HEAVY METAL ACCUMULATION POTENTIAL OF SPONTANEOUS EDIBLE PLANTS IN AGRICULTURAL AREAS

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RESEARCH ARTICLE – Case Study

Abstract
Environmental contamination with toxic elements in agricultural areas represent a growing concern in the modern days. Human activities can contribute to the accumulation of unwanted substances both in soil and vegetation. Given these conditions, plants from the spontaneous flora can represent an important food resource for local populations and at the same time, a possible route for the transfer of contaminants to the food chain.
The aim of this study was to evaluate and compare the accumulation capacity of heavy metals in two plant species, often found in cultivated lands: Amaranthus retroflexus and Chenopodium album.
The study was conducted using data extracted from scientific literature with the main focus on the elements that are closely related to agricultural and industrial pollution: lead (Pb), cadmium (Cd), copper (Cu) and zinc (Zn). The collected data was further analyzed and statistically interpreted in order to evaluate accumulation tendencies in these species. The obtained results indicate that both plants show a variable capacity to accumulate heavy metals. It appears to be influenced by soil characteristics as well as by the physiological traits of each plant. Copper and zinc concentrations were higher than those recorded for lead and cadmium. In certain sampling locations, higher levels of these elements suggested the presence of local contamination sources. A comparison between the two species revealed differences in accumulation efficiency.
Overall, this research highpoint the importance of the role in monitoring spontaneous plants in agricultural areas, especially when they are used in human or animal food. The evaluation of accumulation levels provides valuable information in both assessing the potential risk to health and for understanding the role of these species as indicators of environmental quality. The study contributes to a better comprehension of the behavior of these plants in relation to the studied elements and emphasizes the need for careful management of agricultural soils exposed to different sources of pollution.

Keywords: bioaccumulation, food safety, soil contamination, phytoremediation, weeds
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INTRODUCTION

Pollution and contamination with potentially toxic elements represent one of the most important and current problems regarding environmental pollution (Tőzsér et al, 2023; Ugulu et al, 2022). The accelerated development in the field of agriculture, the use of fertilizers and pesticides, and also emissions coming from industry and traffic, massively favor the accumulation of elements such as Lead (Pb), Cadmium (Cd), Copper (Cu) and Zinc (Zn) in agricultural soils (Sipos et al, 2023). Although some of these elements, such as Cu and Zn, in low concentrations are important in the metabolic processes of plants, high levels can become harmful and can affect both the development of the flora and the quality of agricultural products (Adnan et al, 2022; FAO 2018). On the other hand, elements such as Pb and Cd have no known biological role in plant metabolism and can cause negative effects on living organisms even at lower concentrations.

The soil is the main reservoir of these elements, and the interaction between the soil and plants determines the degree to which they are absorbed and translocated to different plant organs. The absorption process depends on several factors, including the physicochemical properties of the soil, pH, organic matter content and the bioavailability of the elements (Gupta et al, 2007). Once absorbed through the root system, these elements can be transported to the aerial parts of the plants, where they can accumulate in the leaves or stems (Zhou et al, 2024). For this reason, plants can indirectly reflect the level of contamination of the environment in which they grow and are frequently used as bioindicators of soil pollution (Sipos et al, 2023; Ghosh et al, 2005; Zhou et al, 2024).

In agricultural areas, in addition to cultivated species, numerous spontaneous plants also frequently grow (Hamidzadeh et al, 2021). Some of these are considered weeds, but many species are traditionally used as edible or medicinal plants (Lăcătuș et al, 2025; Poonia et al, 2015). Evaluating the levels of potentially toxic elements in these plant species is important from a food safety viewpoint, as they may act as a pathway through which contaminants enter the food chain (Rai et al., 2019). Regular consumption of plants cultivated in polluted environments can gradually lead to long-term exposure of the population to harmful elements.

Among the spontaneous flora frequently encountered in agricultural systems, two species stand out due to their wide distribution: *Amaranthus retroflexus L.* and *Chenopodium album L.* (Hamidzadeh et al., 2021).

Both belong are known for their ability to adapt to various environmental conditions and for their rapid growth in nutrient-rich soils (Flores-Calla et al, 2024; Zhou et al, 2024). In many regions of the world, the young leaves of these plants are consumed as a source of nutrients, due to their high content of proteins, fibers, vitamins and bioactive compounds (Lăcătuș et al, 2025; Poonia et al, 2015). However, these species can also show a significant capacity for absorption and accumulation of various elements from the soil, including those with toxic potential (Flores-Calla et al, 2024; Zulfiqar et al, 2012; Zhou et al, 2024).

Numerous studies have highlighted the fact that certain spontaneous plants can accumulate considerable amounts of elements such as Pb, Cd, Cu or Zn, depending on the level of contamination of the substrate and the physiological characteristics of each species (Flores-Calla et al, 2024; Rashid et al, 2012). For this reason, these plants are both investigated from the perspective of the risks associated with their consumption and for their potential use in phytoremediation processes, through which vegetation can contribute to the reduction of soil contamination. At the same time, the analysis of the accumulation of elements in spontaneous plants provides valuable information about their mobility in agricultural ecosystems (Gupta et al, 2007; Zhou et al, 2024).

In this context, the aim of the present study is to evaluate the accumulation capacity of the elements Pb, Cd, Cu and Zn in two spontaneous species frequently found in agricultural areas: *Amaranthus retroflexus* and *Chenopodium album*. The investigation of these species can contribute to a better understanding of the transfer of elements from soil to plants and to the assessment of potential risks associated with their use in human or animal nutrition. At the same time, the results obtained can provide useful information regarding the role of these plants as indicators of environmental quality in agricultural ecosystems.

MATERIAL AND METHOD

The present study was conducted using sources and data extracted from the specialized literature. Only studies that provided relevant data on elements closely related to agricultural and industrial pollution of *Amaranthus retroflexus* and *Chenopodium album* plants were selected: lead (Pb), cadmium (Cd), copper (Cu) and zinc (Zn). The collected data were further organized in table, analyzed and statistically interpreted to evaluate the accumulation trends of these species. Hierarchical Clustering was performed using PAST version 2.17.c (Hammer et. al., 2001) and the the heatmap was generated using Python (Matplotlib; Hunter, 2007) based on experimental/literature data compiled in this study.

RESULTS AND DISCUSSIONS

In order to assess the accumulation potential of Pb, Cd, Cu, and Zn from this two spontaneous plants, data collected from the scientific literature, were systematically arranged in Table 1, according to plant organs (root, stem, and leaves).

In order to explore the relationships between samples and identify possible combination patterns, hierarchical clustering based on the Ward method was applied (Figure 1). Additionally, variations in metal concentrations are visualized through a heatmap (Figure 2).

Table 1

Metal concentrations in plant parts of *Amaranthus spp.* and *Chenopodium album* [mg/kg DW]

Studied plant	Plant parts		Element Cu	Pb	Zn	Cd	References
Plant 1	Roots	AR1	4	2	24	7	(Sipos et. al., 2023; Lacatus et. al., 2025)
	Stems	AS1	3	1	16	3,6	(Sipos et. al., 2023; Zhou et. al., 2024)
	Leaves	AL1	4	1	26	13,8	(Sipos et. al., 2023; Tőzsér et. al., 2019)
Plant 2	Roots	AR2	1,58	5,66	1,24	0,44	(Alsherif et. al., 2022; Saracin et. al., 2026)
	Stems	AS2	0	7,59	50,97	0,59	(Saracin et. al., 2026; Zou et. al., 2006)
	Leaves	AL2	36	8,29	106	0,55	(Ramteke et. al., 2016; Saracin et. al., 2026)
Plant 3	Roots	CR3	17	0,1	97,6	40,7	(Gupta et. al., 2007; Tőzsér et. al., 2019; Abe et. al., 2008)
	Stems	CS3	11,9	0,1	44,7	14,7	(Gupta et. al., 2007; Tőzsér et. al., 2019; Bhargava et. al., 2008b)
	Leaves	CL3	15,5	2,3	118	1,57	(Gupta et. al., 2007; Ramteke et. al., 2016)
Plant 4	Roots	CR4	0,4	0,1	1,7	46,3	(Tőzsér et. al., 2019; Abe et. al., 2008)
	Stems	CS4	2,7	0,03	1,5	12,2	(Tőzsér et. al., 2019; Bhargava et. al., 2008b)
	Leaves	CL4	19,25	0,03	26,91	14,77	(Tőzsér et. al., 2019; Gao et. al., 2022; Bhargava et. al., 2008a)
MAL		MAL	5	0,1	25	0,05	(EFSA, 2026; WHO, FAO, 1995)

Legend: AR - Amaranthus roots; AS - Amaranthus stems; AL – Amaranthus leaves; CR - Chenopodium roots; CS - Chenopodium stems; CL -Chenopodium leaves; Cu - Copper; Pb - Lead; Zn - Zinc; Cd - Cadmium.

Figure 1 illustrates how metals are distributed among different plant parts, suggesting that both species are capable of growing and persisting even in contaminated environments. With toxic elements such as cadmium (Cd) and lead (Pb) are not limited to the roots, but can also be found in the aerial parts, including tissues of potential nutritional relevance. The clustering analysis reveals several differentiated groups. CR4-CL4, corresponding to *Chenopodium album* plant, are clearly separated from the oher groups and reflect a visible accumulation capacity across all organs. From this group, CR4 stands out showing metal concentrations particularly for lead (Pb) and cadmium (Cd) markedly higher than those recorded in the other samples. AR2-AL2, the second group, belonging to

Amaranthus retroflexus plant, suggests moderate to quite high levels of contamination, with a equally uniform distribution of metals between roots, stems, and leaves. Another set of cluster formed, AR1-AS1 is situated closer to regulatory limits and indicates a lower degree of exposure. At the opposite end, the CR3-CL3 cluster is associated with the lowest concentrations, especially for copper (Cu), and reveals conditions closer to background or nutritional levels. The fact that roots, stems, and leaves tend to remain grouped within the same clusters suggests that metal uptake is followed by internal redistribution, with lead (Pb) and cadmium (Cd) contributing most strongly to the differences observed between samples.

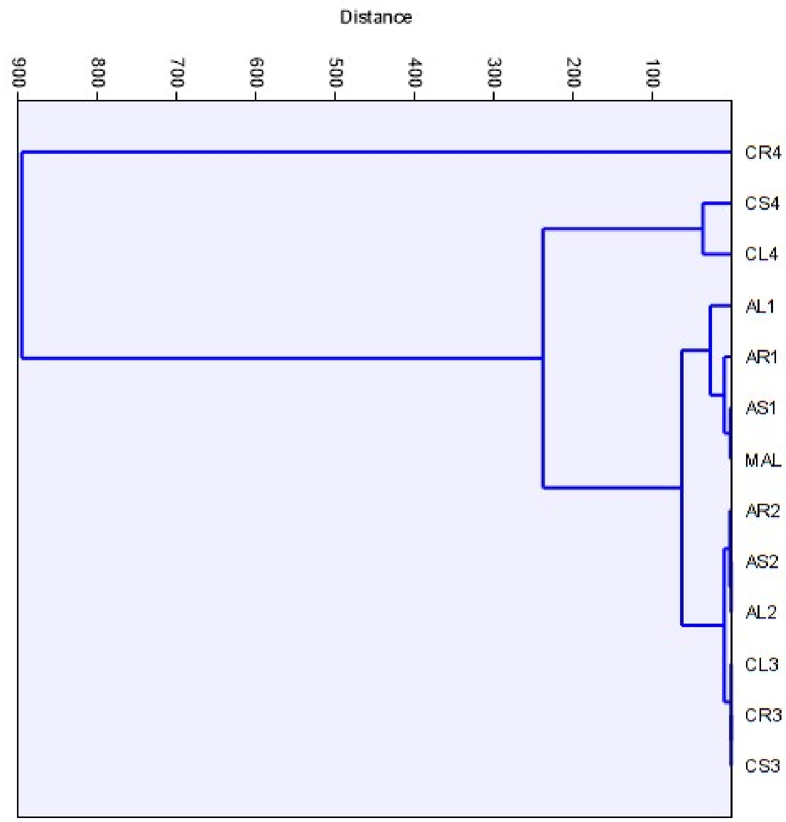

Figure 1. Hierarchical Clustering based on Ward method

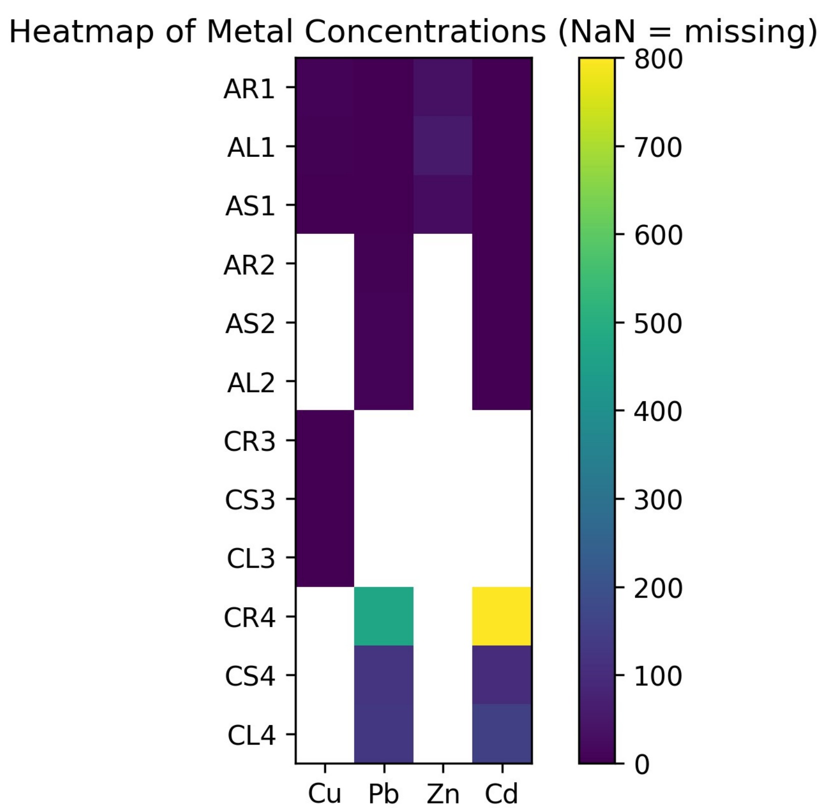

Figure 2. Heatmap of Cu, Pb, Zn, and Cd concentrations across samples with missing values preserved (white cells = missing values)

Color	Concentration Range (mg/kg)	Interpretation
□ **Dark purple**	0 – 50	Very low / background level
□ **Purple**	50 – 150	Low concentration
● **Blue–violet**	150 – 300	Moderate concentration
□ **Green**	300 – 600	High concentration
□ **Yellow**	600 – 800	Very high / extreme contamination

Color scale represents metal concentrations (mg/kg), ranging from low (dark purple) to extreme values (yellow). White cells indicate missing values (not reported in the literature), not zero concentrations.

Risk ranking

Cd - cadmium (highest toxicity, extreme values)
Pb - lead (systematically above limits)
Zn - zinc (secondary concern)
Cu - copper (minor concern).

Figure 2 shows a clear differences in metal levels between samples, with cadmium (Cd) and lead (Pb) driving most of the variation. The highest concentrations appear in the CR4-CL4 group, especially in CR4, which stands out due to very high cadmium (Cd) values. CS4 and CL4 also show elevated levels, indicating that several parts of *Chenopodium album* are consistently affected.

In contrast, AR2-AL2 presents moderate concentrations without extreme values, while AR1-AS1 remains closer to lower levels, suggesting reduced exposure. At the opposite end, CR3-CL3 shows very low metal content, close to background conditions.

Similar distribution patterns across roots, stems, and leaves within each group point to a systemic uptake and internal translocation of metals.

CONCLUSIONS

This study points to clear differences between *Amaranthus retroflexus* and *Chenopodium album* in how they take up and store heavy metals. While both species can absorb contaminants from polluted soils, they do not behave in the same way.

Chenopodium album shows a wide range of values, from low to very high concentrations, which suggests that its accumulation capacity is strongly influenced by environmental conditions. In contrast, *Amaranthus retroflexus* displays a more consistent pattern, with generally moderate levels and a fairly even distribution across plant part (roots, stems, leaves).

The detection of cadmium (Cd) and lead (Pb) in the aerial parts confirms that these metals are not confined to the roots, highlighting a possible pathway into the food chain. At the same time, the differences observed between samples indicate that local factors play a major role in determining accumulation, not just the plant species itself.

Overall, these findings suggest that both species can serve as useful indicators of environmental contamination, but also underline the importance of monitoring their presence in agricultural areas due to potential food safety implications.

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