Assessment of Metal Contents and Phytoremediation Potentials of Legume Species Growing around Iron Mine

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ABSTRACT

Background: Although mines play a crucial role in the economy, their environmental impacts are equally significant. The screening of natural plant species in mining and mining facility sites facilitates the identification of species suitable for phytoremediation. This study aims to investigate the elemental concentrations and assess the phytoremediation potential of selected legume (forage) species growing in the vicinity of the iron mine located in Bingöl province, Türkiye.

Methods: In this area, *Lathyrus sphaericus* Retz., *Trifolium nigrescens* Viv., *Trifolium campestre* Schreb., *Trifolium arvense* L., *Vicia cracca* L., *Lotus gebelia* Vent. Species belonging to the legume family were collected. Element (Al, Cu, Cr, Fe, Mn and Ni) contents were measured in the above- and below-soil parts of the plants and translocation factor (TF) and bioconcentration factor (BCF) values were calculated.

Result: $TF_{Cr, Fe, Mn, Ni}$>1 in *L. sphaericus* and *V. cracca*, $TF_{Al, Cu, Cr, Fe, Mn, Ni}$>1 in *T. nigrescens* and $TF_{Al, Cu, Cr, Mn}$>1 in *L. gebelia*. It is thought that the phytoextraction potential of these species is strong in elements with TF>1. Since the BCF-root value of *T. campestre* was determined as 38.91 for the element Cr, the potential of this species to be used in phytostabilization in Cr contaminated areas is considered important. Although certain species collected from the vicinity of the mine (TF>1) appear to be promising candidates for phytoremediation, further studies using different doses of single-element toxicity in pot trials will provide clearer information on whether the species are phytoextractors or phytostabilizers.

Key words: Legume, Mine, Phytoremediation, TF.

INTRODUCTION

Heavy metals are inorganic elements with a density greater than about 5 g cm^{-3} (Brahma *et al*., 2026). The use of synthetic inputs, industrialization and urbanization activities increase heavy metal pollution that damages the natural environment (Paul *et al*., 2021). Among anthropogenic factors, mining can produce and release large amounts of heavy metals (Lin *et al*., 2023). The waste soils generated from mining activities can accumulate in certain areas, leading to the formation of heavy metal-laden waste zones that may contaminate the soil and groundwater (Fashola *et al*., 2016). Instead of shutting down mining enterprises, which are significant for the country's economy, it is necessary to develop and implement methods and techniques that will minimize the effects of these activities on forests and the environment (Uzun and Bollukcu, 2009). Physical and chemical methods for soil remediation (such as soil exchange, thermal desorption, fixation and immobilization) are included (Rama *et al*., 2021). However, both physical and chemical methods are often costly and are likely to cause irreversible changes in the soil (Chamba-Eras *et al*., 2022). Phytoremediation is a bioremediation method that uses plants to reduce the toxic effects of heavy metals in the environment (Ashraf *et al*., 2019). Plants called hyperaccumulator plants, accumulate heavy metals in their shoots rather than in their roots (Divya *et al*., 2024). Among the phytoremediation technologies that can be applied to soils contaminated, two of the most widely used are phytoextraction and phytostabilization. Phytoextraction is considered a permanent solution for the removal of heavy metals, unlike phytostabilization, which retains metals underground (Yan *et al*., 2020). Phytoremediation potential can be estimated by calculating the bioconcentration factor (BCF) and translocation factor (TF) (Favas *et al*., 2014). If TF>1, the plant has transferred the metal from the root to the stem. BCF>10 means the plant is a hyperaccumulator, BCF>1 means the plant is an accumulator and BCF<1 means the plant is an excluder (Sevencan, 2022).

Plants with BCF, TF values higher than the limit value of 1 were classified as "phytoextractors", while plants with TF values below the limit value and BCF values above the

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limit value of 1 were categorized as “phytostabilizers” (Yang *et al*., 2014). Surveying native plant species at mine sites can identify suitable plants for phytoremediation approaches.

In this study, we aimed to investigate the heavy metal contents of selected species that grow in the natural areas surrounding an iron mine that has been operational for several years and to evaluate their phytoremediation capacities.

MATERIALS AND METHODS

The study was conducted in the natural areas around the Avnik iron mine in Bingöl province of Türkiye (Şahin, 2025). In April, May and June 2024, leguminous forage plants were collected from an area (4 ha) approximately 350-700 m away from the mine site and elemental analyses were performed at the Bingöl University Central Laboratory. The coordinates of the study area (38°39′1″N-40°18′13″E and its neighborhood) were marked on the map and presented in Fig 1.

In this area, leguminous plant species that had entered the generative stage were harvested from the field without damaging their roots as much as possible and were identified. The plants were separated into their organs (roots, stems, leaves and generative parts (flowers and/or pods), washed with tap water and distilled water, dried at 70°C for 2 days and milled.

Soil samples were collected from three different areas within (4 ha) to represent the locations. Characteristics of soil samples from the study region are shown in Table 1. According to the WHO's permitted limit values for toxic metals in soil and plants (WHO/FAO, 2007; Sönmez and Kiliç, 2021), only the Mn content in the soil was found to be higher than the permitted limit value.

Plant species belonging to the legume family

Six common leguminous species were identified and collected (at least 15 plants of each species were randomly collected from the land, element analyses were performed in 3 repetitions and each replication contained 5 plants) from the area surrounding the mining site, then identified using the 11-volume Flora of Turkey and the East Aegean Islands (Davis, 1965-1985). The scientific names and authors of the taxa were checked against the current Turkey Plant List (Güner *et al*., 2012). The plant species identified as a result of the study are shown in Table 2.

The generative parts of the species are pods in *Lathyrus sphaericus* and flowers in *Trifolium campestre*, *Trifolium nigrescens*, *Trifolium arvense*, *Vicia cracca* and *Lotus gebelia*.

Images of species belonging to the legume family are presented in Fig 2.

Determination of Al, Cu, Cr, Fe, Mn and Ni concentrations in plants

The combustion of ground plants was performed using a microwave method adapted from Miller (1998). After dilution and filtration, element contents were determined using an ICP-MS (Inductively Coupled Plasma Mass Spectrometry) device.

Translocation factor (TF)

They indicate the potential for metals to be transported from roots to above-ground organs. If TF>1, the plant has the potential to be considered a bioaccumulator in phytoremediation (Sürmen *et al*., 2019). The following formula is used in its calculation (Ortakcı, 2020; Gökdere *et al*., 2025).

$$TF = \frac{\text{Concentration of the element in the shoot}}{\text{Concentration of the element in the root}}$$

Bioconcentration factor (BCF)

Values such as TF and/or BCF are used in the selection of plants to be used in phytoremediation. The extent to which plants take up metals into their tissues is expressed as the BCF. The BCF value is determined by the ratio of the

$$BCF = \frac{\text{Concentration of the element in the shoot or root}}{\text{Concentration of the element in the soil}}$$

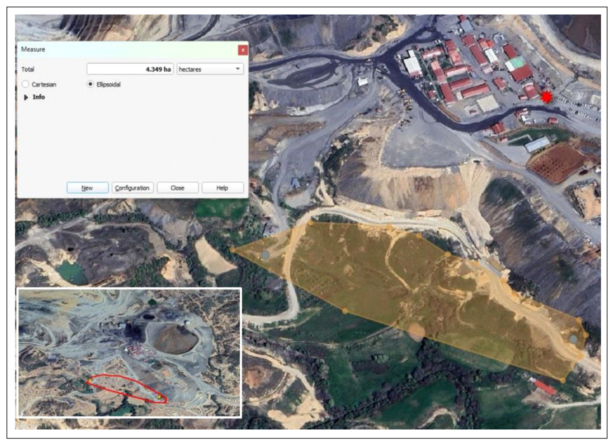


Fig 1: View of the mining area and work area.

Table 1: Characteristics of soil samples collected from the study region.

Texture	pH	EC (µs cm^{-1})	O.M. (%)		Lime (%)
Tınlı	6.60	403.10	0.41		2.58
Total concentration (mg kg^{-1})					
Al	Cr	Cu	Fe	Mn	Ni
21832.8	1.5	1.7	9821.5	117.2	7.6

Table 2: List of identified plant species.

	Species
1	*Lathyrus sphaericus* Retz.
2	*Trifolium campestre* Schreb.
3	*Trifolium nigrescens* Viv.
4	*Trifolium arvense* L.
5	*Vicia cracca* L.
6	*Lotus gebelia* Vent.

metal content in the roots or shoots to the metal content in the soil (Sürmen *et al*., 2019).

Statistics

Two different ANOVAs (analysis of variance) were performed in the evaluation of the data. A two-factor analysis of variance was performed for the species × organ interaction, while a one-factor analysis of variance was performed to evaluate accumulation in a single organ individually. Results found to be significant ($p<0.05$) were compared using the Tukey test (JMP, 2018). Interaction results are presented in tables, while organ-based evaluation results are presented in graphs.

RESULTS AND DISCUSSION

Aluminum (Al) content of species (mg kg^{-1})

According to the two-way ANOVA results for Al concentrations in different legume species, species, organs and the interaction (species × organ) were found to be significant ($p<0.01$). The resulting means and groupings are shown in Table 3.

The highest Al concentrations within the organs were determined in the roots of the plants, while the lowest was in the stem parts. Among species, the highest Al was found in *T. nigrescens* plants.

Aluminum has accumulated most in the roots of *T. campestre* and least in *L. gebelia*, most in the stem of *T. nigrescens* and least in *V. cracca* and *L. gebelia*, most in the leaves of *T. nigrescens* and least in *T. arvense* and most in the generative parts of *T. campestre* and *T. nigrescens* and least in *L. sphaericus* (Fig 3).

Chromium (Cr) content of species (mg kg^{-1})

According to the two-way ANOVA results for Cr concentrations in different legume species, species, organs and the interaction (species × organ) were found to be significant ($p<0.01$). The resulting means and groupings are shown in Table 4.

The highest Cr concentration within organs was found in plant roots, while the lowest was in leaves. Among species, the highest Cr was determined in *T. campestre* plants, while the lowest Cr was determined in *L. sphaericus* species (Table 4).

Chromium is accumulated most in the roots of *T. campestre* and least in *L. sphaericus*, most in the stems of *T. nigrescens* and least in *L. sphaericus*, most in the leaves of *T. nigrescens* and least in *L. gebelia* and most in the generative parts of *T. campestre* and least in *L. sphaericus* and *L. gebelia* (Fig 4).

Copper (Cu) content of species (mg kg^{-1})

According to the two-way ANOVA results for Cu concentrations in different legume species, species, organs and (species × organ) interaction was found to be significant ($p<0.01$). The resulting means and groupings are shown in Table 5.

The images in Fig 2 show species belonging to the legume (Fabaceae) family: a) *Lathyrus sphaericus* Retz., b) *Trifolium campestre* Schreb., c) *Trifolium nigrescens* Viv., d) *Trifolium arvense* L., e) *Vicia cracca* L., f) *Lotus gebelia* Vent.

Fig 2: Images of legume plants in the working region.

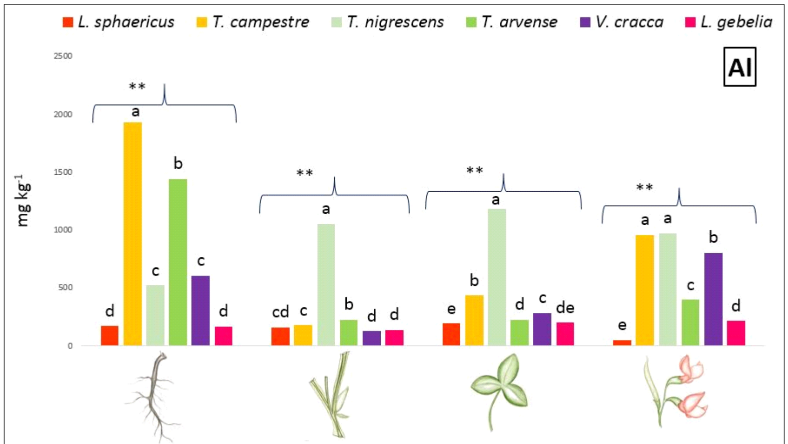
Table 3: Al concentrations in the organs of the species.

Species	Al (mg kg^{-1}) Organs				Average
	Roots	Stem	Leaves	Generative piece	
L. sphaericus	170.54ijk**	159.18ijk	194.45ij	51.18k	143.84E**
T. campestre	1933.43a	178.96ijk	436.58g	959.09d	877.01B
T. nigrescens	524.67fg	1055.44cd	1186.13c	972.30d	934.63A
T. arvense	1442.87b	224.39ij	224.39ij	398.88gh	572.63C
V. cracca	606.82f	128.59jk	286.50hi	803.33e	456.31D
L. gebelia	169.69ijk	136.33jk	201.11ij	215.46ij	180.65E
Average	808.00A**	313.81D	421.53C	566.71B	

**: $p<0.01$ is significant. Capital letters show average groups, small letters show interaction groups.

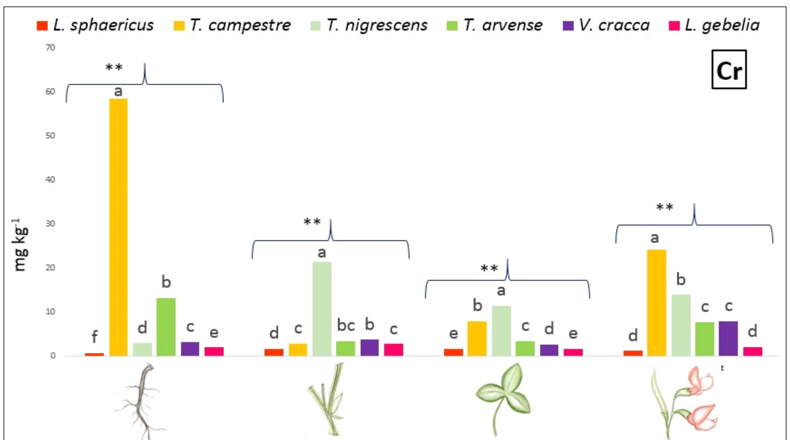
Among species, the highest Cu concentration was found in *L. sphaericus* plants, while the lowest Cu was found in *L. gebelia* plants (Table 5).

Copper accumulated most in the roots of *V. cracca* and least in *T. nigrescens* and *L. gebelia*; most in the stems of *L. sphaericus* and least in *T. nigrescens*; most in the



**: p<0.01. The characteristic shapes used to represent the legume family indicate the root, stem, leaves and generative parts on the left.

Fig 3: Graph showing Al concentrations in plant organs.



**: p<0.01. The characteristic shapes used to represent the legume family indicate the root, stem, leaves and generative parts on the left.

Fig 4: Graph showing Cr concentrations in plant organs.

Table 4: Cr concentrations in the organs of the species.

Species	Cr (mg kg^{-1})				Average
	Organs				
	Roots	Stem	Leaves	Generative piece	
L. sphaericus	0.78m**	1.70kl	1.72kl	1.21lm	1.35F**
T. campestre	58.36a	2.90h	7.94f	24.17b	23.34A
T. nigrescens	3.00gh	21.34c	11.48e	13.94d	12.44B
T. arvense	13.19d	3.41gh	3.41gh	7.74f	6.94C
V. cracca	3.31gh	3.72g	2.63hıj	7.91f	4.40D
L. gebelia	2.00jk	2.81hı	1.66kl	2.11ıjk	2.15E
Average	13.44A**	5.98C	4.81D	9.51B	

**: p<0.01 is significant. Capital letters show average groups, small letters show interaction groups.

leaves of *L. sphaericus* and *T. campstre* and least in *L. gebelia*; and most in the generative parts of *V. cracca* and least in *L. gebelia* (Fig 5).

Iron (Fe) content of species (mg kg^{-1})

According to the two-way ANOVA results for Fe concentrations in different legume species, species, organs and the interaction (species × organ) were found to be significant ($p<0.01$). The resulting means and groupings are shown in Table 6.

The highest Fe concentration within organs was found in plant roots, while the lowest was in stems. Among species, the highest Fe was found in *T. campestre* and *T. nigrescens* plants, while the lowest Fe was found in *L. sphaericus* and *L. gebelia* species (Table 6).

In the roots, *T. campestre* accumulated the most, while *L. sphaericus* and *L. gebelia* accumulated the least; in the stem, *T. nigrescens* accumulated the most, while *V. cracca* and *L. gebelia* accumulated the least; in the leaves, *T. nigrescens* accumulated the most, while *L. sphaericus* accumulated the least. *T. arvense* and *L. gebelia* and in its generative parts, it accumulated the most *T. nigrescens* and the least *L. sphaericus* species (Fig 6).

Manganese (Mn) content of species (mg kg^{-1})

According to the two-way ANOVA results for Mn concentrations in different legume species, species, organs and the interaction (species × organ) were found to be significant ($p<0.01$). The resulting means and groupings are shown in Table 7.

The highest Mn content within the organs was found in the leaves of the plants, while the lowest was in the stems. Among species, the highest Mn was found in *T. campestre* plants, while the lowest Mn was determined in *L. sphaericus*, *T. arvense* and *V. cracca* species (Table 7).

Manganese accumulated most in the roots of *T. campestre* and least in *L. sphaericus* and *L. gebelia*; most in the stems of *T. nigrescens* and least in *V. cracca*; most in the leaves of *T. campestre* and least in *T. arvense*; and most in the generative parts of *T. campestre* and least in *L. sphaericus* (Fig 7).

Nickel (Ni) content of species (mg kg^{-1})

According to the two-way ANOVA results for Ni concentrations in different legume species, species, organs and the interaction (species × organ) were found to be significant ($p<0.01$). The resulting means and groupings are shown in Table 8.

Table 5: Cu concentrations in the organs of the species.

Species	Cu (mg kg^{-1})				Average
	Organs				
	Roots	Stem	Leaves	Generative piece	
L. sphaericus	5.10**	4.08bc	4.34b	3.96c	4.37A**
T. campestre	5.08a	3.13fgh	4.34b	3.55de	4.03B
T. nigrescens	2.13k	2.11k	2.54j	2.58j	2.34D
T. arvense	3.79cd	2.90hı	2.90hı	3.42ef	3.25C
V. cracca	5.34a	3.05gh	3.34efg	4.38b	4.03B
L. gebelia	2.03k	2.61ıj	1.20l	1.49l	1.83E
Average	3.91A**	2.98D	3.11C	3.23B	

**: p<0.01 is significant. Capital letters show average groups, small letters show interaction groups.

Table 6: Fe concentrations in the organs of the species.

Species	Fe (mg kg^{-1})				Average
	Organs				
	Roots	Stem	Leaves	Generative piece	
L. sphaericus	98.72jk**	122.83jk	167.27hıj	39.24k	107.01D**
T. campestre	1758.73a	148.54ıj	407.26g	801.02d	778.89A
T. nigrescens	350.51g	930.50c	1072.93b	882.56cd	809.12A
T. arvense	686.83e	170.51hıj	170.51hıj	249.84h	319.42B
V. cracca	251.79h	90.15jk	226.30hı	494.82f	265.77C
L. gebelia	97.27jk	95.21jk	157.30ıj	168.76hıj	129.63D
Average	540.64A**	259.62D	366.93C	439.37B	

**: p<0.01 is significant. Capital letters show average groups, small letters show interaction groups.

The highest Ni content within organs was found in plant roots, while the lowest was in leaves and stems. Among species, the highest Ni was found in *T. campestre* plants, while the lowest Ni was found in *L. sphaericus* species (Table 8).

Nickel accumulated most in the roots of *T. campestre* and least in *L. sphaericus*; most in the stems and leaves of *T. nigrescens* and least in *L. sphaericus*; and most in the generative parts of *T. campestre* and least in *L. sphaericus* (Fig 8).

Assessment of phytoremediation capacities of legume species (TF and BCF)

The TF, BCF_{root} and BCF_{shoot} values for the examined elements of the species plant are given in Table 9-14.

In *Lathyrus sphaericus*, TF>1 was found for Cr, Fe, Mn, Ni; BCF_{root}>1 for Cu; and BCF_{shoot}>1 for Cr, Cu (Table 9).

Trifolium campestre did not exhibit TF>1 for any element, but BCF_{root}>1 was determined for Cr, Cu, Ni and BCF_{shoot}>1 was determined for Cr and Cu (Table 10).

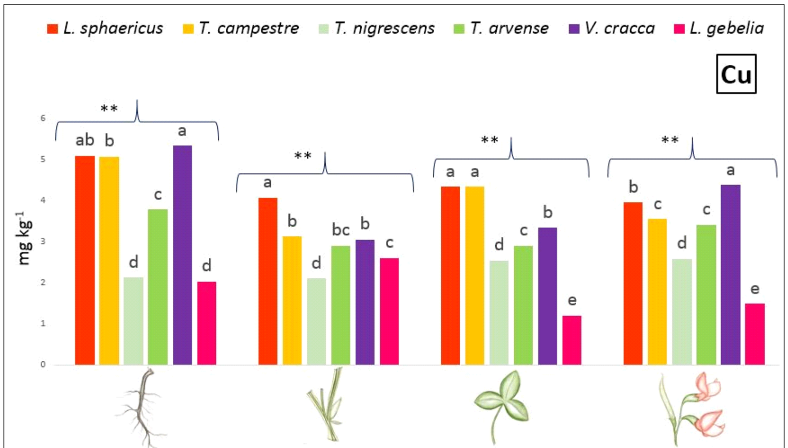
In *Trifolium nigrescens*, TF>1 was determined for all elements, while BCF_{root} and BCF_{shoot}>1 were determined for Cr, Cu (Table 11).

Trifolium arvense did not find TF>1 for any element, but BCF_{root} and BCF_{shoot}>1 were determined for Cr and Cu (Table 12).

In *Vicia cracca*, TF>1 was calculated for Cr, Fe, Mn and Ni while BCF_{root} and BCF_{shoot}>1 were calculated for Cr and Cu (Table 13).

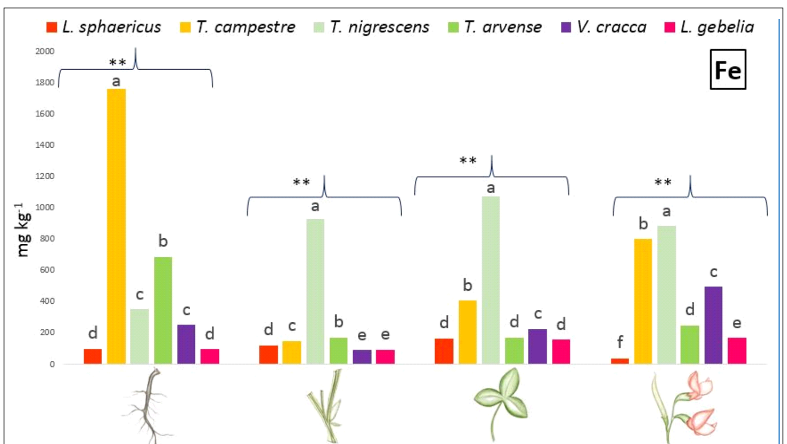
In *Lotus gebelia*, TF>1 was calculated for Al, Cr and Mn elements and BCF_{root} and BCF_{shoot}>1 were calculated for Cr and Cu elements (Table 14).

The uptake of metals by plants is influenced by several factors such as soil metal concentrations, cation exchange



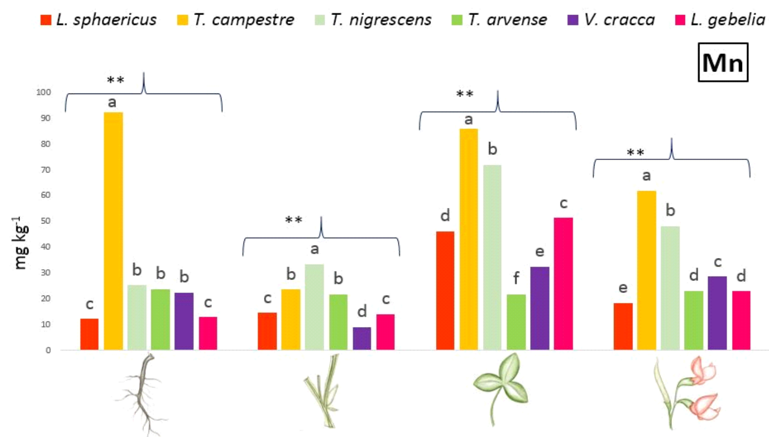
**: p<0.01. The characteristic shapes used to represent the legume family indicate the root, stem, leaves and generative parts on the left.

Fig 5: Graph showing Cu concentrations in plant organs.



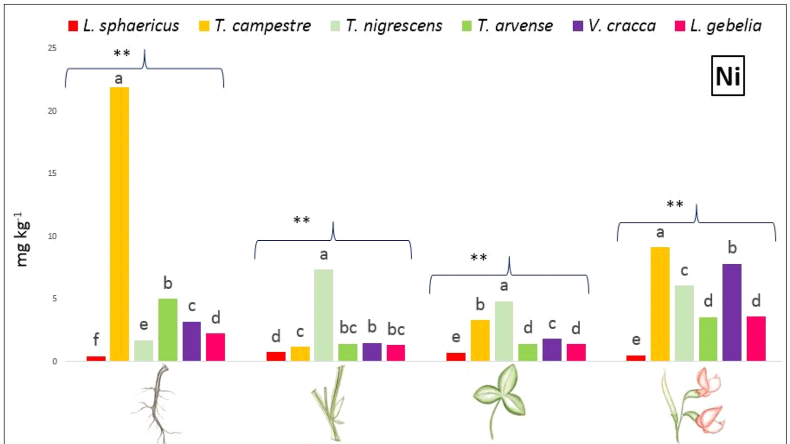
**: p<0.01. The characteristic shapes used to represent the legume family indicate the root, stem, leaves and generative parts on the left.

Fig 6: Graph showing Fe concentrations in plant organs.



**: p<0.01. The characteristic shapes used to represent the legume family indicate the root, stem, leaves and generative parts on the left.

Fig 7: Graph showing Mn concentrations in plant organs.



**: p<0.01. The characteristic shapes used to represent the legume family indicate the root, stem, leaves and generative parts on the left.

Fig 8: Graph showing Ni concentrations in plant organs.

Table 7: Mn concentrations in the organs of the species.

Species	Mn (mg kg^{-1})				Average
	Organs				
	Roots	Stem	Leaves	Generative piece	
L. sphaericus	12.23kl**	14.65k	46.14f	18.47j	22.87D**
T. campestre	92.32a	23.59ı	85.88b	61.97d	65.94A
T. nigrescens	25.29hı	33.56g	71.96c	48.21ef	44.76B
T. arvense	23.82ı	21.78ıj	21.78ıj	23.06ı	22.61D
V. cracca	22.51ı	9.08l	32.45g	28.60h	23.16D
L. gebelia	12.85kl	14.18k	51.38e	22.99ı	25.35C
Average	31.50C**	19.48D	51.60A	33.88B	

**: p<0.01 is significant. Capital letters show average groups, small letters show interaction groups.

Table 8: Ni concentrations in the organs of the species.

Species	Ni (mg kg^{-1}) Organs				Average
	Roots	Stem	Leaves	Generative piece	
L. sphaericus	0.41n**	0.74m	0.72mn	0.51mn	0.60F**
T. campestre	21.89a	1.18l	3.31gh	9.13b	8.88A
T. nigrescens	1.71jk	7.35d	4.84f	6.08e	4.99B
T. arvense	5.00f	1.41kl	1.41kl	3.57g	2.85D
V. cracca	3.20h	1.50jkl	1.81j	7.82c	3.58C
L. gebelia	2.25ı	1.32l	1.38kl	3.60g	2.14E
Average	5.74A**	2.25C	2.24C	5.12B	

**: p<0.01 is significant. Capital letters show average groups, small letters show interaction groups.

Table 9: TF and BCF evaluations for *Lathyrus sphaericus.*

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Assessment
Lathyrus sphaericus	Al	0.79	0.01	0.01	Not suitable
	Cr	1.98	0.52	1.03	Phytoextraction
	Cu	0.81	3.09	2.50	Phytostabilization
	Fe	1.11	0.01	0.01	Phytoextraction
	Mn	2.16	0.10	0.23	Phytoextraction
	Ni	1.60	0.05	0.09	Phytoextraction

Table 10: TF and BCF evaluations for *Trifolium campestre.*

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Assessment
Trifolium campestre	Al	0.27	0.09	0.02	Not suitable
	Cr	0.20	38.91	7.78	Phytostabilization
	Cu	0.72	3.08	2.23	Phytostabilization
	Fe	0.26	0.18	0.05	Not suitable
	Mn	0.62	0.79	0.49	Not suitable
	Ni	0.22	2.88	0.62	Phytostabilization

Table 11: TF and BCF evaluations for *Trifolium nigrescens.*

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Assessment
Trifolium nigrescens	Al	2.04	0.02	0.05	Phytoextraction
	Cr	5.20	2.0	10.39	Phytoextraction
	Cu	1.13	1.29	1.46	Phytoextraction
	Fe	2.74	0.04	0.10	Phytoextraction
	Mn	2.03	0.22	0.44	Phytoextraction
	Ni	3.56	0.23	0.80	Phytoextraction

Table 12: TF and BCF evaluations for *Trifolium arvense.*

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Assessment
Trifolium arvense	Al	0.20	0.07	0.01	Not suitable
	Cr	0.37	8.79	3.24	Phytostabilization
	Cu	0.81	2.30	1.86	Phytostabilization
	Fe	0.29	0.07	0.02	Not suitable
	Mn	0.93	0.20	0.19	Not suitable
	Ni	0.43	0.66	0.28	Not suitable

capacity, soil pH, organic matter content, plant species and varieties and plant age. However, the main factor is the concentration of metals in the soil and hence the existing environmental conditions (Annan *et al*., 2013).

Shahidi *et al*. (1999) reported that the vegetative parts of *L. maritimus* contained more Al than the generative parts. In this study, similar to the studies of Shahidi *et al*. (1999), the vegetative parts (leaves and stem) of *L. sphaericus* accumulated about 3.5 times more Al than the generative parts (seeds and pods). The study of Wheeler and Dodd (1995) with 15 different *Trifolium* and 6 different *Lotus* species is not similar to this study in terms of concentration. It is thought that the reasons for this may be related to the Al concentrations in the study areas. However, if a comparison is made between *Trifolium* and *Lotus* species, *Trifolium* species had higher Al, Cu and Fe content than *Lotus* species in Wheeler and Dodd (1995) study, as in this study. In the leaves of *V. cracca*, about 2.2 times more Al accumulation was observed than in the stem. Similarly, Kolesnichenko *et al*. (2018) found about 2.1 times more Al in the leaves of *V. cracca* than in the stem.

Chromium concentration (1.21 mg kg^{-1}) determined for the generative parts of *Lathyrus sphaericus* in this study was similar to the Cr concentration (1.10 mg kg^{-1}) measured by Kodirova *et al*. (2024) in seeds of twelve different *Lathyrus* genotypes. Chromium concentrations of *Trifolium* species varied between 6.94-23.34 mg kg^{-1}. Gounden *et al*. (2018) reported that the maximum concentration for Cr was 6 mg kg^{-1} in their study with five different *Trifolium* species. Chromium was determined as 2.24 mg kg^{-1} in shoots and 2.00 mg kg^{-1} in roots of *Lotus gebelia*; Sujkowska-Rybkowska *et al*. (2020) determined Cr content of *Lotus corniculatus* as 5.4 mg kg^{-1} in shoots and 20.5 mg kg^{-1} in roots.

Shahidi *et al*. (1999) reported that the vegetative parts of *Lathyrus maritimus* contained more Fe than the generative parts. In this study, similar to the studies of Shahidi *et al*. (1999), the vegetative parts of *Lathyrus sphaericus* contained more Fe than the generative parts. In this study, Fe accumulation in the leaves of *Vicia cracca* was observed to be approximately 2.5 times higher than in the stem, while in Kolesnichenko *et al*. (2018), Fe accumulation in the leaves of *Vicia cracca* was observed to be approximately 3.1 times higher than in the stem.

The Mn level measured in the leaves of *Lathyrus maritimus* by Maslennikov *et al*. (2020) is similar to the Mn level measured in the leaves of *Lathyrus sphaericus* in this study. Wheeler and Dodd (1995), in their study with 6 different *Lotus* species, found that the average Mn concentration in the above-ground organs was similar to the average Mn concentration in the above-ground organs of *Lotus gebelia*, but the average above-ground Mn concentrations of *Trifolium* species were higher than those of *Trifolium* species in this study. While Mn accumulation in the leaves of *Vicia cracca* was observed approximately 3.6 times higher than in the stem, Kolesnichenko *et al*. (2018) observed Mn accumulation in the leaves of *Vicia cracca* plants approximately 4.8 times higher than in the stem.

Lathyrus sphaericus transported Ni to the above-ground organs. However, Jeddou *et al*. (2017) reported that Ni in *Lathyrus ochrus* had limited transport to the upper parts and nickel was mostly accumulated in the roots. Nickel concentrations of *Trifolium* species were found to be similar (<10 mg kg^{-1} Ni) to the study of Gounden *et al*. (2018) with 5 different *Trifolium* species.

The Ni concentration in the leaves and stems of *Vicia cracca* is similar to the Ni concentration in the leaves and stems of *Vicia cracca* in the study of Kolesnichenko *et al*. (2018). Nickel content of *L. gebelia* was determined as 1.35 mg kg^{-1} in shoots and 2.25 mg kg^{-1} in roots; Sujkowska-Rybkowska *et al*. (2020) determined Ni content of *Lotus corniculatus* as 59.5 mg kg^{-1} in shoots and 167.1 mg kg^{-1} in roots. Saruhan *et al*. (2012) reported the Ni content of *Lotus corniculatus* in control plants similar to this study.

Table 13: TF and BCF evaluations for *Vicia cracca*.

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Assessment
Vicia cracca	Al	0.67	0.03	0.02	Not suitable
	Cr	1.44	2.20	3.20	Phytoextraction
	Cu	0.67	3.24	2.18	Phytostabilization
	Fe	1.07	0.03	0.03	Phytoextraction
	Mn	1.04	0.19	0.20	Phytoextraction
	Ni	1.16	0.42	0.49	Phytoextraction

Table 14: TF and BCF evaluations for *Lotus gebelia*.

Species	Elements	TF	BCF_{root}	BCF_{shoot}	Assessment
Lotus gebelia	Al	1.09	0.01	0.01	Phytoextraction
	Cr	1.10	1.30	1.50	Phytoextraction
	Cu	0.87	1.23	1.07	Phytostabilization
	Fe	0.44	0.01	0.01	Not suitable
	Mn	2.30	0.11	0.25	Phytoextraction
	Ni	0.93	0.30	0.28	Not suitable

Plants having TF and especially BCF values less than one (TF<1) are not suitable for phytoextraction (Fitz and Wenzel, 2002), while TF>1 is a decisive factor in the classification of plant species for phytoremediation (Chanu and Gupta, 2016). However, plants having high bioconcentration factor and low translocation factor have phytostabilization potential (Yoon *et al*., 2006).

Unlike the value obtained for Ni (TF>1) in this study, Jeddou *et al*. (2017) reported that BCF and TF values were below 1 in *Lathyrus ochrus*. Wheeler and Dodd (1995) reported that the TF values obtained for Al (0.4), Cu (0.3), Fe (0.2) and Mn (0.7) were below 1 in their study with fifteen different *Trifolium* species. In this study, TF<1 was found for *T. campestre* and *T. arvense*, which was similar to the results of Wheeler and Dodd (1995), but for *Trifolium nigrescens*, contrary to the results of the researchers, Al, Cu, Fe and Mn were found to be TF>1. TF_{Cu}<1 was found in *V. cracca* and Saadaoui *et al*. (2022) found TF<1 (*Vicia faba* L. cv. Mamdouh: TF_{shoot} 0.32, TF_{flower} 0.18) in one of two different *Vicia* plants and TF>1 (*Vicia faba* L. cv. Badii: TF_{shoot} 1.38, TF_{flower} 1.48) in the other. Sujkowska-Rybkowska *et al*. (2020) reported TF values <1 for Cr (contrary to the results of this study) and Ni (similar to the results of this study) of *Lotus corniculatus*. The TF values obtained by Wheeler and Dodd (1995) for Al, Cu, Fe and Mn (<1) were found to be different from the $TF_{Mn,Al}$ values obtained in this study, but similar to the $TF_{Fe,Cu}$ values.

CONCLUSION

The soils of the study area did not exceed the limit according to the toxic metal limit values allowed by WHO, except for Mn (allowed 80 mg kg^{-1}). Considering the values determined in the above-ground organs of plants such as stems and leaves, the permissible limit values for Mn, Cu and Ni were not exceeded, only Cr and Fe concentrations exceeded the limit (Cr: 5 mg kg^{-1} and Fe: 450 mg kg^{-1}) toxic metal level in some species. Since $TF_{Cr, Fe, Mn, Ni}$>1 in *L. sphaericus* and *V. cracca*, $TF_{Al, Cu, Cr, Fe, Mn, Ni}$>1 in *T. nigrescens* and $TF_{Al, Cu, Cr, Mn}$>1 in *L. gebelia*, these legume species are important for phytoextraction. For Cr metal, the BCF root value was 38.91 in *T. campestre* and this high value revealed the potential of this species for phytostabilization of Cr contaminated soils. Among these legume species collected from the mine site, those with TF>1 are promising for phytoremediation. Due to the high levels of Fe and Cr metals in the above-ground organs of some legume species, it is recommended that livestock grazing should be done more carefully in these areas.

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Conflict of interest

I confirm that there are no conflicts of interest regarding this manuscript.

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