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Research Article

THE RESPONSES OF PLANTS TO HEAVY METALS AROUND THE OPEN CHROMIUM MINE PITS IN ADANA, TÜRKİYE

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ABSTRACT. Mining activities lead to the accumulation of mine waste in different ecosystems. There are chromium deposits and a processing plant in the Aladağ district of Adana province, and therefore there are mining wastes around the area. In this study, the accumulation and translocation potential of heavy metals in relatively abundant plants in a chromium mining area was investigated. *Aethionema spicatum*, *Alyssum alyssoides*, *Alyssum floribundum*, *Alyssum oxycarpum*, *Thlaspi oxyceras*, *Convolvulus compactus*, *Onosma cappadocica*, and *Salvia multicaulis* were examined. Heavy metal analyses (Cr, Ni, Co, Pb, Zn, Mn, Cu, and Fe) were performed in different plant parts and rhizosphere soils. Plants were evaluated for the accumulation and translocation of heavy metals using bioconcentration and translocation factor equations. *Ae. spicatum*, *A. floribundum*, *A. oxycarpum*, and *T. oxyceras* (known as hyperaccumulators for nickel) were observed in chromium mining areas, and it was found that they had high concentrations of nickel. However, they could not accumulate or translocate to above-ground parts other heavy metals as much as nickel. Some plants were noteworthy with BCF and TF values of lower than one: *Ae. Spicatum* for Cr and Fe, *A. alyssoides* for Cu and Fe, *A. floribundum* for Zn, *A. oxycarpum* for Cu, *O. cappadocica* for Cu, *S. multicaulis* for Cr, Ni, Co, Mn, Cu and Fe. Also, *T. oxyceras* and *C. compactus* have higher concentrations of all metals analyzed in their aerial parts (only in the stem or leaves or both) than in their roots. The abundance of these plants in the region and their unresponsiveness to related heavy metals suggest that these plants may be indicators, and they may be used for planting in disturbed mining lands.

Keywords: *Bioconcentration, hyperaccumulation, mining, phytoremediation.*

INTRODUCTION

Elements that generally have a density greater than 5g/cm^3 are called heavy metals [1]. Copper (Cu), iron (Fe), zinc (Zn), mercury (Hg), cobalt (Co), lead (Pb), chromium (Cr), cadmium (Cd), and nickel (Ni) are some of them. Heavy metals can be classified as those that are necessary for living things and that are not. Such as Cr, Ni, Mn, Fe, Co, Cu, Zn, and V and some heavy metals are essential for living organisms at trace levels [2]. These metals, which are necessary at the micro level, can have toxic effects in high doses. These metals affect soil microorganisms, metabolic processes in plants and animals, and also threaten human health [3, 4, 5, 6].

Environmental pollution caused by heavy metal accumulation has increased in direct proportion to the increase in industrialization and has become an important problem today. Mining activities are one of the heavy metal pollution sources. Mining processes cause problems, such as the degradation of flora, accumulation of mining waste in the environment, and release of atmospheric pollutants and wastes containing heavy metals into the environment [7, 8]. Mine tailings contain water, sand, heavy metals, and solids [9]. Because of the rising heavy metal concentrations in different environments, it is crucial to remediate polluted environments with effective and reasonable solutions. Although physical and chemical methods are used to remove metals from industrial wastes, the use of biological molecules is an alternative method. Biological applications include biosorption, adsorption, and phytoremediation methods [10]. In phytoremediation, which is a more environmentally friendly and less costly method than other methods, plants are used to remove pollutants from the environment. This cleaning method involves different mechanisms, including rhizofiltration, phytostabilization, phytoextraction, phytovolatilization, and phytodegradation. These mechanisms aim to destroy, neutralize, or immobilize the source of pollution [11, 12]. In plants, metal toxicity adversely affects growth, nutrition, and basic metabolic processes such as photosynthesis and respiration and causes plant death [13]. It is known that some plants are tolerant to these toxic effects. Accumulators, indicators and excluders can be found in metalliferous fields [14]. These plants are needed because of their unique properties for phytoremediation. Therefore, increasing the diversity of these plants is significant.

This study was carried out with plants growing in lands around the chromium mine and processing plant in the Aladağ district of Adana province and aimed to evaluate these plants for their abilities in the uptake of metals from soil and transfer to aerial parts.

MATERIALS AND METHODS

Study area

The study was conducted around open chromium mine deposits at an altitude of around 600-1200 meters in the Aladağ district of the Adana province in Türkiye (Fig. 1). Adana province has significant underground resources. Chromium is one of the metallic mines in the province and is concentrated in the Aladağ district. Therefore, this region has open chromium deposits and processing plants, resulting in much mining waste.

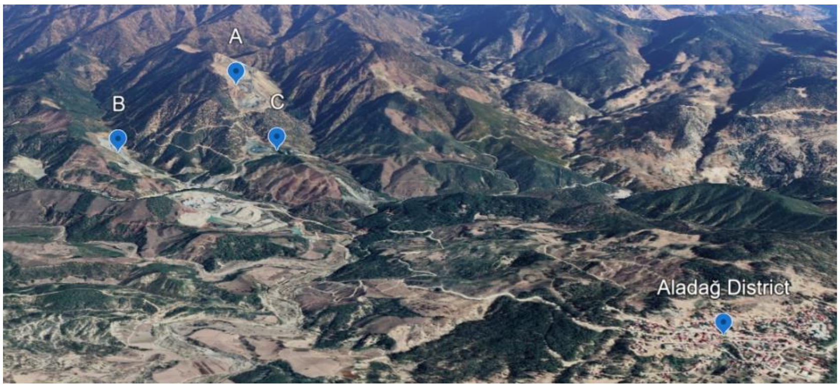

Fig. 1. *The study area includes open chromium mining deposits (A, B, C)*

Plant and soil sampling

Flora of Turkey and the East Aegean Islands [15] were used to identify plant samples. The most abundant plants were selected from the region where they were most widespread. Plants belonging to each taxon were sampled together with the rhizosphere soils. The plant species used in the study were *Aethionema spicatum* Post (Brassicaceae), *Alyssum alyssoides* L. (Brassicaceae), *Alyssum floribundum* Boiss. & Bal. (Brassicaceae), *Alyssum oxycarpum* Boiss. & Bal. (Brassicaceae), *Thlaspi oxyceras* (Boiss.) Hedge (Brassicaceae), *Convolvulus compactus* Boiss. (Convolvulaceae), *Onosma cappadocica* Siehe ex Riedl (Boraginaceae), and *Salvia multicaulis* Vahl (Lamiaceae).

Onosma cappadocicum (in Flora of Turkey and the East Aegean Islands) was used as *Onosma cappadocica* [16].

Plant and soil heavy metal analyses

Collected plants were transferred to the laboratory with rhizosphere soil. The roots, stems, and leaves were separated. Then, the separated parts were washed with the flowing water to remove soil particles around the roots and rinsed with distilled water. Finally, the samples were dried at 65 ^{0}C in the incubator and then powdered.

A sample of 0.2 g was taken from dried and powdered plant samples and burned in a CEM microwave oven with 2 ml H2O2 – 5 ml HNO3. After burning, the samples were topped up to 20 ml with distilled water and filtered through blue band filter paper [17]. The soil samples were dried on a bench in the laboratory and then sifted using a sieve with 2 mm pores. Soil analyses were performed using the EPA-3051A method [18]. Furthermore, the concentrations of researched heavy metals (Cr, Ni, Co, Pb, Zn, Mn, Cu, and Fe) were determined using an atomic absorption spectrophotometer.

Physical and chemical analysis of soil

Soil textures were determined using a hydrometer [19], and soil pH was determined by a pH meter in a 1:2.5 soil-distilled water mixture [20]. The organic carbon concentrations (%) were determined by the Anne method, and the nitrogen concentrations (%) were determined by the Kjeldahl method [21].

Statistical analyses and evaluation of data

Statistical analyses were performed using IBM SPSS 22 software [22]. Analysis of variance (ANOVA with DUNCAN post-hoc test for parametric data) and Kruskal–Wallis (for non-parametric data) tests were used to evaluate the data at 0.05 significance level.

Bioconcentration and translocation factors were calculated to explain the responses of plants to heavy metals.

Bioconcentration factor (BCF) was calculated according to the formula below for roots (BCF_R), stems (BCF_S), and leaves (BCF_L) [23, 24].

$$\mathrm{BCF} = \frac{\text{metal concentrations of plant parts (mg kg}^{-1}\text{)}}{\text{metal concentrations of rhizosphere soil (mg kg}^{-1}\text{)}}$$

The translocation factor (TF) was calculated according to the formula below for the stem (TF_S) and leaves (TF_L) [25].

$$\mathrm{TF} = \frac{\text{metal concentrations of stem or leaves (mg kg}^{-1}\text{)}}{\text{metal concentrations of root (mg kg}^{-1}\text{)}}$$

RESULTS AND DISCUSSION

General properties of rhizosphere soil

The general properties of rhizosphere soils are presented in Table 1. The soil texture is determined as sandy loam and shows slightly alkaline character. Moreover, average nitrogen and carbon concentrations were observed at 0.15% and 4.38%, respectively. It was stated in a study that the soil of the region was sandy clay loam textured and slightly alkaline. Moreover, the carbon content of the soil was determined between 1.34-2.63% while nitrogen content was between 0.15-0.20% [26]. Previous studies have also reported low concentrations of C and N in serpentine areas that similar to this study [27, 28]. Also, it is stated that the acidic or alkaline character of soil affects plant metal uptake in the literature [29].

Table 1. *Data (mean±standard deviation) of General Properties of Rhizosphere Soils*

Plants	Sand%	Clay%	Loam%	pH	N%	C%
Ae. spicatum	67.19 ± 1.33	6.08 ± 0.86	26.73 ± 1.09	7.74 ± 0.23	0.05 ± 0.02	2.84 ± 0.29
A. alyssoides	73.03 ± 0.89	1.64 ± 0.17	25.33 ± 0.96	7.36 ± 0.05	0.32 ± 0.13	8.7 ± 0.56
A. floribundum	71.97 ± 0.76	2.21 ± 1.02	25.82 ± 1.59	7.57 ± 0.2	0.05 ± 0.01	2.71 ± 0.31
A. oxycarpum	65.6 ± 1.19	8.51 ± 0.5	25.89 ± 0.7	7.61 ± 0.09	0.09 ± 0.03	2.39 ± 0.84
T. oxyceras	68.89 ± 1.8	8.36 ± 1.15	22.75 ± 0.71	7.48 ± 0.14	0.38 ± 0.07	9.05 ± 0.58
C. compactus	52.02 ± 0.57	26.1 ± 0.78	21.88 ± 1.18	7.62 ± 0.1	0.12 ± 0	2.66 ± 0.15
O. cappadocica	85.3 ± 0.84	5.47 ± 0.44	9.23 ± 0.47	7.75 ± 0.19	0.04 ± 0	2.21 ± 0.27
S. multicaulis	73.39 ± 1.68	1.83 ± 0.49	24.78 ± 1.19	7.34 ± 0.18	0.11 ± 0.03	4.45 ± 0.45
Average	69.67	7.53	22.8	7.56	0.15	4.38

Heavy metal concentrations in plants and soils, and accumulation (bcf) and translocation (tf) of metals in plants

Concentrations of heavy metals in plant parts (root, stem, and leaves) and soil, and accumulation (BCF) and translocation (TF) of metals in plants were used for evaluating plants. If the BCF_S and BCF_L values are more than one, plants with these values may be suitable for phytoextraction of related heavy metals [30, 31]. They can also be considered as hyperaccumulators if they contain heavy metals higher than the values reported in the literature for hyperaccumulator plants. If BCF_S, BCF_L, and TF values are close to zero and BCF_R is greater than one, these plants may be considered an excluder and used for phytostabilization [32, 33, 34, 35, 36].

Chromium concentrations in plant parts and soil and BCF and TF values are presented in Table 2. The Cr concentrations (mg kg^{-1}) are 103.83-215.78 in soil, 2.15-5.47 in roots, 0.74-13.71 in stems, and 1.01-8.86 in leaves. The chromium concentrations of *O. cappadocica* and *C. compactus* are higher than other species. In general, plants have chromium concentrations of less than 1 mg kg^{-1} [37]. Plants must accumulate 300 mg kg^{-1} of chromium to become hyperaccumulators [38]. Therefore, the investigated plants were not evaluated as hyperaccumulators for chromium. Compared to the literature, it is thought that the chromium concentrations of the study area soils are within normal limits for the mine area surroundings [39].

Table 2. *Chromium concentrations (mean±standard deviation) in plant parts and values (mean) of BCF and TF*

Plants	**Cr Concentrations (mg kg $^{-1}$)**				**BCF and TF Values**				
	Root	**Stem**	**Leaves**	**Soil**	**BCF_R**	**BCF_S**	**BCF_L**	**TF_S**	**TF_L**
Ae. spicatum	4.68±3.23	1.73±1.42	1.01±0.75	112.08±11.20	0.05	0.02	0.01	0.39	0.39
A. alyssoides	4.42±1.54	7.13±2.63	5.10±1.30	123.13±8.16	0.04	0.06	0.04	**1.66**	**1.21**
A. floribundum	2.15±0.97	0.99±0.18	1.81±0.30	161.65±63.55	0.02	0.01	0.01	0.57	**1.23**
A. oxycarpum	5.47±1.74	7.87±0.81	6.89±2.45	215.78±34.63	0.03	0.04	0.04	**1.59**	**1.54**
T. oxyceras	2.29±1.24	0.74±0.32	5.17±5.51	143.18±29.26	0.02	0.00	0.04	0.37	**2.47**
C. compactus	3.96±1.82	12.25±3.54	7.26±5.27	130.53±7.41	0.03	0.09	0.06	**3.68**	**2.50**
O. cappadocica	3.78±1.60	13.71±5.60	8.86±6.24	203.28±6.85	0.02	0.07	0.04	**4.02**	**2.56**
S. multicaulis	7.04±5.48	3.97±1.21	3.07±1.12	95.20±14.78	0.07	0.04	0.03	0.81	0.69

Table 3. *Nickel concentrations (mean±standard deviation) in plant parts and soil and values (mean) of BCF and TF*

Plants	**Ni Concentrations (mg kg $^{-1}$)**				**BCF and TF Values**				
	Root	**Stem**	**Leaves**	**Soils**	**BCF_R**	**BCF_S**	**BCF_L**	**TF_S**	**TF_L**
Ae. spicatum	306.34±45.19	369.02±109.49	1115.83±165.88	873.11±14.30	0.35	0.43	**1.28**	**1.19**	**3.65**
A. alyssoides	11.68±3.74	24.13±2.47	22.77±1.14	878.28±11.85	0.01	0.03	0.03	**2.21**	**2.10**
A. floribundum	1425.19±21.90	1190.03±57.51	1378.56±149.44	882.58±15.01	**1.62**	**1.35**	**1.57**	0.84	0.97
A. oxycarpum	711.50±289.49	1145.01±114.88	1227.35±55.31	893.44±2.92	0.80	**1.28**	**1.37**	**1.78**	**1.94**
T. oxyceras	1159.25±47.64	1076.38±64.22	1539.39±82.01	894.10±2.53	**1.30**	**1.20**	**1.73**	0.93	**1.33**
C. compactus	40.40±23.90	77.56±21.16	85.59±29.80	875.08±11.98	0.05	0.09	0.10	**2.45**	**2.43**
O. cappadocica	56.23±18.08	119.56±53.57	126.96±32.04	894.45±2.44	0.07	0.13	0.14	**2.22**	**2.39**
S. multicaulis	116.63±51.88	55.50±52.06	68.47±64.19	896.22±0.11	0.13	0.06	0.08	0.55	0.69

For chromium, all BCF values were lower than one. BCF values indicate that the plants were unable to accumulate chromium more than soil concentrations. According to TF values it is thought that some evaluated plants may have the more potential to transfer chromium metal to above-ground parts. It is seen that only *Ae. spicatum* and *S. multicaulis* do not tend to transport this metal to stems or leaves at higher concentrations than roots.

Nickel concentrations in plant parts and soil and BCF and TF values are presented in Table 3. The Ni concentrations (mg kg^{-1}) were 873.11-896.21 in soil, 11.68-1425.19 in roots, 24.13-1190.03 in stems, and 22.77-1539.39 in leaves. Nickel is a micronutrient for different biological functions at low concentrations (0.05–10 mg kg-1) but becomes toxic to plants at high concentrations [40, 41]. Nickel concentrations in hyperaccumulator plants are higher than 1000 mg kg^{-1} [42, 38]. Nickel concentrations of *Ae. spicatum*, *A. oxycarpum*, *A. floribundum*, and *T. oxyceras* were found over 1000 mg kg^{-1} in their different parts.

For nickel, BCF values are greater than one for at least one of BCF_R, BCF_S or BCF_L for *Ae. spicatum*, *A. floribundum*, *A. oxycarpum*, and T. *oxyceras*. The BCF values of these plants were found statistically different ($p<0.05$) from other plants. The TF values of *A. floribundum* were not exactly more than one but very close to one. Plants can be used for phytoextraction if the BCF values of the above-ground (harvestable) parts [43, 44, 45], and TF values [46, 47] are higher than one. Therefore, it is thought that these plants are suitable for phytoextraction. According to the literature, *Alyssum* and *Thlaspi* genera have many hyperaccumulator species [48, 49, 50, 51]. There is information that *A. oxycarpum*, *A. floribundum*, *T. oxyceras,* and *Ae. spicatum* can accumulate high levels of nickel [52, 49]. Because the BCF and TF values of *S. multicaulis* are less than one, it can be said that this plant does not have much ability to accumulate or translocate Ni.

Cobalt concentrations in plant parts and soil and BCF and TF values are presented in Table 4. The Co concentrations (mg kg^{-1}) were 235.43-325.65 in soil, 0.67-10.48 in roots, 1.40-11.66 in stems, and 1.40-128.61 in leaves. Hyperaccumulators for this heavy metal should have a Co concentration of 300 mg kg^{-1} [53]. The cobalt concentrations of the researched plants were very low compared to this value.

For cobalt, all BCF values of the plants were foundlower than one. However, TF values were higher than one for at least one of the stems or leaves except *S. multicaulis*.

The lead concentration in plant parts and soil and BCF and TF values are presented in Table 5. The Pb concentrations (mg kg^{-1}) were 4.39-30.11 in soil, 1.13-4.86 in roots, 0.64-3.63 in stems, and 1.12-3.01 in leaves. It has been stated that Pb concentrations may be low in chromium mining areas [39, 54].

For lead, all BCF values were less than one and TF values were greater than one for at least one of the stems or leaves.

Zinc concentrations in plant parts and soil and BCF and TF values are presented in Table 6. The Zn concentrations (mg kg^{-1}) were 52.57-82.39 in soil, 4.83-20.57 in roots, 7.99-21.69 in stems, and 7.21-33.06 in leaves. Considering the metal concentration that hyperaccumulator plants should have for this heavy metal, it can be stated that the metal concentrations of the evaluated plants are very low [38]. For zinc, excluding *A. floribundum*, TF values of plant species were higher than one for at least one of the stems or leaves, but all BCF values were under one.

Table 4. *Cobalt concentrations (mean±standard deviation) in plant parts and soil and values (mean) of BCF and TF*

Plants	Co Concentrations (mg kg^{-1})				BCF and TF Values				
	Root	Stem	Leaves	Soils	BCF_R	BCF_S	BCF_L	TF_S	TF_L
Ae. spicatum	9.92±1.88	8.70±0.85	128.61±42.99	310.93±36.96	0.03	0.03	0.43	0.89	**13.08**
A. alyssoides	0.67±0.11	1.40±0.30	1.40±0.07	259.98±13.86	0.00	0.01	0.01	**2.19**	**2.12**
A. floribundum	6.02±0.37	6.68±0.15	31.13±6.85	240.75±11.69	0.03	0.03	0.13	**1.11**	**5.27**
A. oxycarpum	7.18±0.78	8.28±0.52	18.56±2.08	235.43±40.18	0.03	0.04	0.08	**1.16**	**2.62**
T. oxyceras	7.43±0.57	6.24±0.12	26.84±8.38	237.70±18.63	0.03	0.03	0.11	0.84	**3.69**
C. compactus	8.79±1.19	11.66±1.82	13.12±2.56	325.65±18.35	0.03	0.04	0.04	**1.36**	**1.50**
O. cappadocica	7.32±0.80	11.05±2.27	11.54±1.36	248.05±9.06	0.03	0.04	0.05	**1.51**	**1.58**
S. multicaulis	10.48±2.76	7.00±0.80	7.64±0.52	238.97±2.12	0.04	0.03	0.03	0.72	0.78

Table 5. *Lead concentrations (mean±standard deviation) in plant parts and soil and values (mean) of BCF and TF*

Plants	Pb Concentrations (mg kg^{-1})				BCF and TF Values				
	Root	Stem	Leaves	Soils	BCF_R	BCF_S	BCF_L	TF_S	TF_L
Ae. spicatum	1.95±0.52	2.23±1.15	1.17±0.55	16.84±3.90	0.12	0.14	0.07	**1.31**	0.61
A. alyssoides	4.86±2.80	1.22±1.26	3.01±1.54	29.76±11.99	0.18	0.06	0.11	0.37	**1.02**
A. floribundum	1.43±1.25	1.32±0.74	1.62±1.00	26.82±9.66	0.07	0.06	0.07	**4.12**	**5.38**
A. oxycarpum	1.58±1.10	1.70±0.93	1.57±1.12	13.40±9.43	0.12	0.18	0.19	**2.24**	**1.29**
T. oxyceras	1.78±1.22	0.64±0.31	1.12±1.49	30.11±3.50	0.06	0.02	0.04	0.71	**3.75**
C. compactus	1.81±0.91	3.63±0.72	1.82±1.10	23.02±4.42	0.08	0.16	0.08	**2.60**	**1.72**
O. cappadocica	1.13±0.71	1.25±1.31	1.26±0.99	4.39±1.97	0.37	0.26	0.28	**3.70**	**4.28**
S. multicaulis	1.36±0.89	1.09±1.28	1.48±0.74	26.58±3.61	0.05	0.05	0.06	0.78	**1.88**

Table 6. *Zinc concentrations (mean±standard deviation) in plant parts and soil and values (mean) of BCF and TF*

Plants	Zn Concentrations (mg kg^{-1})				BCF and TF Values				
	Root	Stem	Leaves	Soils	BCF_R	BCF_S	BCF_L	TF_S	TF_L
Ae. spicatum	12.79±1.87	14.55±2.37	16.56±2.85	63.99±6.03	0.21	0.23	0.26	**1.16**	**1.31**
A. alyssoides	19.75±3.01	20.21±0.64	18.19±1.17	82.39±2.64	0.24	0.25	0.22	**1.04**	0.95
A. floribundum	20.57±4.45	16.54±4.58	9.68±2.13	69.35±6.44	0.30	0.24	0.14	0.81	0.48
A. oxycarpum	7.49±0.73	11.53±2.58	7.90±0.77	53.57±12.93	0.15	0.22	0.15	**1.55**	**1.06**
T. oxyceras	19.86±1.15	21.69±2.12	33.06±3.26	77.33±6.30	0.26	0.28	0.43	**1.10**	**1.67**
C. compactus	9.79±1.17	11.74±1.98	10.52±2.18	81.32±3.71	0.12	0.15	0.13	**1.20**	**1.07**
O. cappadocica	4.83±3.76	7.99±2.13	7.21±1.56	52.57±1.58	0.09	0.15	0.14	**2.13**	**1.97**
S. multicaulis	13.32±2.67	14.33±2.78	14.08±3.17	67.26±7.50	0.20	0.22	0.22	**1.08**	**1.06**

Table 7. *Manganese concentrations (mean±standard deviation) in plant parts and soil and values (mean) of BCF and TF*

Plants	Mn Concentrations (mg kg^{-1})				BCF and TF Values				
	Root	Stem	Leaves	Soils	BCF_R	BCF_S	BCF_L	TF_S	TF_L
Ae. spicatum	38.77±18.13	45.95±4.66	207.93±33.83	634.10±23.07	0.06	0.08	0.33	**1.45**	**7.03**
A. alyssoides	23.75±2.11	14.21±1.61	28.37±10.39	673.85±4.55	0.04	0.02	0.04	0.60	**1.20**
A. floribundum	10.30±1.33	11.52±1.48	47.85±11.06	629.43±46.60	0.02	0.02	0.08	**1.13**	**4.76**
A. oxycarpum	17.26±2.03	18.81±2.23	28.22±3.20	584.50±87.90	0.03	0.03	0.05	**1.09**	**1.64**
T. oxyceras	17.92±8.37	15.96±3.15	44.20±20.79	610.05±28.76	0.03	0.03	0.08	**1.00**	**2.86**
C. compactus	31.88±11.85	75.11±19.96	79.74±25.88	725.43±30.51	0.04	0.11	0.11	**2.63**	**2.66**
O. cappadocica	31.17±11.52	70.26±16.98	96.54±14.85	560.15±22.18	0.06	0.13	0.17	**2.37**	**3.46**
S. multicaulis	58.95±16.68	25.91±12.57	27.44±1.75	621.48±35.99	0.10	0.04	0.05	0.48	0.49

Manganese concentrations in plant parts and soil and BCF and TF values are presented in Table 7. The Mn concentrations (mg kg^{-1}) were 560.15-725.43 in soil, 10.30-58.95 in roots, 11.52-75.11 in stems, and 27.44-207.93 in leaves. The hyperaccumulator plants for Mn should have a 10000 mg kg^{-1} concentration in their tissues [55, 38]. Compared with the stated concentration, the Mn concentrations of the plants in this study were found very low. For manganese, while all BCF values were lower than one, TF values of plants except for *S. multicaulis*, for at least the stem or leaves, were more than one.

Copper concentrations in plant parts and soil and BCF and TF values are presented in Table 8. The Cu concentrations (mg kg^{-1}) were 6.08-19.72 in soil, 0.52-1.44 in roots, 0.48-1.31 in stems, and 0.56-1.38 in leaves. For a plant to be a hyperaccumulator for copper, it must have a copper concentration of more than 300 mg kg^{-1} [53]. Accordingly, the plants examined had no potential to be a copper hyperaccumulator. For copper, while TF_S and TF_L values of *A. floribundum, T. oxyceras*, and *C. compactus*, and TF_L value of *Ae. spicatum,* were more than one, all other BCF and TF values were under one.

Iron concentrations in plant parts and soil and BCF and TF values were presented in Table 9. The Fe concentrations (mg kg^{-1}) were 3848.25-4166.75 in soil, 53.73-276.57 in roots, 33.65-313.33 in stems, and 58.67-248.89 in leaves. According to previous studies on soil iron concentrations, it was not found over the normal ranges in studied soils [56, 57]. It is seen that *A. floribundum, A. oxycarpum, C. compactus, O. cappadocica, and T. oxyceras* and B have more ability to transfer iron to aerial parts than other plants.

CONCLUSION

Within the scope of the study, *Ae. spicatum*, *A. floribundum*, *A. oxycarpum*, and *T. oxyceras,* known as hyperaccumulators, were observed in the chromium mining area and it was observed that they had high nickel concentrations. These plants were evaluated for other heavy metals. However, it was determined that they could not accumulate or translocate to above-ground parts other heavy metals as much as nickel. Some plants were noteworthy with BCF and TF values of lower than one: *Ae. Spicatum* for Cr and Fe, *A. alyssoides* for Cu and Fe, *A. floribundum* for Zn, *A. oxycarpum* for Cu, *O. cappadocica* for Cu, *S. multicaulis* for Cr, Ni, Co, Mn, Cu and Fe. Another interesting result is that *T. oxyceras* and *C. compactus* tend to have higher concentrations of all metals analyzed in their aerial parts (only in the stem or leaves or both) than in their roots. The abundance of these plants in the region and their unresponsiveness to related heavy metals suggest that these plants may be indicators, and they may be used for planting purposes such as preventing erosion in disturbed mining lands. Also, the adverse effects of mining processes and waste accumulation on the soil structure in open-pit mining areas negatively affect the vegetation. It is thought that the plants in these areas are tolerant to these adverse conditions. In this study, all plants which heavy metal accumulation capacities were investigated should also be grown under laboratory conditions to obtain detailed information on their heavy metal-related abilities.

Table 8 *Copper concentrations (mean±standard deviation) in plant parts and soil and values (mean) of BCF and TF*

	Cu Concentrations (mg kg^{-1})				BCF and TF Values				
Plants	**Root**	**Stem**	**Leaves**	**Soils**	**BCF$_R$**	**BCF$_S$**	**BCF$_L$**	**TF$_S$**	**TF$_L$**
Ae. spicatum	0.52±0.06	0.48±0.08	0.56±0.16	10.53±1.44	0.05	0.05	0.05	0.93	**1.09**
A. alyssoides	1.32±0.10	0.88±0.01	1.27±0.23	16.14±2.06	0.08	0.06	0.08	0.67	0.98
A. floribundum	0.59±0.10	0.70±0.14	0.62±0.12	19.72±11.82	0.04	0.04	0.04	**1.20**	**1.07**
A. oxycarpum	0.71±0.01	0.56±0.02	0.64±0.05	8.35±2.31	0.09	0.07	0.08	0.79	0.90
T. oxyceras	0.92±0.17	1.06±0.13	1.22±0.17	16.92±3.26	0.05	0.06	0.08	**1.17**	**1.33**
C. compactus	1.30±0.33	1.31±0.20	1.38±0.52	15.81±1.75	0.09	0.08	0.09	**1.02**	**1.14**
O. cappadocica	1.44±0.17	0.91±0.09	0.89±0.07	6.08±0.53	0.24	0.15	0.15	0.64	0.62
S. multicaulis	0.92±0.14	0.64±0.21	0.61±0.09	10.99±1.78	0.09	0.06	0.06	0.69	0.67

Table 9 *Iron concentrations (mean±standard deviation) in plant parts and soil and values (mean) of BCF and TF*

	Fe Concentrations (mg kg^{-1})				BCF and TF Values				
Plants	**Root**	**Stem**	**Leaves**	**Soils**	**BCF$_R$**	**BCF$_S$**	**BCF$_L$**	**TF$_S$**	**TF$_L$**
Ae. spicatum	183.78±37.55	78.80±38.82	58.67±16.43	3990.50±88.33	0.05	0.02	0.02	0.42	0.32
A. alyssoides	276.57±44.41	132.23±13.29	207.49±22.44	3967.75±37.70	0.07	0.03	0.06	0.49	0.77
A. floribundum	53.73±18.80	87.87±10.95	159.49±2.08	3958.25±50.24	0.01	0.02	0.04	**1.75**	**3.27**
A. oxycarpum	146.40±9.46	167.27±11.25	176.53±27.61	3902.50±84.82	0.04	0.04	0.05	**1.15**	**1.20**
T. oxyceras	66.70±10.66	33.65±9.28	109.65±26.53	3892.00±83.48	0.02	0.01	0.03	0.51	**1.71**
C. compactus	194.24±30.55	313.33±36.10	245.54±45.62	4166.75±25.76	0.05	0.08	0.06	**1.65**	**1.29**
O. cappadocica	150.72±33.10	235.60±29.57	248.89±35.77	3848.25±29.64	0.04	0.06	0.06	**1.61**	**1.69**
S. multicaulis	213.04±56.71	126.62±39.11	142.79±30.97	3909.75±55.13	0.06	0.03	0.04	0.65	0.74

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