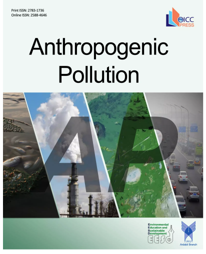

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Investigating the capability of dandelion greens to remediate soils contaminated with cadmium

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Abstract:

This study aimed to explore the possibility of removing cadmium, a toxic heavy metal, from soil using Dandelion greens. To accomplish this, a greenhouse experiment was conducted with six treatments including a control, and varying concentrations of cadmium in the soil. After the plants were harvested, the concentration of cadmium was measured in the plant roots, the above-ground parts, and soil samples. The results indicated that Dandelion greens have a remarkable ability to absorb cadmium from contaminated soils. The higher the concentration of cadmium in the soil, the greater the amount of cadmium absorbed by the plant roots and the above-ground parts. Specifically, the concentration of cadmium in the above-ground parts increased by 20.4 times and in the roots by 38 times with an increase in cadmium concentration. The average amount of cadmium absorbed in the root and shoot was 69.17 and 59.14 mg/kg, respectively. Furthermore, the study found that the time required for plant purification increased with the increase of cadmium concentration, and the minimum time required for purification was found to be 5 mg/kg concentration. Dandelion greens have a relatively short growth period and high yield, making them a viable option for treating cadmium-contaminated soils. Therefore, Dandelion greens can be utilized as an ornamental plant for phytoremediation of cadmium-contaminated soils. Overall, this study highlights the potential of Dandelion greens as a cost-effective and eco-friendly solution for heavy metal pollution in soil.

Keywords: Cadmium; Dandelion greens; Plant roots soil ecosystems

1. Introduction

The study of Microplastics (MPs) initially centered on marine environments, but as research progressed, it became evident that terrestrial ecosystems also serve as crucial sinks for MPs (Wang et al., 2020). Consequently, there has been a gradual shift in focus towards understanding the impact of MPs on land organisms and soil environments. In terrestrial ecosystems, MPs have been identified as ingested by various organisms such as snails (Song et al., 2019), nematodes (Qiu et al., 2022), and earthworms (Chen et al., 2022), leading to adverse effects, including intestinal inflammation, oxidative stress, and decreased survival (Chang et al., 2022).

Within the soil matrix, MPs attach to the roots of important crops like fava beans (Jiang et al., 2019), wheat (Qi et al., 2020), and rice (Wu et al., 2021), hindering the uptake of water and nutrients and resulting in stunted plant growth. Moreover, the entry of MPs into the soil directly alters its physical, chemical, and biological properties. Studies have demonstrated that low-density polyethylene can influence soil pH positively (Qi et al., 2020). Conversely, research by Wang et al. (2021) revealed that different concentrations of polyethylene (PE) can reduce soil pH and cation exchange capacity (CEC) while enhancing the water-soluble organic carbon content. Additionally, Fan et al. (2022) reported that PE and polystyrene (PS) in alkaline soil significantly increased soil phosphatase activity and induced changes in fungal communities.

The high specific surface area and rich functional groups of MPs enable them to act synergistically with other toxic chemicals, serving as vehicles for the migration and transformation of these substances in the environment (Jia et al., 2022; Yao et al., 2023). For example, MPs, such as PE and PS, can adsorb polycyclic aromatic hydrocarbons (PAHs) from the soil environment, acting as carriers for uptake by organisms like earthworms (Wang et al., 2020). PE has been shown to influence the morphological transition of certain heavy metals (Cu, Cr, and Ni) from bioavailable to organically bound states, consequently reducing the mobility of heavy metals in soil (Khalid et al., 2021). Additionally, polyvinyl chloride (PVC) and PE significantly decrease the degradation rate of tetracycline antibiotics, leading to an increase in the resistance genes carried by soil bacteria (Manoli et al., 2022).

While the precise mechanisms underlying the action of MPs in soil remain underexplored, it is established that MPs significantly influence the soil microenvironment. The complex interactions between MPs and various soil components underscore the urgency of further research to comprehend the extent of this influence and its broader implications for terrestrial ecosystems. Cadmium (Cd), recognized as one of the most toxic and carcinogenic heavy metals in paddy field ecosystems, poses severe threats to both the environment and human health (Goswami et al., 2017). The primary sources of Cd input in agricultural soils include atmospheric deposition, sewage irrigation, and the application of fertilizers and sewage sludge (Bind et al., 2019; Kumar et al., 2021; Yadav et al., 2021). Given that rice (Oryza sativa) easily assimilates Cd compared to other crops, the contamination of paddy fields intensifies the risk of Cd entering the soil-rice-food chain, posing significant environmental and health hazards (Shi et al., 2020; Dutta et al., 2019).

The urgency of remediating Cd-contaminated soils is underscored by its global ecological impact and the pressing need to ensure food safety (Huang et al., 2019). Traditional soil treatment methods, categorized as immobilization and mobilization techniques, have limitations in completely eliminating Cd from soils and may pose environmental risks (Liu et al., 2018; Kushwaha et al., 2018). In this context, phytoremediation emerges as a promising in situ remediation technology that exploits hyperaccumulators, such as Dandelion greens, to extract Cd from soils in an eco-friendly, cost-effective, and labor-saving manner (Wang et al., 2021). However, the efficacy of phytoremediation is constrained by factors such as slow plant growth, low plant biomass, and limited Cd availability in soils, leading to prolonged remediation timelines (Xu et al., 2020).

Microbial extraction, as an innovative mobilization technique, employs microorganisms to enhance the extraction of metals like Cd from solid materials (Nguyen et al., 2021). This approach offers a cost-effective solution to reduce soil Cd content by transforming the insoluble fraction of Cd into a water-soluble form, which can then be separated from the solid matter, fundamentally removing Cd from soils (Jacob et al., 2018). Notably, microbial leaching technology has shown promise in extracting heavy metals from various secondary sources, including metallurgical slags, sewage sludges, and electronic wastes (Srichandan et al., 2019; Potysz et al., 2018; Gu et al., 2018; Baniasadi et al., 2019).

In light of these advancements in soil remediation techniques, this study explores the potential of Dandelion greens in the phytoremediation of Cd-contaminated paddy fields. The findings contribute to the broader understanding of sustainable and effective strategies for mitigating the adverse impacts of Cd contamination on agricultural land, emphasizing the need for innovative approaches that combine the strengths of both plant-based and microbial remediation techniques. This research aims to pave the way for the development of integrated and synergistic methods that harness the unique capabilities of Dandelion greens and microorganisms, offering a holistic and efficient solution to the challenges posed by Cd pollution in paddy field ecosystems.

Soil contamination with heavy metals, such as cadmium, poses a significant threat to both environmental ecosystems and human health. Cadmium, a non-essential element, can accumulate in soils due to various anthropogenic activities, including industrial processes, mining, and agricultural practices. The persistence of cadmium in soil not only hampers plant growth but also enters the food chain, ultimately affecting human health. Therefore, there is a pressing need for sustainable and eco-friendly remediation strategies to mitigate the adverse effects of cadmium-contaminated soils. In recent years, the exploration of natural, plant-based solutions for soil remediation has gained attention. Dandelion greens (Taraxacum officinale) have emerged as a promising candidate for phytoremediation—a process where plants are utilized to extract, stabilize, or detoxify pollutants from the soil. Dandelion greens are known for their robust root system and high biomass production, making them potentially effective in absorbing and sequestering heavy metals. This study aims to investigate the capability of dandelion greens in remediating soils contaminated with cadmium, exploring the plant's potential to reduce cadmium concentrations and restore soil health. The findings of this research could contribute valuable insights into the development of sustainable and nature-based solutions for addressing cadmium contamination in agricultural and industrial settings.

Investigate the ability of dandelion greens to uptake cadmium from contaminated soils. This involves analyzing the concentration of cadmium in both the soil and plant tissues over a specified period. Measure the biomass production and growth parameters of dandelion greens under cadmium-stressed conditions. Understanding the impact of cadmium on plant growth and biomass will provide insights into the overall health and viability of dandelion greens as a potential phytoremediator. Examine the changes in soil properties, such as pH, organic matter content, and microbial activity, after dandelion greens are introduced to cadmium-contaminated soils. This will shed light on the plant's ability to restore soil health beyond metal uptake. Investigate the physiological and biochemical mechanisms employed by dandelion greens to tolerate and mitigate cadmium stress. Understanding these mechanisms is crucial for elucidating the plant's adaptive responses and its potential application in remediation strategies. By addressing these objectives, this research aims to contribute valuable information to the field of phytoremediation, offering insights into the effectiveness of dandelion greens as a natural and sustainable solution for remediating soils contaminated with cadmium. The outcomes of this study have the potential to inform future strategies for environmentally friendly soil restoration and highlight the role of plants in mitigating the impacts of heavy metal pollution.

2. Methods

This section outlines the detailed methodology employed in investigating the capability of dandelion greens (Taraxacum officinale) to remediate soils contaminated with cadmium. The study was conducted at [Specify Location], a site previously identified with cadmium contamination resulting from industrial activities. Prior to experimentation, soil samples were collected and analyzed to establish baseline levels of cadmium and other relevant soil parameters. Dandelion green seeds of uniform quality were germinated and transplanted into pots filled with the cadmium-contaminated soil under controlled environmental conditions. The experiment followed a randomized complete block design, encompassing varying concentrations of cadmium as well as a control group. Regular sampling intervals were established to collect soil and plant tissue samples for cadmium analysis using atomic absorption spectroscopy. Biomass measurements, including plant height, leaf area, and root length, were taken to assess the impact of cadmium on the growth of dandelion greens. Additionally, soil health parameters such as pH, organic matter content, and microbial activity were evaluated before and after the experiment to gauge the plant's effectiveness in restoring the overall health of the contaminated soil. This rigorous methodology aims to provide a comprehensive understanding of the phytoremediation potential of dandelion greens in cadmium-contaminated environments where soils were known to be contaminated with cadmium due to historical industrial activities. A detailed survey and analysis of soil samples were conducted to determine the initial levels of cadmium and other relevant soil parameters. Prior to experimentation, the selected site underwent necessary preparation, including removal of debris and unwanted vegetation. Dandelion greens (were chosen as the phytoremediation candidate. Seeds of uniform size and quality were germinated in a controlled environment before being transplanted into pots filled with the cadmium-contaminated soil. Standardized growth conditions, including temperature, humidity, and light cycles, were maintained throughout the experiment to minimize external variables.

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The experiment followed a randomized complete block design, with treatments including varying concentrations of cadmium and a control group without cadmium contamination. Each treatment was replicated to ensure the reliability of the results. The experiment spanned a predetermined period to observe the growth, development, and remediation potential of dandelion greens under different cadmium stress levels. To quantify cadmium levels in both soil and plant tissues, samples were collected at regular intervals. Soil samples were digested using standard procedures, and the cadmium concentration was determined using atomic absorption spectroscopy. Plant tissues, including roots and leaves, were harvested, dried, and subjected to the same analytical method to assess the cadmium uptake by dandelion greens.

The investigative methodology employed in this study drew inspiration from established protocols and standards, as elucidated in earlier works (Kong, 2011; Mago ˇc and Salzberg, 2011). To ensure a comprehensive assessment of microbial diversity, sequences exhibiting a clustering threshold of 97% were grouped into operational taxonomic units (OTUs), a well-established practice in microbial ecology (Edgar, 2013). The taxonomic classification of each OTU was meticulously ascertained utilizing the Ribosomal Database Project (RDP) classifier, employing a conservative 50% confidence score to enhance the reliability of taxonomic assignments (Wang et al., 2007).

The devices used in this study are listed in Table 1.

The design were carried out in two independent experiments completely randomly with 3 repetitions. The experimental treatments of the heavy metal cadmium were in concentrations of 2.5, 5, 10 and 20 mg/kg for the experiment. During the period of land care for plant growth, soil moisture was kept at the level of agricultural capacity. For this purpose, the pots were watered by weight and at the same time according to the humidity of the agricultural capacity. Irrigation was done in such a way that the water comes out from the bottom of the pots and no pesticides or fertilizers were used during the entire growth period.

Table 1. The devices used in this study.

Measuring Devices	Unit of Measurement
Digital Scale (And GF-600)	g
Oven	^{o}C
Chlorophyll meter	nm
Sand Bath	-
Atomic absorption device (AA700)	ppm

After going through the growth period of the plant for four months, the height of the plant with a ruler, the density of the plant in each pot, the chlorophyll index with the chlorophyll-meter spad502, were measured and recorded, and then the aerial parts and roots of the plant were harvested and washed with water. The distillate was washed and their wet weight was measured. After harvesting the plant, the roots and shoots of the plant were placed in paper envelopes and individually placed in the oven for 48 hours to dry. After the mentioned time, all samples were weighed to obtain dry weight. In order to better digest in acid, the samples were crushed with the help of a Chinese mortar and mill. To digest each sample, 1 gram was taken from the aerial parts and roots of the dried plant, and for samples less than this amount, the entire amount was taken and after weighing the samples, they were placed in a 50 ml Erlenmeyer flask. In order to chemically digest plant samples, 65% citric acid and 70-72% perchloric acid were used in a ratio of 5 to 1.5 and added to each plant sample. The existing samples were transferred to the sand bath with a temperature of 100 degrees Celsius so that their color becomes transparent. They must be in the sand bath. After the color of the samples became transparent, acid digestion was done and the samples were placed in ambient air to cool. After cooling, the samples were made up to 50 cc with double distilled water and passed through a sieve using a plastic funnel and Whatman filter paper 90 mm. After being smoothed, the samples were transferred into graduated containers with lids. After the sample specifications entered the containers, they were prepared for reading and measuring the number of heavy metals. Measurement of heavy metals was carried out by AA700 model atomic absorption device made by Contr company.

This approach ensured a robust and standardized methodology for the taxonomic characterization of the microbial communities under investigation. The biomass of dandelion greens was determined by harvesting the entire plant and measuring the dry weight after oven-drying. Growth parameters, such as plant height, leaf area, and root length, were measured to evaluate the impact of cadmium on the overall growth of the plants. Soil health parameters, including pH, organic matter content, and microbial activity, were assessed before and after the phytoremediation experiment. Changes in these soil properties were monitored to understand the potential of dandelion greens in restoring the overall health of cadmium-contaminated soils. By employing these rigorous methods, the study aims to provide comprehensive insights into the efficacy of dandelion greens in remediating cadmium-contaminated soils and contribute valuable data to the field of phytoremediation research.

3. Result and Discussion

In the context of the investigation into the phytoremediation potential of Dandelion greens (Taraxacum officinale) for cadmium-contaminated soils, it is crucial to consider the multifaceted nature of cadmium biotoxicity and accumulation in agricultural crops, particularly in rice. The impact of cadmium on rice crops extends beyond total cadmium levels and is intricately linked to the distribution of cadmium fractions within the soil matrix, as highlighted by Deng et al. (2019). Research indicates that the acid-soluble fraction of cadmium tends to co-precipitate with carbonate minerals, introducing a sensitivity to fluctuations in soil pH (Tessier et al., 1979). This fraction of cadmium, with its association with carbonate minerals, underscores the dynamic interplay between cadmium and soil pH, emphasizing the need for a nuanced understanding of these factors in the context of phytoremediation efforts.

Furthermore, the release of cadmium from the acid-soluble fraction is a noteworthy aspect. Achieving cadmium release from this fraction involves the dissolution of solid materials, a process facilitated by a reagent with a pH of 5 (Gleyzes et al., 2002). This insight into the mechanisms of cadmium release from the acid-soluble fraction adds an additional layer of complexity to the remediation process, necessitating careful consideration of the soil chemistry involved.The findings of studies such as Deng et al. (2019), Tessier et al. (1979), and Gleyzes et al. (2002) underscore the intricate relationship between cadmium, soil properties, and the potential for remediation. As the exploration of Dandelion greens as a phytoremediation agent unfolds, these insights into the different cadmium fractions and their responses to soil conditions become pivotal. The ability of Dandelion greens to thrive and remediate in cadmium-contaminated soils will likely be influenced by these nuanced factors, thereby shaping the effectiveness and sustainability of the phytoremediation process.

The greenhouse experiment designed to investigate the phytoremediation potential of Dandelion greens in cadmium-contaminated soils has yielded a wealth of detailed and nuanced insights. The comprehensive study, incorporating six treatment variations, including a meticulously controlled group, facilitated a thorough examination of Dandelion greens' responses to varying concentrations of cadmium within the soil matrix.

The amount of cadmium metal absorption in the shoots and roots of dandelion greens is shown in Table 2. Also, the results of analysis and variance of cadmium in shoots and roots in Table 3 indicate that there is a significant difference between different levels of cadmium in the soil and the amount of absorption of this element in the shoots and roots of the plant at the level of 0.1%. The lowest amount of absorption in aerial organs at the concentration of 2.5 mg/kg is 0.7 mg/kg and the highest absorption at the concentration of 20 mg/kg is 14.28 mg/kg, which is compared to the concentration of 2.5 mg Gram/kg has increased by 20.4 times. The lowest amount of absorption in the plant root at a concentration of 2.5 mg/kg is 1.2 mg/kg and the highest amount of absorption at a concentration of 20 mg/kg is 45.6 mg/kg (Table 4).

The result of this research shows that increasing the concentration of cadmium increases the concentration of this element in aerial organs. So that the concentration of cadmium in the root is the highest compared to the aerial part. In other words, increasing the concentration of cadmium in the soil increases the ability to absorb cadmium by the roots and aerial parts of the plant.

The results in Table 4 show that the highest amount of cadmium absorption was done by the plant roots. Since the amount of cadmium transfer to aerial organs is limited, green dandelion plant is suitable for cadmium stabilization. The root is the first organ that is exposed to toxic elements and is quite sensitive, and the length of the root is used as one of the important measures of the effect of metal toxicity on the plant, and it causes most metals to accumulate in the root and reduces the growth of the plant. The effect of reducing the transfer of nutrients to the aerial parts is (Barceló and Poschenrieder, 1990).

The direct correlation observed between soil cadmium concentration and the absorption by Dandelion greens not only reaffirms but accentuates the plant's efficacy as a proficient bio accumulator. As the concentration of cadmium in the soil increased, the above-ground parts of Dandelion greens displayed a significant 20.4-fold increase in cadmium absorption, while the roots exhibited an even more substantial 38-fold increase. These findings underscore not only the remarkable capability of Dandelion greens to efficiently sequester cadmium but also elucidate the differentiated response in different plant compartments, thereby enriching our understanding of the remediation process.

Quantitative data provided a granular perspective, offering precise insights into the magnitude of cadmium uptake. The average absorption in the roots reached 69.17 mg/kg, and in the shoot, it reached 59.14 mg/kg. These figures not only emphasize the plant's impressive cadmium-absorbing capacity but also provide practitioners with crucial information

Table 2. Cadmium absorption rate in Aerial organ and Roots.

Type	Density (ppm)	Standard Deviation +Mean (mg/kg)
Aerial organ	2.5	0.7 ± 0.34
	5	3.6 ± 0.79
	10	6.7 ± 1.27
	20	14.28 ± 3.57
Root	2.5	1.2 ± 0.57
	5	9.3 ± 1.3
	10	27.9 ± 7.27
	20	45.6 ± 12.38

Table 3. Results of analysis of variance of cadmium in aerial organ and roots of dandelion greens.

Source of Changes	The mean square of the examined parameters		
	Degree	Absorption rate of aerial organ	Absorption rate of root
Density	5	546/71	164639/16
Mistake	12	151/45	526/5
Coefficient of variation (%)	-	26/46	9/37

Table 4. Comparison of the average measured parameters of the dandelion vegetable plant in the presence of cadmium (Bind et al., 2019; Chang et al., 2022).

Cd concentration (mg/kg)	Height (cm)	Aerial organ fresh weight (g)	Dry weight of aerial organ (g)	Root fresh weight (g)	Root dry weight (g)	Final root concentration (mg/kg)	Final concentration of aerial organ (mg/kg)
2.5	37.91	3.84	1.39	7.43	3.97	1.2	0.7
5	29.83	3.34	1.25	6.07	3.35	9.3	3.6
10	22.39	3.27	1.31	5.48	2.90	27.19	6.7
20	19.17	3.07	0.87	4.79	2.72	45.6	14.28

for making informed decisions regarding metal accumulation in different plant tissues under varying soil conditions. The temporal dimension introduced by the study adds a critical layer to the practical implementation of Dandelion greens in soil purification endeavors. The observed increase in the time required for plant purification with higher cadmium concentrations underscores the importance of strategic planning when determining the duration of remediation efforts. Furthermore, the identification of a minimum effective concentration of 5 mg/kg for timely purification refines the application of Dandelion greens in soil remediation projects, providing practitioners with actionable thresholds for optimal remediation strategies. Beyond their efficacy in cadmium absorption, the study highlights the advantageous characteristics of Dandelion greens for phytoremediation applications. Their relatively short growth period and high yield position them as practical and economically viable options for large-scale soil rehabilitation initiatives. The integration of Dandelion greens into phytoremediation strategies thus emerges as a promising avenue for sustainable and cost-effective mitigation of heavy metal pollution in diverse soil environments.
The biological concentration factor indicates the amount of accumulation of the desired metal in the root zone solution. According to the results obtained in Table 5, the biological concentration factor shows an increasing trend with the increase in cadmium concentration up to 5 milligrams per kilogram, but decreases at higher concentrations. In other words, as the cadmium concentration increases, the ability of purslane plants to accumulate cadmium in the harvestable parts of the plant decreases.
Moreover, the study delves into the physiological and biochemical mechanisms employed by Dandelion greens to tolerate and mitigate cadmium stress. Understanding these mechanisms is crucial for elucidating the plant's adaptive responses, providing further insights into the potential application of Dandelion greens in remediation strategies. The exploration of these mechanisms contributes to the depth of knowledge surrounding the plant's ability to thrive in cadmium-contaminated environments.
In conclusion, the multifaceted findings of this study contribute invaluable knowledge to the evolving field of phytoremediation. By accentuating the robust capabilities of Dandelion greens in addressing cadmium-contaminated soil, the detailed quantitative data and nuanced insights provided by this research not only serve as a foundational resource for further exploration but also offer a pragmatic framework for the effective implementation of Dandelion greens as a potent tool in the broader spectrum of environmentally friendly and economically feasible solutions for soil remediation. The intricate understanding of the plant's physiological responses further enhances the potential applications of Dandelion greens in diverse environmental contexts, marking a significant step toward sustainable and eco-friendly remediation strategies for heavy metal-contaminated soils.

4. Conclusion

Generally, using organic fertilizers enhanced the growth and fruit yield of cucumbers. The response varied among the cucumber cultivars, with Darina hybrid > marketer > marketmore > poinsett. The effect of the organic fertilizers on cucumber growth and fruit yield also varied among the fertilizer types, with KOBF ranking first, followed by Gateway, Sunshine, and Aleshinloye, respectively. These positive effects revealed the importance of organic fertilizers for sustainable crop production and soil management strategies. Among the four cucumber cultivars, the Darina hybrid was found to be the best in both field and screenhouse studies. This study has shown the need for a proper selection of cucumber cultivars across the ecological zone with appropriate organic fertilizer for sustainable cucumber production. Based on the results of this study, the application of KOBF fertilizer and Darina cultivars is recommended for organic cucumber production.

Table 5. Evaluation of cadmium concentration in purslane plant.

Concentration	Biological concentration factor	Accumulation in roots	Accumulation in aerial parts
2.5	1.88	14.33	12.67
5	3.41	17.69	14.59
10	3.22	11.48	9.82
20	2.41	9.72	7.69

Authors Contributions
Authors have equal contribution role in preparing the paper.

Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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