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Bioremediation of Various Pollutants in The Ecosystem

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Pollutants are constituents of varieties of ecological hazards which are harmful to human beings and the environment. Bioremediation is becoming more and more popular for getting rid of toxic waste from contaminated locations. Among the many microorganisms used in bioremediation to treat contaminated environments are aerobes and anaerobes. Because pesticides and heavy metals are persistent in the environment, they build up and pollute the food chain. As a result, cleaning up pesticide and heavy metal contaminations must be given top attention. Microbial remediation plays a critical role in both simplifying heavy metal extraction and preventing heavy metal leaching or mobilization into the environment. In this case, bioremediation has been promoted as a viable substitute for conventional methods due to technological advancements in heavy metals based on bacteria. Therefore, several detoxification systems have evolved in some bacteria to combat these hazardous metals' detrimental effects. The ecosystem still faces significant challenges in the removal of heavy metal contamination, which is why this review clarified the significance, mode of action, and future prospects of bioremediation technology.

1. Introduction

Heavy metal (HM) contamination is a major problem since it has spread rapidly around the globe, endangering not only humans but also animals, vegetation, and the environment. The progressive development of the food chain and the infiltration of HMs and metalloids into plants, animals, and people are caused by the bioaccumulation of these substances through various mediums such as air and water (Briffa et al., 2020). Due to the increased use of agrochemicals and artificial fertilizers, modern farming techniques have resulted in agricultural pollution, which has harmed the ecosystem and the environment (Malik et al., 2017).

While the health of living things is greatly impacted by trace amounts of some metals, elevated levels of heavy metals can also have harmful effects (Ahuti 2015; Ahemad 2019). Moreover, heavy metals are difficult for scientists to fully detoxify as they can scarcely be broken down in the soil. The world continues to experience the dangerous effects of heavy metal pollution despite the efforts made to address the problem. Therefore, in order to stop the heavy metal pollution disaster, new technologies like bioremediation should be developed (Raghunandan et al. 2014, 2018). Physico-chemical (traditional) methods such membrane filtration, ion exchange, redox, electrochemical approaches, and precipitation are among the many ways that have been developed to manage heavy metal contamination (Nissim et al., 2018; Qasem et al., 2021).

The disadvantages of conventional methods include their inability to permanently detoxify heavy metals, as well as their affordability and the possibly harmful byproducts produced during the removal process. (Sun et al., 2020). Nonetheless, the traditional approach is thought to be successful in vast regions with low levels of heavy metal contamination as well as in heavily polluted local locations (Huët & Puchooa, 2017). Therefore, scientists face a difficulty in developing new technology that prioritizes the total removal of heavy metals. Among the decontamination techniques, it's interesting to note that microbial remediation of heavy metals has a broad, progressive potential. Microorganisms, particularly soil microbes, are able to withstand elevated concentrations of heavy metals. However, certain microorganisms require specific metals as micronutrients (e.g., $Fe3+$ is practically used by all bacteria, whereas $Fe2+$ is important for anaerobic bacteria) in order to carry out their metabolic processes (Ahemad 2019).

2. Method

The study begins with a comprehensive literature review to gather information on various pollutants, available bioremediation methods, and recent advancements in bacterial technologies for heavy metal detoxification. This approach ensures a solid foundation of knowledge and informs the direction of the research.

Case studies are likely included to showcase real-world applications of bioremediation in cleaning up contaminated sites. These examples illustrate both the effectiveness of bioremediation techniques and the challenges encountered in practical implementations.

Quantitative analysis is conducted through the distribution of questionnaires, often employing Likert scales to measure respondents' perceptions and experiences regarding functional, psychological, and context-specific barriers in EMR use. This method provides numerical data essential for understanding the factors influencing resistance to EMR adoption.

Structural Equation Modeling (SEM) is utilized to analyze the relationships among variables such as functional, psychological, and context-specific barriers, and their impact on EMR use resistance. SEM allows for testing hypotheses and determining the strength and direction of these relationships, offering insights into effective strategies for overcoming resistance.

Descriptive and inferential statistics further enhance the analysis by describing data distributions and testing hypotheses related to factors affecting EMR adoption resistance. These statistical methods provide robust evidence to support conclusions drawn from the research findings.

In summary, this multidisciplinary approach and robust methodology are employed to explore the impact and utilization of bioremediation in addressing pesticide and heavy metal contamination effectively. It aims to contribute significant insights into overcoming environmental challenges through innovative biotechnological solutions.

3. Result and Discussion

THE TOXICITY OF VARIOUS CONTAMINANTS TO LIVING ORGANISMS

Aluminum and some other heavy metals are among the pollutants released into the environment by the agricultural sector's use of fertilizers, pesticides, and herbicides (Ayilara et al., 2020; Prabagar et al., 2021). Similar negative effects on the environment are caused by untreated pollutants from agri-food industry wastewaters that are dumped into river canals and other waterbodies (Siric et al., 2022a; AL-Huqail et al., 2022). Additionally, crude oil contributes significantly to environmental pollution, especially when it leaks during transit, vandalizes pipelines, or spills unintentionally (Ogunlaja et al., 2019). Certain hazardous substances to the nearby environment are discharged during mining, including lead, arsenic, cadmium, and copper (Liu et al., 2020).

During the mining process, several other ecologically hazardous chemicals are employed, such as sulfuric acid and cyanide (Ayangbenro et al., 2018; Orlovic-Leko et al., 2022). Additionally, additional industrial wastes, such as those produced by the cement industry, are found in the top soils and release zinc, copper, and cadmium (Jafari et al., 2019). Pharmaceutical effluents have chromium and lead in them. (Kumari and Tripathi, 2020). Human exposure to air pollution can result in cancer, cardiovascular illness, developmental difficulties, and respiratory troubles, among other health problems. For example, it has been documented that exposure to airborne particulate matter is linked to a higher risk of premature human death (Pope et al., 2019).

Combustion activities release nitrogen oxides, which are serious air pollutants. They aggravate asthma, aggravate respiratory conditions, and induce coughing and dyspnea (Zhao et al., 2020). On the other hand, sulfur dioxide, which is created when fossil fuels are burned, can lead to heart and respiratory conditions like bronchoconstriction, coughing, and shortness of breath. According to a recent study, exposure to sulfur dioxide was linked to a higher risk of respiratory disease-related death in China (Luo et al., 2015).

VARIOUS MICROORGANISMS EMPLOYED AS BIOREMEDIATION AGENTS

hazardous elements can be transformed by microorganisms into less hazardous molecules like carbon dioxide, water, and others. This process is known as mineralization, and it is carried out by other microbes (Mahmoud, 2021; Kumar et al., 2022). It is possible to use algae, fungi, bacteria, etc. in bioremediation. Microbes can be found in strange places where they can take up a wide range of contaminants because they are so prevalent in nature and can use a variety of substrates as a source of carbon (Kour et al., 2022). Additionally, their adaptability to strange surroundings increases their efficiency. As an illustration, psychrophiles flourish in cold temperatures, acidophiles live in acidic settings, and halophiles survive in saline regions (Perera & Hemamali, 2022).

Microbes aid in the mineralization process, converting contaminants into final products including carbon dioxide, water, and other intermediate metabolic compounds. Analogously, immobilization refers to the transformation of substances into a state that renders them inaccessible within the surroundings. Nitrate nitrogen can be converted into organic nitrogen, for example (Pratush et al., 2018). The technique is typically applied to the bioremediation of heavy metals, particularly in situations with significant levels of contamination. Both the in-situ and ex-situ techniques can be used to immobilize a patient (Pratush et al., 2018). According to Ayangbenro and Babalola (2017), the ex-situ approach entails moving contaminated soils from their original position to a different area where they will go through a microbiological process that would immobilize the metal ions causing the contamination. Conversely, the contamination is treated on location when using the in-situ technique (Cao et al., 2020). According to reports, heavy metals that contaminate the environment can be immobilized by microbes like B. cereus and E. asburiae (Fashola et al., 2020a).

SOURCES OF HEAVY METALS

Global industrialization is both a means of supplying the population's needs and exposing the environment to a wide range of pollutants, including heavy metals. According to Aluko et al. (2021), these pollutants have detrimental effects on both the environment and living things. Moreover, even at slightly higher concentrations than required for regular metabolism, these pollutants infiltrate the food chain and have a fatal effect on health (Sayed et al., 2019). According to current data, 66 million people worldwide may be at risk from lead, mercury, chromium, cadmium, and cadmium due to human intervention (Seltenrich, 2015). Global Health In addition, some 150 million people worldwide were impacted by tainted drinking water (Brammer & Ravenscroft, 2009). For the sake of environmental preservation, removing heavy metals from contaminated places is a challenging task.

BIOREMEDIATION OF DIFFERENT POLLUTANTS

Due to their extensive and pervasive use in the environment, organic compounds (OCs), such as flame retardants and biocides, are today seen as a threat to almost all kinds of life on Earth. Microbes have the ability to break down the majority of organic compounds (OCs), including polychlorinated biphenyls (PCBs), polybrominated biphenyl ethers (PBEs), and polycyclic aromatic hydrocarbons (PAHs). The process by which bacteria convert organic substances into residues that are either completely non-toxic or less hazardous is known as biodegradation (Yaashikaa et al., 2022). The microbes eat the organic substrate to obtain energy and organic carbons. When a microbial species is isolated from other microorganisms, it typically does not break down any organic material (Bhatt et al., 2021) and thrives in a community. The transmission of genetic information among microbial species results in the conferment of resistance, chemical-degrading capacity, and tolerance as a result of community microbe interactions. The absence of globally accepted standards and methodologies for microbial identification causes many OC-degrading bacteria to be misidentified (Leung et al., 2019).

MICROBIAL REMEDIATION FOR THE REMOVAL OF HEAVY METALS

Because they contaminate drinking water and the food chain, heavy metals harm the ecosystem and the general public's health (Kumar, et al., 2018).

Bacteria

Depending on the microorganisms, metal species, and surrounding environment, there may be a direct or indirect interaction between microbes and heavy metals. A few factors that influence how bioavailable and mobile heavy metals are for microbial transformation processes are temperature, pH, food sources, and metal ions. Bacteria are easily cultivated in a wide range of environmental circumstances due to their tiny size, rapid growth rate, and ease of cultivation. They have therefore been extensively employed to eliminate dangerous metals from the environment. Functional groups including amino, carboxyl, sulfate, and phosphate groups that are present on the polysaccharide layers of bacterial cell walls are often bound by heavy metals (Khalid et al., 2021; Yaashikaa et al., 2022).

Fungi

Fungi can adsorb heavy metal ions and can survive in environments where heavy metal contamination exists. Through coordination and ion exchange, the presence of chitin, polysaccharides, phosphate, and glucuronic acid in or on fungal cells is essential for the adsorption of heavy metals (Masindi and Muedi, 2018). Adsorption capacity is influenced by a variety of functional groups and ionizable group types; fungal strain sensitivity to the heavy metal ion also affects adsorption rate. Better at biosorbing Pb (II), Aspergillus niger can remove it (Gałwa-Widera & Biochar, 2021). By adsorbing Cr(VI) onto the surface through phosphate, imidazole, hydroxyl, carboxyl, and sulfhydryl groups, Termitomyces clypeatus can detoxify Cr(VI) (Anning et al., 2021). It has been documented that Saccharomyces cerevisiae removes Cu(II) from wastewater sources (Xia et al., 2021). It is well known that trichoderma detoxifies Cd(II) (Van der Veken et al., 2022).

Algae

Studies have shown that algae are an effective means of eliminating heavy metals from contaminated areas. High potency Pb(II) adsorption was demonstrated by research on Fucus vesiculosus (Tripathi et al., 2014). It is well known that Cladophora fascicularis removes Pb(II) from wastewater. According to the Langmuir and Freundlich isotherm models, the maximum adsorption potential was calculated to be 198.5 mg/g (Sen et al., 2019). Cu(II) from aqueous solutions may be detoxified by sargassum marine algae (Basu et al., 2018). The copper adsorption characteristics of Cystoseira crinitophylla were investigated; a maximum adsorption capacity of 160 mg/g was observed (Gaur et al., 2018). Zn(II), Cd(II), and Cu(II) can all be detoxified by Saccharina fusiforme and Saccharina japonica (Bustard et al., 1998).

4. Conclusion

These days, the outstanding benefits of low cost and high efficacy of using microbes to remediate pesticides and heavy metals are used to detoxify contaminants. That being said, there are several limitations to its extensive applicability. To increase the molecular detoxification mechanism's ability to augment pesticide and heavy metal deposition by microorganisms, more clarification is needed. This review has covered a number of technological approaches, including hybrid and microbe-based approaches, that are currently being used to reduce heavy metal contamination in soils and other contaminated environments. It is believed that the environmental microbiome is essential for controlling the biogeochemical cycles that affect soil fertility, climate, and soil structure. From a practical perspective, microbe-mediated bioremediation should receive a lot of attention because bacteria have a number of natural roles and mechanisms that make them an excellent choice for waste management, sustainable agriculture, and polluted site cleanup. There is still potential for improvement even with the use of microbes to increase the efficiency of HM removal from the soil.

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