2013) (Kang, Rico, & Lee, 2012)
Pleurotus pulmonarius	Degredation for crude oil	(Olusola & Anslem, 2010)
Pleurotus ostreatus	Oxo-Biodegradable plastic was degraded by Mushrooms	(da Luz, Paes, Nunes, da Silva, & Kasuya, 2013)
Pleurotus pulmonarius	Radioactive cellulosic-based waste with mushroom mycellium was solidified with portland cement	(skander SB, 2012)
Pleurotus florida	Cultivation and Bioconversion of Handmade paper and cardboard industrial waste	(Shweta Kulshreshtha, Mathur, Bhatnagar, & Jain, 2010)
Ganoderma lucidum, Phellinus rimosus, Pleurotus florida and *Pleurotus pulmonaris*	Used as antioxidant and antitumor agent	(Ajith & Janardhanan, 2007)
Pleurotus citrinopileatus	Bioconversion of Handmade paper and cardboard industrial waste	(Shweta Kulshreshtha, Mathur, Bhatnagar, & Kulshreshtha, 2013)
Grifola frondosa Coriolus versicolor, Ganoderma Schizophyllan	Used as medicine to increase immune responses against cancer	(Maehara et al., 2012), (Gao, Dai, Chen, Ye, & Zhou, 2003)

commune, Ganoderma lucidum, Pleurotus, Agaricus,

Applications of fungi and their surprising characteristics for construction materials and degrade pollutants while making circularity truly "biological". Fungi have natural function and it is considered as super-powered decomposers and nutrient dispersers. Their mycelial "root systems" help to almost all ecosystems as the backbone by ingesting nutrients from the plant matter (Deshmukh, Khardenavis, & Purohit, 2016). They decompose and re-dispersing them to other plants and trees (M Akram, 2010; Muhammad Akram et al., 2022; Deshmukh et al., 2016; Inam, Khan, Akram, Khan, Park, et al., 2019; Inam, Khan, Akram, Khan, & Yeom, 2019; Inam et al., 2021; Nairn, 2021). Remediation through fungi is also known as mycoremediation. Mycoremediation tool generally refers to mushrooms and their enzymes because they have natural ability to degrade several types of environmentally persistent contaminants, and convert industrial and agro-industrial wastes into products for a beneficial effect. Mycoremediation through fungi play vital role for waste disposal and ecosystem restoration (Nairn, 2021). Mushrooms have ability to work with waste through mycoremediation (Deshmukh et al., 2016; S. Kulshreshtha, Mathur, & Bhatnagar, 2014).

3. Mycoremediation today: Fungal products and benefits

Mycocycle purposes to support in the change to zero waste by decontaminating toxic building materials such as asphalt and petrochemical-based waste that previously could not be reused. Fungi may be engaged in different types of work for the environment. Earthen building materials have a variety of fascinating characteristics, for example their ability to induce natural regulation of the indoor air humidity. They reduce environmental impact and their low cost. Existing ecological concerns are leading us to contribute greater attention to the environmental impact of building materials. Mycocycle claims that its trash-fed mycelium is fire and water-resistant and can be manufactured into a host of new products such as styrofoam, insulation, packaging and building materials. Fungi may even be able to restore habitat destroyed by wildfire, a vital possibility in an age of climate change. Mycoremediation, particularly through the use of native fungi, is one of many tools for community restoration projects aimed at regenerating areas hit hard by human-made hazards, where erosion, decay, disaster, pollution or mismanagement have caused the ecosystems to falter (Deshmukh et al., 2016). . It's both water-retardant and fire-resistant, making it a perfect intermediary for environmental recovery and disaster prevention. In addition, bioremediation of toxic organics by fungi is considered as the most sustainable and green route for cleanup of contaminated sites. It is an excellent tools in our hands as genomics and bioinformatics. Several studies have discussed the multiple modes employed by fungi for detoxification of several toxic and recalcitrant compounds including prominent fungal enzymes viz., laccases, peroxidases catalases, and cyrochrome P450 monooxygeneses (Deshmukh et al., 2016).

In addition, both bacterial and fungal have been used in several industries such as their microflora throughout the manufacturing process and the impact of extreme humidity, simulating a hydric accident, on microflora development analyzed on the surface of and inside earthen bricks. These results provide a better understanding of microbial proliferation on these materials. Some other industries get benefits from mycoremediation such as decolourisation of dyes in greywater by mycoremediation (Noman, Talip, Al-Gheethi, Mohamed, & Nagao, 2020), Mycoremediation of industrial dyes by laccases (Bhuvaneswari, Subashini, Winny Fred Crossia, & Vijayalakshmi, 2020), Mycoremediation: Expunging environmental pollutants (Akhtar & Mannan, 2020) and for Pharmaceuticals (Dai et al., 2018).

4. Benefits of Fungi for the Environment and Humans

There are several benefits of Fungi for the environment and humans. Fungi are known to be very diverse groups of organisms; about 100,000 species have already been identified. Some of them are microscopic and some of them have large fruiting bodies with underground systems that extend for miles or even hectares. They have a wide range of life forms e.g single celled to very complex multicellular organisms. In addition, some of them are detrimental to humans, animals and plants, such as mildews, canker, ringworm or thrush. Fungi can help tackle global challenges, including climate change and hunger because they are in diverse group of organisms. However, due to its vast diversity, they are are responsible for important ecosystem services, which benefit humans and the overall environment and ecosystem. They are also an important part of soil biodiversity. Fungi are closely interlinked with vegetation and carbon and nutrient cycling. As a result, they are major drivers of soil health and carbon sequestration, among other ecosystem functions. Benefits are given in the table 2.

Table 2 Benefits of Fungi for the Environment and Humans

S.No	Benefits	Remarks	Reference
1	*Human Health*	• Fungi provide health benefits for humans. • Mushrooms possess medicinal properties, which can help prevent diseases • Mushrooms boost our immune system. • Fungi produce antibiotics such as penicillin • Mushrooms figure prominently in the human diet • Mushrooms are rich in nutrients such as vitamin B, C and D, • Shiitake, for example, present antiviral properties and can reduce serum cholesterol. • Other species are known to possess a number of other benefits such as anti-oxidative property and antidiabetic effect.	(Pérez, 2021; Rather, Shahid ul, & Mohammad, 2015; Viana, 2021)
2	*Environmental protection*	• Fungi help in degradation of various pollutants from the environment, such as plastic, pharmaceuticals, personal care products, and other petroleum-based products. • Fungi can act as a powerful tool to reduce environmental pollution. • Fungi help in breaking down organic matter and releasing carbon, oxygen, nitrogen, and phosphorus into the soil and the atmosphere. • Fungi can help in ecosystem restoration by advancing reforestation in degraded soils and act as pest control. • Fungi could play a huge role in sustainability by remedying existing environmental damage.	(Falandysz & Treu, 2017; Kües, 2015; Ohmiya, Sakka, Kimura, & Morimot, 2003; Tortella, Diez, & Duran, 2005; Viana, 2021; Zhao et al., 2019)
3	*Nutrient Cycling*	• Fungi have the ability to transform nutrients in a way that makes them available for plants. • They can also propel nitrogen fixation and phosphorus mobilization, two of the main nutrients required for plant development and productivity. • Some fungi (e.g *Saprotrophic Fungi*) are decomposers which mean that they break down plant and animal debris, thus cycling nutrient and increasing their availability in the soil. • *Ectomycorrhizal fungi* (EcMF) are involved in soil nutrient cycling in forest ecosystems.	(Liu, Li, & Kou, 2020; "Nutrient Cycling by Saprotrophic Fungi in Terrestrial Habitats," 2007; Read & Perez-Moreno, 2003; Viana, 2021)
4	*Carbon Cycling and Climate regulation*	• Fungi are heterotrophic organisms; therefore, they rely on photosynthetic carbon to produce energy. • They break down organic material to get nutrients and energy. • Fungi are important contributors to the soil carbon stock. • Fungi are an integral part of the global carbon cycle. • They play a major part in the carbon cycle through the soil food web (i.e., *mycorrhizal fungi*). • They can move carbon from decomposing material into the atmosphere as carbon dioxide. • Together, plants and fungi perform a process called soil carbon sequestration, capturing carbon from the atmosphere and storing it into the soil for decades.	(Verbruggen, Struyf, & Vicca, 2021; Viana, 2021; Zhao et al., 2019)
5	*Sustainable materials*	• Mycelium, which is the root structure of mushrooms are now being used to replace unsustainable materials, such as plastic, leather-like material biofabrication using fungi, sustainable textiles made from fungi, disposable healthcare products, compostable packaging, synthetic and animal-based products. • The products from Mycelium are biodegradable and require less water and land resources to be produced.	(Alemu, Tafesse, & Mondal, 2022; Heisel et al., 2017; Jones et al., 2020; Joshi, Meher, & Poluri, 2020; Maximino C. Ongpeng,

	• Some of the mycelium-based products already in the market include packaging, clothes, shoes, sustainable leather, skincare products and others.	Inciong, Sendo, Soliman, & Siggaoat, 2020; Travaglini, Dharan, & Ross, 2014; Viana, 2021)

5. Conclusion

This study concluded that Fungi are green response to the earth. Benefits of fungi for the environment and humans have been highlighted such as human health, environmental protection, nutrient cycling, carbon cycling and climate regulation, sustainable materials. In addition, it is a tremendous boon to the idea of using this for mycoremediation process as a real-world solution. Mycoremediation through mushroom cultivation will alleviate two of the world's major problems i.e. waste accumulation and production of proteinaceous food simultaneously. Mycoremediation is getting attention these days, because this is process of harnessing fungi's ability to break down things for a valuable effect. In industry, bioenergy, biomaterials, biochemicals, and bio-fertilizer are converted from bio-waste and agricultural crop residues with the help of such fungal products. Besides producing nutritious mushroom, it reduces genotoxicity and toxicity of mushroom species. Thus, there is a need for further research towards the exploitation of potential of mushroom as bioremediation tool and its safety aspects for consumption as product.

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