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Araştırma Makalesi / Research Article

Determination of Heavy Metal Transfer from Soil to *Beta vulgaris* L. (Sugar Beet) and Evaluation of Human Health Risks

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Abstract

Heavy metals pass from the soil to plants and negatively affect the development of plants such as sugar beet.In our study aimed to investigate the accumulation of heavy metals on sugar beet plants grown in Kayseri. Six different locations were selected: Kesik, Dağılgan, Hacılımezarlığı, Kıraç Tepe, Hacıbektaş and the control area (Kilcan). Leaf, beet, root and soil samples were taken from *Beta vulgaris* plant. Heavy metal contents were analyzed using ICP-MS device. In terms of sugar beet consumption in Kayseri province, determining heavy metal accumulation and health risks will be very important in terms of these metals. Heavy metal concentration levels in sugar beet samples collected from the region are as follows; copper (Cu) > nickel (Ni) > chromium (Cr) > arsenic (As) > lead (Pb) > cadmium (Cd). When As, Cd and Cr elements are compared with the limit values determined by WHO/FAO, it is seen that they are within the permissible limits.Cu (3.25 µg g^{-1}), Ni (2.49 µg g^{-1}) and Pb (0.26 µg g^{-1}) indicate the potential for negative contributions to health through sugar beet consumption. The study reveals health concerns in terms of heavy metal contents of Cu, Ni and Pb elements evaluated in sugar beet samples grown in Yeşilhisar, Kayseri province.

Keywords: *Beta vulgaris* L., heavy metal, bio-transfer factor, health risk.

Beta vulgaris L.'e (Şeker Pancarı) Topraktan Ağır Metal Transferinin Belirlenmesi ve İnsan Sağlığı Risklerinin Değerlendirilmesi

Öz

Ağır metaller topraktan bitkilere geçerek, şeker pancarı gibi bitkilerin gelişimini olumsuz etkilemektedirler. Çalışmamızda Kayseri'de yetiştirilen şeker pancarı bitkilerinde ağır metal birikiminin araştırılması amaçlanmıştır. Kesik, Dağılgan, Hacılımezarlığı, Kıraç Tepe, Hacıbektaş ve kontrol alanı (Kilcan) olmak üzere, altı farklı lokasyon seçilmiştir. *Beta vulgaris* bitkisinin yaprak, gövde, kök kısımlarından ve yetiştiği toprak örnekleri alınmıştır. Ağır metal içerikleri ICP-MS cihazı kullanılarak analiz edilmiştir. Kayseri ilinde şeker pancarı tüketimi açısından ağır metal birikiminin ve sağlık risklerinin belirlenmesi, bu metaller açısından oldukça önemli olacaktır. Bölgeden toplanan şeker pancarı örneklerinde ağır metal konsantrasyon düzeyleri şu şekildedir; bakır (Cu) > nikel (Ni) > krom (Cr) > arsenik (As) > kurşun (Pb) > kadmiyum (Cd). As, Cd ve Cr elementleri WHO/FAO tarafından belirlenen sınır değerlerle karşılaştırıldığında izin verilen sınırlar içerisinde olduğu görülmektedir. Cu (3.25 µg g^{-1}) Ni (2.49 µg g^{-1}) ve Pb (0.26 µg g^{-1}) değerleri incelendiğinde, sonuçlar şeker pancarı tüketiminin sağlığa olumsuz katkı potansiyeline işaret etmektedir. Çalışma, Kayseri ili Yeşilhisar'da yetiştirilen şeker pancarı örneklerinde değerlendirilen ağır metal içeriklerine ilişkin Cu, Ni ve Pb elementleri açısından sağlık endişelerini ortaya koymaktadır.

Anahtar Kelimeler: *Beta vulgaris* L., ağır metal, biyotransfer faktör, sağlık riski.

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1. Introduction

Considering the ecological conditions in Türkiye, one of the most produced products is sugar beet (Ekinci et al., 2022). Sugar beet, which is an industrial plant, can be evaluated both by itself and by-products formed during its processing. Although some heavy metals are necessary for sugar beet, the excessive accumulation of these metals in plants shows that the pollution load increases in these plants growing in contaminated agricultural lands (Gomaa et al., 2017). In these plants grown in agricultural areas, beyond the range permitted by the WHO heavy metal pollution and accumulation is observed. In most studies, it has been reported that there is a correlation between high metal concentrations detected in plants and in soil (Ahmed et al., 2022; Kumar et al., 2022). Limit concentrations of heavy metals should not be exceeded in plants, which have an important place in human nutrition, for the benefit of human health. Therefore, it is very important to follow it regularly (Giri et al., 2022; İzol and İnik, 2022). Methods determined by international organizations such as the United States Environmental Protection Agency (USEPA) and WHO encourage scientists to evaluate heavy metals through methods such as daily heavy metal intake amount and total risk indices calculations and limits (Khan et al., 2023; Leblebici et al., 2020; İzol et al., 2021).

Heavy metals, which cause environmental pollution, accumulate in plant tissues, they cause changes in living activities such as transpiration, enzyme activity, photosynthesis, DNA structure and chlorophyll biosynthesis (Xie et al., 2022). Uncontrolled use of fertilizers with high phosphorus content in order to maximize productivity in agriculture, industrial activities, and atmospheric accumulation can accumulate some heavy metals in the soil (Chen et al., 2022; İzol et al., 2023). As a result of plant activities with various fertilizers applied to the soil, the pH of the soil may be change. In this case, heavy metal transfer from soil to plants is affected. Heavy metals also negatively affect the uptake of nutrients in the soil. In this case, insufficient intake of the elements leads to shortening of the root body and length of the plant, decrease in the number of leaves, reduction of the leaf surface area and many other negative effects (Alfaro et al., 2022; Gao et al., 2022; Zhang et al., 2022;). In excess, it causes burns on the leaves, stunting of the roots and stems, and negativities in amino acid binding and protein synthesis.

This study area is located within the borders of Kayseri province, located in the Central Anatolia region. The agricultural areas in Yeşilhisar district of Kayseri province, where sugar beet production is intense, constitute our study area. Industrially in the region; Paddy, corn, sugar beet, potato, cotton and sunflower are produced. Therefore, determining the pollution and possible risk factors in these regions is of great importance for public health.

In this study, sugar beet and soil samples taken from six different regions in Yeşilhisar district of Kayseri province were measured. Bioconcentration factors of heavy metals, estimated daily metal intake (EDI) and target hazard risk quotient (THQ) indices were also calculated to evaluate whether they pose a risk to human health.

2. Materials and Methods

In this study, Sugar beet (*Beta vulgaris*) parts and soil samples collected from six different stations (Kesik, Dağilgan, Hacılımezarlığı, Kıraç Tepe, Hacıbektaş and the control area (Kilcan)) in Kayseri province, were used as materials (Figure 1).

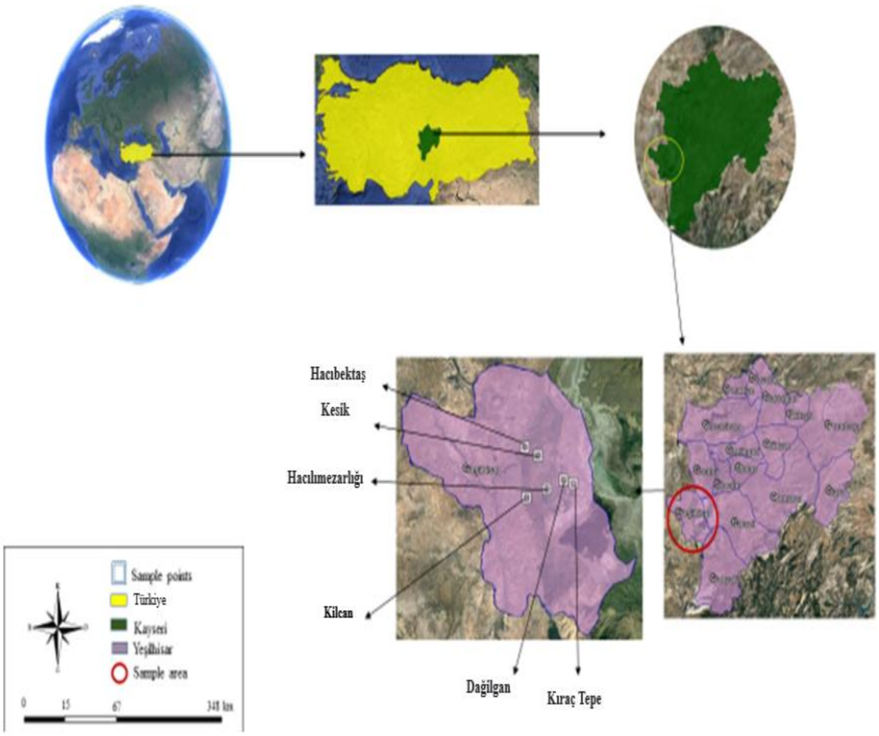

Figure 1. Map of the sampling sites

2.1 Sample Preparation

Three plant and soil samples were collected from each point in the research area. Soil samples were taken from a depth of 10 centimeters. Plant samples washed with double distilled water to remove superficial contamination. All samples were dried in an oven at 80 °C for 24 hours. The samples were ground in a mortar and transferred to bags to make homogeneous

2.2 Sample Digestion and Heavy Metal Analysis

Examples, after dissolving in the microwave using 10 mL pure HNO_3, the volume of the samples was completed to 10 mL with double distilled water. Standard solutions of elements measured with, high sensitivity ICP-MS (ICP MS/MS Agilent 8800 Triple quad) and compared according to NIST SRM® standards (NIST: National Institute of Standards and Technology, Gaithersburg, USA). Multimetal solution specification and standard reference material list given in Table 1. All chemicals used were of analytical purity (Merck, Darmstadt, Germany).

Table 1. Multimetal solution specification and standard reference material list

Element	Specification (µg/mI)	NIST SRM
As	100.0 ± 1.0	3103
Pb	100.0 ± 1.2	3128
Cd	100.0 ± 0.6	3108
Ni	100.0 ± 0.8	3136
Cu	100.0 ± 0.6	3144
Cr	100.0 ± 1.5	3032

Soil samples were dried in a drying oven at 80 °C for 24 hours and homogenized using a 2 mm sieve. Samples were dissolved with 10 ml HNO_3/HCl (1/3) mixture using a microwave device (MileStone). The final volume was completed to 10 ml with ddH_2O. Heavy metal distributions in the samples were determined using the ICP-MS device. All experiments were performed three times (Leblebici and Kar, 2018).

2.3 Bio-transfer Factor of PTEs

To determine the transfer capacity of heavy metals from soil to plant, the bio-transfer factor (BTF) of the samples was calculated. Additionally, the bio-transfer factor (BTF) of the samples was calculated to determine the yield of vegetables (Rahmani and Stenberg, 1999). Formula below used for (1)

$$\text{BTF calculation: } TF = \frac{Cv}{Cs} \qquad (1)$$

where Cv is the metal concentration detected in sugar beets and Cs is the metal concentration in the soil.

2.4 Estimated Daily Intakes

Estimated daily intake (EDI) of heavy metals adult life expectancy living in Kayseri Yeşilhisar district was calculated using the formula (Mwelwa et al., 2023);

$$EDI=\frac{(Dc \times Mc)}{W} \quad (2)$$

According to this formula (2), Dc is daily sugar beet product consumption and Mc is mean metal concentrations in each sugar beet and W is the average weight of an adult. In this study, the average weight of an adult was determined to be 75 kg and the average consumption of sugar beet products per person was taken as 95 g/day as declared by the WHO.

2.5 Health Risk Index of PTE

The health risk index (HQ) is used to characterize the HRI when contaminated sugar beet products are ingested (USEPA, 2001). The HQ index expresses the ratio between exposure to contaminated sugar beets and references oral dose. If the ratio is below one, there is no risk.
The equation of HRI is as follows (3):

$$HQ= (Div) \times \frac{C\ (metal)}{RfD} \quad (3)$$

Daily sugar beet products intake is 95 grams per person, according to WHO (WHO 2004). In the formula, Div refers to daily sugar beet intake (kg/day), (C metal) refers to the metal concentration (mg/kg) in sugar beet and RfD refers to the reference oral dose for metal (mg/kg body weight/day). RfD reference data for elements were used as follows: 0.003, 0.001, 0.04, 0.04, 0.002 and 0.001 in As, Cd, Pb, Cu, Ni and Cr respectively (Mwelwa et al., 2023).

2.6 Statistical Analysis Method

For heavy metal concentrations in soil and sugar beets mean and standard deviation values were calculated. Tests were performed to verify normality, and Kolmogorov-Smirnov test and Levene test were applied for homogeneity of variances, respectively. To determine whether there is a statistically significant difference in metal accumulation in plants; One-way ANOVA and post-hoc Duncan and Kruskal-Wallis and post-hoc Tamhane tests were used. Pearson correlation coefficient was also calculated to show the relationship between metal concentration in the soil and the amount of metal accumulated in sugar beet. All statistical analyses were performed in SPSS 22.

3. Findings and Discussion

In our study, sugar beet parts and soil samples collected from 6 different stations; Heavy metal accumulations, transfer factors, correlation, EDI and THQ detected. When the concentrations of toxic elements in soil and sugar beet samples are compared according to stations, similarities are observed. (Table 2 and Table 3). Average PTE concentrations in sugar beet samples are as follows in decreasing order: Cu > Ni > Cr > Pb > As > Cd, and in soil samples it is Cr> Ni > As > Cu > Pb > Cd.

When heavy metal concentrations in sugar beet samples are examined, it is seen that there are significant differences. It is seen that heavy metal accumulation is higher in Hacılımezarlığı and Kıraçtepe stations. However, at Kilcan station, heavy metal accumulation is observed to be low (Table 2). When the highly toxic elements such as As, Cd and Cr in sugar beet samples were examined according to WHO/FAO limit values it seems that there is no risk in terms of human consumption except for some stations (Hacılımezarlığı and Kıraçtepe) (FAO/WHO, 2011).

Table 2 Heavy metal concentrations (mean ± SD, μg g^{-1}) in sugar beets in Kayseri Province, Türkiye

Stations	As	Pb	Cd	Ni	Cu	Cr
Kilcan	$0.01^{a} \pm 0.00$	$0.13^{ab} \pm 0.00$	$0.01^{b} \pm 0.00$	$1.09^{a} \pm 0.00$	$1.69^{a} \pm 0.01$	$1.15^{ab} \pm 0.00$
Kesik	$0.10^{b} \pm 0.00$	$0.08^{a} \pm 0.00$	$0.01^{b} \pm 0.00$	$1.13^{b} \pm 0.00$	$1.84^{a} \pm 0.00$	$1.59^{b} \pm 0.00$
Dağılgan	$0.02^{b} \pm 0.00$	$0.26^{c} \pm 0.00$	$0.00^{a} \pm 0.00$	$1.56^{b} \pm 0.00$	$2.17^{b} \pm 0.00$	$1.14^{a} \pm 0.00$
Hacılımezarlığı	$0.25^{c} \pm 0.00$	$0.21^{b} \pm 0.00$	$0.07^{c} \pm 0.00$	$2.49^{c} \pm 0.01$	$3.25^{c} \pm 0.01$	$2.23^{c} \pm 0.00$
Kıraç Tepe	$0.20^{b} \pm 0.00$	$0.23^{b} \pm 0.00$	$0.06^{b} \pm 0.00$	$1.84^{b} \pm 0.00$	$3.03^{b} \pm 0.00$	$2.18^{b} \pm 0.00$
Hacıbektaş	$0.02^{b} \pm 0.00$	$0.22^{b} \pm 0.00$	$0.04^{b} \pm 0.00$	$1.13^{b} \pm 0.00$	$3.10^{b} \pm 0.01$	$1.74^{b} \pm 0.00$
FAO/WHO	0.1	0.20	0.1	1.5	5	5

For a given metal, mean concentrations followed by the same letter are not significantly different ($p<0.05$).

When soil samples are examined, it is seen that the contamination is higher at Hacılımezarlığı and Kıraçtepe stations. At Kilcan station, which is the control group, it is seen that the pollution is less (Table 3).

Table 3 Heavy metal concentration (mean ± SD, μg g^{-1}, n= 50 per location) in soils in Kayseri Province, Türkiye

Stations	As	Pb	Cd	Ni	Cu	Cr
Kilcan	$29.88^{a} \pm 1.31$	$3.04^{a} \pm 0.05$	$0.08^{a} \pm 0.00$	$10.57^{a} \pm 1.84$	$12.99^{ab} \pm 0.19$	$31.68^{a} \pm 1.80$
Kesik	$137.78^{c} \pm 0.61$	$20.15^{bc} \pm 0.09$	$0.34^{c} \pm 0.00$	$107.07^{bc} \pm 0.4$	$18.74^{ab} \pm 0.08$	$121.53^{b} \pm 0.54$
Dağılgan	$39.56^{b} \pm 0.44$	$6.84^{ab} \pm 0.12$	$0.22^{b} \pm 0.00$	$33.14^{ab} \pm 0.14$	$8.81^{a} \pm 0.03$	$69.01^{ab} \pm 0.30$
Hacılımezarlığı	$90.57^{bc} \pm 0.40$	$21.46^{c} \pm 0.09$	$0.22^{b} \pm 0.00$	$119.97^{c} \pm 0.5$	$28.22^{b} \pm 0.12$	$120.05^{b} \pm 0.53$

Kıraç Tepe	**58.13^{b}±0.26**	**20.85^{bc}±0.09**	**0.21^{b}±0.00**	**105.25^{bc}±0.4**	**21.70^{b}±0.09**	**122.01^{c}±0.54**
Hacıbektaş	**58.86^{b}±0.26**	**10.98^{ab}±0.04**	**0.14^{ab}±0.00**	**78.93^{ab}±0.35**	**33.22^{c}±0.14**	**109.79^{b}±0.49**
FAO/WHO	**0.2**	**0.5**	**0.3**	**20**	**75**	**20**

For a given metal, mean concentrations followed by the same letter are not significantly different ($p<0.05$).

Statistical correlation analysis was performed to examine the relationship between sugar beet parts and soil. When the correlation between sugar beet parts and soil samples was examined, it was determined that there was a close relationship between them. In the samples collected from Yeşilhisar region, A significant positive relationship was observed between root and sugar beet samples (r = 0.978**). A significant correlation was also observed between root and leaf samples (r = 0.873*). Additionally, a significant correlation was determined between leaf and sugar beet samples (r = 0.805*) (Table 4) (FAO/WHO, 2011).

Table 4 Correlation coefficients for heavy metal concentrations between sugar beet parts and soils

Parts	Root	Leaf	Sugar beet	Soil
Root	1			
Leaf	.873*	1		
Sugar beet	.978**	.805*	1	
Soil	.306	-.001	.488	1

Using the BTF equation is a very convenient method to evaluate heavy metal accumulation from soil to plants. Different samples have different BTFs. Those that can be easily transferred from soil to sugar beet parts are high, others are lower. The BTF value based on the sum of PTE concentration in soil and sugar beet fractions is shown in Table 5. Sugar beet parts showed different BTF values against the same elements.

BTF values of PTEs in root samples follow the decreasing table; As<Cr < Ni< Pb< Cd<Cu, in leaves; Cr< Pb< Ni <As <Cu<Cd| in sugar beet samples; Cr<Ni<Pb<Cd<Cu. Lower and higher BTF values are Cu (0.07–0.23), Cd (0.043–0.22), Pb (0.012–0.073), while As, Ni, and Cr was very low. When BTF values are examined in general; below one indicates low PTE bioaccumulation.

Table 5 Bio-transfer factors of metals from soil to sugar beets in Kayseri Province, Türkiye

Parts	As	Pb	Cd	Ni	Cu	Cr
Root	0.00	0.017	0.043	0.015	0.23	0.011
Leaf	0.02	0.073	0.22	0.008	0.21	0.007
Sugarbeet	0.002	0.012	0.05	0.006	0.07	0.005

Estimated daily PTE intake from humans It is shown in sugar beet in Fig 2. EDI values calculated in sugar beet samples. According to the calculation, a person with an average body weight of 75 kg consumes approximately 95 g of sugar beet product per day. If the calculation takes into account the consumption in different periods, such as seasonal situation, people's ages, nutrition and living standards, etc., the ratio of average PTE intake from different samples.

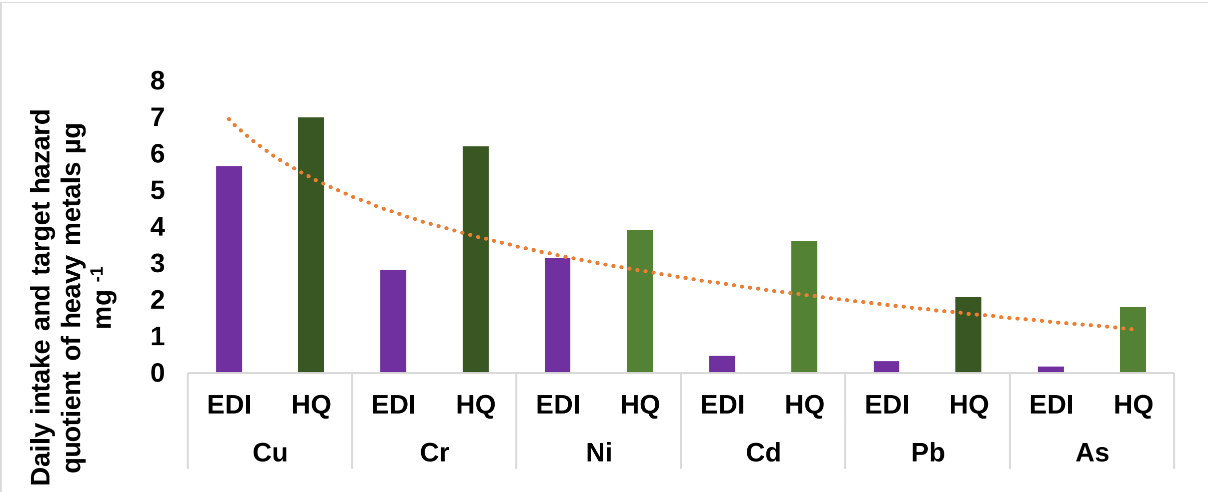

Figure 2. Daily intake of heavy metals and target hazard quotient values through consumption of sugar beet

The value of Cu is 5.67, and according to WHO 2004 data, the limit value is 2.0–3.0, which is twice as high as this value (WHO, 2004) Ni 3.15, limit value 1.4 according to USEPA 2009, exceeds the permissible limits by two times (USEPA, 2009). Pb is 0.32, the limit value according to FAO 1998 is 0.24, when compared, it is observed that the amount slightly exceeds it (FAO 1998). When As, Cd and Cr elements are compared with the limit values, it is observed that they are within the allowed limits. Cu, Ni and Pb indicate the potential for negative contributions to health through sugar beet consumption (Table 6).

Table 6 Daily intake of heavy metals and target hazard quotient values through consumption of sugar beets

	EDI	HQ	RfD(mg/day)	References
As	0.18	1.8	0.3	USEPA 2009
Pb	0.32	2.08	0.24	FAO 1998
Cd	0.08	5.6	0.4-0,6	WHO 2004
Ni	3.15	3.92	1.4	USEPA 2009
Cu	5.67	7	2.0-3.0	WHO 2004
Cr	2.82	6.2	3	USEPA 2009

Anthropogenic activities such as pesticides applied to the soil and environmental industrial factors often pollute the soil and cause the transfer of heavy metals along food chains (Xing et al. 2020; Schrögel and Wätjen, 2019; Butt et al. 2018) Plants growing in soils contaminated with toxic pollutants accumulate higher concentrations of metals in their tissues (Xing et al. 2020; Hossein

Baghaie et al. 2019; Kayika et al. 2017; Liu et al. 2022). A positive correlation is observed between heavy metals determined in plants and metal concentrations in the soil during the study.

In our study, high concentrations of As, Pb, Ni and Cr were detected in the soil samples taken from the stations. This is thought to be caused by the pesticides and environmental pollutants used. Higher concentrations of polluting elements such as pesticides compared to soils indicate a higher accumulation of heavy substances such as As and Pb in plants. Cadmium and lead do not have any affects physiological and biochemical processes (Nagajyoti et al., 2010). In fact, arsenic and cadmium concentrations in sugar beet were found to be lower than in copper, chromium, lead and nickel, which is not surprising since plants have a more developed detoxification mechanism against certain heavy metals (Janssens et al., 2009). On the other hand, it is stated that the reason for the high levels of heavy metals in soil and plant samples is the result of increased exposure to dissolved chemicals due to drought and decreased quality of irrigation water (Marvin et al., 2013).

When we examined the BTF values of the samples in the study area according to heavy metals, it was determined that they varied greatly. Copper and Arsenic had the highest and lowest values, respectively, in different samples. Results showed that the samples in the studied region preferred to accumulate Cu. This situation that could endanger human health. Order of redundancy of BTF values possibly determined by experimental conditions. (Antoniadis et al., 2019) BTF is an important parameter indicating the accumulation of heavy metals in plants (Garg et al., 2014). Differences in BTF values may be due to different environmental characteristics; this may be caused by differences in soil quality, plant species and physiology, the presence of heavy metals and the variety of areas in the study area (Gupta et al., 2008). Previous study has indicated that plants vary in their ability to absorb, transport and absorb heavy metals. Different heavy metals its accumulation in the same vegetable can differ significantly. According to Liu et al. (2022), vegetables with low bioaccumulation in fields contaminated with heavy metals ensure the safety of agricultural products(Liu et al., 2022).

Daily intake of heavy metals from plants to one's health and the risks it poses were estimated based on the average content of heavy metals. The examined copper, nickel and lead EDI values were found to be higher compared to the limit values. Jalali and Meyari (2022) examined 19 edible wild plants sampled from rural areas. It was found that the Cd, Cu, Fe, Mn, Ni and Zn values of the market areas of Hamadan and Kermanshah in the Western Iran region were less than 1 (Jalali and Meyari, 2022). Among the samples examined, the daily intake amount of some heavy metals was high. Among these, lead and nickel are the main sources of potential health risks. Lead and Nickel cause cancer, bone fractures and malformations, problems related to cardiovascular diseases, kidney dysfunction, hypertension and various diseases, liver, lungs, nervous system and immunological system disorders (Rai et al., 2021).

As a result, it seems that some steps need to be taken to prevent heavy metals from entering the food chain. It is also possible for people to reduce the amount of each product in their diet to reduce health hazards (Liu et al., 2022; İzol et al., 2023). In health risk-based evaluations such as EDI and HQ, it was determined that Cu, Ni and Pb elements were high in sugar beet samples. Navas-Acien et al. (2004) stated in their study that high levels of Pb in the blood increase the risk of peripheral artery disease (Navas-Acien et al., 2004). The study reveals health concerns regarding the heavy metal content of sugar beet samples grown in Yeşilhisar, Kayseri province and recommends that necessary measures be taken to reduce the occurrence of Cu, Ni and Pb observed in sugar beet samples from this region.

4. Conclusions and Recommendations

According to the results of the risk assessment for human health in the sugar beet samples collected from the research areas, it does not pose a significant health risk at the level of 90%. As a result, it is important to take measures to prevent heavy metal pollution in the soil and reduce the transfer of heavy metals from soil to food. Monitoring heavy metals and reducing metal concentrations in soil and plants is vital. The results of the study will shed light on comprehensive studies to be carried out in this field.

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Statement of Research and Publication Ethics

The authors declare that this study complies with Research and Publication Ethics.

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