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Elemental interaction analysis between *Anthemis cretica* subsp. *anatolica* (Boiss.) Grierson plant and soil

Bülent ESKİN[1], Aynur DEMİR[* 1], Adeleh RASHIDI [2]
ORCID: 0000-0002-7990-4138; 0000-0002-7856-2789; 0000-0002-4831-7539

[1] Aksaray University, Faculty of Economics and Administrative Sciences, Department of Urbanization and Environmental Problems, 68100 Aksaray, Türkiye
[2] Hacettepe University, Engineering Faculty, Department of Environmental Engineering, 06800 Ankara, Türkiye

Abstract

Purpose: This study investigates the concentrations of macro and micronutrients in *Anthemis cretica* subsp. *anatolica*, a taxon whose ecological responses to edaphic conditions remain underexplored.
Method: Samples of plant and soil were obtained from Yuva village, Aksaray Province-Türkiye, in April 2023. Concentrations of Al, Ba, Cr, Co, Cu, Fe, Mn, Ni, Pb, S, and Zn were determined using ICP-MS for plants and XRF for soils. Statistical analyses were conducted using SPSS (v25).
Findings: Findings of the study showed that Al, Mn, and Ni concentrations in soils exceeded established optimal reference values. In plant tissues, levels of Al, Co, Cu, and Pb were within acceptable ranges, whereas Cr and Fe concentrations surpassed reference values. Additionally, Mn in stems and Zn in roots were below reference values, whereas Ni in leaves was elevated. Bioconcentration factor (BCF) and translocation factor (TF) values were calculated, with Ni and Cr showing high translocation to aerial parts.
Conclusion: These findings suggest that *A. cretica* subsp. *anatolica* is tolerant to heavy metals and capable of both phytostabilization and phytoextraction.

Keywords: Anthemis, macro and micronutrients, Aksaray, bioconcentration factor, translocation factor, bioindicator

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***Anthemis cretica* subsp. *anatolica* (Boiss.) Grierson bitkisi ve toprak arasındaki elementel etkileşim analizi**

Özet

Amaç: Bu çalışmada, edafik koşullara ekolojik tepkileri henüz yeterince araştırılmamış bir takson olan *Anthemis cretica* subsp. *anatolica*'daki makro ve mikro besin konsantrasyonları araştırılmıştır.
Metod: Bitki ve toprak örnekleri Nisan 2023'te Türkiye-Aksaray ili, Yuva köyünden elde edilmiştir. Ba, Cr, Co, Cu, Fe, Mn, Ni, Pb, S ve Zn konsantrasyonları bitkiler için ICP-MS ve topraklar için XRF kullanılarak belirlenmiştir. İstatistiksel analizler SPSS (v25) kullanılarak gerçekleştirilmiştir.
Bulgular: Çalışmanın bulguları, topraklardaki Al, Mn ve Ni konsantrasyonlarının belirlenen optimum referans değerlerini aştığını göstermiştir. Bitki dokularında Al, Co, Cu ve Pb seviyeleri kabul edilebilir aralıklarda iken, Cr ve Fe konsantrasyonları referans değerlerini aşmıştır. Ayrıca, gövdedeki Mn ve köklerdeki Zn referans değerlerinin altında iken, yapraklardaki Ni yükselmiştir. Biyokonsantrasyon faktörü (BCF) ve translokasyon faktörü (TF) değerleri hesaplanmış ve Ni ve Cr'nin toprak üstü kısımlarına yüksek translokasyon gösterdiği görülmüştür.
Sonuç: Bu bulgular, *A. cretica* subsp. *anatolica*'nın ağır metallere toleranslı olduğunu ve hem fitostabilizasyon hem de fitoekstraksiyon yeteneğine sahip olduğunu göstermektedir

Anahtar kelimeler: Anthemis, makro ve mikro besinler, Aksaray, biyokonsantrasyon faktörü, translokasyon faktörü, biyoindikatör

[*] *Corresponding author*: Tel.: +03822882505; Fax.: +903822882401; E-mail: aynurdemir@aksaray.edu.tr
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1. Introduction

Anthemis cretica L., a member of the Asteraceae family, includes 12 subspecies in Turkey [1]. Among them, *Anthemis cretica* subsp. *anatolica* is naturally distributed across the Eastern Aegean Islands and Turkey, particularly in Central, Western, Southern, and Southwestern Anatolia [2; 3].

This species exhibits morphological traits such as decumbent or ascending stems (10–30 cm), This plant (Figure 1) is often gray in color and sometimes woody at the base. The plant's leaves are usually under 2 cm and may be entire or divided. In addition, this plant, possessing either radiate or discoid capitula, has tuberculate achenes, particularly those located on the outer part [4].

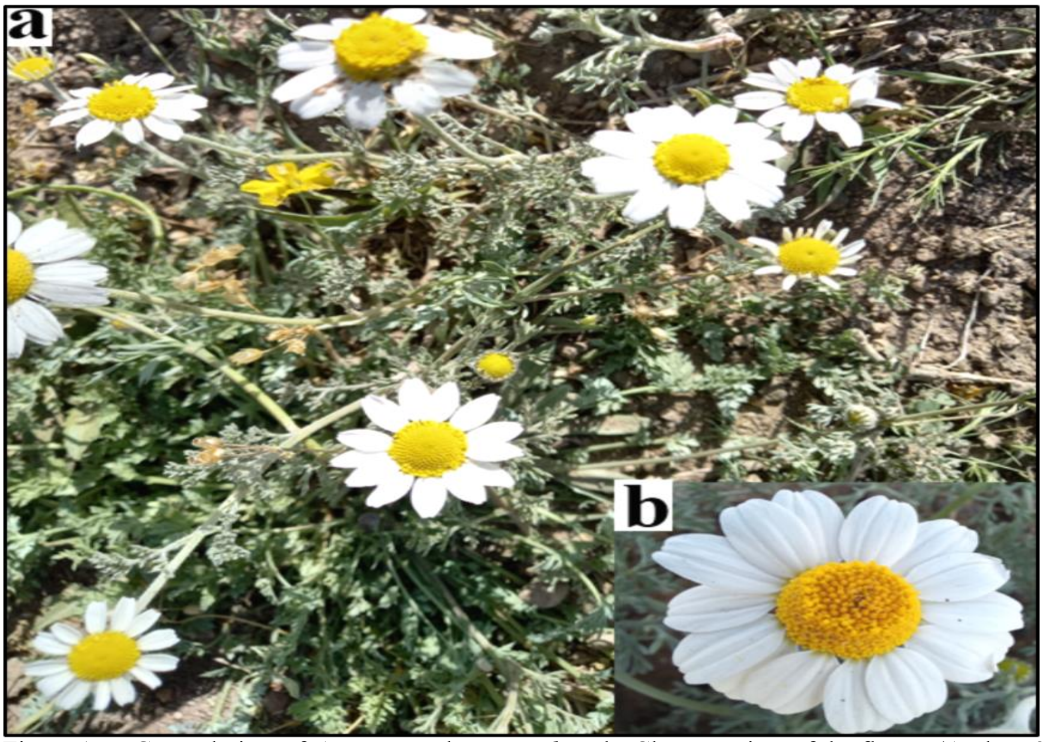

Figure 1. a- General view of *A. cretica* subsp *anatolica*, b- Close up view of the flower (Author, 2023)

Commonly known as cockerel daisy in Turkey, it has a wide ecological abundance area from 280 m to 2285 m above sea level. This plant, which can be found between May and July in its natural habitat, grows in steppes, roadsides and limestone slopes [3; 4].

To date, only one academic study has specifically addressed *A. cretica* subsp. *anatolica* at the subspecies level [1]. Other available research has focused on the broader species *A. cretica* or on different subspecies. All these academic studies have mainly addressed antioxidant, antimicrobial, taxonomic, or phytochemical characteristics [5; 6; 7; 8; 9]. However, there is a notable lack of studies investigating its ecological interactions and trace element dynamics. This study fills that gap by providing the first comprehensive evaluation of soil–plant element relationships in *A. cretica subsp. anatolica*. By focusing on its potential as a bioindicator and phytoremediation species, this research contributes novel ecological insights that extend beyond classical phytochemical perspectives. Therefore, the interactions between soil and plants of elements such as Al (aluminum), Ba (barium), Co (cobalt), Cr (chromium), Cu (copper), Fe (iron), Mn (manganese), Ni (nickel), Pb (lead), S (sulfur), and Zn (zinc), which are thought to play important roles in ecological processes, are discussed in detail.

2. Materials and methods

2.1. Description of the sampling sites

Samples of *A. cretica* subsp. *anatolica* were collected from the roadside entrance of Yuva village in Aksaray province, Central Anatolia, Turkey. Yuva village (Figure 2) is located approximately 21 km from the city center Aksaray lies between 33°10′–34°29′ E and 38°58′–39°02′ N, at an elevation ranging from 900 to 3300 meters covering an area of 7798 km² [10; 11]. The population of Aksaray in 2024 was 433,055. It is bordered by Nevsehir, Nigde, Konya, Ankara, and Kırsehir provinces [12; 13].

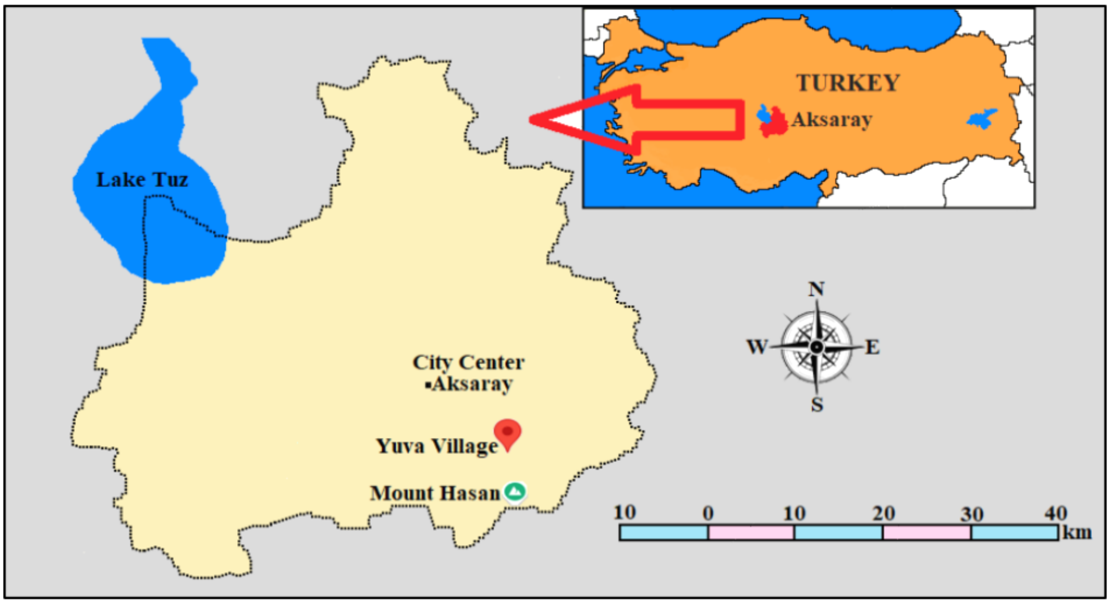

Figure 2. The research area: location of Yuva Village in Aksaray, Türkiye

2.2. Collection, preparation and analysis of samples

Plant samples were collected during the flowering period in April. From sites where *A. cretica subsp. anatolica* populations were abundant, both plant and soil samples were taken. Soil samples were extracted from a 0–15 cm depth beneath each plant and homogenized into composite samples (~1000 g each). Plant material was oven-dried at 80°C for 48 hours, ground, and sieved through 1.5 mm mesh. Plant samples (0.2 g) were placed in Teflon containers, followed by the addition of 4 mL of 65% HNO_3. Subsequently, all plant samples were mineralized in a microwave oven (CEM MARS 5) at 145°C for 5 minutes, 165°C for 5 minutes, and 175°C for 20 minutes. The samples underwent mineralization and cooling, after which they were filtered using Whatman filters. The solution was brought to a final volume of 50 mL using ultrapure water and transferred into Falcon tubes. A multi-element standard solution at a concentration of 1000 ppm (Merck) was prepared from the stock solution. The concentrations of heavy metals and mineral elements were determined using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS; Thermo, Xseries 2 Serial number: SN02132C).

Quantitative data on the analysis of the same mineral elements in soil samples were obtained using an XRF device (Pan Analytical, Axios Max Serial number: DY5970). In this study, soil samples were ground to a particle size of 20 µm using a tungsten carbide vane. A total of 5 grams of the powdered sample was homogeneously mixed with 1 gram of Micropulver Wachs C. The resulting mixture and the wax were then pelletized under pressure using a Die Attacher. The prepared sample was subsequently analyzed using an XRF device to determine the elemental composition. The $CaCO_3$ content in the soil was determined using the Scheibler calcimeter method. Soil pH was measured with an electronic pH meter. Organic matter content was analyzed following the Walkley-Black method. Total phosphorus concentrations were assessed using the Olsen and Sommers method, while available potassium levels were determined via the photometric method [14].

2.3. Statistical analysis

The Pearson correlation coefficients, along with the mean and standard deviation values, were computed using IBM SPSS Statistics 25 software. The results indicated statistical significance at the $P < 0.01$ and $P < 0.05^*$ levels.

2.4. Bioconcentration and translocation factors

The Bioconcentration Factor (BCF) is a quantitative measure of the extent to which a plant species can take metals from the soil. It is determined by dividing the metal concentration in plant tissue by the corresponding concentration in the soil, based on the analysis of elements. Plants exhibiting a BCF value exceeding one (>1) are promising for extracting contaminants from soil through phytoremediation [15]. Translocation factor (TF=Shoots/Roots) shows the efficiency of the plant in translocating the accumulated elements from roots to shoots. “It is a ratio of the concentration of the metals in shoots to that in its roots”. It is calculated as given Equation 2 [16].

3. Results

In this study, table 1 presents the average concentrations of mineral elements and heavy metals in plant samples of *A. cretica* subsp. *anatolica* and the corresponding soil samples. The mean concentrations (mg/kg) of Al, Ba, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in the soil samples were determined as 67800; 490.67; 28.80; 100; 24.93; 34633.33; 700; 57.77; 23.10; and 60.80, respectively. The concentration ranges of elements in the plant parts (mg/kg) were measured as follows: Al (206.02–553.60), Ba (6.05–17.48), Co (0.21–0.44), Cr (1.88–13.14), Cu (5.82–8.12), Fe (190.87–609.01), Mn (25.37–50.59), Ni (1.52–5.60), Pb (0.24–0.98), and Zn (13.43–23.01).

ICP-MS results indicated that Al, Co, Cu, and Pb concentrations in plant tissues were within acceptable limits. In contrast, Cr and Fe levels surpassed reference values (Table 2).

Table 1. Chemical analysis of the plant parts (root, stem, leaf and flower) and soil samples of *A. cretica* subsp *anatolica* and soil samples.

Elements	Root	Stem	Leaf	Flower	Soil
			mg/kg		
Al	463.27	218.60	553.60	206.02	67800
Ba	17.48	15.68	10.56	6.05	490.67
Co	0.37	0.25	0.44	0.21	28.80
Cr	1.88	13.14	3.37	2.25	100.00
Cu	6.96	5.82	7.67	8.12	24.93
Fe	450.16	190.87	609.01	222.93	34633.33
Mn	33.10	25.37	50.59	37.21	700.00
Ni	2.09	2.36	5.60	1.52	57.77
Pb	0.30	0.40	0.98	0.24	23.10
Zn	13.43	21.54	23.01	18.99	60.80

Table 2. Optimum values (Min.-Max.) of elements for plant and soil samples

Elements	Values in Plant	Values in Soil
	mg/kg	
Al	7-3400	10000-40000
Ba	-	-
Cr	0.1-0.5	5-120
Co	0.02-0.5	1-10
Cu	5-30	5-30
Fe	50-250	5000-50000
Mn	30-300	270-525
Ni	0.1-5	10-50
Pb	0.05-3	10-30
Zn	20-150	10-300

References for limit values in soil and plant [17; 18; 19; 20; 21; 22; 23; 24]

The results of BCF and TF values are as table 3. These values indicate that *A. cretica* subsp. *anatolica* has a moderate capacity to uptake and accumulate Ni, Cr, and Co, while showing lower accumulation for Al, Mn, and Zn. TF values indicate that *A. cretica* subsp. *anatolica* shows effective translocation of Ni and Cr to aerial parts, suggesting its suitability for phytoextraction. Moderate TF values for Co and Cu also support mobility, while lower TFs for Mn, Fe, and Zn suggest retention in root tissues, indicating a possible phytostabilization strategy. Despite elevated levels of Al, Mn, and Ni in the soil, *A. cretica* subsp. *anatolica* exhibited healthy growth in its natural habitat. These findings suggest that the plant shows a notable tolerance to heavy metal exposure in its environment.

Table 3. Vules of bioconcentration factor (BCF) and translocation factor (TF)

Elements	BCF	TF
Al	0.0032	0.45
Ba	0.0069	0.72
Co	0.0312	0.88
Cr	0.0440	1.02
Cu	0.0204	0.91
Fe	0.0122	0.57
Mn	0.0015	0.60
Ni	0.0520	1.73
Pb	0.0173	0.69
Zn	0.0115	0.43

Table 4 presents the physical analysis results of soil samples collected from the distribution area of *A. cretica* subsp. *anatolica*. These findings indicate that the species' natural habitat is characterized by loamy and soils with a pH value of 7.73. The $CaCO_3$ content 1,09 %, and the saturation value is 0.018 %. In addition, organic matter content in the soil, measured 1.15%.

Table 4. Physical analysis results of the soil samples of *A. cretica* subsp *anatolica* habitats

Soil		
Analysis Type	**Numerical value**	**Status**
Texture (%)	46.64	Loamy
CaCO3 (%)	1.09	Low Calcareous
pH	7.73	Slightly Alkaline
Saturation (%)	0.018	Without salt
Potassium (K_2O) kg/da	168.75	Sufficient
Phosphorus (P_2O5) kg/da	4.02	Low
Organic Matter (%)	1.15	Low

Table 5 shows the correlation between plant parts. There is a high correlation (=1) coefficient between the Cr, Pb and Zn elements in the root and the Fe and Cr in the stem, the Co and Mn in the flower and the Co and Zn elements in the leaf. In addition, there is a high correlation (=1) between the elements Al, Ba, Co, Cr, Cu, Fe and Ni in the soil and Ba, Co, Mn, Ni and Pb in the root, Co, Cr and Ni in the stem, Al, Co, Mn, Pb and Zn in the leaf and Co, Mn and Ni in the flower.

There is a low correlation (>0.381, 0.586) between Al in the stem and Al, Cr, Cu, Fe, Ni and Zn in the root. There is also a low correlation (Table 6) between Al in the stem and Al and Cu in the soil (>0.508, 0.601), between Cu in the root and Mn in the soil (0.640) and between Zn in the flower and soil Mn, Ni and Pb (>0.482, 0.664).

Table 5. Correlation relationship between mineral nutrients in root and stem, leaf and flower

Correlation Matrix (R)										
	Al Root	Ba Root	Cr Root	Co Root	Cu Root	Fe Root	Mn Root	Ni Root	Pb Root	Zn Root
Al Stem	0.508	0.662	0.469	0.606	0.381	0.574	0.604	0.515	0.713	0.586
Al Leaf	0.916	0.975	0.897	0.957	0.850	0.944	0.956	0.919	0.988	0.949
Al Flower	0.945	0.990	0.930	0.977	0.890	0.968	0.976	0.948	0.997*	0.971
Ba Stem	0.912	0.973	0.892	0.953	0.844	0.941	0.953	0.915	0.9870	0.946
Ba Leaf	0.924	0.979	0.906	0.962	0.860	0.951	0.962	0.927	0.991	0.955
Ba Flower	0.970	0.998*	0.958	0.992	0.926	0.986	0.991	0.972	0.999*	0.988
Cr Stem	0.994	0.996	0.989	0.999**	0.970	0.999*	0.999**	0.995	0.987	1**
Cr Leaf	0.895	0.963	0.874	0.941	0.823	0.927	0.941	0.899	0.980	0.933
Cr Flower	0.781	0.885	0.753	0.849	0.685	0.828	0.848	0.787	0.916	0.836
Co Stem	0.984	0.999**	0.975	0.998	0.949	0.994	0.998*	0.972	0.996	0.996
Co Leaf	0.966	0.997*	0.953	0.989	0.919	0.983	0.989	0.985	1**	0.985
Co Flower	0.966	0.997*	0.953	0.989	0.919	0.983	0.989	0.968	1**	0.985
Cu Stem	0.961	0.995	0.948	0.987	0.913	0.980	0.987	0.964	0.999*	0.983
Cu Leaf	0. 998*	0.998*	0.959	0.992	0.927	0.986	0.992	0.972	0.999*	0.988
Cu Flower	0.997*	0.992	0.993	0.998*	0.978	0.999**	0.979	0.998*	0.981	0.999*
Fe Stem	0.861	0.973	1**	0.986	0.995	0.991	0.986	0.998*	0.952	0.989
Fe Leaf	0.993	0.983	0.916	0.969	0.873	0.958	0.968	0.936	0.994	0.962
Fe Flower	0.977	0.870	0.737	0.837	0.668	0.814	0.836	0.772	0.906	0.823
Mn Stem	0.899	0.988	0.997*	0.996	0.985	0.998	0.996	0.999*	0.973	0.998*
Mn Leaf	0.978	0.995	0.949	0.987	0.913	0.980	0.987	0.964	0.999**	0.983
Mn Flower	0.975	0.996	0.953	0.989	0.919	0.983	0.989	0.968	1**	0.985
Ni Stem	0.999*	0.947	0.851	0.924	0.796	0.909	0.924	0.877	0.969	0.915
Ni Leaf	0.996	0.977	0.905	0.962	0.860	0.950	0.961	0.926	0.991	0.955
Ni Flower	0.978	0.995	0.948	0.987	0.913	0.980	0.987	0.964	0.999**	0.983
Pb Stem	0.994	0.981	0.912	0.967	0.868	0.956	0.966	0.933	0.993	0.960
Pb Leaf	0.982	0.993	0.942	0.984	0.906	0.956	0.984	0.959	0.999*	0.979
Pb Flower	0.978	0.874	0.742	0.841	0.674	0.819	0.840	0.777	0.909	0.827
Zn Stem	0.885	0.957	0.864	0.934	0.811	0.919	0.933	0.889	0.975	0.924
Zn Leaf	0.976	0.997*	0.951	0.988	0.917	0.982	0.988	0.966	1**	0.984
Zn Flower	0.684	0.865	0.958	0.899	0.981	0.916	0.900	0.942	0.828	0.910

** Correlation is significant at level of 0.01 (2-tailed), * Correlation is significant at level of 0.05 (2-tailed)

Table 6. Correlation relationship between mineral nutrients in plant parts and soil

	Correlation Matrix (R)									
	Al Soil	Ba Soil	Cr Soil	Co Soil	Cu Soil	Fe Soil	Mn Soil	Ni Soil	Pb Soil	Zn Soil
Al Root	0.990	0.955	0.983	0.916	0.993	0.963	0.742	0.873	0.806	0.973
Al Stem	0.508	0.740	0.656	0.810	0.601	0.720	0.954	0.864	0.919	0.692
Al Leaf	0.916	0.993	0.973	1**	0.955	0.990	0.948	0.995	0.975	0.983
Al Flower	0.945	0.999*	0.988	0.996	0.975	0.998*	0.920	0.984	0.955	0.995
Ba Root	0.684	0.994	1**	0.975	0.996	0.996	0.856	0.949	0.903	0.999*
Ba Stem	0.912	0.992	0.971	0.999**	0.952	0.988	0.952	0.996	0.978	0.981
Ba Leaf	0.924	0.995	0.978	0.999*	0.960	0.992	0.942	0.993	0.971	0.987
Ba Flower	0.970	0.998*	0.998*	0.986	0.991	0.999*	0.882	0.964	0.925	0.999**
Cr Root	0.999*	0.941	0.974	0.898	0.987	0.950	0.712	0.850	0.779	0.962
Cr Stem	0.994	0.980	0.996	0.952	1**	0.985	0.807	0.918	0.862	0.991
Cr Leaf	0.895	0.987	0.961	0.998*	0.939	0.981	0.963	0.998	0.985	0.973
Cr Flower	0.781	0.931	0.882	0.965	0.846	0.920	0.998	0.986	0.999*	0.904
Co Root	0.993	0.983	0.997*	0.957	1**	0.988	0.816	0.924	0.870	0.993
Co Stem	0.984	0.992	1**	0.973	0.997*	0.995	0.850	0.945	0.898	0.998*
Co Leaf	0.966	0.999*	0.996	0.988	0.988	1**	0.890	0.969	0.931	0.999*
Co Flower	0.966	0.999*	0.996	0.988	0.988	1**	0.890	0.969	0.931	0.931
Cu Root	0.904	0.904	0.947	0.851	0.968	0.988	0.640	0.795	0.714	0.931
Cu Stem	0.999*	0.999*	0.995	0.991	0.986	1**	0.897	0.973	0.937	0.998*
Cu Leaf	0.998*	0.998*	0.998*	0.985	0.991	0.999*	0.881	0.964	0.924	0.999**
Cu Flower	0.979	0.973	0.993	0.941	0.999*	0.979	0.785	0.903	0.844	0.986
Fe Root	0.999*	0.975	0.994	0.945	0.999*	0.981	0.792	0.908	0.850	0.988
Fe Stem	0.998*	0.939	0.973	0.896	0.987	0.949	0.709	0.847	0.776	0.960
Fe Leaf	0.933	0.997*	0.983	0.999*	0.967	0.995	0.933	0.989	0.964	0.990
Fe Flower	0.767	0.922	0.870	0.959	0.833	0.910	0.999	0.982	0.998*	0.894
Mn Root	0.993	0.983	0.997*	0.956	1**	0.988	0.815	0.923	0.869	0.993
Mn Stem	0.999*	0.964	0.988	0.929	0.996	0.971	0.763	0.887	0.824	0.980
Mn Leaf	0.962	0.999*	0.995	0.991	0.986	1**	0.897	0.972	0.937	0.999*
Mn Flower	0.966	0.999*	0.996	0.988	0.988	1**	0.890	0.969	0.931	0.999*
Ni Root	1**	0.957	0.984	0.920	0.994	0.965	0.748	0.876	0.811	0.9751
Ni Stem	0.873	0.978	0.947	0.995	0.922	0.972	0.974	1**	0.992	0.962
Ni Leaf	0.923	0.995	0.977	0.999*	0.960	0.992	0.942	0.993	0.971	0.986
Ni Flower	0.961	0.999*	0.995	0.991	0.986	1**	0.897	0.973	0.937	0.999*
Pb Root	0.921	0.999*	0,996	0.988	0.988	1**	0.890	0.988	0.931	0.999*
Pb Stem	0.870	0.997*	0.981	0.999*.	0.965	0.994	0.936	0.991	0.967	0.989
Pb Leaf	0.907	1**	0.993	0.993	0.983	0.999*	0.905	0.977	0.943	0.998*
Pb Flower	0.677	0.925	0.874	0.961	0.838	0.913	0.999*	0.984	0.998	0.897
Zn Root	0.995	0.978	0.996	0.988	0.999*	0.984	0.801	0.914	0.857	0.990
Zn Stem	0.885	0.983	0.955	0.999*	0.931	0.977	0.968	0.999*	0.988	0.968
Zn Leaf	0.964	0.999*	0.996	0.993	0.988	1**	0.893	0.970	0.933	0.999*
Zn Flower	0.944	0.806	0.869	0.961	0.902	0.823	0.482	0.664	0.568	0.844

** Correlation is significant at level of 0.01 (2-tailed), * Correlation is significant at level of 0.05 (2-tailed)

4. Conclusions and discussion

The elevated concentrations of certain heavy metals particularly Al, Mn, and Ni in the soils of the study area present a challenging growth environment for most plant species. However, the persistence and apparent health of *A. cretica* subsp. *anatolica* under these conditions suggest that it has evolved effective physiological or biochemical mechanisms to tolerate or mitigate heavy metal toxicity. The excessive levels of Cr and Fe in plant tissues, relative to reference values, imply that the species actively uptakes and potentially compartmentalizes these elements without exhibiting signs of metal stress.

This aligns with known strategies in tolerant plant species, including metal sequestration in vacuoles, complexation with organic ligands, and the enhancement of antioxidant enzyme activities [25].

The organ specific variation observed in elemental uptake such as elevated Ni in leaves and reduced Mn in stems indicates selective translocation and compartmentalization processes. These patterns are ecophysiologically significant, as they demonstrate that the plant may differentially manage elemental distribution to minimize cytotoxicity.

The BCF values calculated for each element further support this observation. The relatively higher BCFs for Ni, Cr, and Co suggest that the species possesses active uptake mechanisms for these metals, potentially making it suitable for phytoremediation in contaminated habitats. Similarly, the calculated Translocation Factors (TFs) reveal that Ni and Cr are efficiently translocated from roots to aerial tissues, a characteristic important for phytoextraction applications. In contrast, lower TF values for Mn, Fe, and Zn suggest root-level immobilization, which could serve in phytostabilization contexts. From a bioindicator perspective, *A. cretica* subsp. *anatolica* demonstrates key diagnostic traits: (i) a natural presence in metal-exposed environments; (ii) species-specific accumulation patterns distinguishable from background levels; and (iii) detectable, organ-specific concentration gradients of key pollutants (notably Ni and Cr). These features are aligned with accepted criteria for bioindicator plants and underscore its monitoring potential in semi-arid Anatolian ecosystems.

In light of these findings, *A. cretica subsp. anatolica* represents a promising model for further ecological and physiological studies. Investigating its metabolic pathways, gene expression profiles under metal stress, and interaction with rhizosphere microorganisms could provide valuable insights into its resilience mechanisms and broaden its application potential in environmental monitoring and rehabilitation.

As a result, given these traits, it represents a valuable plant for future studies in ecological monitoring and restoration of polluted **environments**.

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