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Potential of Two Vegetable Plants in Reducing Lead Contamination in Soil

Mahayu Woro Lestari[1*], Anis Rosyidah[1]

[1] Faculty of Agriculture, University of Islam Malang, MT. Haryono Street No. 193, Malang, East Java, Indonesia

* Corresponding author's e-mail: mwlestari@unisma.ac.id

ABSTRACT

Phytoremediation is the technique of using green plants to remove toxic pollutants from heavy metal contaminated soil through degradation and detoxification mechanisms. Therefore, this research examines the potential of two types of vegetable crops, namely *Crassocephalum crepidioides* and *Amaranthus* sp., in reducing Pb contamination in polluted soil. The treatments tested were planting media in polybags dosed with 0.3 and 6 g/polybag of Pb 1 week before planting. The method used was a randomized block design, with each treatment being repeated three times. Furthermore, each treatment consists of three sample plants. The growth evaluation started 6 days after planting and was performed every 6 days. The evaluation was conducted on plant height, leaf area, leaf chlorophyll content, fresh and dry weight of roots and shoots, Pb levels in roots and shoots, and Translocation Factor (TF). The results showed that the higher the Pb in the media, the lower the rate of change in plant height, leaf area, biomass, and chlorophyll content. Additionally, *C. crepidioides* and *Amaranthussp*. absorb Pb in the soil with a phytoextraction mechanism, thereby remediating heavy metal contaminated soil, as indicated by the TF value > 1. In conclusion,soil remediation should be performed using *C. crepidioides*, considering that it is less popular as a vegetable in Indonesia.

Keywords: *Amaranthussp*., *C. crepidioides,* lead, phytoremediation, vegetable.

INTRODUCTION

Heavy metal pollution is increasing yearly, not only in Indonesia but in almost all countries of the world. Organic and inorganic sources of pollutants have been widely reported (Saxena and Bharagava, 2017). Heavy metals cause a decrease in crop quality and agricultural production (Lei et al., 2016). Furthermore, it poses a severe threat to human health by accumulating in the body through the food chain and respiration (Yadav, 2010; Maszenan et al., 2011; Dixit et al., 2015; Sarwar et al., 2017). Lead (Pb) is a heavy metal well-known as a pollutant because of its high presence and non-biodegradable nature.

Pb is a minor element and has no biological function in the body. However, it can cause serious health hazards and is listed as a significant pollutant by many environmental protection agencies worldwide (Jaishankar et al.,2014; Dixit et al.,2015; Sarwar et al.,2017). Therefore, removing Pb from contaminated soil is an urgent means of protecting the environment and human health. This is performed through phytoremediation, an effective, low-cost, and environmentally friendly solution for preventing and controlling Pb pollution (Muthusaravanan et al.,2018; Chandra et al.,2015; Ali et al.,2013; Mahar et al.,2016).

Phytoremediation uses green plants to remove toxic pollutants from the contaminated soil and water/waste through degradation and detoxification mechanisms (Bharagava et al., 2017; Ali et al., 2013). It is a non-intrusive and environmentally friendly technology to remove heavy metal pollutants from contaminated sites (Lee, 2013; Chandra et al., 2015; Chirakkara et al., 2016). Therefore, this research aims to prove the potential of hyperaccumulator plants such as *C. crepidioides* and *Amaranthus* sp. on a field scale to remove heavy metals from polluted soil.

*Amaranthus sp.*is a vegetable plant commonly consumed by humans, while *C. crepidioides* is better known as a weed, especially for the people of Indonesia. Cadmium (Cd) has been the focus of the majority of research on *C. crepidioides*, while lead (Pb) has received less attention (Lestari, 2021; Cheng et al., 2021; Xie et al., 2021). Plants have different abilities to accumulate heavy metals (Kacalkova et al., 2015). Therefore, the selection of its species for heavy metal phytoremediation depends on the capacity and biomass of the selected plant (Rezania et al., 2016). The higher the biomass produced, the more accumulation of heavy metals in plant tissues. This research aimed to examine the potential of *C. crepidioides* and *Amaranthus* sp. in remediating Pb in soil. It is expected that *C. crepidioide*s can absorb more Pb than *Amaranthus* sp. This is because it isnot yet popularly used as a vegetable in Indonesia, reducing the hazardous risk of heavy metals to human health.

METHODOLOGY

Time and place

The research was conducted from April to July 2021 at the Greenhouse of the Faculty of Agriculture, the University of Islam Malang, with an altitude of 540 meters above sea level and a temperature of 21–30°C.

Materials

Seedlings of *C. crepidioides* (C) and *Amaranthus* sp. (A) *w*ere sown and transferred after two weeks into polybags containing a mixture of soil and compost in 1:1. Before planting, the Pb content in the media was analyzed to ensure that it was contaminant free. This heavy metal was added 1 week before planting at a dose of 0.3 and 6 g/polybag. Furthermore, it was mixed with the media and stirred evenly as well as each polybag was planted with 1 plant. ZA, TSP, and SP-36 fertilizers were administered twice, namely 2 g/polybag ZA, TSP, and SP-36 at 7 DAT and 1 g/polybag ZA, TSP, and SP-36 at 14 DAT.

Parameters measured

The growth evaluation started 6 days after planting and was performed every 6 days. This was conducted on the variables such as plant height, leaf area, leaf chlorophyll content, fresh and dry weight of roots and shoots, Pb levels in roots and shoots (was determined using an Atomic Absorption Spectrophotometer), and Translocation Factor (TF). It is calculated as follows:

$$\frac{\text{Pb on crop}}{\text{Pb on root}} \tag{1}$$

Experimental design

This study used a randomized block design, whereby each treatment was repeated 3 times, with each consisting of 5 sample plants.

Statistical analysis

SPSS was used to conduct the statistical analysis. The data were reported as means with standard errors, and the means were compared statistically at the 0.05 percent level using Duncan's multiple range test (DMRT).

RESULTS AND DISCUSSION

Plant growth

The common symptoms of Pb poisoning are stunted plant growth, root growth, blackening of the root system, and chlorosis of the leaves. This heavy metal can cause inhibition of photosynthesis and enzyme activity (Sharma and Dubey, 2005). Therefore, there were morphological differences between Pb-treated and control plants. Table 1 shows that *C. crepidioides* and *Amaranthus sp.* experienced increased plant height from the beginning to the end of the observation. However, it was lower at 30 DAT except for the control treatment. The higher the Pb dose in the soil, the lower the increase in plant height. Meanwhile, the leaf increase until 12 DAT. Table 2 shows that the increase in leaf area was not significant between treatment and harvest.

Biomass is an excellent indicator to characterize plant growth performance due to the presence of Pb. This research shows that plant growth rate and overall biomass production increase as Pb dose decreases. Similar results were observed in various plants (Brunet et al., 2008). Furthermore, the decrease in plant growth is related to inhibiting the mitotic index due to Pb treatment (Dalla et al., 2005). On the other hand, low Pb

Table 1. The average height of two vegetable plants due to Pb contamination in the soil

Treatment	Average plant height (cm) at various ages of observation (DAT)				
	6	12	18	24	30
C0	6.42 f	8.36 d	11.28 cd	19.24 e	24.18 c
C3	5.77 e	7.13 bc	9.15 ab	13.52 bcd	14.99 ab
C6	5.17 de	6.18 a	8.10 a	9.21 a	10.92 a
A0	4.35 bc	8.32 d	13.04 d	21.84 e	27.28 c
A3	4.42 c	7.25 c	11.95 d	16.87 de	19.92 bc
A6	3.54 a	6.10 a	9.91 bc	13.62 cd	14.63 a

Table 2. Average leaf area (cm^2) of two vegetable plants due to Pb contamination in soil

Treatment	Average leaf area (cm^2) at various ages of observation (DAT)				
	6	12	18*	24*	30*
C0	8.21 d	23.21 d	33.98	44.40	48.09
C3	7.85 cd	17.10 abcd	22.52	29.01	38.29
C6	2.25 a	8.57 a	19.09	32.26	35.52
A0	9.77 d	23.38 d	35.96	54.47	65.53
A3	7.08 bcd	18.79 cd	28.29	54.21	62.81
A6	5.35 abc	17.52 bcd	26.69	32.47	34.06

Note: * means not significant.

concentrations regulate the absorption and transport of Fe, Zn, and N in plants to increase photosynthesis, increasing plant height and biomass (Soares et al., 2019; Carvalho et al., 2020). Therefore, *C. crepidioides a*nd *Amaranthus* sp. plants continuously increased plant height and leaf area at a dose of 6 g Pb/polybag.

Plant biomass

The highest fresh and dry weight of roots and shoots was discovered in the control treatment for *C. crepidioides* and *Amaranthus sp*. Figure 1 & 2 shows that the higher the Pb content in the soil, the lower the variable. *Amaranthus sp.*produced a significantly higher fresh and dry weight of roots and shoots than *C. crepidioides*. This indicates that the biomass formed by *Amaranthus* sp. was the highest. The Pb toxicity levels in plants depend on the species involved (Khan et al., 2018). Plants that produce higher biomass facilitate the phytoextraction process, hence, they have a higher absorption rate of heavy metals (Ho et al., 2008). The results are consistent with some other research which stated that on high Pb concentrations, root, shoot, and leaf growth, fresh and dry biomass was significantly reduced in *Pisum Sativum* (Kevresan et al., 2001) and *Zea mays* (Cimrin et al., 2007).

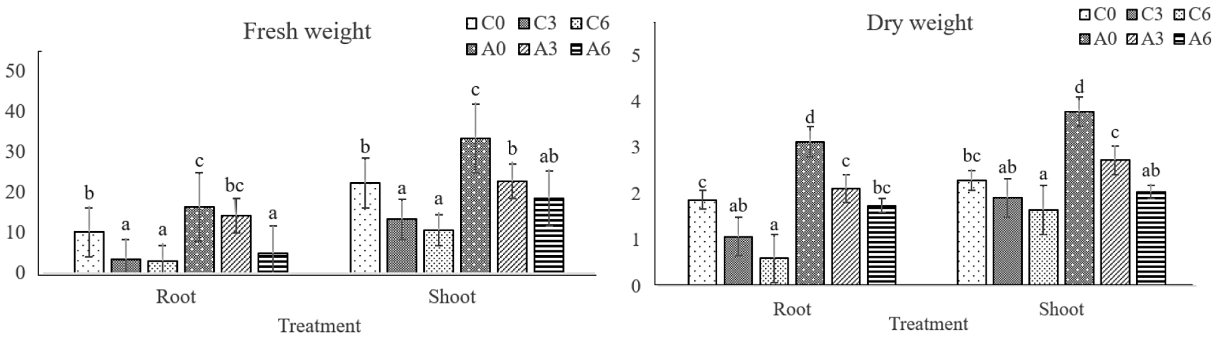

Figure 1. The fresh and dry weight of roots and shoots in *Crassocephalum* and *Amaranthus*

Chlorophyll content

Based on observations, the chlorophyll content decreased with increasing Pb dose in *C. crepidioides* and *Amaranthus sp.* (Figure 2). High Pb concentrations affect plant growth due to damage to chlorophyll synthesis (Xin et al., 2018). A decreased chlorophyll content due to Pb contamination has also been reported in many plants (Choudhury & Panda, 2004). Therefore, chlorophyll pigment appears to be one main symptom of Pb damage in plants. This heavy metal can indirectly cause stress by interfering with the electron transport of photosynthesis. The chlorophyll content decreases due to a striking change in the fine structure of chloroplasts and damage to the marginal membrane of meristematic cells (Fargasova, 2001). This is consistent with changes in the biomass of *C. crepidioides* and *Amaranthus* sp. because Pb inhibits photosynthesis, leading to a decrease in biomass. Saygideger et al. (2004) stated that the mechanism of inhibition of the chlorophyll biosynthesis process due to Pb is by blocking the action of enzymes needed. Changes in chlorophyll content due to increasing Pb concentration damage the chloroplast structure. Furthermore, the formation of this structure is strongly influenced by Mg and Fe. The excessive intake of Pb in plants reduces the absorption of Mg and Fe, causing changes in the volume and number of chloroplasts.

In many plant species, the photosynthetic pigments, including chlorophyll-a, b, and carotenoids, decrease after exposure to Pb (Singh et al., 2010). Furthermore, changes in photosynthetic activity and essential nutrient distribution reduce plant growth. This is attributed to changes in the composition of pigments in the photosynthesis process which have lower light-harvesting chlorophyll proteins (LHCPs) (Gill et al., 2012). Decreased levels of LHCPs are an adaptive defense mechanism of leaves and plants, which helps them to survive in adverse conditions. For example, photosynthesis in higher plants is more sensitive to Pb treatment, affecting the biosynthesis of chlorophyll and accessory pigments (Gill et al., 2012; Iqbal et al., 2010). Therefore, it is assumed that the heavy metal inhibits the biosynthesis of chlorophyll by interfering with the absorption of important photosynthetic pigment elements, such as magnesium, potassium, calcium, and ions (Piotrowska et al., 2009).

Pb uptake in roots and shoots

The results showed that the higher the dose of Pb in the soil, the higher the uptake in the roots and shoots. The highest Pb concentration was in Amaranthus roots treated with 6 g/polybag, which differed from other treatments (Figure 3). According to Gupta and Sinha (2008), plants actively have their mechanism to prevent movement from roots to shoots by sequestering metals in the roots, especially in the vacuoles or cell walls. Additionally, Yoon et al. (2006) stated that roots sometimes have a metal transport stop system to the leaves, hence there is accumulation in the roots. Therefore, Pb, one of the non-essential metals for plants, tends to be piled up by the roots rather than transferred to the canopy.

This is in line with the report by Li et al. (2016) that the cell wall plays an essential role in the detoxification and accumulation of Pb in the roots of *T. sacchariflora* seedlings. The cell wall is mainly composed of polysaccharides and proteins with carboxyl, hydroxyl, amino, and other functional groups, which provide massive binding sites with metal ions, limiting their transport across membranes, and decreasing their content in protoplasts (Zhang et al., 2014). Meanwhile, Pb can increase pectinase activity and low-twisted pectin content on the cell wall. Also, it induces the rearrangement of pectin in the cell wall chamber (Krzeslowska, 2011). Furthermore, root exudates, such as soluble sugar, free amino acids, and citric acid, combine with metal ions to form complexes or change the pH around the root system, encouraging the absorption and accumulation of heavy metals by cell walls (Zu et al., 2015).

Cenkci et al. (2010) also showed that Pb accumulation was higher in the roots than in the canopy of *Brassica Rapa*. The ability of *Amaranthus sp.*plants in accumulation and tolerance to Pb ions shows efficient hyperaccumulation mechanisms for removing the heavy metal ions from contaminated soil.

Translocation factor (TF)

This shows the efficiency of plants in the translocating metal accumulation from roots to canopy (Padmavathiamma and Li, 2007), which is a ratio between the concentration of Pb in the canopy and at the root.

Table 3 shows the value of TF *C.crepidioides*and *Amaranthus* > 1 in the control

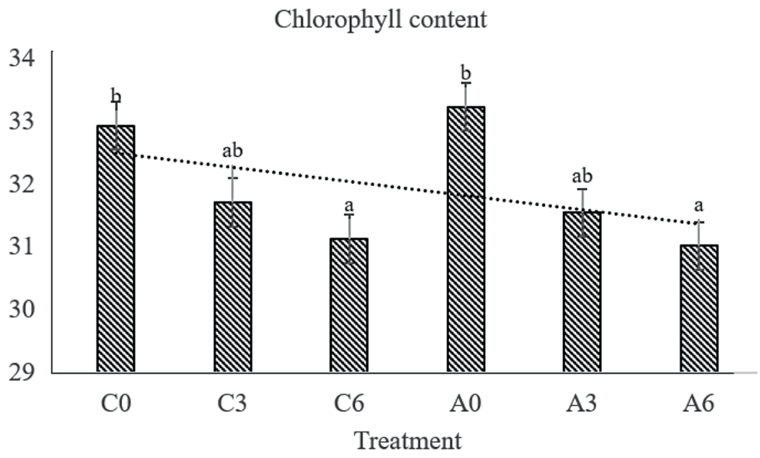

Figure 2. Chlorophyll concentration in *C. crepidioides* and *Amaranthus*

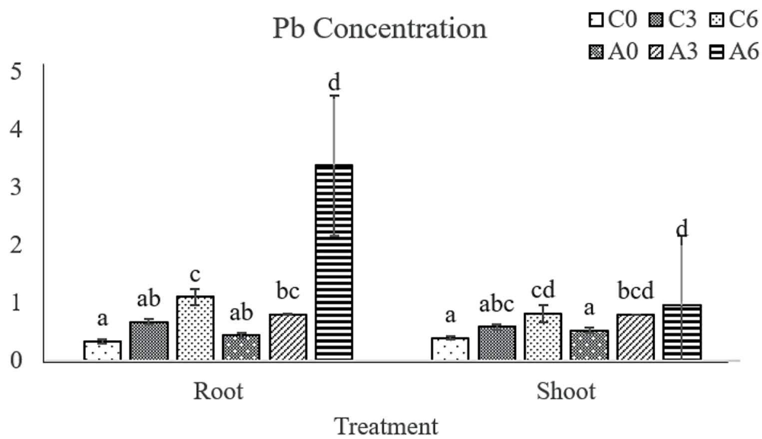

Figure 3. Pb concentration in the roots and shoots of *C. crepidioides*and *Amaranthus* sp.

Table 3. The average value of translocation factor in crassocephalum and amaranthus

Treatment	The average TF value (ppm)
C0	1.18 bc
C3	0.87 ab
C6	0.74 abc
A0	1.20 c
A3	0.99 abc
A6	0.28 a

treatment and decreases with the increase in the dose of Pb. According to Yoon et al. (2006), only plant species with TF> 1 are used for phytoextraction. This research shows that *C.Crepidioides* and *Amaranthus sp.* function as phytoextraction because their TF value is > 1 at 1.15 ppm in *C. crepidioides* and 1.34 ppm in *Amaranthus* sp. Phytoextraction, also known as Phytoaccumulation/Phytoabsorption, is the absorption of contaminants from the soil or water by plant roots and translocated to as well as accumulated in biomass above the ground, canopy (Yoon et al., 2006). Metal translocation to the shoot is an essential and desirable biochemical process for effective phytoextraction since root biomass harvesting is not generally possible (Guerin et al., 2011).

CONCLUSIONS

*C. crepidioides*and *Amaranthus sp.*have a phytoextraction mechanism, hence, they can be used for heavy metal remediation, especially Pb. These plantsare classified as vegetables, however *Amaranthus* sp. is known to most people, while *C. crepidioides* is considered a weed in Indonesia, and a small number of people use it as vegetables. Therefore, *C. crepidioides* should be used to treat soil contaminated with Pb.

REFERENCES

1. Ali H., Khan E., Sajad M.A. 2013. Phytoremediation of heavy metals – concepts and applications. Chemosphere, 91(7), 869–881.
2. Bharagava R.N., Chowdhary P., Saxena G. 2017. Bioremediation: an eco-sustainable green technology: its applications and limitations. In Environmental Pollutants and Their Bioremediation Approaches, 1–22.
3. Brunet J., Repellin A., Varrault G., Terryn N., Zuily-Fodil Y. 2008. Lead accumulation in the roots of grass pea (*Lathyrus sativus* L.): a novel plant for phytoremediation systems?. Comptes Rendus Biologies, 331(11), 859–864.
4. Carvalho M.E., Castro P.R., Azevedo R.A. 2020. Hormesis in plants under Cd exposure: from toxic to beneficial element?. Journal of Hazardous Materials, 384, 121434.
5. Cenkci S., Ciğerci İ.H., Yıldız M., Özay C., Bozdağ A., Terzi H. 2010. Lead contamination reduces chlorophyll biosynthesis and genomic template stability in *Brassica rapa* L. Environmental and Experimental Botany, 67(3), 467–473.
6. Chandra R., Saxena G., Kumar V. 2015. Phytoremediation of environmental pollutants: an eco-sustainable green technology to environmental management. In Advances in Biodegradation and Bioremediation of Industrial Waste, 15–44.
7. Cheng D., Liu X., Zhang H., Zou Z., Zhu G. 2021. The Potentiality of *Crassocephalum crepidioides* for Phytoremediation of Cd Contaminated Soil under the Application of EDTA. In IOP Conference Series: Earth and Environmental Science, 687, IOP Publishing.
8. Chirakkara R.A., Cameselle C., Reddy K.R. 2016. Assessing the applicability of phytoremediation of soils with mixed organic and heavy metal contaminants. Reviews in Environmental Science and Bio/Technology, 15(2), 299–326.
9. Choudhury S., Panda S.K. 2004. Induction of oxidative stress and ultrastructural changes in moss *Taxithelium nepalense* (Schwaegr.) Broth. under lead and arsenic phytotoxicity. Current Science, 10, 342–348.
10. Çimrin K.M., Turan M., Kapur B. 2007. Effect of elemental sulphur on heavy metals solubility and remediation by plants in calcareous soils. Fresenius Environmental Bulletin, 16(9), 1113–1120.
11. Dalla Vecchia F, La Rocca N., Moro I., De Faveri S., Andreoli C., Rascio N. 2005. Morphogenetic, ultrastructural and physiological damages suffered by submerged leaves of *Elodea canadensis* exposed to cadmium. Plant Science, 168(2), 329–338.
12. Dixit R., Malaviya D., Pandiyan K., Singh U.B., Sahu A., Shukla R., Singh B.P., Rai J.P., Sharma P.K., Lade H., Paul D. 2015. Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes. Sustainability, 7(2), 2189–2212.
13. Fargašová A. 2001. Phytotoxic effects of Cd, Zn, Pb, Cu and Fe on *Sinapis alba* L. seedlings and their accumulation in roots and shoots. Biologia Plantarum, 44(3), 471–473.
14. Gill S.S., Khan N.A., Tuteja N. 2012. Cadmium at high dose perturbs growth, photosynthesis and nitrogen metabolism while at low dose it up regulates sulfur assimilation and antioxidant machinery in garden cress (*Lepidium sativum* L.). Plant Science, 182, 112–120.
15. Guerin T.F., Horner S., McGovern T., Davey B. 2002. An application of permeable reactive barrier technology to petroleum hydrocarbon contaminated groundwater. Water Research, 36(1), 15–24.
16. Gupta A.K., Sinha S. 2008. Decontamination and/or revegetation of fly ash dykes through naturally growing plants. Journal of Hazardous Materials, 153(3), 1078–1087.
17. Ho W.M., Ang L.H., Lee D.K. 2008. Assessment of Pb uptake, translocation and immobilization in kenaf (*Hibiscus cannabinus* L.) for phytoremediation of sand tailings. Journal of Environmental Sciences, 20(11), 1341–1347.
18. Iqbal N., Masood A., Nazar R., Syeed S., Khan N.A. 2010. Photosynthesis, growth and antioxidant metabolism in mustard (*Brassica juncea* L.) cultivars differing in cadmium tolerance. Agricultural sciences in China, 9(4), 519–527.
19. Jaishankar M., Tseten T., Anbalagan N., Mathew B.B., Beeregowda K.N. 2014. Toxicity, mechanism and health effects of some heavy metals. Interdisciplinary Toxicology, 7(2), 60.
20. Kacálková L., Tlustoš P., Száková J. 2015. Phytoextraction of risk elements by willow and poplar trees. International journal of phytoremediation, 17(5), 414–421.
21. Kevresan S., Petrovic N., Popovic M., Kandrac J. 2001. Nitrogen and protein metabolism in young pea plants as affected by different concentrations of nickel, cadmium, lead, and molybdenum. Journal of Plant Nutrition, 24(10), 1633–1644.
22. Khan M.M., Islam E., Irem S., Akhtar K., Ashraf M.Y., Iqbal J., Liu D. 2018. Pb-induced phytotoxicity in para grass (*Brachiaria mutica*) and Castorbean (*Ricinus communis* L.): Antioxidant and ultrastructural studies. Chemosphere, 200, 257–265.
23. Krzesłowska M. 2011. The cell wall in plant cell response to trace metals: polysaccharide remodeling and its role in defense strategy. Acta Physiologiae Plantarum, 33(1), 35–51.
24. Lee J.H. 2013. An overview of phytoremediation as a potentially promising technology for environmental pollution control. Biotechnology and Bioprocess Engineering, 18(3), 431–439.

25. Lei K., Giubilato E., Critto A., Pan H., Lin C. 2016. Contamination and human health risk of lead in soils around lead/zinc smelting areas in China. Environmental Science and Pollution Research, 23(13), 13128–13136.
26. Lestari M.W. 2021. Heavy metal content in the leaves of *Crassocephalum crepidioides* due to the application of various types of manure. In IOP Conference Series: Earth and Environmental Science, IOP Publishing, 733.
27. Li H., Liu Y., Chen Y., Wang S., Wang M., Xie T., Wang G. 2016. Biochar amendment immobilizes lead in rice paddy soils and reduces its phytoavailability. Scientific Reports, 6(1), 1–8.
28. Mahar A., Wang P., Ali A., Awasthi M.K., Lahori A.H., Wang Q., Li R., Zhang Z. 2016. Challenges and opportunities in the phytoremediation of heavy metals contaminated soils: a Review. Ecotoxicology and Environmental Safety, 126, 111–121.
29. Maszenan A.M., Liu Y., Ng W.J. 2011. Bioremediation of wastewaters with recalcitrant organic compounds and metals by aerobic granules. Biotechnology Advances, 29(1), 111–123.
30. Muthusaravanan S., Sivarajasekar N., Vivek J.S., Paramasivan T., Naushad M., Prakashmaran J., Gayathri V., Al-Duaij O.K. 2018. Phytoremediation of heavy metals: mechanisms, methods and enhancements. Environmental Chemistry Letters, 16(4), 1339–1359.
31. Padmavathiamma P.K., Li L.Y. 2007. Phytoremediation technology: hyper-accumulation metals in plants. Water, Air, and Soil Pollution, 184(1), 105–126.
32. Piotrowska A., Bajguz A., Godlewska-Żyłkiewicz B., Czerpak R., Kamińska M. 2009. Jasmonic acid as modulator of lead toxicity in aquatic plant *Wolffia arrhiza* (Lemnaceae). Environmental and Experimental Botany, 66(3), 507–513.
33. Rezania S., Taib S.M., Din M.F., Dahalan F.A., Kamyab H. 2016. Comprehensive review on phytotechnology: heavy metals removal by diverse aquatic plants species from wastewater. Journal of Hazardous Materials, 318, 587–599.
34. Sarwar N., Imran M., Shaheen M.R., Ishaque W., Kamran M.A., Matloob A., Rehim A., Hussain S. 2017. Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives. Chemosphere, 171, 710–721.
35. Saxena G., Bharagava R.N. 2017. Organic and inorganic pollutants in industrial wastes: ecotoxicological effects, health hazards, and bioremediation approaches. In: Environmental Pollutants and Their Bioremediation Approaches, 23–56.
36. Saygideger S., Dogan M., Keser G. 2004. Effect of lead and pH on lead uptake, chlorophyll and nitrogen content of *Typha latifolia* L. and *Ceratophyllum demersum* L. International Journal Agriculture and Biology, 6(1), 168–172.
37. Sharma P., Dubey R.S. 2005. Lead toxicity in plants. Brazilian Journal of Plant Physiology, 17(1), 35–52.
38. Singh R., Tripathi R.D., Dwivedi S., Kumar A., Trivedi P.K., Chakrabarty D. 2010. Lead bioaccumulation potential of an aquatic macrophyte *Najas indica* are related to antioxidant system. Bioresource Technology, 101(9), 3025–3032.
39. Soares C., Carvalho M.E., Azevedo R.A., Fidalgo F. 2019. Plants facing oxidative challenges—A little help from the antioxidant networks. Environmental and Experimental Botany, 161, 4–25.
40. Xie Y., Wang L., Yang L., Yan W., He Z., Tang Y., Liao M.A., Zhou X. 2021. Intercropping with Eclipta prostrata and *Crassocephalum crepidioides* decrease cadmium uptake of tomato seedlings. International Journal of Environmental Analytical Chemistry, 101(9), 1231–1239.
41. Xin J.P., Zhang Y., Tian R.N. 2018. Tolerance mechanism of *Triarrhena sacchariflora* (Maxim.) Nakai seedlings to lead and cadmium: Translocation, subcellular distribution, chemical forms and variations in leaf ultrastructure. Ecotoxicology and Environmental Safety, 165, 611–621.
42. Yadav S.K. 2010. Heavy metals toxicity in plants: an overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants. South African Journal of Botany, 76(2), 167–179.
43. Yoon J., Cao X., Zhou Q., Ma L.Q. 2006. Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Science of The Total Environment, 368(2–3), 456–464.
44. Zhang S.J., Li T.X., Huang H.G., Zhang X.Z., Yu H.Y., Zheng Z.C., Wang Y.D., Zou T.J., Hao X.Q., Pu Y.O. 2014. Phytoremediation of cadmium using plant species of *Athyrium wardii* (Hook.). International Journal of Environmental Science and Technology, 11(3), 757–64.
45. Zu Y., Li Y., Min H, Zhan F., Qin L., Wang J. 2015. Subcellular distribution and chemical form of Pb in hyperaccumulator Arenaria orbiculata and response of root exudates to Pb addition. Frontiers of Environmental Science & Engineering, 9(2), 250–258.