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Chapter 10

Myconanoremediation of various environmental toxicants: challenges and future perspectives

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ABSTRACT

The application of nanotechnology in the area of environment has been studied extensively. With the rise in environmental challenges, one of biotechnology's primary concerns is the remediation of the environment. This technique can be called bioremediation and it works to decontaminate the environment by using microorganisms like fungi or their enzymes to break down hazardous compounds into non-hazardous ones. The combination of various particle and organism types, including fungi along with nanotechnology, can offer ecologically responsible alternatives for bioremediation. Nanoparticles are one of the varieties of nanomaterials and have found extensive use in a wide range of applications. Iron oxide nanoparticles were considered a good candidate for nanoparticles that is appropriate for usage in biosystems because of their chemical stability and low toxicity. As a result, components like bioactive nanoparticles, nanocomposites, and nanocatalysts have been used more in the creation of procedures and techniques for cleaning up an environment contaminated with chemical waste.

Keywords: nanosensor, nanoremediation, fungi, nanoencapsulation, nanocatalyst

10.1 INTRODUCTION

Environmental pollution and natural contamination are key issues in society. Innovations are reconnoitered steadily for the remediation of pollutants in the air, water, and soil (Masciangoli *et al.*, 2003). Particulate matter, herbicides, weight metals, pesticides, manures, oil slicks, harmful gases, sewage effluents, and natural mixtures are some of the instances of the many concerning impurities (Vaseashta *et al.*, 2007). As the altered form of environmental contamination can be trying because of the difficulty of the combination of various mixtures, high instability, and low reactivity, late investigations have zeroed in on the utilization of nanomaterial and the advancement of new natural remediation innovation.

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Numerous studies and applications of nanotechnology are being made in the field of the environment. Together with other fields of knowledge, this 'new' scientific field can significantly advance environmental research and application. The advancement and significant growth of nanotechnology will enhance human well-being and contribute to environmental preservation (Kango *et al.*, 2013). The basic sciences, engineering, and their corresponding applications have been revolutionized by this science, which has developed into a multidisciplinary discipline (Lodhia *et al.*, 2010). The decontamination of environments is one of biotechnology's primary concerns in light of the growing environmental issues. This process is known as bioremediation and this process uses microorganisms and their enzymes to break down toxic substances into non-toxic ones to decontaminate the environment.

Nanoparticles are created due to their normal systems for the detoxification of metallic particles through biosystems (Vijay Pradhap Singh *et al.*, 2021). In any case, such cycles are frequently not achievable because of the cost of production, harmful muck synthesis, and the requirement for a persistent contribution of synthetic compounds (Han *et al.*, 2006). In this circumstance, metal-poisoning bioremediations have arisen as an innovation that welcomes nature. A few microorganisms are powerful that eliminate metal particles through biosorption instruments (Volesky, 2022). As a result, they can adapt to grow in abnormal pH, temperature, and nutrient availability conditions and at high heavy metal fixation levels (Anand *et al.*, 2006). Additionally, important to reduction are the infectious microbial structures. A practical strategy for both the biosynthesis of nanoparticles and contemporary bioremediation is bioreduction, one of the crucial cycles of biosynthesis (Malik, 2004; Srivastava *et al.*, 2013).

10.2 SYNTHESIS OF MYCONANOPARTICLES

Each extracellular active organism produces metal nanoparticles. There are numerous studies on fungi that can produce nanoparticles both intracellularly and extracellularly. In intracellular active organisms, the fungal biomass reacts with metals intracellularly and the desired nanoparticles are produced. Whereas in extracellular synthesis the enzyme in the cell wall of the microbes reduces the metal ions and aggregates to produce the nanoparticles. Therefore, extracellular synthesis is mostly preferred (Yadav *et al.*, 2015). When the fungi were exposed to metal ions during extracellular nanoparticle production, the result has been unused enzymes and the generation of very stable myconanoparticles (Kashyap *et al.*, 2013). The fungus species was made to treat extracellularly and the gold nanoparticles have been produced (Du *et al.*, 2011). The extracellular synthesis started after the resolution of $AuCl_4$ was incubated with fungal biomass for 8 h, whereas the golden nanoparticles were obtained when $AuCl_4$ ions reacted with the fungal cell deposit over a period of time. A living thing's biosynthesis may be a time-limited problem that depends on in vivo cell synthesis because there are two fundamentally different extracellular syntheses, namely fast synthesis and slow synthesis (Moghaddam, 2010). Apart from the two processes, an additional process is added to produce the uncontaminated nanoparticles. Hence, the extracellular production process is significantly more favorable than the intracellular method (Kuber *et al.*, 2006).

The extracellular and intracellular fungal nanoparticle synthases have been reported by various researchers (Table 10.1). Fatima *et al.* (2016) stated that the 50 nm silver nanoparticle produced from *Aspergillus flavus* has significant antibacterial activity against pathogenic bacteria and fungi. Myconanoparticles are said to be microbiological agents on agricultural grounds. Ingle *et al.* (2009) reported that *Fusarium solani* is a unique biohazard that has been used in the fusion of silver nanoparticles in a separate investigation.

10.3 BIOSYNTHESIS OF NANOPARTICLES USING FILAMENTOUS FUNGI

Fungi are heterotrophic, eukaryotic cells that could not produce chlorophyll but can produce spores (Veglio & Beolchini, 1997). The fungus is capable of absorbing and accumulating the metals through

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Table 10.1. List of fungal synthesis of nanoparticles.

Fungal Species	Nano Particles	Synthesis	Reference
Mucorhils	Silver	Intracellular	Aziz *et al.* (2016)
Aspergills KF934407)	Silver	Extracellular	Fatima *et al.* (2016)
Coriolusr	Silver	Intracellular Extracellular	Sanghi and Verma (2009)
Fusarium oxysporm	Platinum	Extracellular	Syed and Ahmad (2012)
Aspergillus terreus	Zinc oxide	Extracellular	Baskar *et al.* (2013)
Fusarium solani	Silver	Extracellular	Ingle *et al.* (2009)
Saccharomyces cerevisiae	Cds	Extracellular	Prasad and Jha (2010)
Alternaria alternata	Silver	Extracellular	Sarkar *et al.* (2011)
Aspergillus clavatus	Silver	Extracellular	Verma *et al.* (2010)
Aspergillus flavus	Silver	Intracellular	Vala *et al.* (2014)
Aspergillus fumigatus	Silver	Extracellular	Ranjbar-Navazi *et al.* (2010)
Aspergillus fumigatus	Silver	Extracellular	Bhainsa and D'souza (2006)
Aspergillus niger	Silver	Extracellular	Gade *et al.* (2008)
Aspergillus niger	Silver	Extracellular	Kathiresan *et al.* (2010)
Aspergillus tamarii	Silver	Extracellular	Kumar *et al.* (2012)
Aspergillus terreus	Silver	Extracellular	Li *et al.* (2011)
Aspergillus species	Zinc	Extracellular	Pavani *et al.* (2012)
Cladosporium cladosporioides	Silver	Extracellular	Balaji *et al.* (2009)
Coriolus versicolor	Cadmium sulfide	Extracellular	Sanghi and Verma (2009)
Fusarium acuminatum	Silver	Extracellular	Ingle *et al.* (2008)
Fusarium semitectum	Silver	Extracellular	Basavaraja *et al.* (2008)
Fusarium solani	Silver	Extracellular	Ingle *et al.* (2009)
Fusarium oxysporum	Silver	Extracellular	Ahmad *et al.* (2003)
Fusarium oxysporum	Zirconia	Extracellular	Bansal *et al.* (2004)
Fusarium oxysporum	Silica/titanium	Extracellular	Bansal *et al.* (2005)
Fusarium oxysporum	Magnetite	Extracellular	Bharde *et al.* (2006)
Fusarium oxysporum	Gold	Extracellular	Mukherjee *et al.* (2002)
Fusarium oxysporum f.sp. *lycopersici*	Platinum	Intra-/extracellular	Riddin *et al.* (2006)
Hormoconis resinae	Gold	Extracellular	Varshney *et al.* (2009)
Helminthosporium tetramera	Silver	Extracellular	Shelar and Chavan (2014)
Mucor hiemalis	Silver	Extracellular	Aziz *et al.* (2016)
Neurospora crassa	Gold, silver	Extracellular	Castro-Longoria *et al.* (2011)
Nigrospora oryzae	Gold	Extracellular	Kar *et al.* (2014)
Penicillium brevicompactum	Gold	Extracellular	Mishra *et al.* (2011)
Penicillium citrinum	Silver	Extracellular	Honary *et al.* (2013)
Penicillium citrinum	Copper oxide	Extracellular	Honary *et al.* (2012)
Penicillium fellutanum	Silver	Extracellular	Kathiresan *et al.* (2009)
Penicillium nalgiovense	Silver	Extracellular	Maliszewska *et al.* (2014)
Penicillium purpurogenum NPMF	Silver	Extracellular	Nayak *et al.* (2011)
Penicillium glabrum	Silver	Extracellular	Nanda and Majeed (2014)

(*Continued*)

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Table 10.1. List of fungal synthesis of nanoparticles. (*Continued*)

Fungal Species	Nano Particles	Synthesis	Reference
Phanerochaete chrysosporium	Silver	Extracellular	Vigneshwaran *et al.* (2006)
Phoma glomerata	Silver	Extracellular	Birla *et al.* (2009)
Phoma gardenia	Silver	Extracellular	Rai *et al.* (2014)
Phoma sp.3.2883	Silver	Extracellular	Chen *et al.* (2003)
Pleurotus sajor-caju	Silver	Extracellular	Nithya and Ragunathan (2009)
Thermomonospora sp.	Gold	Extracellular	Ahmad *et al.* (2003)
Trichoderma asperellum	Silver	Extracellular	Mukherjee *et al.* (2008)
Trichoderma viride	Silver	Extracellular	Fayaz *et al.* (2010)
Trichothecium sp.	Gold	Intra-/extracellular	Ahmad *et al.* (2005)
Verticillium sp.	Magnetite	Extracellular	Bharde *et al.* (2006)
Yeast cells	Cadmium telluride	Extracellular	Bao *et al.* (2010)

its metal-binding functional group present in it via a biological metabolism-based mechanism (Sastry *et al.*, 2003). The characteristic of microbes as potent secretors of oxidative enzymes being utilized in metallic nanoparticle synthesis and an additional evaluation of distinct microorganisms makes the fungi seen as a promising tool for large-scale nanoparticle manufacturing (Kitching *et al.*, 2015; Prasad, 2016, 2017). This technique uses fungi to synthesize clean and economical fungal nanoparticles produced either in the laboratory or on a commercial scale (Moghaddam *et al.*, 2015). Through the use of biomimetic mineralization and lowering enzymes either intracellularly or extracellularly, fungi can produce metal nanoparticles and nanostructures (Ahmad *et al.*, 2003).

Due to its operational flexibility and affordability, using fungal dead biomass in the design of nanomaterials is particularly advantageous (Salvadori *et al.*, 2013). The filamentous fungus *Verticillium* sp. mediates the biosynthesis of silver nanoparticles. It has been noted by one of the earliest reviews on the synthesis of nanoparticles by a fungus that was illustrated by Mukherjee *et al.* (2001). *Rhizopus oryzae* has produced other noble metallic nanoparticles as nano gold-bio coupled within the side of the floor cell, with the length of 10 nm fungal lines isolated from wastewater present in a copper mine located in the Amazon region of Brazil as *Hypocrealixii* and *Trichoderma.* Steel or copper nanoparticles are not produced by yeasts (Salvadori *et al.*, 2013, 2014a). So, many fungi revealed a plethora of potential metal nano adsorbents for bioremediation.

10.4 FACTORS THAT AFFECT SYNTHESIS OF MYCO NANOPARTICLE

The factors such as temperature, biomass, concentration, substrate utilization time, pH, and the presence of a specific catalyst all have an impact on the biosynthesis of fungus nanoparticles. These are widely acknowledged as the primary factors that are influencing the shape and size of the nanoparticles (Kashyap *et al.*, 2013). Khan *et al.* (2016) investigated different parameters such as pH, quantity of fungal biomass, temperature, and concentration of nitrate, which could be improved to produce silver nanoparticles produced by *Aspergillus niger.* It has been stated that an increase in the above-mentioned factors can improve both the yield and synthesis of silver nanoparticles. Birla *et al.* (2013) looked into ways to improve the social and environmental conditions that were involved in the synthesis of the nanoparticles from *Fusarium oxysporum* and the produced nanoparticle was silver.

The pH is considered as one of the important factors that help in the improvement of fungal nanoparticles production. The properties and size of nanoparticles that have been synthesized are strongly influenced by the pH (Armendariz *et al.*, 2004; Gardea-Torresdey *et al.*, 1999). The nanoparticles that are synthesized from the species *Aspergillus terreus* and their efficacy against *E. coli* have been discussed by Priyadarshini *et al.* (2014) and the type of nanoparticle produced is gold. The nanoparticles

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have a size range between 10 and 19 nm. Fourier transform infrared spectroscopy (FTIR) has been used for the characterization of the nanoparticles that were synthesized. The regulation of biological activity and the transport of ions were greatly influenced by temperature (Dhillon *et al.*, 2012). Temperatures less than or near 100°C are required for the environmentally friendly method of synthesizing nanoparticles. Fayaz *et al.* (2009) investigated the effect of temperature on the production of plant-based nanoparticles. They discovered that raising the temperature of the reaction can cause a reduction in the size of the nanoparticles but an increase in monodispersity. Another crucial thing influencing the advent of fungal nanoparticles is the incubation period. The response medium's simple composition in large part impacts the type of nanoparticle that is produced and consequently, their quality (Darroudi *et al.*, 2011). Due to combining the debris, the nanoparticle can be stored for an extended period of time, and the quality can be modified by making changes in the incubation time (Baer, 2011).

For the biosynthesis of nanoparticles, there are extensive strategies. Mistreatment of the upstream and downstream processes is regularly combined. Physical strategies, including diffusion, thermal breakdown, irradiation, and so on, are used in the upstream method. In the downstream method, nanoparticles have created the usage of organic strategies which include organic entities and chemical strategies like a chemical discount, seeded growth, chemical technological know-how synthesis, and polyol synthesis (Tikariha *et al.*, 2012). Etching and machining tactics are used in the upstream method, where huge substances slowly decrease to nano-sized substances (Lengke *et al.*, 2011). Fungal nanoparticle synthesis has probably finished the usage of a downstream strategy. The majority of mycosynthesis reactions that bring about nanoparticles resemble backside-up processes due to the fact they encompass substrate oxidation or discount that ends in combined structures. The downstream method has more benefits over different processes due to the fact of a better probability of the usage of structures in nanoscale such as nanotubes, nanorods, nanowires, nanocubes, nanosheets, and so forth with better chemical composition homogeneity. This is regularly carried out because of the method, which is guided especially via lower chemist-unfastened power that moves the synthesized nanomaterials or nanostructures toward the nation of thermodynamic equilibrium (Kashyap *et al.*, 2013).

10.5 FUNGAL DEAD BIOMASS IN THE BIOREMEDIATION PROCESS

Microscopic fungi-like yeast and fungi that are single cellular can grow facultatively anaerobically and are frequently spherical or oval. The last electron acceptor allows yeast to utilize oxygen or a natural substance. This is a priceless trait that enables the fungi to survive and thrive in a variety of situations. It was one of the first attempts to employ organic materials for this purpose, producing CdS nanoparticles intracellularly using *Schizosaccharomyces pombe* and *Candida glabrata* (Dameron *et al.*, 1989). Silver NPs were created using yeast pressure MKY3, while gold nanoparticles were created using the humid marine yeast *Yarrowia lipolytica* NCIM 3589 (Agnihotri *et al.*, 2009). Kowshik *et al.* (2003) extracted Au and Ag's nanoparticles using *Candida guilliermondii* and *Saccharomyces cerevisiae* (Lim *et al.*, 2011; Mishra *et al.*, 2011). As part of the bioremediation process, the yeast develops the ability to synthesize intracellular metal copper nanoparticles with a length of 10.5 nm and round shaped, simultaneously for the metal ions in wastewater (Salvadori *et al.*, 2014b).

There have been few studies on the formation of nanoparticles by contagious dead biomass, such as the growth of fungi. *Hypocrealixii* can deliver extracellular metallic copper nanoparticles as well as intra and extracellular NiO_2 nanoparticles (Salvadori *et al.*, 2015). Extracellular metallic copper nanoparticles were produced by *Trichoderma koningiopsis*. *Aspergillus aculeatus* could produce extracellular nickel oxide nanoparticles in the form of film structures. *Rhodotorula mucilaginosa* could approve intracellular, metallic copper nanoparticles, and appealing Ni/NiO_2 center shell nanostructured nanoparticles in film structures (Salvadori *et al.*, 2016). Because the metal ions cannot biodegrade, substance or real treatment is largely responsible for removing them from contaminated soil and water. The readily available treatment methods are precipitation, particle exchange, electrolysis, and converse membrane partition.

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Today, progressively more research is being done on the bioremediation process and the synthesis of metallic nanoparticles (Gad, 2010). The primary method commonly used for each nanoparticle production and bioremediation using fungal waste biomass includes a process known as biosorption that involves floor-level adherence of ions that are metallic to the wall of the molecular surface (Bishnoi, 2005; Dhankhar & Guriyan, 2011). The chitin, chitosan, glucan, lipid, and phospholipid walls of the fungal biomass are composed of COH groups, amino organization phosphates, lipids, melanin, sulfates, and hydroxides. The great advantage of waste biomass is attributed to its superior ability to bind metals compared to living cells, mathematical modulation of the metallic elimination reactors, lack of need for media and supplements present in solution feed, reusability of the biomass regenerated, and low toxicity (Kapoor & Viraraghavan, 1996; Kogej & Pavko, 2001; Merrin *et al.*, 1998; Salvadori *et al.*, 2013).

Physicochemical factors such as concentration of biomass, pH, temperature, agitation rate, contact time, and metallic ion concentration, on biosorption must be highlighted to improve a green nanoparticle biosynthesis process. The amount of biosorbents is a crucial factor in determining the system's sorbents equilibrium (Hanif *et al.*, 2007; Sari *et al.*, 2007). The pH of the solution indicates how well the organizations are ionized at the molecular floor of the biomass wall (Ozer & Ozer, 2003). The extracellular nanoparticles within the molecular wall of the fungi *Trichoderma koningiopsis* impregnated with copper were confirmed by the transmission electron microscope (TEM) as having a mean diameter of 87.5 nm, with a majority of them being round shaped, and few aggregates of NPs having a mean diameter of 328.27 nm. The bottom of the copper nanoparticle was covered with a capping fabric made of proteins, as revealed by the energy-dispersive and x-ray photoelectron spectra.

10.5.1 Microorganisms used in bioremediation

Microorganisms play a vital part in the dietary process and are a dominant part of life's organic stability. Bioremediation is the process of removing contaminated substances with the service of multicellular organisms such as yeast, fungi, and algae. Microbes can expand in subzero temperatures and maximum conditions of heat in the presence of hazardous compounds or streams of waste. The changeability of microbes and properties that are machinable make them fit for remediation. The activity of microorganisms is determined based on the amount of carbon. In exceptional environments, the monopoly of microorganisms can also be used for bioremediation. *Achromobacter, Arthrobacter, Alcaligenes, Bacillus, Corynebacterium, Pseudomonas, Flavobacterium, Mycobacterium, Nitrosomonas, Xanthobacter*, and other microorganisms are among these (Jaiswal, 2016). Aerobic microorganisms have degradative properties to degrade complex compounds along with *Pseudomonas, Acinetobacter, Sphingomonas, Nocardia, Flavobacterium, Rhodococcus,* and *Mycobacterium*. The above-mentioned microorganisms are used to degrade pesticides, hydrocarbons, alkanes, and polyaromatic compounds. Many microorganisms use carbon from pollutants as a sole representation of strength.

Cardio microorganisms are not often used as anaerobic microorganisms. A growing hobby in cardio microorganisms used for bioremediation of fragmented compounds that are chlorinated, polychlorinated biphenyls, and de-chlorination belong to the solvents trichloroethylene and chloroform, breakdown pollutants to reduce them further.

10.6 SOIL AND GROUNDWATER BIOREMEDIATION WITH METAL NANOPARTICLES

An important natural resource that significantly helps the ecosystem is the soil. Agriculture is a major part of the economy in many countries. The area is polluted by industrial effluents, metals from miners, and home wastes as a result of anthropogenic activities. Excavation and landfilling with incineration have been used to remediate soil, but this process takes a long time and uses items to create toxic gases as well as involves months to complete (Theng & Yuan, 2008). The Green era method of bioremediation currently reduces environmental pollution and the utilization of electricity consumption (Chozhavendhan *et al.*, 2021). Pollutants are continuously released by households and businesses, mixing with the surrounding

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soil. Their greatest attributes are agricultural damage, chemical harm, and landfill leakage. Ex-situ soil cleaning, pump-and-deal operations, chemical oxidation, in-situ thermal treatment, reactive boundary use, and iron treatment are all examples of traditional remediation technology (Hodson, 2010). The cost of soil and groundwater cleanup is frequently quite high, and conventional methods either fail or take a very long time to be effective. Pump-and-deal techniques, according to Bezbaruah *et al.* (2009), require several years of preparation than 1–2 years of actual use.

The containment of the groundwater is indirectly impacted by methods aimed at reducing soil contamination and vice versa. Metallic nanoparticles are being used to complete small paintings on topsoil remediation. Globally, natural or metallic substances that are carcinogenic can contaminate soil and groundwater. Halogenated substances or herbicides are also frequently found in groundwater resources. Chemical pesticides and metals in wastewater can also be purified using nanoparticles. Bootharaju and Pradeep (2010) discussed that the relationship between Hg^{2+} ions and silver nanoparticles is identified with the unification of mercury into the silver nanoparticle. As a way to create nanoparticle alloys, silver nanoparticles can decrease other metals that are apparent. For instance, the development of Pd–Ag and Pt–Ag nanoparticles using the electroplating method serves as an illustration of the development of alloy nanoparticles. Through the use of nanomaterials and colorimetric techniques, several heavy metals, including lead, arsenic, and mercury have been identified. Ono and Togashi (2004) stated that the exhaustion of steel ions mixture and nucleotides in which the Hg^{2+} facilitated the creation of thymine–thymine base pairs.

Using nanomaterials to eliminate insecticides play a favorable solution in significant surroundings because pesticides are currently heavily used in agricultural operations as organophosphorus groups, leaving toxic residues in potable water. Numerous techniques have been improved with nanotechnology in recent decades to reduce the impact of insecticides on the environment. The adsorption of organophosphorus insecticides was discovered by Das *et al.* (2009) using gold nanoparticles produced by the fungus *Rhizopus oryzae*.

10.6.1 Application in environmental areas

10.6.1.1 Heavy metals removal by mycoremediation

Heavy metals are a major problem for the ecosystem because they are frequently released into the earth and groundwater (Gupta *et al.*, 2010). The finding of metals, effective treatment, and heavy metal removal from the water bodies are the more pressing environmental problems. Due to their increased discharge, acute toxicity, non-biodegradable, harm to the environment, and propensity for bioaccumulation, these metals have been a major worry for decades (Feng *et al.*, 2010). These factors could be caused by a variety of activities, including agricultural and manufacturing activities and mineral extraction (Xu *et al.*, 2012). Prominent heavy metals and lead contaminants cause neurological effects on the central nervous system, the brain, and kidneys (Southichak *et al.*, 2006; Xu *et al.*, 2012). The abundant presence of a beneficial group of fungi has an upper hand in binding heavy metals and the elimination system (Cheng *et al.*, 2015).

10.6.1.2 Textile industries effluent treatment by myconanoparticles

The textile industry's effluent water causes major contamination of the environment because of the intake of huge quantities of water consumed in complex processes discarding the difficult ones. The effluent water from the textile industries contains a dye and its by-product which causes deleterious effects like carcer (Saharan *et al.*, 2014). Around 15% of the dye used for dyeing is directly released as effluents into the water and makes them unusable (Mollea *et al.*, 2005).

10.6.1.3 Phenol removal by mycoremediation

The phenol substance, which is harmful even in low quantities, can be ingested, touched, or inhaled, is another significant environmental pollution issue (Huang *et al.*, 2015). Acute phenol exposure disrupts the central nervous system, resulting in coma and collapse (Nair *et al.*, 2008). This contaminant

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is typically found in contaminated rivers, lakes, and industrial effluents. This harmful pollutant is removed from these environments using microbes and nanoparticles (Martnkova *et al.*, 2009). Large concentrations of this contaminant have been discovered in effluent from coal gasification facilities, phenol polymer manufacturing facilities, and petroleum refineries.

Magnetic nanoparticles are being employed frequently in the bioremediation process to create distinct systems that are removed using a peripheral system of magnets. A biological material possesses diamagnetic properties and can enable the efficient and selective separation of materials with magnetic modifications, this capability is crucial for biological applications.

Huang *et al.* (2015) revealed removal of phenol from effluents under the influence of Fe_3O_4 nanoparticles and Pc fungus (BKMF-1767, *P. chrysosporium*). The experiment was carried out at various concentrations of Fe_3O_4 nanoparticles, phenol concentrations, and the oxalate generation process. The binding of two important ligninolytic enzymes, MnP and LiP, released by Pc (BKMF-1767), with the phenol degradation was recorded.

10.6.1.4 Treatment of radioactive pollutants

Li *et al.* (2015) investigated *Aspergillus* with Fe_3O_4 nanoparticles as a successful application in nanobiocomposites to eliminate radioactive uranium oxide ions from uranium $(UO_2)^{2+}$ polluted water. The fungus-derived iron oxide bio-nanocomposite had a better capacity for adsorbing radioactive $(UO_2)^{2+}$ ions, with a 55% increase in comparison to the fungus and a 170% increase in comparison to the Fe_3O_4 nanoparticles. The biological system can create a magnetic adsorbent with the magnetic nanoparticles attached to the fungus and allow for the separation of the fungus from water using a magnet (Li *et al.*, 2015).

Ding *et al.* (2015) carried out a similar experiment with nanocomposites that are bio-based like fungus like *Penicillium* sp. and particles of nano-size Fe_3O_4 (VI) for the elimination of the radionuclides such as U, Th (IV), and Sr (II). This technique was low-cost and during *Penicillium* sp. growth, nano- Fe_3O_4 particles are trapped on the core of the pellet mycelia. The new bio-nanocomposites of fungus- Fe_3O_4 are more economical and environmentally friendly than the other mentioned templates because they may expand evenly on the fungal wall without aggregation. According to their studies, the fungus–Fe_3O_4 has a higher adsorption capacity than *Penicillium* sp., nano- Fe_3O_4, and other adsorbents. Sr (II), U (VI), and Th (IV) had the highest sorption capacities of the fungus–Fe_3O_4 at pH's of 5.0 and 3.0, respectively.

As a result of their capacity to alter or degrade substances, as well as their role as decomposing organisms and recyclers, fungi are extensively studied. However, when combined with magnetic nanoparticles, they create novel systems that might provide exceptional processes that are often absent when simply fungus or nanoparticles are employed. These nanobiocomposites have degraded from the polluted environment using a magnetic separation technique, which makes them potentially effective in the remediation of habitats contaminated with various pollutants, as we have already seen in multiple situations. For usage in remediation contexts, inexpensive technology, quick, and large-scale approaches are crucial.

10.6.1.5 Other pollution removal

Xenobiotic compounds are persistent organic pollutants that are manmade chemicals released from various industrial and agricultural activities. The release of xenobiotic compounds creates an impact on the environment and the ecosystem through the outbreak of adverse diseases (Karthigadevi *et al.*, 2021). Activated mono-adsorbents interact with contaminants over other things at various adsorption sites to absorb the contaminants by flexible chemistry (Kurwadkar *et al.*, 2019).

10.7 CONCLUSION

The amazing potential of using fungal dead biomass as a remediation method in the synthesis of nanoparticles in contaminated areas using hazardous metals left over from industry. Biomass is utilized (biosorption based on bioremediation) through sustainable management and reduced cost of

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operation, which may be employed both on small and bioremediation processes expands, contributing to sustainability in various industries like galvanoplasty industries, foundry, and mining industries. This attractive commercial waste-cleaning method of fungal dead biomass biosorption can produce metallic nanoparticles in an economical and environmentally friendly way, opening up new markets for unique herbal nanotechnologies. Promising dazzling advancements have been shown alongside the effective application of nano remediation in the feature of the current review.

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