http://www.doi.org/10.62341/RKEL1520

Received	**2024/12/23**	**تم استلام الورقة العلمية في**
Accepted	**2025/01/20**	**تم قبول الورقة العلمية في**
Published	**2025/01/23**	**تم نشر الورقة العلمية في**

Evaluate Cumulative Ability of *Phalaris minor* Grasses for Some Heavy Metals in area of Shahat, Libya

Reem Yousuf, Khaled Al- Mokhtar

Natural Resources & ecology Faculty, Al-Goba Branch
University of Derna- Libya

khaledalmokhtar@gmail.com

Abstract

This research was carried out in the Shahat Forest to evaluate the ability of *P. minor* to absorb heavy metals in its tissues. The study involved analyzing the concentrations of heavy metals, (Zn), (Fe), (Cd) and (Pb), in both the aerial and root parts of *P. minor*, as well as in the soil at a depth of 0-40 cm beneath the grasses. Importantly, the concentrations of these heavy metals were found to be within the acceptable limits set by the (WHO). The results noted that *P. minor* evidenced a significant ability for the uptake and accumulation of heavy metals, with (BAF) for Zn, Fe, Cd, and Pb recorded at (3.4, 1.9, 1.9, and 2), respectively. Additionally, the (BCF) of the roots parts were higher than (BCF) of the aerial parts, and (TF) remained below (1) for all analyzed elements. As a result, *P. minor* can be considered a potential bioaccumulator with phytostabilization strategy. Statistical analysis indicated significant differences ($p<0.05$) in heavy metal concentrations among the various parts of the plant.

Keywords: Phalaris minor, Heavy Metals, Cumulative, Shahat, forest.

http://www.doi.org/10.62341/RKEL1520

تقييم القدرة التراكمية لنبات ابورويس *Phalaris minor* لبعض المعادن الثقيلة في منطقة شحات، ليبيا

ريم يوسف، خالد المختار
قسم العلوم البيئية، كلية الموارد الطبيعية و علوم البيئة، فرع القبة – جامعة درنة – ليبيا

الملخص

أجري هذا البحث في غابة شحات لتقييم قدرة نبات (ابورويس) P. minor على امتصاص المعادن الثقيلة في أنسجته. حيث تضمنت الدراسة تحديد تركيز العناصر الثقيلة (Zn) و(Fe) و(Cd) و(Pb) في الأجزاء الخضرية والجذرية لنبات ابورويس P. minor وكذلك في التربة على عمق (0–40 سم) تحت الأعشاب. وقد كانت تركيزات هذه المعادن الثقيلة ضمن الحدود المقبولة التي حددتها منظمة الصحة العالمية. ايضاً أشارت النتائج إلى أن نبات ابورويس P. minor أظهر قدرة كبيرة على امتصاص وتراكم المعادن الثقيلة، حيث سجل (BAF) للزنك والحديد والكادميوم والرصاص (3.4، 1.9، 1.9، و2) على التوالي. بالإضافة إلى ذلك، كانت (BCF) أعلى في الأجزاء الجذرية مقارنة بالأجزاء الخضرية، ايضا (TF) كان أقل من (1) لجميع العناصر التي تم تحليلها. ونتيجة لذلك يمكن اعتبار نبات ابورويس P. minor مراكماً حيوياً متبعاً لاستراتيجية التثبيت النباتي phytostabilization. ايضاً أشارت التحليل الإحصائي إلى وجود اختلافات معنوية (P<0.05) في تركيزات العناصر الثقيلة بين أجزاء النبات المختلفة.

الكلمات المفتاحية: Phalaris minor – ابورويس – القدرة التراكمية – المعادن الثقيلة – غابة شحات .

Introduction

Plants have been recognized as effective biomonitors for evaluating the rise in heavy metal levels in the surroundings (Sarwar et al., 2017; Zhu et al., 2021Cesur et al., 2021). Plants have the capability to absorb heavy metals from their surroundings, often accumulating these metals in concentrations that surpass those present in the soil. However, the efficiency of different plant species in taking up toxic metals varies considerably (Zhao et al., 2014). Additionally, plants play a crucial

http://www.doi.org/10.62341/RKEL1520

role in ecosystems by enabling the transfer of elements from the non-living environment to living organisms (Hu et al., 2014; Georgiev et al., 2016; Najafi & Jalali, 2016; Aljerf & Choukaife, 2018) .Urban vegetation plays a vital role in environmental monitoring and remediation, (Young et al., 2014; Bahiru & Yegrem, 2021). Regarding heavy metal accumulation, plants can be categorized into three distinct groups: heavy-metal accumulators, heavy-metal excluders (or non-accumulators), and indicator plants. Heavy-metal-accumulating plants demonstrate a concentration ratio of the metal within the plant that exceeds that in the soil, with a ratio greater than 1. In contrast, non-accumulating plants exhibit a ratio of less than 1, while indicator plants maintain a ratio that is approximately equal to 1 (Cunningham & Ow, 1996; Marques et al., 2009; van der Ent et al., 2013; Suman et al., 2018; Yan et al., 2020; Sladkovska et al., 2022; Chitimus et al., 2023; Kord et al., 2024) .To date, around 400 species of hyperaccumulators have been identified across 22 distinct families are capable of hyperaccumulating metals, primarily from families such as Brassicaceae, Poaceae, Cyperaceae, Asteraceae, Caryophyllaceae, Fabaceae, Lamiaceae, Euphorbiaceae, Violaceae, and Cunoniaceae (Gleba et al., 1999; Prasad and Freitas, 2003; McIntyre, 2003; Ghosh & Singh, 2005; Rascio & Navari-Izzo, 2011; Sladkovska et al., 2022; Khan et al., 2023). To counteract heavy metal toxicity, plants generally adopt two main defense mechanisms: avoidance and tolerance. These mechanisms allow plants to maintain intracellular heavy metal concentrations at levels that do not cause harm (Raklami et al., 2022; Hall, 2002). Avoidance strategies enable plants to limit the uptake and movement of heavy metals into their tissues, with root cells acting as the first line of defense at the extracellular level. This is accomplished through various mechanisms, including root adsorption, precipitation of metal ions, and exclusion of metals. Plants facing exposure to heavy metals first engage in strategies to immobilize these elements, primarily through root adsorption or modification of metal ions. Additionally, a range of root exudates, including organic acids and amino acids, serve as ligands for heavy metals, promoting the formation of stable complexes in the rhizosphere (Yan et al., 2020). The mechanism of metal exclusion establishes a protective barrier between the root and shoot systems, thereby limiting the uptake of heavy metals from the soil into the roots. This process is crucial for protect the aerial parts of the plant

http://www.doi.org/10.62341/RKEL1520

from the detrimental effects of heavy metals by restricting their absorption and subsequent translocation from roots to shoots. Moreover, arbuscular mycorrhizae play a significant role in mitigating the entry of heavy metals into the roots through various mechanisms, such as absorption, adsorption, or chelation of these metals in the rhizosphere, effectively functioning as a barrier against heavy metal uptake (Hall, 2002; Anum et al., 2019). Upon the infiltration of heavy metal ions into the cytosol, plants activate multiple resistance mechanisms to mitigate the toxicity associated with the accumulation of these ions, representing a secondary defense at the subcellular level. The mechanisms involved include inactivation, chelation, and compartmentalization of heavy metal ions (Dalvi & Bhalerao, 2013). In the context of phytoremediation, plants employ a range of strategies such as phytostabilization, phytoextraction, rhizodegradation, and phytovolatilization to either passively stabilize or actively remove contaminants from their environment (Raskin et al., 1994; Tangahu et al., 2011; Patra et al., 2021; Sladkovska et al., 2022; Chitimus et al., 2023; Zia-ul-Haq et al., 2024). Among these approaches, phytostabilization is a key technique utilized for the remediation of heavy metals by plants (Ali et al., 2013; Hao et al., 2014). This method specifically involves the use of metal-tolerant plant species to immobilize heavy metals in the soil, thereby decreasing their bioavailability and preventing their movement into ecosystems, which in turn mitigates the risk of metals entering the food chain. The process can occur through various mechanisms, such as precipitation or reduction of metal valence in the rhizosphere, uptake and sequestration within root tissues, or adsorption onto root cell walls (Gerhardt et al., 2017). A notable benefit of phytostabilization is that it does not necessitate the removal of toxic biomass (Wuana & Okueimen, 2011; Sarwar et al., 2017; Ashraf et al., 2019). The choice of suitable plant species is crucial for effective phytostabilization, as these plants must exhibit tolerance to heavy metals to achieve optimal performance. The root systems of these species are essential for immobilizing heavy metals, maintaining soil structure, and preventing erosion. Consequently, it is essential for these plants to possess robust and dense root systems, along with the ability to generate significant biomass and demonstrate rapid growth (Marques et al., 2009; Ali et al., 2013; Huang et al., 2017; Jacob et al., 2018; YAN et al., 2020; Venegas-Rioseco et al., 2021; Siyar et al., 2022). Grasses, known for their rapid and

http://www.doi.org/10.62341/RKEL1520

vigorous growth, serve as effective bioindicators for evaluating soil contamination by heavy metals (Ali et al., 2019; Khan et al., 2023). Plant family is one of the main factors affecting the heavy metals distribution in the above- and underground parts of plants. Plants from the Poaceae family accumulate less chemical elements in their aboveground parts than the other plants (Chaplaygin, 2018). The Poaceae family, which encompasses grasses, includes around 780 genera and 12,000 species that are widely distributed across the globe (Christenhusz and Byng, 2016). Grasses fulfill various roles, including food and fuel production, the establishment of lawns and meadows, soil erosion control, remediation of toxic metals, and ecological restoration of contaminated environments (Engelhardt and Hawkins, 2016; Rabêlo et al., 2021). The Poaceae family has proven to be highly effective in remediating contaminated environments due to their ease of cultivation, rapid growth rates, and resilience to adverse conditions. These grasses can accumulate significant amounts of heavy metals in their rhizosphere while limiting translocation to above-ground parts. Studies have shown that species within the Poaceae family can alleviate metal toxicity and improve the uptake of contaminants from polluted sites (Ashraf et al., 2019; Patra et al., 2021).
This study was conducted in the Shahat Forest to assess the capacity of *P. minor* to accumulate heavy metals from contaminated soil. and what is the strategy mechanisms will utilizes by *P. minor* in dealing with heavy metals?.

Material and methods

Study aria

The study was conducted during 2023, in a site exposed to sewage in a forest inside Shahat city, located (32°49′40″N 21°51′44″E) which has a mild climate that tends to be warm and rainy in winter and hot in summer; where maximum temperature in the studied area varies from 35.3ºC in summer to 20.1ºC in winter, Minimum temperature ranges from 20.2ºC in summer and 7.5ºC in winter. (Othman & Al-Habbat, 2023).

Sample collection: Ten *P. minor* grasses were selected to conduct this study, fresh samples of *P. minor* grasses from both aerial and root part, soil parts at depth (0 cm - 40 cm) were collected in polyethylene bags and transported to the laboratory for analysis. Five macro elements including total Nitrogen (N), Phosphorus (P),

http://www.doi.org/10.62341/RKEL1520

Potassium (K), Calcium (Ca) and Sodium (Na), four heavy metals including zinc (Zn), Iron (Fe), cadmium (Cd) and lead (Pb) were analyzed in the samples of *L. multiflorum* grasses parts and soil parts.

Sample Preparation: The Collected samples were homogenized and crushed into small particles, decomposed by dry digestion method for the determination of various metals. First of all the crucibles and the glass wares used in the experiment were washed with distilled water and then dried in oven. Weight of each crucible was made constant by keeping it in muffle furnace at 750 °c for one hour. Then transferred it to desiccator and weighted it. The purpose was to remove all the moisture. This action was repeated until the weight became constant, A known quantity, 2g of each sample (aerial part, root part of *P. minor* grasses and soil parts) was introduced into the Porcelain crucible. The crucibles were burned at around 200 °C until the end of organic matter smoke generation, then crucibles kept in muffle furnace at 600 °C for 5 hours, cooled to the room temperature in the desiccator for 40 minutes. The obtained white ash is moistened with a few drops of de-ionized water, an aliquot of 2.0 mL of concentrated HCl are added, left in contact for 10 minutes and filtered into 100 ml volumetric flasks, the volume was made up to the mark with de-ionized water, All samples were performed in triplicates (Ahmad et al., 2018; Huang et al., 2020).

Elemental analysis of samples: Determination of element concentrations in all the samples were made directly on each of the final solution by using the appropriate Instrumentation and methods.

1-Total Nitrogen (TN) and total phosphorus (TP) in soil samples were determined using an automatic elemental analyzer (Elemetar Vario Max CN, Germany) and the Olsen method, respectively (Iatrou et al., 2014; Zhao et al., 2022).

2-Total potassium (TK), Sodium (Na) and Calcium (Ca) were determined using an inductively coupled plasma mass spectrometer (ICP-MS) at labs of National Institute of Oceanography & Fisheries – Alexandria – Egypt. (Agilent 7500ce) (Nogueira et al., 2013; Zhao et al., 2022).

3-Trace elements (Iron, Zinc, Cadmium & lead) were determined by atomic absorption spectrophotometer (AAS) (Oumlouki et al., 2021; Cardoso-Silva et al., 2013).

http://www.doi.org/10.62341/RKEL1520

Biological factors:

1- Bioconcentration factor (BCF) is described as the ability of plants for elemental accumulation from the substrate. It can be measured for each plant part, such as roots, stems, and leaves using the equation:

$$BCF = \frac{C_{\text{plant part}}}{C_{\text{Soil}}}$$

where C_{plant} shows the accumulation of heavy metals in plant part (aerial or roots) and C_{soil} denoted the amount of heavy metals in soil. BCF values more than 1 demonstrate the potential success of a plant species for phytoremediation (Nouha et al., 2024).

2-**Translocation factor (TF)** is an important tool used to assess a plant's potential for phytoremediation purposes. It is calculated from the ratio of the element's presence in the plant's aerial parts compared to that in the plant's roots parts using the equation (Nouha et al., 2024; Wu et al., 2011).

$$TF = \frac{\text{Metal(aerial parts)}}{\text{Metal(roots parts)}}$$

A (TF) value greater than 1 in the metal phytoextactors and less than 1 in the metal phytosabilizer species was observed (Mellem et al., 2012; Pandey et al., 2012; Mishra and Pandey, 2019; Khermandar et al., 2016).

3-Bioaccumulation factor (BAF) is used to calculate metals transfer from soil to various plant parts (total biomass) used the following equation :

$$BAF = \frac{C_{\text{plant}}}{C_{\text{Soil}}}$$

where C_{plant} shows the accumulation of heavy metals in plant (total biomass) and C_{soil} denoted the amount of heavy metals in soil. (BAF) values more than 1 demonstrate the potential success of a plant species for bioaccumulation . (Zhuang et al., 2009; Khermandar et al., 2016; He et al.,2021; Hussain et al., 2022;). Plants having both (TF) and (BAF) >1 can be employed as phytoremediators. (BAF) values greater than two are regarded as

http://www.doi.org/10.62341/RKEL1520

high values (Usman et al., 2013). If a plant has (BAF) >1 and (TF) <1, it can be used as a phytostabilizer; if it has (BAF) < 1 and (TF) >1, it can be used as a phytoextractor (Sopyan et al., 2014; Takarina & Pin, 2017).

Statistical analysis

The obtained data were subjected to the statistical analysis of variance ANOVA one way of the combined analysis in completely randomized design (CRD), the least significant difference (LSD) at 0.05% was used to compare between the means of treatments using COSTAT software (pacific Grove, CA, USA) (Ott and Longnecker, 2015).

The results

The data present in Table (1) demonstrates a significant elevation in the concentrations of essential macro elements. Specifically, the concentrations measured in the aerial parts were (0.1.25%, 0.012, 7.74, 2.11 and 0.89 g kg^{-1}) for (N), (P), (K), (Ca), and (Na), respectively. In comparison, the root parts displayed concentrations of (0.73%, 0.024, 2.49, 2.38, and 0.74 g kg^{-1}) for the same elements. The soil parts revealed concentrations of (0.55%, 0.031, 0.765, 3.84and 0.16 g kg^{-1}) for N, P, K, Ca, and Na, respectively.

Table (1) The macro elements in *P. minor* and soil

parts	N%	P g kg^{-1}	K g kg^{-1}	Ca g kg^{-1}	Na g kg^{-1}
Aerial	1.25	0.012	7.74	2.11	0.89
Roots	37.0	0.024	2.49	2.38	0.74
Soils	0.55	0.031	0.765	3.84	0.16

Table (2) presents the concentrations of heavy metals in the aerial parts, recorded as (0.106, 0.96, 0.044, and 0.095 mg kg^{-1}) for (Zn), (Fe), (Cd), and (Pb), respectively. The root parts exhibited elevated concentrations of heavy metals, with values of (0.426, 1.51, 0.077, and 0.097 mg kg^{-1}) for Zn, Fe, Cd, and Pb, respectively. The soil parts indicated concentrations of (0.153, 1.3, 0.061, and 0.097 mg kg^{-1}) for the same metals. This information suggests that *P. minor* has a tendency to preferentially accumulate heavy metals within its root system rather than in the aerial parts

http://www.doi.org/10.62341/RKEL1520

Table (2) concentration of heavy metals in *P. minor* and soil

parts	Zn mg kg^{-1}	Fe mg kg^{-1}	Cd mg kg^{-1}	Pb mg kg^{-1}
Aerial	0.106^{C}	0.96^{C}	0,044^{C}	0.095^{A}
Roots	0.426^{A}	1.51^{A}	0.077A	0,097^{A}
Soils	0.153^{B}	1.30^{B}	0.061^{B}	0.097^{A}
LSD	0,025	0.092	0.002	0.004

According to figure (1), (BCF) for the root parts was consistently greater than that of the aerial parts for all heavy metals, with values of (2.7, 1.1, 1.2, and 1.) for Zn, Fe, Cd, and Pb, respectively, in contrast to (0.6, 0.7, 0.7, and 0.9) for the aerial parts. Additionally, (TF) values for all heavy metals remained below (1), with measurements of (0.2, 0.6, 0.5, and 0.9) for Zn, Fe, Cd, and Pb, respectively. Conversely, (BAF) exceed (1) for all heavy metals, with values of (3.4, 1.9, 1.9 and 2) for (Zn, Fe, Cd and Pb) respectively. Figure (1) demonstrates that all assessed parameters, including (BCF) for both aerial and root parts, as well as the (TF) and (BAF), suggest that *P. minor* shows a propensity for heavy metal uptake from the soil and utilizes a phytostabilization mechanism to sequester these metals within its root system.

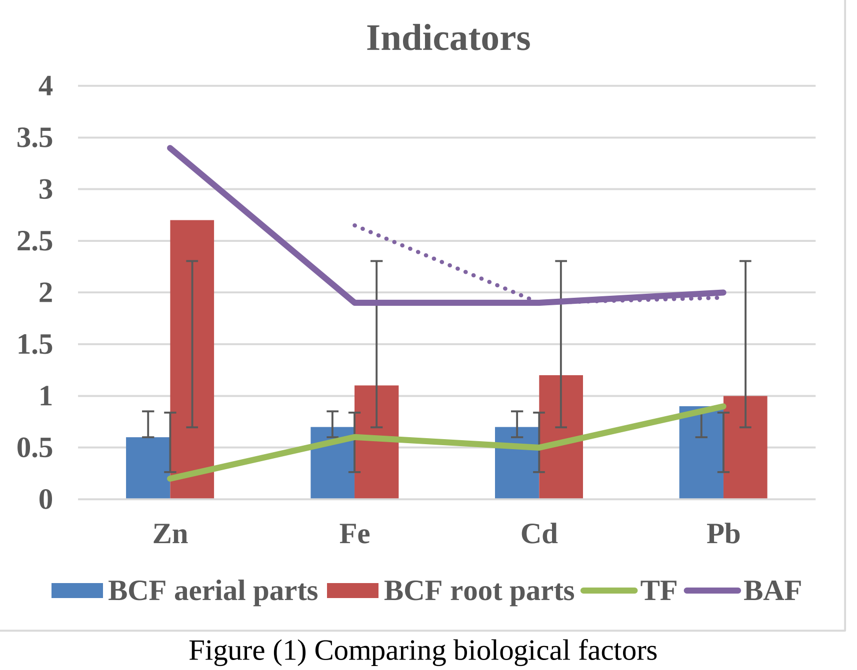

Figure (1) Comparing biological factors

http://www.doi.org/10.62341/RKEL1520

Discussion

The observed increases in the concentrations of (N), (P), (K), and (Na) can be linked to the impact of sewage water, as evidenced by the studies conducted by Smith and Giller (1992), Farahat and Linderholm (2015), and Yu et al. (2022). The elevated levels of (K) are further correlated with the presence of various minerals such as feldspar, mica, and illite, which are rich in this element (Ben Mahmoud, 1995). The rise in (Ca) concentration is largely attributed to the parent material of the soil, which contains significant amounts of calcium carbonate (Ben Mahmoud, 1995). Importantly, the concentrations of heavy metals were found to remain within the acceptable thresholds established by the World Health Organization (WHO, 1997). It is significant to note that the root system of P. minor displayed the highest concentrations of heavy metals, aligning with the findings of Prelac et al. (2016), Rabêlo et al. (2021), and Masotla et al. (2023), who reported that certain heavy metals are preferentially absorbed in the root systems compared to the aerial parts of various species within the Poaceae family. The assessment of the transfer factor (TF) indicates values below 1 for all analyzed heavy metals, suggesting that P. minor primarily accumulates these metals in its root systems. Furthermore, the bioaccumulation factor (BAF) values indicate that P. minor is categorized as a bioaccumulator, as it exceeds 1 for all heavy metals, a finding supported by the research of Zhang et al. (2006), Sarathchandra et al. (2022), and Masotla et al. (2023), among others. It has been observed that while the genus Phalaris is not classified as a hyperaccumulator, it possesses the capability to thrive in contaminated environments and effectively uptake heavy metals, as noted in studies by Mugica-Alvarez et al. (2015), Rabêlo et al. (2021), Korzeniowska & Stanislawska-Glubiak (2023), Pinna et al. (2024), and Dradrach et al. (2024). Additionally, researches conducted by Platace et al. (2011), Senze et al. (2022), Ramadan & Balah (2022), Boynukisa et al. (2023), and Khan et al. (2023) suggests that Phalaris may be a viable option for the accumulation of heavy metals. Studies by Kwiatkowska-Malina and Maciejewska (2013), Borowiak et al. (2018), Cakaj et al. (2023), and Ghandali et al. (2024) indicate that several species within the Poaceae family exhibit significant capabilities in the phytoestabilization of heavy metals. These species are characterized by their low water requirements and rapid growth in adverse soil conditions, facilitating the

http://www.doi.org/10.62341/RKEL1520

establishment of a vegetative cover that reduces the dispersion of contaminated dust while progressively sequestering heavy metals, thereby improving soil quality.

Conclusion

This study was conducted to analyze the capacity of *Phalaris minor* grasses to absorb heavy metals and store them within their tissues, as well as to determine the specific storage parts for these metals within the plant. The results revealed that P. minor grasses effectively absorb heavy metals, with a higher concentration found in the root system compared to the shoot system. Consequently, this plant is recognized as employing a phytoestabilization strategy for the immobilization of heavy metals, therefore can accumulate significant amounts of heavy metals in their rhizosphere while limiting translocation to above-ground parts. The study have shown that P. minor species can alleviate metal toxicity and improve the uptake of contaminants from polluted sites.

References

Ahmad, M., Usman, A. R., Al-Faraj, A. S., Ahmad, M., Sallam, A., & Al-Wabel, M. I. (2018). Phosphorus-loaded biochar changes soil heavy metals availability and uptake potential of maize (Zea mays L.) plants. Chemosphere, 194, 327-339.

Ali, H., Khan, E., & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation. Journal of chemistry, 2019(1), 6730305.

Ali, H., Khan, E., & Sajad, M. A. (2013). Phytoremediation of heavy metals—concepts and applications. Chemosphere, 91(7), 869-881.

Aljerf, L., & Choukaife, A. E. (2018). Review: assessment of the doable utilisation of dendrochronology as an element tracer technology in soils artificially contaminated with heavy metals. Biodiversity Int J, 2(1), 00037.

Angelova, V. (2022). Heavy metal accumulation and chemical composition of essential oil of Juniperus oxycedrus L.(Cupressaceae) grown on serpentine soils in

http://www.doi.org/10.62341/RKEL1520

Bulgaria. Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, 11.

Anum, S., Khan, S. M., Chaudhary, H. J., Ahmad, Z., & Afza, R. (2019). Phytoremediation of nickel polluted ecosystem through selected ornamental plant species in the presence of bacterium Kocuria rhizophila. Bioremediation Journal, 23(3), 215-226.

Asbabou, A., Hanane, T., Gourich, A. A., Siddique, F., Drioiche, A., Remok, F., ... & Zair, T. (2024). Phytochemical profile, physicochemical, antioxidant and antimicrobial properties of Juniperus phoenicea and Tetraclinis articulate: in vitro and in silico approaches. Frontiers in Chemistry, 12, 1397961.

Ashraf, S., Ali, Q., Zahir, Z. A., Ashraf, S., & Asghar, H. N. (2019). Phytoremediation: Environmentally sustainable way for reclamation of heavy metal polluted soils. Ecotoxicology and environmental safety, 174, 714-727.

Bahiru, D. B., & Yegrem, L. (2021). Levels of heavy metal in vegetable, fruits and cereals crops in Ethiopia: A review. International Journal of Environmental Monitoring and Analysis, 9(4), 96.

Barbieri, M. (2016). The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. Journal of Geology & Geophysics, 5(1), 1-4.

Ben Mahmoud, K. R. (1995). Libyan soils (Their Genesis, Classification, Properties and Agricultural potentials) NASR. Tripoli, Libya, 615.

Borowiak, K., Budka, A., Hanć, A., Kayze, D., Lisiak, M., Zbierska, J., ... & Łopatka, N. (2018). Relations between photosynthetic pigments, macro-element contents and selected trace elements accumulated in Lolium multiflorum L. exposed to ambient air conditions. Acta Biologica Cracoviensia s. Botanica, 60(1).

Boynukisa, E., Schück, M., & Greger, M. (2023). Differences in metal accumulation from stormwater by three plant species

http://www.doi.org/10.62341/RKEL1520

growing in floating treatment wetlands in a cold climate. Water, Air, & Soil Pollution, 234(4), 235.

Cakaj, A., Lisiak-Zielińska, M., Hanć, A., Małecka, A., Borowiak, K., & Drapikowska, M. (2023). Common weeds as heavy metal bioindicators: a new approach in biomonitoring. Scientific Reports, 13(1), 6926.

Cardoso-Silva, C. B., Melo, J., Pereira, A., & Cerqueira-Silva, C. B. (2013). Aoac. 1997. Official Methods Of Analysis Of The Association Of Official Analytical. Caracterização, Propagação E Melhoramento Genético De Pitaya Comercial E Nativa Do Cerrado, 29(1), 48.

Cesur, A., Zeren Cetin, I., Abo Aisha, A. E. S., Alrabiti, O. B. M., Aljama, A. M. O., Jawed, A. A., ... & Ozel, H. B. (2021). The usability of Cupressus arizonica annual rings in monitoring the changes in heavy metal concentration in air. Environmental Science and Pollution Research, 28(27), 35642-35648.

Chandrajith, R., Dissanayake, C. B., & Tobschall, H. J. (2005). The abundances of rarer trace elements in paddy (rice) soils of Sri Lanka. Chemosphere, 58(10), 1415-1420.

Chaplygin, V., Minkina, T., Mandzhieva, S., Burachevskaya, M., Sushkova, S., Poluektov, E., ... & Kumacheva, V. (2018). The effect of technogenic emissions on the heavy metals accumulation by herbaceous plants. Environmental monitoring and assessment, 190, 1-18.

Christenhusz, M. J., & Byng, J. W. (2016). The number of known plants species in the world and its annual increase. Phytotaxa, 261(3), 201-217.

Chitimus, D., Nedeff, V., Mosnegutu, E., Barsan, N., Irimia, O., & Nedeff, F. (2023). Studies on the accumulation, translocation, and enrichment capacity of soils and the plant species phragmites australis (common reed) with heavy metals. Sustainability, 15(11), 8729.

http://www.doi.org/10.62341/RKEL1520

Cunningham,S.D., and Ow, D.W.(1996):Promises and prospects of phytoremediation. – Plant Physiol. 110; 715-719 .

Dalvi, A. A., & Bhalerao, S. A. (2013). Response of plants towards heavy metal toxicity: an overview of avoidance, tolerance and uptake mechanism. Ann Plant Sci, 2(9), 362-368.

Diaconu, D., Nastase, V., Nănău, M. M., Nechifor, O., & Nechifor, E. (2009). Assessment of some heavy metals in soils, drinking water, medicinal plants and their liquid extracts. Environmental Engineering & Management Journal (EEMJ), 8(3).

Dradrach, A., Karczewska, A., Bogacz, A., Kawałko, D., & Pruchniewicz, D. (2024). Accumulation of Potentially Toxic Metals in Ryegrass (Lolium perenne, L.) and Other Components of Lawn Vegetation in Variously Contaminated Sites of Urban Areas. Sustainability, 16(18), 8040.

Engelhardt, K. A., & Hawkins, K. (2016). Identification of low growing, salt tolerant turfgrass species suitable for use along highway right of way (No. MD-16-SHA-UMCES-6-3).

Farahat, E., & Linderholm, H. W. (2015). The effect of long-term wastewater irrigation on accumulation and transfer of heavy metals in Cupressus sempervirens leaves and adjacent soils. Science of the Total Environment, 512, 1-7.

Georgiev, P., Groudev, S., Spasova, I., & Nicolova, M. (2016). Remediation of a grey forest soil contaminated with heavy metals by means of leaching at acidic pH. Journal of soils and sediments, 16, 1288-1299.

Gerhardt, K. E., Gerwing, P. D., & Greenberg, B. M. (2017). Opinion: Taking phytoremediation from proven technology to accepted practice. Plant Science, 256, 170-185.

Ghandali, M. V., Safarzadeh, S., Ghasemi-Fasaei, R., & Zeinali, S. (2024). Heavy metals immobilization and bioavailability in multi-metal contaminated soil under ryegrass cultivation as

http://www.doi.org/10.62341/RKEL1520

affected by Zn and Mn nanoparticle-modified biochar. Scientific Reports, 14(1), 10684.

Ghosh, M., & Singh, S. P. (2005). A review on phytoremediation of heavy metals and utilization of it's by products. Asian J Energy Environ, 6(4), 18.

Gleba D.,Borisjuk,N.V.,Borisjuk, L. G.,Kneer,R., Poulev, A.,Skarzhinskaya,M., Dushenkov, S. Logendra, S. Gleba, Y. Y., Raskin, I. (1999): Use of Plant root for phytoremediation and molecular farming. – Proc. Natl.Acad.Sci, USA. 96; 5973-5977.

Gola, D., Malik, A., Shaikh, Z. A., & Sreekrishnan, T. R. (2016). Impact of heavy metal containing wastewater on agricultural soil and produce: relevance of biological treatment. Environmental Processes, 3, 1063-1080.

Hall, J. Á. (2002). Cellular mechanisms for heavy metal detoxification and tolerance. Journal of experimental botany, 53(366), 1-11.

Hao, X., Taghavi, S., Xie, P., Orbach, M. J., Alwathnani, H. A., Rensing, C., & Wei, G. (2014). Phytoremediation of heavy and transition metals aided by legume-rhizobia symbiosis. International Journal of Phytoremediation, 16(2), 179-202.

He, Y., Su, S., Cheng, J., Tang, Z., Ren, S., & Lyu, Y. (2021). Bioaccumulation and trophodynamics of cyclic methylsiloxanes in the food web of a large subtropical lake in China. Journal of Hazardous Materials, 413, 125354
.

Hu, Y., Wang, D., Wei, L., Zhang, X., & Song, B. (2014). Bioaccumulation of heavy metals in plant leaves from Yan′ an city of the Loess Plateau, China. Ecotoxicology and environmental safety, 110, 82-88.

Huang, C., Lai, C., Xu, P., Zeng, G., Huang, D., Zhang, J., ... & Wang, R. (2017). Lead-induced oxidative stress and antioxidant response provide insight into the tolerance of

http://www.doi.org/10.62341/RKEL1520

Phanerochaete chrysosporium to lead exposure. Chemosphere, 187, 70-77.

Huang, J., Wang, C., Qi, L., Zhang, X., Tang, G., Li, L., ... & Lu, M. (2020). Phosphorus is more effective than nitrogen in restoring plant communities of heavy metals polluted soils. Environmental Pollution, 266, 115259.

Hussain, B., Abbas, Y., Ali, H., Zafar, M., Ali, S., Ashraf, M. N., ... & Valderrama, J. R. D. (2022). Metal and metalloids speciation, fractionation, bioavailability, and transfer toward plants. In Metals metalloids soil plant water systems (pp. 29-50). Academic Press.

Iatrou, M., Papadopoulos, A., Papadopoulos, F., Dichala, O., Psoma, P., & Bountla, A. (2014). Determination of soil available phosphorus using the Olsen and Mehlich 3 methods for Greek soils having variable amounts of calcium carbonate. Communications in Soil Science and Plant Analysis, 45(16), 2207-2214.

Jacob, J. M., Karthik, C., Saratale, R. G., Kumar, S. S., Prabakar, D., Kadirvelu, K., & Pugazhendhi, A. (2018). Biological approaches to tackle heavy metal pollution: a survey of literature. Journal of environmental management, 217, 56-70.

Khan, S. N., Nafees, M., & Imtiaz, M. (2023). Assessment of industrial effluents for heavy metals concentration and evaluation of grass (Phalaris minor) as a pollution indicator. Heliyon, 9(9).

Khermandar, K., Mahdavi, A., & Ahmady Asbchin, S. (2016). Differential expression of Lead accumulation during two growing seasons by desert shrub Acacia victoriae L. Desert, 21(2), 143-154.

Kord, B., Khademi, A., Madanipour Kermanshahi, M., Pourabbasi, S., & Hashemi, S. A. (2024). Phytoremediation potential of tree species in soil contaminated with lead and cadmium. Caspian Journal of Environmental Sciences, 1-9.

http://www.doi.org/10.62341/RKEL1520

Korzeniowska, J., & Stanislawska-Glubiak, E. (2023). The Phytoremediation Potential of Local Wild Grass Versus Cultivated Grass Species for Zinc-Contaminated Soil. Agronomy, 13(1), 160.

Kumar, A., Maiti, S. K., Tripti, Prasad, M. N. V., & Singh, R. S. (2017). Grasses and legumes facilitate phytoremediation of metalliferous soils in the vicinity of an abandoned chromite–asbestos mine. Journal of soils and sediments, 17, 1358-1368.

Kwiatkowska-Malina, J., & Maciejewska, A. (2013). Uptake of heavy metals by darnel multifloral (Lolium multiflorum Lam.) at diverse soil reaction and organic matter content. Soil Science Annual, 64(1), 19.

Manohara, B., & Belagali, S. L. (2014). Characterization of essential nutrients and heavy metals during municipal solid waste composting. International Journal of Innovative Research in Science, Engineering and Technology, 3(2), 9664-9672.

Marques, A. P., Rangel, A. O., & Castro, P. M. (2009). Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. Critical Reviews in Environmental Science and Technology, 39(8), 622-654

.
Masotla, M. K. L., Melato, F. A., & Mokgalaka-Fleischmann, N. S. (2023). Extraction Potential of Lolium perenne L.(Perennial Rye Grass) for Metals in Landfill Soil: Its Tolerance and Defense Strategies. Minerals, 13(7), 873.

McIntyre, T., 2003. Phytoremediation of heavy metals from soils. Advances in Biochemical Engineering/ Biotechnology 78, 97-123.

Mellem, J. J., Baijnath, H., & Odhav, B. (2012). Bioaccumulation of Cr, Hg, As, Pb, Cu and Ni with the ability for hyperaccumulation by Amaranthus dubius. African Journal of Agricultural Research, 7(4), 591-596.

http://www.doi.org/10.62341/RKEL1520

Mishra, T., & Pandey, V. C. (2019). Phytoremediation of red mud deposits through natural succession. In Phytomanagement of polluted sites (pp. 409-424).

Mng'ong'o, M., Munishi, L.K., Ndakidemi, P.A., Blake, W., Comber, S., Hutchinson, T.H., 2021. Toxic metals in East African agro-ecosystems : key risks for sustainable food production. J. Environ. Manage. 294, 112973.

Mugica-Alvarez, V., Cortés-Jiménez, V., Vaca-Mier, M., & Domínguez-Soria, V. (2015). Phytoremediation of mine tailings using Lolium multiflorum. Int. J. Environ. Sci. Dev, 6(4), 246.

Najafi, S., & Jalali, M. (2016). Effect of heavy metals on pH buffering capacity and solubility of Ca, Mg, K, and P in non-spiked and heavy metal-spiked soils. Environmental monitoring and assessment, 188(6), 342. https://doi.org/10.1007/s10661-016-5329-9.

Naser, H. M., Shil, N. C., Mahmud, N. U., Rashid, M. H., & Hossain, K. M. (2009). Lead, cadmium and nickel contents of vegetables grown in industrially polluted and non-polluted areas of Bangladesh. Bangladesh Journal of Agricultural Research, 34(4), 545-554.

Nogueira, T. A. R., Franco, A., He, Z., Braga, V. S., Firme, L. P., & Abreu-Junior, C. H. (2013). Short-term usage of sewage sludge as organic fertilizer to sugarcane in a tropical soil bears little threat of heavy metal contamination. Journal of Environmental Management, 114, 168-177.

Noor-ul, A., & Tauseef, A. (2015). Contamination of soil with heavy metals from industrial effluent and their translocation in green vegetables of Peshawar. Pakistan RSC Advances, 5, 14322-14329.

Nouha, k., mounira, g. M., lamia, h., shahhat, i., mehrez, r., & arbi, g. (2024). Physiological and biochemical responses in mediterranean saltbush (atriplex halimus l., amaranthaceae

http://www.doi.org/10.62341/RKEL1520

juss.) To heavy metal pollution in arid environment. Pak. J. Bot, 56(5), 1717-1726.

Othman, A., & Al-Habbat, N. (2023). Modeling Trends in Rainfall Rates at Shahat Meteorological Station (1961-2050) Using Statistical Techniques. Journal of Humanitarian and Applied Sciences, 8(16), 176-188.

Ott, R. L. and Longnecker M. T. (2015) An introduction to statistical methods and data analysis: Nelson Education. 1296.

Oumlouki, K. E., Salih, G., Jilal, A., Dakak, H., Amrani, M. E., & Zouahri, A. (2021). Comparative study of the mineral composition of carob pulp (Ceratonia siliqua L.) from various regions in Morocco. Moroccan Journal of Chemistry, 9(4), 9-4.

Pandey, R., Shubhashish, K., & Pandey, J. (2012). Dietary intake of pollutant aerosols via vegetables influenced by atmospheric deposition and wastewater irrigation. Ecotoxicology and environmental safety, 76, 200-208.

Patra, D. K., Acharya, S., Pradhan, C., & Patra, H. K. (2021). Poaceae plants as potential phytoremediators of heavy metals and eco-restoration in contaminated mining sites. Environmental Technology & Innovation, 21, 101293.

Pinna, M. V., Diquattro, S., Garau, M., Grottola, C. M., Giudicianni, P., Roggero, P. P., & Garau, G. (2024). Combining biochar and grass-legume mixture to improve the phytoremediation of soils contaminated with potentially toxic elements (PTEs). Heliyon, 10(5).

Platace, R., Adamovics, A., & Poiša, L. (2011). Content of Heavy Metals in the Reed Canarygrass (Phalaris Arundinacea L.) in the First Year of Harvest. Scientific Journal of Riga Technical University. Environmental and Climate Technologies, 5(1).

Prasad, M. N. V., & De Oliveira Freitas, H. M. (2003). Metal hyperaccumulation in plants—biodiversity prospecting for phytoremediation technology. Electron J Biotechnol, 6(3), 110-146.

http://www.doi.org/10.62341/RKEL1520

Prelac, M., BILANDŽIJA, N., & ZGORELEC, Ž. (2016). The phytoremediation potential of heavy metals from soil using Poaceae energy crops: A review. Journal of Central European Agriculture.

Rabêlo, F. H. S., Vangronsveld, J., Baker, A. J., van Der Ent, A., & Alleoni, L. R. F. (2021). Are grasses really useful for the phytoremediation of potentially toxic trace elements? A review. Frontiers in Plant Science, 12, 778275.

Raklami, A., Meddich, A., Oufdou, K., & Baslam, M. (2022). Plants—Microorganisms-based bioremediation for heavy metal cleanup: Recent developments, phytoremediation techniques, regulation mechanisms, and molecular responses. International Journal of Molecular Sciences, 23(9), 5031.

Ramadan, W. F., & Balah, M. A. (2022). The use of some weeds type in the disposal of heavy metals in contaminated soil. Journal of the Saudi Society of Agricultural Sciences, 21(5), 289-295.

Rascio, N., & Navari-Izzo, F. (2011). Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting?. Plant science, 180(2), 169-181.

Raskin, I, Kumar, P.B.A.N., Dushenkov, S. and Salt, D. (1994): Bioconcentration of heavy metals by plants. – Current Opinion Biotechnology 5; 285-290.

Sarathchandra, S. S., Rengel, Z., & Solaiman, Z. M. (2022). Remediation of heavy metal-contaminated iron ore tailings by applying compost and growing perennial ryegrass (Lolium perenne L.). Chemosphere, 288, 132573.

Sarwar, N., Imran, M., Shaheen, M. R., Ishaque, W., Kamran, M. A., Matloob, A., ... & Hussain, S. (2017). Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives. Chemosphere, 171, 710-721.

http://www.doi.org/10.62341/RKEL1520

Senze, M., Kowalska-Góralska, M., Czyż, K., & Wondołowska-Grabowska, A. (2022). Possibility of metal accumulation in reed canary grass (Phalaris arundinacea L.) in the aquatic environment of south-western Polish rivers. International Journal of Environmental Research and Public Health, 19(13), 7779.

Siyar, R., Doulati Ardejani, F., Norouzi, P., Maghsoudy, S., Yavarzadeh, M., Taherdangkoo, R., & Butscher, C. (2022). Phytoremediation potential of native hyperaccumulator plants growing on heavy metal-contaminated soil of Khatunabad copper smelter and refinery, Iran. Water, 14(22), 3597.

Sladkovska, T., Wolski, K., Bujak, H., Radkowski, A., & Sobol, Ł. (2022). A review of research on the use of selected grass species in removal of heavy metals. Agronomy, 12(10), 2587.

Sopyan, S., Sikanna, R., & Sumarni, N. K. (2014). Fitoakumulasi Merkuri Oleh Akar Tanaman Bayam Duri (Amarantus Spinosus Linn) Pada Tanah Tercemar. Natural Science: Journal of Science and Technology, 3(1).

Suman, J., Uhlik, O., Viktorova, J., & Macek, T. (2018). Phytoextraction of heavy metals: a promising tool for clean-up of polluted environment?. Frontiers in plant science, 9, 1476.

Taghipour, H., & Mosaferi, M. (2013). Heavy metals in the vegetables collected from production sites. Health promotion perspectives, 3(2), 185.

Takarina, N. D., & Pin, T. G. (2017). Bioconcentration factor (BCF) and translocation factor (TF) of heavy metals in mangrove trees of Blanakan fish farm. Makara Journal of Science, 77-81.

Tangahu, B. V., Sheikh Abdullah, S. R., Basri, H., Idris, M., Anuar, N., & Mukhlisin, M. (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. International journal of chemical engineering, 2011(1), 939161.

Usman, A.R.A., R.S., Alkredaa and M.I. Al-Wabel (2013) Heavy metal contamination in sediments and mangroves from the

http://www.doi.org/10.62341/RKEL1520

coast of Red Sea: Avicennia sp. marina as potential metal bioaccumulator.Ecotoxicol. Environ. Saf. 97: 263-270.

Van der Ent, A., Baker, A. J., Reeves, R. D., Pollard, A. J., & Schat, H. (2013). Hyperaccumulators of metal and metalloid trace elements: facts and fiction. Plant and soil, 362, 319-334.

Venegas-Rioseco, J., Ginocchio, R., & Ortiz-Calderón, C. (2021). Increase in phytoextraction potential by genome editing and transformation: a review. Plants, 11(1), 86.

Wen, W., Zhao, H., Ma, J., Li, Z., Li, H., Zhu, X., ... & Liu, Y. (2018). Effects of mutual intercropping on Pb and Zn accumulation of accumulator plants Rumex nepalensis, Lolium perenne and Trifolium repens. Chemistry and Ecology, 34(3), 259-271.

World Health Organization (WHO). (1996). Permissible limits of heavy metals in soil and plants. Geneva, Switzerland.

Wu, Q., Wang, S., Thangavel, P., Li, Q., Zheng, H., Bai, J., & Qiu, R. (2011). Phytostabilization potential of Jatropha curcas L. in polymetallic acid mine tailings. International Journal of phytoremediation, 13(8), 788-804.

Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. International Scholarly Research Notices, 2011(1), 402647.

Yan, A., Wang, Y., Tan, S. N., Mohd Yusof, M. L., Ghosh, S., & Chen, Z. (2020). Phytoremediation: a promising approach for revegetation of heavy metal-polluted land. Frontiers in plant science, 11, 359.

Youning, Hu., W. Dexiang, W. Lijing, Z. Xinping and S. Bin (2014). Bioaccumulation of heavy metals in plant leaves from Yan'an city of the Loess Plateau, China. Ecotoxicology and Environmental Safety, 110: 82–88.

Yu, H., Xiao, H., Cui, Y., Liu, Y., & Tan, W. (2022). High nitrogen addition after the application of sewage sludge

http://www.doi.org/10.62341/RKEL1520

compost decreased the bioavailability of heavy metals in soil. Environmental Research, 215, 114351.

Zhang, L., Li, H. X., Ma, W. F., & Zhao, X. H. (2006). Phytoremediation of complex contaminations in dredged sewage river sediment by Lolium multiflorum Lam. Journal of Agro-Environment Science, 25(1), 107-112.

Zhang, M., Cui, L., Sheng, L., & Wang, Y. (2009). Distribution and enrichment of heavy metals among sediments, water body and plants in Hengshuihu Wetland of Northern China. *Ecological engineering*, *35*(4), 563-569.

Zhao, Q., Thompson, A. M., Callister, S. J., Tfaily, M. M., Bell, S. L., Hobbie, S. E., & Hofmockel, K. S. (2022). Dynamics of organic matter molecular composition under aerobic decomposition and their response to the nitrogen addition in grassland soils. Science of the Total Environment, 806, 150514.

Zhao, X., Liu, J., Xia, X., Chu, J., Wei, Y., Shi, S., ... & Jiang, Z. (2014). The evaluation of heavy metal accumulation and application of a comprehensive bio-concentration index for woody species on contaminated sites in Hunan, China. Environmental Science and Pollution Research, 21, 5076-5085.

Zhu, Y. Q., Wang, H. J., Lv, X., Song, J. H., Wang, J. G., & Tian, T. (2021). Effect of biochar on soil cadmium content and cadmium uptake of cotton (Gossypium hirsutum L.) grown in northwestern China. Applied Ecology & Environmental Research, 19(5).

Zia-ul-Haq, M., Iqbal, F., Shafiq, S., Nawaz, M., Ali, B., Ibrahim, M. U., & Abd_Allah, E. F. (2024). Exploring the Phyto-Remediation Potential of Different Winter Weeds for Lead Toxicity. Polish Journal of Environmental Studies, 33(4), 4481-4492.