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RESEARCH

# Assessment of metals (Ni, Ba) deposition in plant types and their organs at Mersin City, Türkiye

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**Abstract** The increase in heavy metal concentrations in the air, especially after the Industrial Revolution, is notable for the scientific world because of the adverse effects that threaten environmental and human health. Among the trace elements, nickel (Ni) is carcinogenic, and all barium (Ba) compounds are toxic. Trace elements are critical for human and environmental health. Their threat further increases, especially in the urban areas and surroundings with a high population. In urban areas, the trace element contamination in the airborne can be reduced using plants. However, which plant and plant organs absorb trace elements could not be determined. In the present study, Ni and Ba concentrations in the branch, wood, and leaf samples of 14 species collected from the city center of Mersin province were determined. As a result, broad-leaved species' Ni and Ba concentrations in their leaf sample were generally higher than other species. Almost all species had the lowest Ni and Ba concentrations in their wood samples. Among these 14 species, it was found that Ni concentration was very high, especially in non-washed leaves of *Platanus orientalis*, *Photinia serrulata*, and *Citrus reticulate*, and Ba concentration was very high in *Citrus reticulata*, *Chamaecyparis lawsoniana, Laurus nobilis*, and *Acer hyrcanum*. Using broad-leaved species in urban areas where pollution is at high levels will significantly contribute to reducing Ni and Ba pollution. It is recommended that these points be considered in future urban landscaping projects.

**Keywords** Air pollution · Heavy metal · Phytoremediation · Urban air

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## Introduction

In the last century, the rapid increase in global population and industrialization brought many problems to them. Extraction of mineral sources from underground and their uncontrolled and intense use in industry after the Industrial Revolution caused a significant increase in concentrations of various elements in water, air, and soil during and after the nineteenth century (Koç, 2021a; Liu et al., 2022; Ucun Ozel et al., 2019). The increased concentrations of specific elements became one of the problems threatening human health (Sevik et al., 2019) and causing global climate change by altering the natural composition of the atmosphere (Cantürk & Kulaç, 2021; Varol et al., 2021). Furthermore, the migration from the countryside to urban areas, which was initiated in order to meet the need for a labor force needed in industrial activities, increased population density in urban areas, and thus, following global climate change, urbanization became an irreversible dilemma that the earth has to cope with (Cetin et al., 2023; Kilicoglu et al., 2021; Koç & Nzokou, 2023; Koç et al., 2022; Koç, 2021b, 2021c).

Because of the increasing concentration of population in urban areas and the increasing level of pollution due to the effects of anthropogenic factors on these areas, the environmental pollution in urban areas increased on the global scale and became a problem threatening human health (Bisht et al., 2022; Isinkaralar et al., 2022a, 2022b). Heavy metal (HM) pollution poses a more critical problem in the city centers of provinces with high population density (Sevik et al., 2020a; Isinkaralar et al., 2023). Although there are different anthropogenic sources of HM pollution in urban areas, previous studies showed that the most important one among them is traffic exhaust, and traffic-originated pollution constituted more than half of the total anthropogenic pollution sources (Cobanoglu et al., 2023; Xie et al., 2021). Throughout the world, diseases related to environmental pollution have caused more than 9 million deaths, more than 15 times the total number of casualties from wars and other violent cases (Heidari et al., 2021). From the aspect of humans, the most dangerous part of environmental pollution is air pollution. Air pollution has become one of the main reasons of death globally (Cetin et al., 2019). Nowadays, 1 out of every 8 deaths is because of factors related to air pollution, and 92% of the global population, which is approx. 8 billion, live in places with low air quality (Cetin & Jawed, 2022).

Amongst the components of air pollution becoming a global problem, HMs have specific importance. Some HMs can be carcinogenic, venomous, and even fatal when present in small amounts. HMs essential as a nutrient or structural component might have hazardous effects at high concentrations (Ucun Ozel et al., 2020). Thus, the effects of mist between the 5th and 9th December of 1952 in London caused approx. 4000 deaths from diseases related to the respiratory system, such as bronchitis and pneumonia, and 8000 more deaths occurred in the following couple of months. The samples collected from victims showed that their livers were severely contaminated with fine particles, including most studied HMs such as Zn, Pb, and Fe (Shahid et al., 2017; Turkyilmaz et al., 2018). Only one of the remarkable cases shows how dangerous the HMs can be.

Some HMs can be hazardous and destructive for living things and ecosystems, even in small amounts. Due to these effects, international health organizations classify HMs, dangerous even at low concentrations, as priority pollutants. ATSDR (Agency for Toxic Substances and Disease Registry) has included 23 elements in the list of priority pollutants, and these are Ag, Al, As, Ba, Be, Cd, Co, Cr, Cu, Pb, Mn, Hg, Ni, Pd, Pu, Sb, Se, Sr, Tl, Th, U, V and Zn (Badea et al., 2018).

Because of its physical and chemical characteristics, nickel (Ni) is used as a catalyzer in chemistry and the food industry in several metallurgic processes, such as alloy such as alloy and nickel–cadmium battery production and electro-deposition. Ni and its compounds have various commercial and industrial uses because of their chemical properties, affordability, and brightness. However, Ni is considered one of the human health's most dangerous trace elements. IARC (The International Agency for Research on Cancer) classified the soluble and nonsoluble Ni compounds in Group 1 (carcinogenic for humans) and Ni and its alloys in Group 2B (possible carcinogenic for humans). It was reported that Ni might cause various medical problems, such as respiratory tract cancer, asthma, cardiovascular diseases, lung fibrosis, and contact dermatitis (Genchi et al., 2020; Henderson et al., 2012).

The element of barium (Ba) plays an essential function in several industrial merchandise production. Ba compounds, isotopes, and alloys are used in the manufacture of Zn, Ag, and Pb, brake bold pad, rubber, dye, vacuum tubes, machine oils, plastic, detergents, optic glass, glue, batteries, special glasses, oil paints, oil industry, etc. However, Ba is one of the most hazardous trace elements; all its alloys are toxic (Aktaş, 2019). Inhalation of toxic and poisonous elements into the human body is much more dangerous (Savas et al., 2021). For this reason, decreasing the amount of both Ni and Ba in the air is vital. Plants are one of the most effective instruments for this purpose. Fulfilling many ecological, economic, social, and esthetic functions, the plants can also reduce air pollution where they are grown (Ozel et al., 2021; Yigit et al., 2021; Yucedag et al., 2019).

Studies show that the concentrations of trace elements in nature increase due to anthropogenic sources. It is stated that the pollution level is much higher in urban areas. The main reasons are vehicles, combustion processes to meet energy needs, and pollutants concentrated in urban areas, such as domestic waste (Erasmus et al., 2022; Islam et al., 2022; Istanbullu et al., 2023). It is stated that pollutants in the atmosphere, in particular, are retained in significant amounts by tall trees growing in urban neighborhoods and are stored in the aboveground organs of these trees, thus helping to reduce air pollution. Many studies have determined that metal element concentrations in plants growing in urban regions are much higher than in plants growing in areas with low levels of air pollution (Sevik et al., 2019; Turkyilmaz et al., 2018).

It was determined that plants are useful in reducing air pollution, and various plants can be used for this purpose (Ma et al., 2022; Oladoye et al., 2022; Wu et al., 2022). However, plants can effectively reduce the trace element pollution in the air if it can be determined which plants have a higher capacity to retain which trace elements in their organisms. Since studies examining trace elements are expensive, the studies are carried out on fewer species. In landscaping practices in urban regions, plant selection is primarily based on visual quality. However, although many plants offer visually similar features, their physiological characteristics can be quite different from each other. Suppose sampling and analysis can be done simultaneously by taking as many plant samples as possible from plants growing in the same environment. In that case, the plants that will help reduce air pollution the most can be determined, and the priority use of these plants in landscaping works can be ensured. Thus, air pollution can be reduced more effectively with the help of plants. In the current study, it was aimed to determine which of 14 different plant species (most preferred landscape species in the Mersin city center, Türkiye) and which of their organs (bark, leaf, and wood) based on washing status can accumulate more Ni, which is a carcinogenic element, and Ba, all the compounds of which are poisonous, amongst the trace elements that are extremely dangerous to human health in urban areas.

## Materials and methods

The study was carried out in a large coastal park (36°47′46.0″N—34°37′46.9″E) located in Mersin city center (Fig. 1). Mersin province, a port city in the Mediterranean region in the south of Turkey, is the 11th largest city in Turkey in terms of population (1,916,432) (Mersin Valiliği, 2023). In addition to the location of Mersin province, its abundance of tourism areas and the presence of a port trade zone cause intense tourism and ship traffic in the province.

For this purpose, among the species frequently used in landscaping projects, *Cupressus sempervirens* L. (T1), *Thuja occidentalis* L. (T2), *Citrus reticulata* Blanco (T3), *Platanus orientalis* L. (T4), *Prunus cerasifera* Ehrh. (T5), *Photinia serrulata* Lindl. (T6), *Eucalyptus camaldulensis* Dehnh. (T7), *Chamaecyparis lawsoniana* (A. Murr.) Parl. (T8), *Laurus nobilis* L. (T9), *Cercis siliquastrum* L. (T10), *Schinus molle* L. (T11), *Pyracantha coccinea* M. J. Roemer (T12), *Acer hyrcanum* F. et Mey (T13), and *Pinus brutia* Ten. (T14) were studied with three replicates. Branch samples [including its leaf ($n=10$), bark ($n=10$), and wood ($n=5$)] were collected from 1-year-old shoots of species (last year's shoot) at the end of the vegetation season of 2021 (late October). They were organized and brought to the laboratory. Then, these branches were separated into organs deprived of using metal instruments. Half bark ($n=5$) and leaf samples ($n=5$) were washed and rinsed with pure water. In order to evaluate the contamination of the particulate matter on the leaves with used trace elements, the washing process was applied. Studies show that washing removes particulate matter contaminated with metal elements from the organs. The washing process in these studies was applied in similar studies (Kuzmina et al., 2023; Sulhan et al., 2023). Washing was not applied to the wood samples since

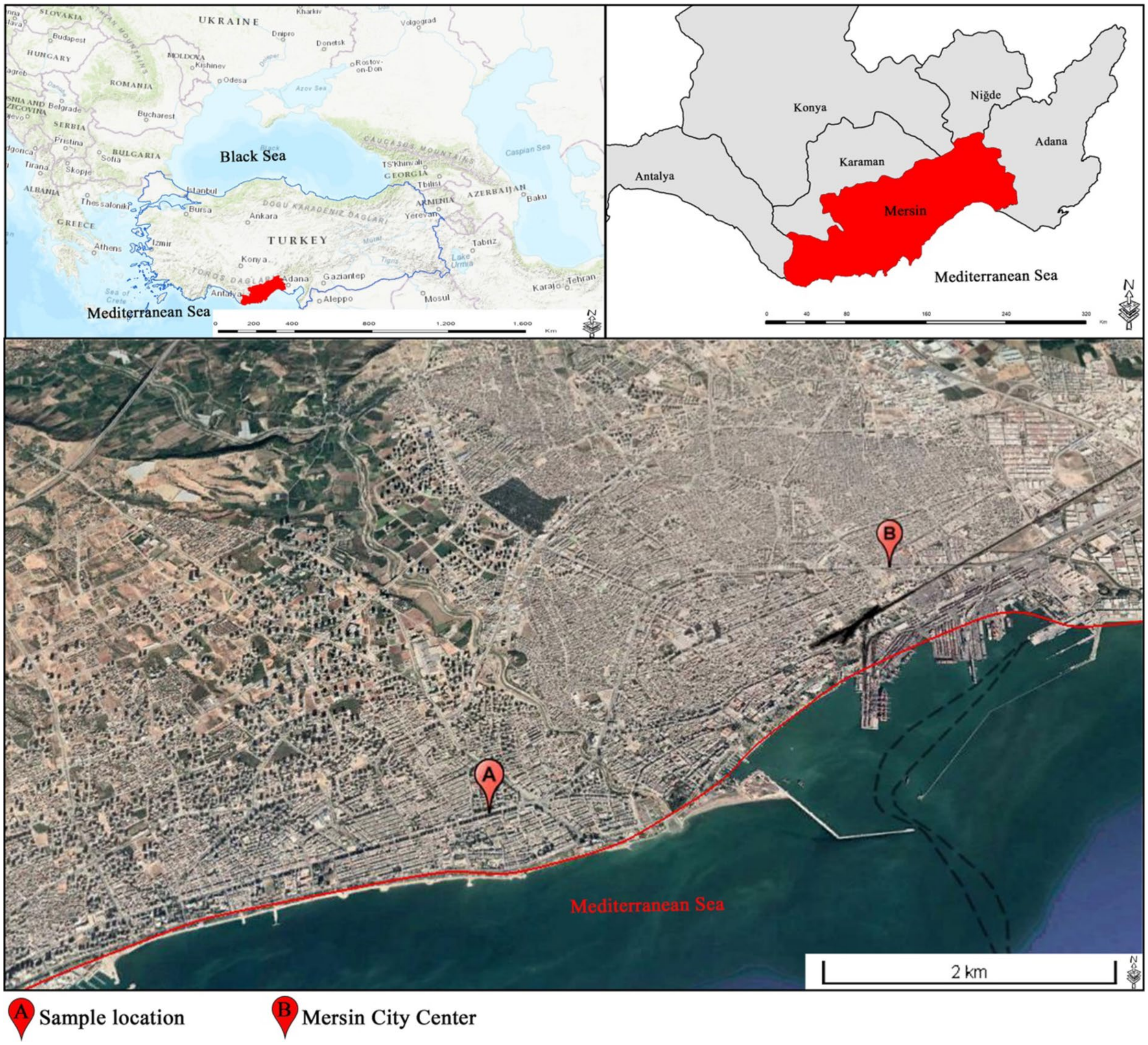


**Fig. 1** Map of sample collection location in Mersin city, Türkiye

they were not in contact with air. After the bark samples were taken from the upper part of the wood, at least 1 mm of the cambium layer was cut off with the help of steel knives, and wood samples were taken from the inner part, which has absolutely no connection with the cambium or bark layer.

In the next step, all the samples were labeled according to the washing status. Washed leaves were labeled with "WL", non-washed leaves with "U-WL", washed bark with "WB", non-washed bark with "U-WB", and wood samples with "W".

After the pre-treatment, the labeled samples were kept under room conditions until air-dried without direct sunlight. Then, they were placed in a drying oven (45 °C) to dry for 2 weeks. Dried plant samples were ground. Half-grams of them were placed into a flask specially designed for microwaving. They were added with 10 mL 65% $HNO_3$. The flasks were then combusted in the microwave (180 ºC and under 280 PSI pressure) for 20 min. Then, the solutions in the flasks were taken out of the microwave and sat for cooling. The solution in the flask was filled up to 50 ml by adding deionized water.

The prepared specimens were then filtered through filter paper and scanned using an ICP-OES instrument (GBC Scientific Equipment Pty Ltd., Melbourne, Australia) at proper wavelengths. The obtained values were multiplied by the dilution factor, and the concentrations of the analyzed elements were calculated. The previous studies used all these procedures (Isinkaralar et al., 2022c; Yayla et al., 2022).

The obtained concentration values for each element were subjected to ANOVA (analysis of variance) using the SPSS 21.0 software program. The groups with statistically significant differences ($p < 0.001$) were subjected to Duncan's test, and homogeneous groups were found. The PCA (principal component analyses) were applied using PC ORD software to achieve the Ni and Ba differences between species based on organs and washing status. Interpretations were made based on these outcomes.

## Results

### Variation of Ni concentrations (mg/kg) in dry mass by the tree species, organs, and washing status

The concentrations of Ni in 3 organs of 14 species examined here are presented with statistical analysis results in Table 1. As a result of the ANOVA, it was determined that Ni concentration significantly ($p < 0.001$) varied between all the species by organs and all the organs by species.

Examining the change of Ni concentration by species, the first point of interest is that all the highest Ni concentrations were found in T3 (Fig. 2a, b, c and d), except for wood (Fig. 2e). The values obtained from some organs were much higher than all other species. For instance, the value found in U-WB (21.60 mg/kg) is approx. 6 folds of the second-highest value (3.60 mg/kg) (Fig. 2d). Besides that, Ni concentrations obtained from leaves were higher in T4, T6, and T3 when compared to other species. It was also determined that the values obtained from all the organs in species T1, T2, and T14 were very low (Fig. 2a, b, c and d).

Examining the change by organs, given the results of Duncan's test, the concentrations obtained from wood in all plant species, except for T9, T10, and T12, were found to be in the same group (Fig. 2e). Moreover, it can also be seen that the Ni concentrations found in wood ranged within a very narrow range despite the other organs. Ni concentration varying between 0.51 mg/kg and 2.98 mg/kg in wood ranges between 1.27 mg/kg and 14.32 mg/kg in U-WL (Fig. 2b), between 0.79 mg/kg and 17.42 mg/kg in WL (Fig. 2a), between 0.99 mg/kg and 21.60 mg/kg in U-WB (Fig. 2d), and between 0.79 mg/kg and 17.19 mg/kg in WB (Fig. 2c). In general, bark samples had a lower Ni concentration than leaf samples, and non-washed leaf samples had a higher Ni concentration than washed ones.

**Table 1** Summary of variance analysis for Ni and Ba concentration for organs of 14 plant species based on washing status

| Source of variation | df | P-value | |
|---|---|---|---|
| | | Nickel | Barium |
| Species (S) | 13 | $< 0.0001$ | $< 0.0001$ |
| Organ (O) | 4 | $< 0.0001$ | $< 0.0001$ |
| S x O | 52 | $< 0.0001$ | $< 0.0001$ |

### Variation of Ba concentrations (mg/kg) in dry mass by the tree species, organs, and washing status

The concentrations of Ba, the other element examined here, in 3 organs of 14 species are presented with statistical analysis results in Table 1. As with Ni concentration, it was determined that Ba concentration statistically meaningfully varied between all the species by organs and all the organs by species ($p < 0.001$).

Examining the change of Ba concentration by species, the lowest values were found from wood samples in all the species (Fig. 3a, b, c, d and e). The values obtained from wood did not significantly change by the species except for T10 (Fig. 3e). Ba concentration in T10 wood samples was 10.40 mg/kg but ranged between 1.90 and 4.66 mg/kg in wood samples of all other species (Fig. 3e). However, there were statistically significant differences between other organs by species. For instance, the highest value in U-WL (42.82 mg/kg) was approx. 9 times the lowest value (4.83 mg/kg) (Fig. 3b). Similarly, Ba concentrations ranged from 3.97 mg/kg to 35.98 mg/kg in WL (Fig. 3a), 4.96 mg/kg to 26.09 mg/kg in U-WB (Fig. 3d), and 5.86 mg/kg to 26.41 mg/kg in WB (Fig. 3c).

Examining the values by species, the highest values were found in T3, T8, T9, and T13, especially in leaves (Fig. 3a), and the values found in T4 and T14

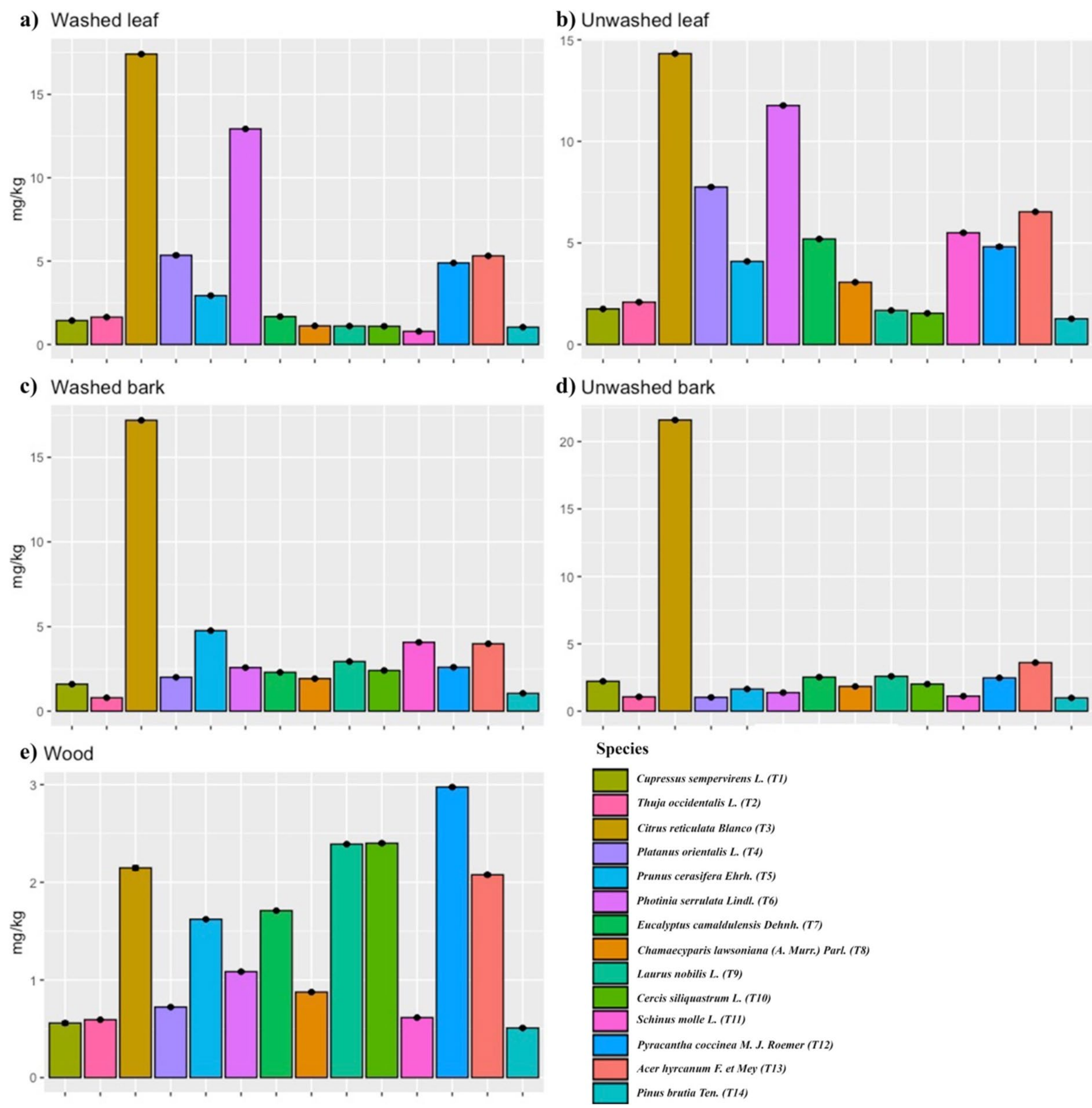


**Fig. 2** Change of Ni concentration (mg/kg) in three plant organs based on washing status

were the lowest for all the organs. Furthermore, it was also determined that considering the leaves and barks, the concentrations obtained from washed samples were generally lower than those obtained from non-washed samples (Fig. 3a, b, c and d). The difference between washed and non-washed samples was more significantly distinguished in leaves.

## Principal component analysis of Ni and Ba based on tree species, organs, and washing status

As a result of the PCA analysis, variance explanation ratios (%) of the axes are given. While the total variance explanation rate of Axis 1 and Axis 2 for the Ni element is 88.934% (Fig. 4), the explanation rate of

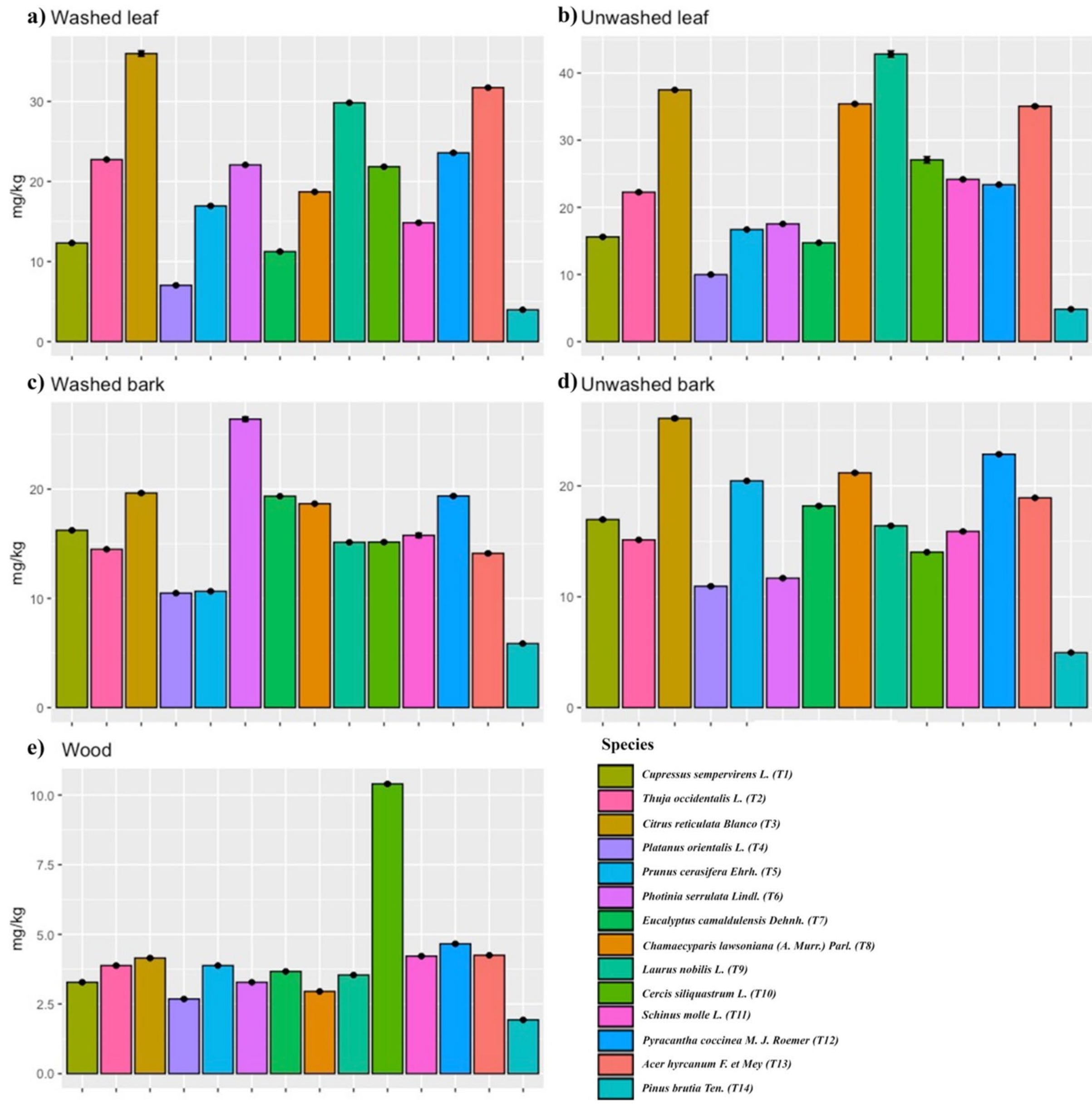


**Fig. 3** Change of Ba concentration (mg/kg) in three plant organs based on washing status

the Ba element is 75.12% (Fig. 5). When the graph for the Ni element was examined, UWL, WL, UWB, and WB values had a high positive relationship with each other but a weak positive relationship with the W value (Fig. 4f). In the relationship between species of Ni values measured in unwashed leaves, the highest value was obtained in T3 (14.32 mg/kg) and T6 (11.77 mg/kg) species, while the lowest was obtained in T14 (1.27 mg/kg) and T10 (1.54 mg/kg) species (Fig. 4a). Ni values in washed leaves, the highest two values were obtained in T3 (17.42 mg/kg) and T6 (12.93 mg/kg) species, while the lowest was obtained in T11 (0.79 mg/kg) and T14 (1.04 mg/kg) species (Fig. 4b).

In the relationship between species of Ni values measured in unwashed bark, the two highest values were obtained in T3 (21.60 mg/kg) and T13 (3.60 mg/kg) species, while the two lowest were obtained in T14

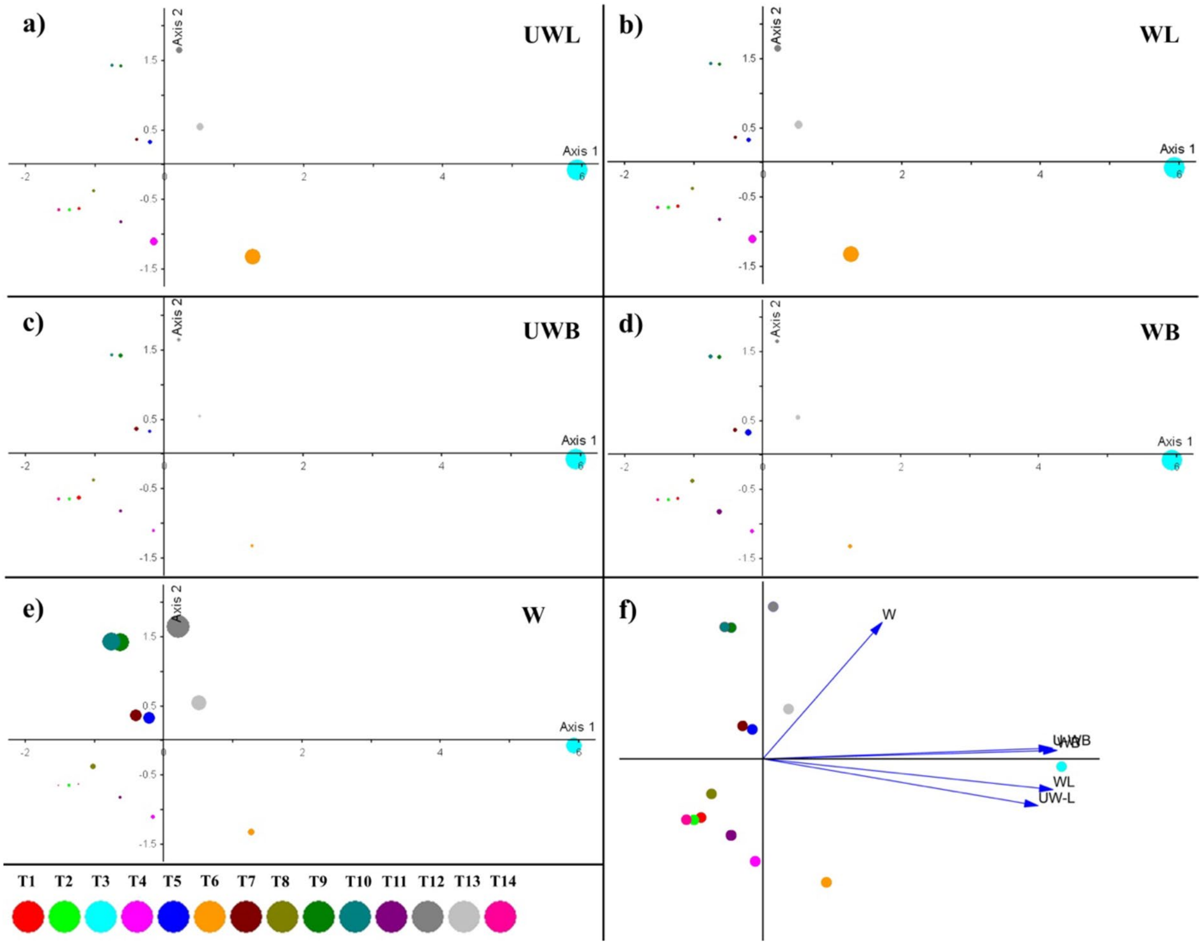


**Fig. 4** The correlation of Ni element between species based on organ and washing status

(0.99 mg/kg) and T4 (1.03 mg/kg) species (Fig. 4c). Ni values in washed barks, the two highest values were obtained in species T3 (17.19 mg/kg) and T5 (4.76 mg/kg), while the two lowest were obtained in species T12 (2.60 mg/kg) and T14 (1.05 mg/kg) (Fig. 4d). In wood, the two highest values were obtained in the T12 (2.98 mg/kg) and T10 (2.40 mg/kg) species, while the lowest values were obtained in the T14 (0.51 mg/kg) and T1 (0.56 mg/kg) species (Fig. 4e).

When the PCA analysis results for the Ba element were examined, the UWL, WL, UWB, and WB values had a high positive relationship (Fig. 5f). In contrast, they had a weak positive relationship with the W value (Fig. 5f). The highest Ba values measured in unwashed leaves were found in T9 (42.82 mg/kg) and T3 (37.50 mg/kg) species, while the lowest was obtained in T14 (4.84 mg/kg) and T4 (9.99 mg/kg) species (Fig. 5a). In the washed leaf, the two highest values were obtained in the T3 (35.98 mg/kg) and T13 (31.73 mg/kg) species, while the two lowest were obtained in the T14 (3.97 mg/kg) and T4 (7.04 mg/kg) species (Fig. 5b).

The two highest values in unwashed bark were obtained in the T3 (26.10 mg/kg) and T12 (22.85 mg/kg) species, while the two lowest were in the T14 (4.96 mg/kg) and T4 (10.95 mg/kg) species (Fig. 5c). In the washed bark, the two maximum values were found in the T6 (26.42 mg/kg) and T3 (19.64 mg/kg) species, while the two lowest were obtained in the T14 (5.86 mg/kg) and T4 (2.69 mg/kg) species (Fig. 5d). The two maximum values in wood were obtained in the T10 (10.40 mg/kg) and T12 (4.66 mg/kg) species, while the two lowest were obtained in the T14 (1.93 mg/kg) and T4 (2.69 mg/kg) species (Fig. 5e).

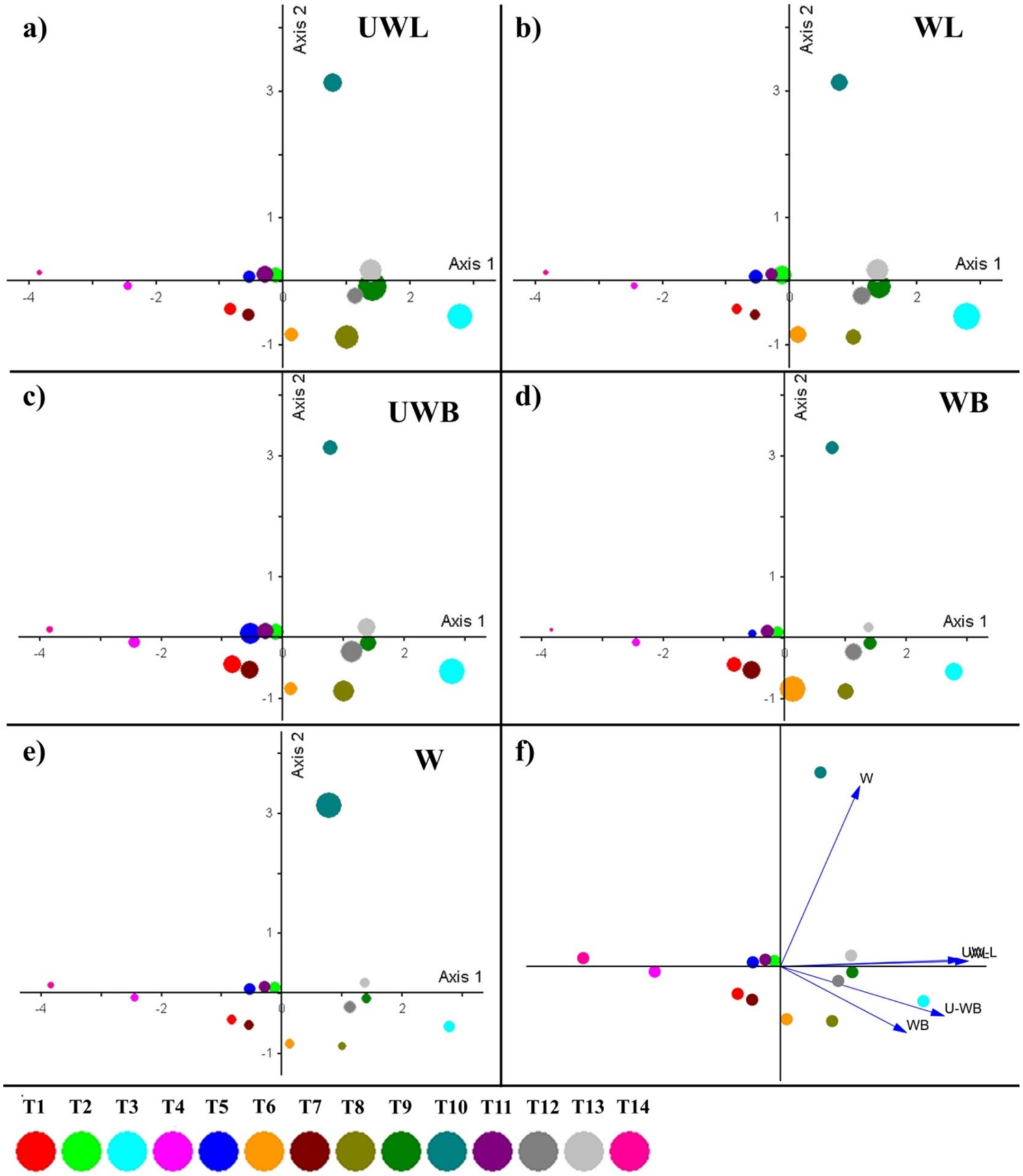


**Fig. 5** The correlation of Ba element between species based on organ and washing status

## Discussion

Studies aiming to determine the change in trace element concentration reported that the plant type was the leading factor affecting the trace element concentration change most (Karacocuk et al., 2022). It is predominantly related to the structure of plant organs. In the current study, the highest Ni concentrations were obtained from *Citrus reticulata* for all organs except wood. Besides that, it is interesting that Ni concentrations obtained from leaves were higher in *Platanus orientalis*, *Photinia serrulata*, and *Citrus reticulata* than in other species. The results achieved in *Cupressus sempervirens*, *Thuja occidentalis*, and *Pinus brutia* were very low for all the organs.

In this study, the highest Ba in U-WL is 42.82 mg/kg. Ba concentrations ranged from 3.97 mg/kg to 35.98 mg/kg in WL, 4.96 mg/kg to 26.09 mg/kg in U-WB, and 5.86 mg/kg to 26.41 mg/kg in WB. Different values for Ba concentration have been obtained in various studies. Çobanoğlu et al. (2022) determined that the Ba concentration in *Cotoneaster franchetii* and *Euonymus japonica* woods was below the detectable limits. In contrast, Ba concentration was measured at 15.74 mg/kg in *Pyracantha coccinea* woods and 11.91 mg/kg in *Platycladus orientalis* woods in that study. In a study comparing Ba concentrations in wood, leaves, and bark, the highest Ba concentrations were found in wood in *Aesculus hippocastanum* (25.75 mg/kg), in unwashed leaves in *Tilia tomentosa* (23.35 mg/kg) and washed bark in *Ligustrum vulgare* (21.57 mg/kg) was obtained (Hmeer, 2020). In their study, where they evaluated the branches without separating the wood, Cetin and Jawed (2022) determined that the Ba concentration in the branches reached a maximum level of 3370.1 mg/kg.

In this study, Ni concentration varying between 0.51 mg/kg and 2.98 mg/kg in wood ranges between 1.27 mg/kg and 14.32 mg/kg in U-WL, between 0.79 mg/kg and 17.42 mg/kg in WL, between 0.99 mg/kg and 21.60 mg/kg in U-WB, and between 0.79 mg/kg and 17.19 mg/kg in WB. In a study conducted on different species, the highest Ni concentrations were obtained in the leaves of *Aesculus hippocastanum* (36.85 mg/kg), in the leaves of *Tilia tomentosa* (1.30 mg/kg), and in the seeds of *Prunus cerasifera* (36.21 mg/kg) (Pinar, 2019). As can be seen, different results can be obtained in different types of studies. Therefore, to determine the most suitable biomonitor and phytoremediation types, conducting simultaneous studies on many species growing in the same region is necessary. The amount of metal element accumulation in distinct organs of plant species grown in a similar ecosystem varies based on the structure of the organ, surface area, morphology, surface tissue, and size (Aricak et al., 2020; Koç, 2021a; Sevik et al., 2020b).

The entry of trace elements into the plant body can occur in three different ways: from the soil through the roots, from the air through the leaves, and by direct adsorption from the stem parts (Chen et al., 2022). A leaf is an organ that has the highest contact and interaction with air. The air intake and outlet in leaves occur through stomas; in this process, trace elements can be taken in the leaf (Karacocuk et al., 2022). Similarly, the leaf surface is also a determinant factor in trace element accumulation (Ghoma et al., 2022). Thus, trace element concentrations found in broad-leaved species are expected to be higher than in others. In addition, in species with hairy or serrated leaf surfaces, it is easier for particulate matter to adhere to the surface. A similar situation applies to barks. In addition, the duration of exposure of the plant organ to trace elements also increases the concentration of trace elements because trace elements can enter the plant through the body parts (Cobanoglu et al., 2023; Key et al., 2023). As a result of the current study, the highest concentrations in leaves were generally obtained in *Photinia serrulata*, *Citrus reticulata*, and *Laurus nobilis* species, and for the bark in *Citrus reticulata*, *Acer hyrcanum*, and *Pyracantha coccinea* species. When these species are examined, it is seen that the species with the highest concentrations in the leaves are species with both serrated leaf surfaces and short heights. *Photinia serrulata* and *Laurus nobilis* are small species covered with leaves from the bottom; therefore, they have leaves in sections that are not too high from where the exhaust smoke is highest. Therefore, its leaves are heavily exposed to traffic pollution, considered one of the most important sources of trace elements. *Citrus reticulata*, Acer *hyrcanum*, and *Pyracantha coccinea* are small-height species whose barks have a serrated structure. Therefore, the study results confirm a relationship between the structure of the plant organ, the duration of exposure to trace element pollution, and the amount of trace elements taken into the plant.

One of the crucial outcomes of the present study is that Ni and Ba concentrations found in woods were much lower than in the other organs. In many studies carried out to date, the concentrations of elements such as Pb (Sevik et al., 2020a), Ni (Cesur et al., 2021), Cd (Aricak et al., 2019), and Co and Ba (Turkyilmaz et al., 2019) in wood were much lower when compared to leaves and barks. However, species that can store more elements in the wood part are more effective in phytoremediation studies because the wood part is the largest part of the trees in terms of mass (Key et al., 2023; Koc et al., 2023). The transport of elements within the wood part is primarily related to the cell structure and cell wall (apoplastic pathway). Apoplasts, found between the cell wall and plasma membrane (CWPM) in plants, are apoplastic membrane barriers and flexible structures that detect and create signals in metal/metalloid stress. Cell wall proteins (CWP) are activated in diverse abiotic strains (Wani et al., 2018). Plants frequently face strain factors, especially abiotic stress, in their lives. Plants' most common strain factor is climatic stress (Tekin et al., 2022). Because plant development depends on the relations of genetic structure (Hrivnak et al., 2023; Kurz et al., 2023) and environmental constraints (Zeren Cetin et al., 2023; Tandoğan et al., 2023). Therefore, factors such as global climate change that cause significant and permanent changes in climatic parameters (Varol et al., 2021), as well as factors such as UV-B stress, radiation, and trace element pollution, are important sources of stress for plants (Ozel et al., 2021; Canturk., 2023). Since the CWPM interface accumulates most trace elements, this region is believed to be the potential region responsible for metal tolerance (Wani et al., 2018).

As a result, Ni and Ba concentrations found in non-washed leaves were higher than in the washed samples. This outcome can be because the particle matters. Particle matters are among the remarkable pollution factors in the city centers (Cetin et al., 2019; Elsunousi et al., 2021). Metal elements can attach to particles' surfaces and act as a sink for metal elements (Cetin et al., 2020; Turkyilmaz et al., 2020). Since the particles contaminated with trace elements can attach to the surface of plant organs, the trace element concentrations found in non-washed samples were higher in the washed samples (Aricak et al., 2020; Cesur et al., 2021). If metal elements do not contaminate the particles attached to the plant organs, the trace element concentrations in washed samples are higher. The Ni and Ba concentrations of non-washed samples were higher than the values found in washed samples in this study, and this finding may suggest that Ni and Ba pollution in the study area was at a high level.

The results showed that Ni and Ba pollution in the examined city center was high. It was emphasized that Ni concentrations were high in both the soils in city centers (Kaur et al., 2022; Yuan et al., 2021) and in various organs of plants grown in soil in city centers (Cetin & Jawed, 2022; de Almeida Bezerra et al., 2021; Mortazavi et al., 2019) and it was stated that the increase in Ni level was related to the traffic density (Koç, 2021a; Levei et al., 2021). Even though few studies were conducted on Ba, it was reported that Ba concentration increased with traffic density (Cetin & Jawed, 2022). One of the ways that trace elements enter the plant body is through the roots. Therefore, high Ni and Ba concentrations in the soil will also increase the element concentrations taken into the plant through the roots.

Similarly, particulate matter contaminated with Ni and Ba will adhere to the bark and leaves, increasing these organs' Ni and Ba concentrations and entering the plant through the stem parts. As a result, the concentrations of these elements will be at high levels in the organs of plants growing in areas polluted in terms of Ni and Ba. It was reported that the Ba element was found in *Eugenia uniflora* leaves but not in the soil, and its concentration in the leaves in urban areas was much higher when compared to the values found in the leaves in forest areas (de Almeida Bezerra et al., 2021). It was emphasized in previous studies that Ba has a remarkable industrial area of use and the potential for an atmospheric pollutant in high-traffic areas (de Almeida Bezerra et al., 2021; Goddard et al., 2019; Lima et al., 2021). Similar results were obtained for Ni (Cobanoglu et al., 2023; Key et al., 2023).

## Conclusion

In conclusion, the accumulations of Ni and Ba in organs of species examined here (except for wood) significantly differed by species. It was also determined that Ni and Ba concentrations in the leaves of broad-leaved species were much higher, and the concentrations in needle- and scale-leaved species were much lower. Thus, broad-leaved species should be preferred for urban areas.

In addition, Ni and Ba concentrations obtained in the wood part did not change significantly depending on the species. On the other hand, Ni and Ba concentrations in all species are above detectable limits and are at a very high level compared to studies in the literature. In studies that reduce metal pollution, element concentration in wood is more important than in other organs. The wood part is the most significant part of the tree in terms of mass, and unlike many other organs, it does not separate from the tree and re-enter the ecosystem. Thus, metals taken into the wood are trapped there and removed from the ecosystem. Therefore, plants with a high potential to accumulate metals in their wood can be used very effectively in reducing heavy metal pollution in the air. Some of the species used in this study are in shrub or tree form. However, *Cupressus sempervirens*, *Platanus orientalis*, and *Pinus brutia* are the taller trees in this study. These species are also recommended for reducing Ni and Ba pollution.

Among 14 plant species, Ni concentration was very high in the leaves of *Platanus orientalis*, *Photinia serrulata*, and *Citrus reticulata*. In contrast, Ba concentration was very high in *Citrus reticulata*, *Chamaecyparis lawsoniana, Laurus nobilis*, and *Acer hyrcanum* leaves. Using these species in urban areas and sites with high Ni and Ba pollution would significantly reduce the Ni and Ba pollution.

In conclusion, Ni and Ba concentrations were relatively high in *Citrus reticulata* organs. It is frequently used in landscaping in almost all Mediterranean regions, and its fruits are consumed as food. However, Ba and Ni can threaten human health even at low doses. Therefore, using plants grown in areas with high levels of trace element pollution for food purposes should be avoided.

The results suggest that Ni and Ba contaminated the particle materials in the urban area examined. Since these elements are related to traffic, this problem will probably be observed in any city center with high traffic density. The particles contaminated by trace elements are hazardous to human and public health. Thus, it is necessary to reduce the Ni and Ba concentrations in these areas first and then take measures to decrease the amount of particles in the air.

This study was carried out on 14 species with different characteristics, and remarkable differences were found between Ni and Ba concentrations in the organs of these species. Since studies examining trace elements are costly, the studies are carried out on a limited number of species. However, the present study emphasizes the importance of studying many species having different characteristics. Hence, it is suggested that future studies be carried out with more and different species and more individuals to determine which organ collects the highest amount of trace elements.

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