



Determination of Heavy Metal (Cr, Co, and Ni) Accumulation in Selected Vegetables Depending on Traffic Density

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Abstract In recent years, air pollution has increased with rapid urbanization, industrial activities, and traffic density, especially in developing countries. The consumption of the vegetables grown in city centers with high levels of traffic-related pollution poses a major risk to human health due to the heavy metals contained by these plants. Heavy metals have toxic and carcinogenic effects on the human body even when consumed in low concentrations. The aim of this study is to determine the change in the accumulation of Cr, Co, and Ni elements in cucumber (*Cucumis sativus* L.), tomato (*Solanum lycopersicum* L.), and pepper (*Capsicum annuum* L.) vegetables grown in heavy, light, and almost no traffic areas in Ankara province based on plant species, plant organs, and washing condition. The change of Co, Cr, Ni concentrations based on traffic density showed differences depending on the factors studied. It was remarkable that the Cr and Co concentrations in the washed fruits increased depending on the traffic

density in general. This increase means that Cr and Co penetrate into the fruits. These results indicate how harmful the consumption of products grown near areas with heavy traffic and industrial facilities can be since heavy metals are found in high levels in these areas.

Keywords Accumulation · Air pollution · Heavy metal · Traffic density · Vegetables

1 Introduction

Today, many problems in the world are related to rapid population growth and the high concentration of population in urban areas. In respect to the rapid increase in the world population, the increasing demand for food and the difficulty in finding productive agricultural land create problems in the food supply (Fukase & Martin, 2020). It is stated that approximately 830 million people worldwide are still suffering from chronic hunger and 1 child dies of hunger every 5 s. In order to meet the demand for food around the world, the supply has doubled in the last 35 years and is expected to also double in the next 15 years. It is predicted that the food problem will get even more serious with the effect of many factors, especially global climate change (Folwarczny et al., 2021; Sevik et al., 2020b).

In order to solve the food scarcity problem around the world, various solutions are offered such

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as developing production methods to increase the amount of product obtained per unit area (hormone use, fertilizer use, breeding studies, GMO applications, etc.), protein production in the laboratory, use of insects for food purposes (García-Oliveira et al., 2022; Sevik et al., 2020b). The production of agricultural crops in urban areas is one of the studies carried out in this context. In recent years, practices such as growing crops in hobby gardens, terraces, and balconies and using edible plants in the landscaping areas (edible landscaping) have become widespread (He & Zhu, 2018; Sevik et al., 2020b). Edible landscaping which is one of the solution proposals aims to grow edible plants in parks, roofs, and road refuges. This can ensure enough food accessibility. However, with such applications, significant risks arise as production areas are moved to urban areas (Şen et al., 2018; Sevik, Cetin, et al., 2019).

Air pollution has become one of the considerable problems due to the increasing population and industrialization in urban centers throughout the world. Every year, millions of people have been suffering from air pollution and lose their lives (Turkyılmaz et al., 2020). Heavy metals are among the most important sources of air pollution. Heavy metals, which are very common in our daily life and have a density of more than 5 g/cm^3 , are as follows: titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe) cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), molybdenum (Mo) (Briffa et al., 2020).

Anthropogenic sources of heavy metals are industrial activities, urban transportation, gaseous pollutants, and mining activities (Alahabadi et al., 2017; Kilicoglu et al., 2020). Traffic activities especially are among the most important sources of heavy metal pollution (Turkyılmaz et al., 2018c). Heavy metals can be toxic to human health even at low concentrations, many of which are carcinogenic and toxic. They are not easily degraded in nature and tend to bioaccumulate in the human body (Vareda et al., 2019).

Growing plants on roofs, balconies, roadsides, and wherever plants can grow is recommended in edible landscaping, which is proposed to solve the world's food shortage (Bozdogan Sert et al., 2019). Therefore, the movement of plant cultivation to urban centers includes a significant risk in terms of human health. Several studies have found a link between high metal levels in the air and increased metal accumulations

in plants (Cesur et al., 2021; Cetin & Jawed, 2022). However, it is needed to examine the degree of accumulation based on edible plant species, plant organs, and the urban centers. This emphasizes the significance of this research by identifying the accumulation of traffic-related heavy metals in selected vegetables growing in the city center.

Heavy metals can be found in high concentrations in plants grown and consumed as food in areas with heavy traffic. Cr, Co, and Ni elements are among the harmful heavy metals and these heavy metals can cause serious health problems (Renu et al., 2021). However, there are few studies investigating heavy metal concentrations in agricultural crops grown as edible landscape plants in urban centers and industrial zones based on the traffic density (Sevik et al., 2020b). In this study, it was aimed to determine the change in the accumulation of Cr, Co, and Ni elements in tomato, cucumber, and pepper plants grown in the Ankara city center depending on plant organs, washing condition, and traffic density.

2 Materials and Methods

2.1 Preparation of the Samples

The study was carried out on the seedlings grown in the campus of the Ministry of Agriculture and Forestry in the Yenimahalle District of Ankara on Fatih Sultan Mehmet Avenue. Ankara is the capital of Turkey with a population of 5,747,325 (TUİK, 2021). Ankara is one of the most crowded provinces in Turkey. Fatih Sultan Mehmet Avenue, which is located on the Ankara-Istanbul route, has a high traffic density during the day. Considering traffic density variation, plants were grown in the median strip of the main road (heavy traffic) and areas 50 (light traffic) and 100 m (almost no traffic) from the main road. The area where the samples were collected from is shown in the map in Fig. 1.

Within the scope of the study, cucumber (*Cucumis sativus* L.), tomato (*Solanum lycopersicum* L.), and pepper (*Capsicum annuum* L.) vegetables were grown in the designated areas. *Cucumis sativus* L. (CS), *Solanum lycopersicum* L. (SL), *Capsicum annuum* L. (CA) seedlings were planted in the last week of April and grown fruits and leaves were collected as five samples each throughout the year.



Fig. 1 Areas of sample collection

To compare the heavy metal concentrations in leaves and fruits properly, samples were collected from the same branches. In this way, it is aimed that deviations that may arise from position differences do not affect the results.

The collected leaves and fruit samples were labeled and brought to the laboratory. Leaves and fruit samples were crushed and dried in glass Petri dishes. The samples, which were aerated by stirring at least twice a week for about 2 months in the laboratory, were taken into cardboard glasses after they became air dry, and then they were placed in the drying oven. Samples were dried in the oven at 50 °C for 1 month. Metal tools were not used during the procedure. The dried samples were bagged and sealed airtightly to avoid getting affected by the air humidity, then they were coded and sent for analysis (Sevik et al., 2020b).

2.2 Determination of Heavy Metal Concentrations

There are several techniques to detect the heavy metal concentrations. In this study, ICP-OES (inductively coupled plasma-optical emission spectrometry) device was used. For example, MP-AES (microwave plasma atomic emission spectrometers) was used in the previous study (Bozdogan Sert et al., 2019). However, ICP-OES has higher sensitivity and is faster than MP-AES. In order to perform heavy metal analysis on completely dried samples, the samples were powdered with a stainless steel blender. Two grams of the powdered samples was weighed and kept in 10 ml of 65% HNO₃ at room temperature for 1 day in the fume cupboard. The prepared samples were then boiled in a microwave at 180 °C for 1 h. Tubes were removed from the microwave and left to cool. Twenty milliliters of distilled water was added to the solutions

and the solutions were filtered through a 45- μm filter paper. Cr, Co, and Ni concentrations in the solutions obtained from the filtrate with the ICP-OES instrument were determined. The detection limits used in the study were Cr > 0.311 ppb, Co > 10 ppb, and Ni > 0.171 ppb. The method used in the study is a common method that is frequently used in other studies in this field (Turkylmaz et al., 2018a, b).

2.3 Statistical Analysis

The data obtained were arranged in tables using the Microsoft Excel program and evaluated with the help of the SPSS program (Version 22.0). By applying variance analysis to the data, it was determined that there were statistically significant differences at a minimum 95% confidence level and the Duncan test was applied to these data. Variance analysis and Duncan test results were simplified and tabulated and the results were interpreted.

3 Results

3.1 Change of Cr Concentration (ppb)

Within the scope of the study, the change of Cr concentration depending on plant species, organs, and washing

condition was determined in areas with heavy, light, and almost no traffic. Mean values, F value, and significance level obtained by variance analysis and homogeneous groups resulting from the Duncan test are shown in Table 1. It was determined that the change of Cr concentration in all kinds of samples and their organs was statistically significant ($p < 0.05$) based on traffic density.

Based on the average values, the lowest concentration was observed in washed tomato fruit in the areas with low traffic density as 294.933 ppb, while the highest concentration value was obtained in washed tomato leaves in the areas with almost no traffic as 2472.2 ppb. The highest proportional difference was found in washed tomato fruit and Cr concentration in heavy traffic areas was calculated to be almost 7.1 times the concentration obtained from low traffic density.

Cr concentration in unwashed pepper leaves grown in areas with high traffic density was 1.42 times more than the ones grown in areas with low traffic density and 1.57 times more than the ones grown in the areas with no traffic density. In washed cucumber fruit, the Cr concentration was calculated as 1.49 times more in the areas with high traffic density compared to areas with low traffic density, and the Cr concentration in the samples grown in the areas with high traffic density was 2.47 times more than the concentration for the areas with no

Table 1 Change of Cr concentration (ppb) on the species and organs depending on traffic density

| Species | Organ | Washing | Traffic density | | | F value |
|-----------|-------|----------|-----------------|------------|------------|-------------|
| | | | High | Low | No | |
| CA | Leaf | Unwashed | 1081.4 Cc | 759.9 Be | 690.8 Ab | 215.311*** |
| | | Washed | 496.1 Aab | 570.6 Ad | 1620.8 Be | 62.973*** |
| | Fruit | Unwashed | 1729.3 Be | 510.3 Ac | 1729.3 Be | 2734.025*** |
| | | Washed | 1006.0 Cc | 408.8 Ab | 967.7 Bd | 2141.533*** |
| SL | Leaf | Unwashed | 425.5 Aa | 1012.7 Bg | 1599.8 Ce | 393.994*** |
| | | Washed | 1473.4 Bd | 1420.2 Ai | 2472.2 Cf | 3163.234*** |
| | Fruit | Unwashed | 374.8 Aa | 940.0 Bf | 407.7 Aa | 645.247*** |
| | | Washed | 2094.9 Cf | 294.9 Aa | 469.8 Ba | 4698.583*** |
| CS | Leaf | Unwashed | 1419.2 Cd | 506.2 Ac | 1007.5 Bd | 277.790*** |
| | | Washed | 578.2 Bb | 492.4 Ac | 535.3 Ba | 10.962* |
| | Fruit | Unwashed | 575.0 Bb | 503.3 Ac | 732.9 Cbc | 249.048*** |
| | | Washed | 2057.3 Cf | 1381.8 Bh | 832.4 Ac | 57.562*** |
| F value | | | 206.007*** | 950.328*** | 223.637*** | |

The letters are groups formed as a result of the Duncan test. Capital letters are values in rows. Lower case letters are groups of values in columns

*Significant at 0.05 level, **significant at 0.01 level, ***significant at 0.001 level

Pepper (CA: *Capsicum annum* L.), tomato (SL: *Solanum lycopersicum* L.), and cucumber (CS: *Cucumis sativus* L.)

traffic density. The lowest values were obtained in unwashed SL leaves and fruits, while the highest values were obtained in washed SL and CS fruits in plants grown in areas with high traffic density. For all samples, the concentration of Cr in washed fruits increased as the traffic density increases.

3.2 Change of Co concentration (ppb)

Changes in the Co concentration depending on plant species, organs, and washing condition was determined in areas with heavy, light, and almost no traffic. Mean values, *F* value, and significance level obtained by variance analysis and homogeneous groups resulting from the Duncan test are presented in Table 2.

When the change of the Co element is examined, it is seen that the change of Co concentration in all kinds of samples and their organs was statistically significant ($p < 0.05$) based on traffic density. According to the average values, the lowest concentration was obtained with 99.800 ppb in the unwashed leaves of tomatoes grown in the areas with high traffic density, while the highest concentration was obtained in the unwashed pepper fruits with 1453.6 ppb in the areas with high traffic density. The highest proportional difference was found in unwashed pepper fruit. Co concentration in the unwashed pepper fruit grown

in the areas with heavy traffic was 3.63 times higher than the samples grown in the areas with light traffic.

When the results were examined according to the traffic density in the unwashed pepper leaves, the concentration of Co element was calculated as 1.28 times more in the areas with high traffic density compared to areas with low traffic density. Similarly, Co concentration in areas with high traffic density was 1.48 times more compared to areas with no traffic density. In the areas with heavy traffic, the lowest values were obtained in unwashed SL leaves and fruits, while the highest value was obtained in CA fruits. The Co concentration obtained in unwashed CA fruits is about 2 times the Co concentration obtained in the washed fruits. The Co concentration in washed tomato and cucumber fruits showed an increase based on traffic density.

3.3 Change of Ni concentration (ppb)

The change of Ni concentration depending on plant species, organ, and washing condition was determined according to the traffic density. Mean values, *F* value, and significance level obtained by variance analysis and homogeneous groups resulting from the Duncan test are given in Table 3. Similar to Co and Cr concentration, the change of Ni concentration in

Table 2 Change of Co concentration (ppb) on the species and organs depending on traffic density

| Species | Organ | Washing | Traffic Density | | | <i>F</i> value |
|----------------|-------|----------|-----------------|------------|-------------|----------------|
| | | | High | Low | No | |
| CA | Leaf | Unwashed | 650.3 Cf | 509.9 Bg | 438.6 Af | 369.487*** |
| | | Washed | 490.9 Bd | 573.0 Ch | 373.0 Ae | 299.047*** |
| | Fruit | Unwashed | 1453.6 Bh | 400.0 Ae | 1453.4 Bi | 699.971*** |
| | | Washed | 787.3 Bg | 445.6 Af | 1173.5 Ch | 331.234*** |
| SL | Leaf | Unwashed | 99.8 Aa | 261.4 Bc | 423.0 Cf | 12,691.329*** |
| | | Washed | 479.0 Bd | 356.9 Ad | 726.1 Cg | 334.005*** |
| | Fruit | Unwashed | 123.7 Aa | 242.6 Bc | 239.0 Bb | 286.475*** |
| | | Washed | 515.4 Bde | 185.0 Aa | 207.9 Aa | 748.672*** |
| CS | Leaf | Unwashed | 286.0 Bc | 189.2 Aab | 199.6 Aa | 80.981*** |
| | | Washed | 499.0 Cd | 182.3 Aa | 340.6 Bd | 136.337*** |
| | Fruit | Unwashed | 234.2 Ab | 206.6 Ab | 308.0 Bc | 23.726** |
| | | Washed | 539.6 Ce | 393.7 Ae | 441.8 Bf | 38.206*** |
| <i>F</i> value | | | 890.548*** | 430.451*** | 2040.868*** | |

The letters are groups formed as a result of the Duncan test. Capital letters are values in rows. Lower case letters are groups of values in columns

*Significant at 0.05 level, **significant at 0.01 level, ***significant at 0.001 level

Pepper (CA: *Capsicum annum* L.), tomato (SL: *Solanum lycopersicum* L.), and cucumber (CS: *Cucumis sativus* L.)

Table 3 Change of Ni concentration (ppb) on the species and organs depending on traffic density

| Species | Organ | Washing | Traffic Density | | | F value |
|---------|-------|----------|-----------------|------------|------------|-------------|
| | | | High | Low | No | |
| CA | Leaf | Unwashed | 2139.8 Cd | 1520.8 Aef | 1949.0 Bc | 688.484*** |
| | | Washed | 1281.7 Ab | 1220.0 Ac | 3180.4 Bf | 73.195*** |
| | Fruit | Unwashed | 2971.3 Bf | 2160.6 Ag | 2971.3 Be | 852.269*** |
| | | Washed | 1346.2 Ab | 3680.8 Ch | 2096.9 Bc | 126.421*** |
| SL | Leaf | Unwashed | 451.9 Aa | 1240.9 Bc | 2029.8 Cc | 1537.549*** |
| | | Washed | 1744.1 Bc | 1465.2 Ade | 2664.1 Cd | 1439.403*** |
| | Fruit | Unwashed | 421.4 Aa | 1321.6 Ccd | 643.4 Ba | 1771.647*** |
| | | Washed | 1438.4 Cb | 433.3 Aa | 783.4 Ba | 3929.651*** |
| CS | Leaf | Unwashed | 1916.4 Cc | 988.6 Ab | 1451.4 Bb | 290.383*** |
| | | Washed | 290.2 Aa | 1301.2 Ccd | 795.7 Ba | 942.086*** |
| | Fruit | Unwashed | 1775.1 Bc | 1419.2 Ade | 4257.4 Cg | 4472.782*** |
| | | Washed | 2457.6 Be | 1649.0 Af | 3068.7 Cef | 29.289** |
| | | F value | 148.985*** | 210.353*** | 278.872*** | |

The letters are groups formed as a result of the Duncan test. Capital letters are values in rows. Lower case letters are groups of values in columns

*Significant at 0.05 level, **significant at 0.01 level, ***significant at 0.001 level

Pepper (CA: *Capsicum annuum* L.), tomato (SL: *Solanum lycopersicum* L.) and cucumber (CS: *Cucumis sativus* L.)

all kinds of samples and their organs was statistically significant ($p < 0.05$) based on traffic density.

When the average values are examined, the lowest value was obtained in the washed cucumber leaves (290.2 ppb) grown in the areas with high traffic density, whereas the highest concentration was obtained in the unwashed cucumber fruit (4257.4 ppb) grown in the areas with no traffic density. According to the traffic density, the highest proportional difference was found in the washed tomato fruit. The Ni concentration in the washed tomato fruit grown in the areas with heavy traffic is 3.32 times more than the ones grown in the areas with light traffic. However, the Ni concentration in the washed tomato fruit grown in areas with heavy traffic was 1.84 times more compared to the concentration calculated for the areas with no traffic density.

The Ni concentration increases in the unwashed pepper leaves, in the washed tomato fruit, and in the unwashed cucumber leaves, whereas it decreases in the leaves and fruits of the other species depending on the traffic density. The highest values in tomato leaves and cucumber fruit were obtained from the plants grown in the areas with no traffic density. According to these results, it can be said that the change of Ni concentration is not affected by the traffic density but by other factors.

4 Discussion

The heavy metals considered within the scope of this study are among the most harmful elements in terms of human health (Sevik et al., 2020a). Cr is a carcinogen that can cause lung cancer, skin lesions, and respiratory problems. Co is a toxic element that may cause lung, liver and heart disorders, miscarriage, and infertility (Briffa et al., 2020). Ni heavy metal exposure to humans may cause severe health problems such as asthma, heart disorders, and allergic reactions. In addition, Ni has been shown to produce free radicals, which is part of the carcinogenic mechanisms (Renu et al., 2021).

As a result of the study, it was determined that the change of heavy metals in many organs is not linear with the washing condition or traffic density. Heavy metal concentrations are higher in both some washed and unwashed organs. For instance, it has been determined that as the traffic density increases, the Cr concentration increased in 2 of the 6 unwashed organs belonging to 3 species, while it increased in 4 of the 6 washed organs (Table 1). Similar to Cr concentration, Co concentration increased in the same number of unwashed and washed organs with Cr concentration based on traffic density (Table 2). On the other hand, Ni concentration increased in only 1 of the 6 washed organs belonging to 3 species (Table 3).

Furthermore, it is still difficult to observe the clear relationship between traffic density and heavy metal concentrations in plants since there are many other factors affecting the concentrations detected. For example, in the area where traffic is heavy, the amount of particulate matter in the air increases with the number of vehicles and when this particulate matter adheres to the plants, it can significantly affect the heavy metal concentration in the plant. This effect can be in both directions (Pietrelli et al., 2022; Sevik et al., 2020b). That is if the particulate matter is contaminated with heavy metals, the heavy metal concentration in the unwashed organs is higher, and if the particulate materials are not contaminated with heavy metals, the heavy metal concentration in the washed organs is higher (Karacocuk et al., 2022). Similarly, if these particulate materials are contaminated with heavy metals, heavy metal entry into the plant is more, and if the particulate matter is not contaminated with heavy metals, it can act as a buffer between the organ and the heavy metals in the air, preventing the entry of heavy metals into the organ (Sevik et al., 2020a).

Studies conducted in recent years showed that heavy metal concentrations are found at high levels in the leaves and fruits of the plants grown around industrial zones, energy lines, and main roads (Bierza, 2022; Shahid et al., 2013). In addition, as the cultivation areas get further away from the traffic, it has been determined that the heavy metal concentrations detected in the products decrease (Arıcak et al., 2019). This result shows that heavy metals accumulated in plant organs are related to the level of air pollution (Arıcak et al., 2020; Shahid et al., 2017).

Traffic is one of the most important factors causing air pollution. Exhaust gases and wear of vehicle tires are important sources of pollution due to the increasing number of vehicles in cities (Mossi, 2018). Many studies have been conducted to investigate the adverse effects of traffic density on the environment and heavy metal accumulation. These studies also confirm that heavy metal accumulation increases as traffic density increases (Sevik, Ozel, et al., 2019).

The results of the study showed that the concentration of these heavy metals varied significantly depending on the organs of species and the areas where the plants are grown. However, it is not correct to explain this change in heavy metal concentration solely based on traffic density. One of the other reasons is that heavy metals can be transported hundreds

of kilometers far from their sources (Turkyilmaz et al., 2018c). Thus, it is possible that heavy metal pollution, which is effective in some areas, can suppress the effects of more local and short-distance heavy metal pollution such as traffic.

Another explanation is that heavy metal accumulation in plants occurs with the effect of many factors such as plant habitus, organ structure, the interaction between plant and heavy metal, surface area, heavy metal exposure time, and physical and chemical properties of metals (Arıcak et al., 2020; Cetin et al., 2020). The characteristics listed differ according to the subspecies of the plant, type, variety, and origin (Cetin et al., 2020; Yigit et al., 2016).

The accumulation of heavy metals in plants is also closely correlated with environmental conditions (Shahid et al., 2017). In addition, plant metabolism is directly affected by environmental factors, and thus the entry of heavy metals into the plant body varies. Besides, it is noted that there is a significant relationship between the entry of heavy metals into the plant structure and environmental conditions, especially air humidity and precipitation (Mossi, 2018; Shahid et al., 2017). The biological and metabolic processes in the plant are also affected by climate conditions and eventually influence the uptake and metabolism of metals by the leaves. Climatic factors such as humidity, heat, and light are effective in the attachment of heavy metals to the leaves of the plants and penetration into the depths of the leaf tissue (Sevik et al., 2020a). Studies also show that, in some cases, microenvironmental conditions are even more effective on the anatomical and morphological characteristics of the plant than the main type of climate (Cetin et al., 2018a, b). Different findings are therefore likely to be obtained when identical experiments are conducted on the same species in different climatic conditions.

The washing condition is one of the variables considered within the framework of the analysis. When heavy metal concentrations were measured, the highest concentrations were obtained in both unwashed and washed samples depending on plant species. One of the most important factors in the accumulation of heavy metals in plants is the volume and composition of particulate matter in the air. Heavy metals can hold onto the various particulate matter in the atmosphere, after being separated from their source (Mossi, 2018; Shahid et al., 2017). Studies have shown that particulate matters in the air serve as a sink for heavy

metals and these matters can reach or remain on the plant surface in different ways. The amounts of heavy metals in the plants are closely related to the amount of particulate matter contaminated with heavy metals. Therefore, in the atmosphere, particulate matters are composed of a complex mixture of different heavy metals that all are extremely toxic and can cause serious problems in terms of human and environmental health (Shahid et al., 2017; Xiong et al., 2014).

Some research on the relationship between plant heavy metal concentrations and washing condition has also been carried out (Mossi, 2018). The washing method affects heavy metal accumulation due to the contamination of the particulate matter on the plant surface with heavy metals. If the concentration of heavy metal in the particulate matter is higher than the concentration in the plant, the concentration decreases as a result of the washing process. Otherwise, it increases. It is therefore common for heavy metal concentrations in some washed samples to be higher than those in unwashed samples, and numerous studies have reported similar results (Mossi, 2018; Sevik, Ozel, et al., 2019).

The heavy metal content levels in each vegetable were found to be substantially diverse in this study. However, Cr, Co, and Ni are no upper limits for vegetables in the Turkish Food Codex (Türk Gıda Kodeksi Teblig, 2011). For example, in terms of Pb concentration, the highest limit determined for cabbage-type vegetables, leafy vegetables, and fresh herbs is 0.10 mg/kg wet weight. It is important to specify the upper limits of Cr, Co, and Ni elements in the codex to compare the results. As a result, appropriate heavy metal concentrations for different vegetables should be determined independently.

When the results of the study are compared with similar studies, the heavy metal concentrations obtained in this study are generally at higher levels than the ones found in other studies. For example, the Cr concentrations were quite high and the plants grown in the areas with heavy traffic exceeded 1000 ppb in 7 out of 12 organs reaching 2057.3 ppb. On the other hand, Gültekin (2020) found in his study that the Cr concentration exceeded 1000 ppb in only pepper leaves among the samples of the peppers, beans, corn, and tomato leaves, and fruits collected from the villages.

Similarly, in this study, it was observed that the Co concentration increased up to 1453.6 ppb. However,

Batır (2019) stated that the concentration of Co in different species was found up to 453 ppb in leaves and 456 ppb in branches in his study on edible landscape plants in Eskişehir. In the study, it was determined that the Ni concentration could be detected high as 4257.4 ppb and this value was obtained in CS fruits. Ozel (2019) determined in his study that Ni concentration was 432 ppb for cherry fruits and 419 ppb for apple fruits grown in areas with heavy traffic.

5 Conclusions

This study showed that Cr, Co, and Ni concentrations vary significantly depending on the type and organs of the crop grown. It can be said that especially Cr and Co concentrations increase with traffic density in washed fruits. The increase in washed fruits indicates that these heavy metals Cr and Co do not derive from dust but penetrates into the fruits. Heavy metals can be quite harmful to humans even at low exposure levels, as there is no effective tolerance or excretion mechanism. The results of the study are important in terms of showing how dangerous it can be to consume crops grown in urban areas where there is a high risk of heavy metal contamination. In this regard, information campaigns about the risk of consuming heavy metal-contaminated food can be organized for people living in city centers.

In this study, three plant species were analyzed. However, there are many other vegetables and fruits grown near urban centers with high industrial pollution levels. People also grow some vegetables and greens on the balconies and roofs in city centers. It is critical to determine the potential risks and the maximum limits of heavy metal concentrations of these plants by conducting similar research. Further studies should be conducted to determine the potential hazards of different vegetable species.

Author Contribution İnci Sevinç Kravkaz Kuşçu, and Barış Tunçer conceived and designed the study. Material preparation, data collection, and analysis were performed by Barış Tunçer and Mukaddes Kılıç Bayraktar. The first draft of the manuscript was written by Mukaddes Kılıç Bayraktar and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations**Ethics Approval and Consent to Participate** Not applicable.**Consent for Publication** Not applicable.**Competing Interests** The authors declare no competing interests.**References**

- Alahabadi, A., Ehrampoush, M. H., Miri, M., Ebrahimi-Aval, H., Yousefzadeh, S., Ghaffari, H. R., Ahmadi, E., Talebi, P., AbaszadehFathabadi, Z., Babai, F., Nikoohad, A., Sharafi, K., & Hosseini-Bandegharai, A. (2017). A comparative study on capability of different tree species in accumulating heavy metals from soil and ambient air. *Chemosphere*, *172*, 459–467. <https://doi.org/10.1016/j.chemosphere.2017.01.045>
- Aricak, B., Cetin, M., Erdem, R., Sevik, H., & Cometen, H. (2019). The change of some heavy metal concentrations in Scotch pine (*Pinus sylvestris*) depending on traffic density, organelle and washing. *Applied Ecology and Environmental Research*, *17*(3), 6723–6734. https://doi.org/10.15666/aeer/1703_67236734
- Aricak, B., Cetin, M., Erdem, R., Sevik, H., & Cometen, H. (2020). The usability of Scotch pine (*Pinus sylvestris*) as a biomonitor for traffic-originated heavy metal concentrations in Turkey. *Polish Journal of Environmental Studies*, *29*(2), 1051–1057. <https://doi.org/10.15244/pjoes/109244>
- Batur, D. (2019). Heavy metal accumulation in some edible landscape plants breeding in Eskişehir, Kastamonu University Graduate School of Natural and Applied Sciences Department of Landscape Architecture. MSc Thesis.
- Bierza, K. (2022). Metal accumulation and functional traits of *Maianthemum bifolium* (L.) F. W. Schmidt in acid beech forests differing with pollution level. *Water, Air, & Soil Pollution*, *233*, 60. <https://doi.org/10.1007/s11270-022-05530-y>
- BozdoganSert, E., Turkmen, M., & Cetin, M. (2019). Heavy metal accumulation in rosemary leaves and stems exposed to traffic-related pollution near Adana-Iskenderun Highway (Hatay, Turkey). *Environmental Monitoring and Assessment*, *191*, 553. <https://doi.org/10.1007/s10661-019-7714-7>
- Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*, *6*(9), e04691. <https://doi.org/10.1016/j.heliyon.2020.e04691>
- Cesur, A., Zeren Cetin, I., Abo Aisha, A. E. S., Alrabiti, O. B. M., Aljama, A. M. O., Jawed, A. A., Cetin, M., Sevik, H., & Ozel, H. B. (2021). The usability of Cupressus arizonica annual rings in monitoring the changes in heavy metal concentration in air. *Environmental Science and Pollution Research*, *28*(27), 35642–35648. <https://doi.org/10.1007/s11356-021-13166-4>
- Cetin, M., & Jawed, A. A. (2022). Variation of Ba concentrations in some plants grown in Pakistan depending on traffic density. *Biomass Conversion and Biorefinery*. <https://doi.org/10.1007/s13399-022-02334-2>
- Cetin, M., Sevik, H., & Yigit, N. (2018a). Climate type-related changes in the leaf micromorphological characters of certain landscape plants. *Environmental Monitoring and Assessment*, *190*(7), 404. <https://doi.org/10.1007/s10661-018-6783-3>
- Cetin, M., Sevik, H., Yigit, N., Ozel, H. B., Aricak, B., & Varol, T. (2018b). The variable of leaf micromorphological characters on grown in distinct climate conditions in some landscape plants. *Fresenius Environmental Bulletin*, *27*(5), 3206–3211.
- Cetin, M., Sevik, H., & Cobanoglu, O. (2020). Ca, Cu, and Li in washed and unwashed specimens of needles, bark, and branches of the blue spruce (*Picea pungens*) in the city of Ankara. *Environmental Science and Pollution Research*, *1–10*. <https://doi.org/10.1007/s11356-020-08687-3>
- Folwarczny, M., Christensen, J. D., Li, N. P., Sigurdsson, V., & Otterbring, T. (2021). Crisis communication, anticipated food scarcity, and food preferences: Preregistered evidence of the insurance hypothesis. *Food Quality and Preference*, *91*, 104213. <https://doi.org/10.1016/j.foodqual.2021.104213>
- Fukase, E., & Martin, W. (2020). Economic growth, convergence, and world food demand and supply. *World Development*, *132*, 104954. <https://doi.org/10.1016/j.worlddev.2020.104954>
- García-Oliveira, P., Fraga-Corral, M., Pereira, A. G., Prieto, M. A., & Simal-Gandara, J. (2022). Solutions for the sustainability of the food production and consumption system. *Critical Reviews in Food Science and Nutrition*, *62*(7), 1765–1781.
- Gültekin, Y. (2020). Variation of heavy metal concentrations in some cultivar plants in the Ordu City Center. Kastamonu University Graduate School of Natural and Applied Sciences Department of Sustainable Agriculture and Natural Plant Resources. MSc Thesis.
- He, B., & Zhu, J. (2018). Constructing community gardens? Residents' attitude and behaviour towards edible landscapes in emerging urban communities of China. *Urban Forestry & Urban Greening*, *34*, 154–165. <https://doi.org/10.1016/j.ufug.2018.06.015>
- Karacocuk, T., Sevik, H., Isinkaralar, K., Turkyilmaz, A., & Cetin, A. (2022). The change of Cr and Mn concentrations in selected plants in Samsun city center depending on traffic density. *Landscape and Ecological Engineering*, *18*, 75–83. <https://doi.org/10.1007/s11355-021-00483-6>
- Kilicoglu, C., Cetin, M., Aricak, B., & Sevik, H. (2020). Site selection by using the multi-criteria technique-a case study of Bafra, Turkey. *Environmental Monitoring and Assessment*, *192*(9), 1–12. <https://doi.org/10.1007/s10661-020-08562-1>
- Mossi, M. M. M. (2018). Determination of heavy metal accumulation in some shrub formed landscape plants. Kastamonu University Institute of Science Department of Forest Engineering. PhD Thesis.
- Ozel, S. (2019). The variation of heavy metal accumulation in some fruit tree organelles due to traffic density. Kastamonu University Graduate School of Natural and Applied Sciences Department of Sustainable Agriculture and Natural Plant Resources. MSc Thesis.

- Pietrelli, L., Menegoni, P., & Papetti, P. (2022). Bioaccumulation of heavy metals by herbaceous species grown in urban and rural sites. *Water, Air, & Soil Pollution*, 233, 141. <https://doi.org/10.1007/s11270-022-05577-x>
- Renu, K., Chakraborty, R., Myakala, H., Koti, R., Famurewa, A. C., Madhyastha, H., Vellingiri, B., George, A., & Gopalakrishnan, A. V. (2021). Molecular mechanism of heavy metals (lead, chromium, arsenic, mercury, nickel and cadmium)- induced hepatotoxicity – A review. *Chemosphere*, 271, 129735.
- Şen, G., Güngör, E., & Şevik, H. (2018). Defining the effects of urban expansion on land use/cover change: A case study in Kastamonu, Turkey. *Environmental Monitoring and Assessment*, 190(8), 454. <https://doi.org/10.1007/s10661-018-6831-z>
- Sevik, H., Cetin, M., Ozel, H. B., & Pinar, B. (2019a). Determining toxic metal concentration changes in landscaping plants based on some factors. *Air Quality, Atmosphere & Health*, 12(8), 983–991. <https://doi.org/10.1007/s11869-019-00717-5>
- Sevik, H., Ozel, H. B., Cetin, M., Ozel, H. U., & Erdem, T. (2019b). Determination of changes in heavy metal accumulation depending on plant species, plant organism, and traffic density in some landscape plants. *Air Quality, Atmosphere & Health*, 12(2), 189–195. <https://doi.org/10.1007/s11869-018-0641-x>
- Sevik, H., Cetin, M., Ozel, H. B., Akarsu, H., & Cetin, I. Z. (2020). Analyzing of usability of tree-rings as biomonitors for monitoring heavy metal accumulation in the atmosphere in urban area: A case study of cedar tree (*Cedrus sp.*). *Environmental Monitoring and Assessment*, 192(1), 23. <https://doi.org/10.1007/s10661-019-8010-2>
- Sevik, H., Cetin, M., Ozel, H. B., Ozel, S., & Cetin, I. Z. (2020b). Changes in heavy metal accumulation in some edible landscape plants depending on traffic density. *Environmental Monitoring and Assessment*, 192(2), 78. <https://doi.org/10.1007/s10661-019-8041-8>
- Shahid, M., Xiong, T., Castrec, R. M., Leveque, T., & Dumat, C. (2013). Water extraction kinetics of metals, arsenic and dissolved organic carbon from industrial contaminated poplar leaves. *Journal of Environmental Science*, 25, 2451–2459. [https://doi.org/10.1016/S1001-0742\(12\)60197-1](https://doi.org/10.1016/S1001-0742(12)60197-1)
- Shahid, M., Dumat, C., Khalida, S., Schreck, E., Xiong, T. & Nabeel N. K (2017). Foliar heavy metal uptake, toxicity and detoxification in plants: A comparison of foliar and root metal uptake. *Journal of Hazardous Materials*, 325, 36–58. <https://hal.archives-ouvertes.fr/hal-01436218>
- TÜİK (2021), Türkiye İstatistik Kurumu. *Adrese Dayalı Nüfus Kayıt Sistemi Sonuçları*. Retrieved May 5, 2022, from <https://data.tuik.gov.tr/Bulten/Index?p=Adrese-Dayali-Nufus-Kayit-Sistemi-Sonuculari-2021-45500>
- Türk Gıda Kodeksi Tebliğ, 2011. *Türk gıda kodeksi bulaşanlar yönetmeliği*. 29.12.2011 tarih ve 28157 Sayılı Resmi Gazete. Gıda, Tarım ve Hayvancılık Bakanlığı, Ankara.
- Turkyilmaz, A., Sevik, H., & Cetin, M. (2018a). The use of perennial needles as bio-monitors for recently accumulated heavy metals. *Landscape and Ecological Engineering*, 14(1), 115–120. <https://doi.org/10.1007/s11355-017-0335-9>
- Turkyilmaz, A., Cetin, M., Sevik, H., Isinkaralar, K., & Saleh, E. A. A. (2020). Variation of heavy metal accumulation in certain landscaping plants due to traffic density. *Environment, Development and Sustainability*, 22(3), 2385–2398. <https://doi.org/10.1007/s10668-018-0296-7>
- Turkyilmaz, A., Sevik, H., Cetin, M., & Ahmaida Saleh E. A. (2018b). Changes in heavy metal accumulation depending on traffic density in some landscape plants. *Polish Journal of Environmental Studies*, 27(5), 2277–2284. <https://doi.org/10.15244/pjoes/78620>
- Turkyilmaz, A., Sevik, H., Isinkaralar, K., & Cetin, M. (2018c). Using acer platanoides annual rings to monitor the amount of heavy metals accumulated in air. *Environmental Monitorin and Assessment*, 190, 578. <https://doi.org/10.1007/s10661-018-6956-0A>
- Vareda, J. P., Valente, A. J. M., & Durães, L. (2019). Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. *Journal of Environmental Management*, 246, 101–118. <https://doi.org/10.1016/j.jenvman.2019.05.126>
- Xiong, T. T., Leveque, T., Austruy, A., Goix, S., Schreck, E., Dappe, V., Sobanska, S., Foucault, Y., & Dumat, C. (2014). Foliar uptake and metal(loid) bioaccessibility in vegetables exposed to particulate matter. *Environmental Geochemistry and Health*, 36(5), 897–909.
- Yigit, N., Sevik, H., Cetin, M., & Gul, L. (2016). Clonal variation in chemical wood characteristics in Hanönü (Kastamonu) Günlüburun black pine (*Pinus nigra* Arnold. subsp. *Pallasiana* (Lamb.) Holmboe) seed orchard. *Journal of Sustainable Forestry*, 35(7), 515–526. <https://doi.org/10.1080/10549811.2016.1225512>

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