Phytoremediation: A Green Approach to Fight Heavy Metal Contamination in the Soil

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Literature review

Abstract: *The purpose of this review paper is to present the extent and importance of the problem of heavy metal contamination in the environment, most notably in the soil. Phytoremediation is one approach for tackling this issue through the use of leafy plants for the uptake of excess heavy metals from the soil. An example of such plant species are the members of the Brassica genus which, when put in contact with different heavy metals present in soil, will act to remove them and therefore decrease their concentration. Heavy metals that are mostly observed in this context were copper, lead, and zinc, because of their abundance in different ecological environments. Different plants in general have a satisfactory phytoremediation potential, depending on the plant part, heavy metals in question, as well as used remediation technique. Therefore, introducing Brassica spp. into use would be a good way of enhancing the quality of the environment.*

Keywords: Brassica spp., Bioremediation, Heavy metals, Phytoremediation, Pollution.

1. Introduction

Heavy metal pollution is a growing concern throughout the recent period. Possible solutions were suggested through different scientific methods that require the natural science approach to solve these issues. Bioremediation, a technique used to face the problems regarding environmental contamination, is one of the solutions that scientists aim to implement. This is a method that recycles the harmful waste materials while avoiding any damage to the nature. Additionally, the recycled harmful materials can become a new source of food for different microorganisms. Oil spills are an example of the hazardous material that causes major issues in the ecosystem. Bioremediation is using different microorganisms to resolve these issues, as they are capable to survive different environmental conditions due to their metabolic characteristics [1-3].

The twentieth century was the period in which heavy metals became a major issue in the world because of wars, industrialization improvement, and intensive usage of large-scale heavy metals in different industries. Bioremediation faces this challenge to sustain suitable life conditions for humans [3,4].

Water and soil are the main parts of the Earth, as well as the main factors upon which the quality of the food depends, meaning they should be especially well-protected. Phytoremediation is a technique in which plants are used to eliminate the hazardous materials that are a threat to the soil, water, and air. A variety of physical and chemical methods are used so that metalloids and heavy metals could be removed, whereby a variety of potentially dangerous outcomes could be minimalized [5,6]. This branch of research uses several methods in which the soil quality could be improved, including chemical leaching, soil replacement, and electrokinetic remediation, that are all capable of soil remediation. Phytoremediation is therefore an appropriate green technique that works on eliminating all contaminants and its success depends on the type and concentration of the toxin that is remediated by the plants [7,8].

Different plant species can act to remove the toxic concentrations of zinc (Zn) and copper (Cu), with the most prominent example being the plants from the *Brassica* genus. Certain plant- growth-assisting (PGP) bacteria are capable of enhancing the growth of plants when dealing with different heavy metals. Other plants that were also used in bioremediation studies are *Micromeria cristata, Mentha spicata* var. *crispa, Mirabilis rotundifolia,* and *Celosia argentea.* When studying the phytoremediation capacity of plant species, different factors are analyzed, including the remediation capacity for different parts of the plant, its height, tolerance index, and root and shoot biomass [9,10]. An additional factor that must be accounted for is not to overwhelm the plant with the potentially toxic metals (PTMs). Long-term effect of toxic metals is observed at increased temperatures, through measurement of biochar production during pyrolysis of biomass in the absence of oxygen. This represents an oxidation resistance whereby small amounts of carbon (C) are lost. As a safe strategy for organic waste management, thermal conversion of phytoremediation plant waste material into biochar can be used. At 350, 550, and 750 degrees Celsius, a potential phytoremediation plant, *Silphium perfoliatum*, was pyrolyzed for biochar synthesis. The oxidation resistance and long-term leaching risk of PTMs in the produced biochar were examined. With the increased pyrolysis temperature, PTMs in biochar might change into more stable and less hazardous forms, according to the findings [11].

Brassica plants are popular species in plant technology research because they are used for different purposes, such as phytoremediation, agriculture, and horticulture. These plant species are used to reduce symptoms that are caused by specific diseases because plants are able to take up these toxins and reduce the harmfulness towards humans. They reduce the concentrations of insect pests that could potentially cause damage to some plants [11,12]. In addition, *Brassica* spp. are used as excellent phytoremediation tool. Heavy metals can appear in the environment as a natural process, for example due to volcanic eruptions or weathering of rocks but can also be man-made. *Brassica* spp. are used in resolving these issues because these plants can adapt to different pH and heavy metal concentrations in the soil, giving them an advantage in further growth and heavy metal uptake [13].

2. Methodology

For this review paper, 25 original research papers were analyzed. All articles were obtained for the purpose of determining the effects *Brassica* spp. when in contact with different heavy metals. The databases from which research data were obtained are Elsevier, PubMed, Springer, and PubMed Central (PMC). In order to be included in this review, the article had to present original research or literature review on phytoremediation capacity of *Brassica* spp., the used species and heavy metal(s) must be clearly identified, used heavy metal concentrations had to be specified, and the experiment outcomes must be clearly presented. This review is a summary of obtained data with the goal of identifying experimental setup in which *Brassica* spp. can act as potent phytoremediator. The time period in which original studies were conducted is from 2014 until 2021, with the conclusion that the usage of *Brassica* spp. for this purpose has increased recently compared to previous period.

2. Phytoremediation and its Applications

A specific critical concentration of each heavy metal is known at which it becomes a serious threat for the environment (Table 1). Lead (Pb) is a toxic heavy metal that can cause extensive health problems to humans. It can be recognized by its silvery texture and has the capability to tarnish with air. A previous study that was done has concluded that approximately 53,500 children between ages of 1-5 will have elevated blood lead concentrations because of the poisoning in their early childhood. Children under the age of one year had consistently lower rates of increased blood lead concentrations than children aged one to four years, owing to the fact that lead is a cumulative toxin and that young children are more mobile and engage in more hand-to-mouth activities than babies. In general, the percentage of individuals with increased blood lead levels is not as severe [14,15]. Lead poisoning has a major impact on human health, since it can cause anemia, among other problems. Lead poisoning experiments in rats showed that if lead nitrate concentration was too high, the rats were suffering from diabetes [16].

Table 1. A comparison of soil concentration and critical concentration of the most commonly encountered heavy metals (taken and adapted from [25]).

Heavy Metal	Source	Concentration in soil (μg/g)	Critical concentration in soil (μg/g)	References
Copper (Cu)	Industrial waste, landfills, agriculture, and phosphate fertilizers	50-100	100	[14,25]
Lead (Pb)	Industrial activities, fertilizers, burning fossil fuels, pesticide manufacturing, and fertilizers	150-200	100	[15,25]
Zinc (Zn)	Mining, mine tailing, discharges of wastes, coal, and fly ash	100-200	100-150	[21,25]

Copper (Cu) is one of the most common heavy metals that are found in waste waters, but it does not disturb certain physiological systems as lead does (Table 1). Copper is needed for proper functioning of human organs and tissues, and can be found in higher concentrations in kidneys, brain, and liver. The essential copper intake in humans is one to 100 mg/day; however, an increased copper concentration in the body is toxic. Copper poisoning can be induced by eating acidic meals cooked in uncoated Cu cookware, or by drinking water or other environmental sources containing too much Cu [17]. Heavy metals not only select for metal resistance, but they can also co-select for antibiotic resistance, which is a major public health problem. The tests have been performed to measure the heavy metal effect on bacterial resistance in water, where Cu and zinc (Zn) were among the heavy metals found to contribute to this phenomenon, due to their excessive presence in water samples [18].

Zinc is therefore another source of contamination found in mining areas (Table 1). The mining areas were analyzed in China, and they showed that the heavy metal concentrations were above average, meaning that the ecological situation could be threatened if not treated properly. Zn concentration was ranging from 60.44 mg/kg to 4,946.59 mg/kg, and an average of 736.55 mg/kg, which is much above its critical concentration value. Other two heavy metals were also analyzed in the study. Pb concentration was ranging from 54.60 mg/kg to 10,053.90 mg/kg and an average of 777.24 mg/kg, while Cu had concentrations between 6.06 mg/kg and 120.52 mg/kg and an average of 24.18 mg/kg, therefore being the only heavy metal within the accepted limits of concentration in the environmental samples. Such high heavy metal concentrations are also potential sites of phytoremediation with adequate plant organisms. The soil samples in this investigation were neutral to slightly acidic, according to some of the findings. Cu and nickel (Ni) concentrations in the soil were found to be within acceptable limits, while Pb, cadmium (Cd), and Zn concentrations were greatly above the Chinese Soil Environmental Quality Standard's equivalent limitations [21, 22].

In one previous research, *Brassica* was used in the form of a grown plant samples from different areas of Zhejiang province, China, together with the soil sample in which it was growing. Plant samples were washed with tap water and then in distilled water and later tested for the uptake of heavy metals of different concentrations. The salts of heavy metals were detected from the soil in which *Brassica* was grown. The detection limits for Cd, Pb, arsenic (As), mercury (Hg), and Cr were 0.001, 0.005, 0.002, and 0.01 mg/kg, respectively. The Chinese cabbage (*Brassica campestris* spp. Pekinensis), pakchoi (*Brassica chinensis* L.), celery (*Apium graveolens*), cherry tomato (*Lycopersicon esculentum*), cucumber (*Cucumis sativus*), cowpea (*Vigna unguiculata*), pumpkin (*Cucurbita pepo* L.), and eggplant (*Solanum melongena*) were used in the mentioned experiment. The average values of Cd, Pb, and Cr in 97 vegetable samples, including those from the *Brassica* family, were 0.020, 0.048, and 0.043 mg/kg, respectively [22].

In another study, plants were also tested in order to check for their heavy metal absorption abilities. The plants have been tested on different types of soil that contained a variety of heavy metals, namely Hg, Pb, Cd, and Cr. The cabbage plant from the *Brassica* genus that has been tested was from China, where the heavy metals have a major impact on the soil and water contamination. The procedure was to carefully wash and prepare the entire vegetables with deionized and tap water so that all excess materials could be removed. The samples were digested in a protocol using nitric acid and hydrogen peroxide, followed by the transfer of the digests into a volumetric flask and filtration. In order to determine heavy metal concentration in the plants, an inductively coupled plasma-mass spectrometry was used. The bio- concentration factors (BCF) have been used to compare the pollutant concentration in the soil environment with the plants that contained the pollutant residues. The results of this study imply satisfactory phytoremediation capability of *Brassica* spp., while the best results were more generally obtained with leafy vegetables. Metal concentrations in vegetables and the soils in which they grew demonstrated a strong positive association, especially for green plants like cabbage. The BCF for Cd is higher than that of Pb and Cr. As a result, heavy metal pollution in leafy and stem vegetables, notably Cd, should be given more attention [22].

The process of phytoremediation encompasses several different processes, some of them being particularly useful in clearing the metal waste from the environment, while others are aimed at dealing with other types of waste such as organic pollutants. For example, the process of rhizofiltration is aimed almost exclusively at plant roots adsorbing and absorbing metals as pollutants, whereas phytodegradation is a process of degradation of organic pollutants, such as DDT [5]. Different species of plants were used for processes of phytoremediation involving removal of metal pollutants, and a summary of their main characteristics can be found in Table 2, in particular with respect to *Brassica* species, which is in focus of this review.

Table 2. Advantages and disadvantages of different plant species used for soil bioremediation with focus on metal decontamination.

Process in phytoremediation of metal pollutants	Process explanation	Typical pollutants	Measurement	Plant used and its characteristics (advantages or disadvantages)
Phytoextraction	Uptake of contaminants by plant roots and their accumulation in shoots	Cd, Pb, Zn	Shoot metal concentration and shoot biomass [26]	*Brassica juncea* - accumulates metals to a lesser degree but produces more biomass above ground. This is a disadvantage because it makes the plant less safe to handle when disposing large amounts of the accumulated metals, as well as costly due to large biomass *Trifolium spp.* – offer multiple harvests throughout the growth time, high adaptability to stress conditions [27]
Rhizofiltration	Roots absorb and adsorb pollutants (mainly metals)	Zn, Pb, Cd,	Not quantified directly	*Zea mays* - a high potential for absorption and accumulation of mercury [29] *Brassica campestris* – high potential for accumulation of uranium [30]
Phytostabilization	Reducing the bioavailability of pollutants in the environment (e.g., through changing its oxidative state)	Cu, Cd, Cr, Ni, Pb, Zn	Oxidative state of the metal in question	*Brassica juncea* – good tolerance for PTE toxicity *Dactylis glomerata* – functions better in a less contaminated soil. Both plants work better through their roots, rather than shoots [31]

4. Conclusion

Brassica spp. is offering very promising results regarding its ability to remove heavy metal contaminants from the environment. It was shown effective for absorbing different metal concentrations and different elements. A variety of plants are promising for the purpose of reducing heavy metals in the environment by means of phytoremediation. Since this technique is generally getting more interesting for the research community, more experimental results for *Brassica* spp. and other plant species are necessary to assess their optimum usage conditions as phytoremediators. In addition, certain areas of the world are representing the heavy metal concentrations significantly exceeding the critical values. Plants are an excellent tool to reduce the heavy metal concentrations and create a healthier ecological environment for microorganisms and animals. Further research is needed to improve the usage of phytoremediation technique for tackling this issue.

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