Change of Aluminum Concentrations in Specific Plants by Species, Organ, Washing, and Traffic Density

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One of the most critical problems throughout the world is air pollution, causing the death of millions of individuals annually, and it is reported that 90% of the global population breathes polluted air. Among the components of air pollution, the most harmful ones are the heavy metals, which can remain non-degraded in nature for a long time, bio-accumulate in living organisms, and be toxic or carcinogenic at low concentrations. Hence, monitoring and reducing heavy metal pollution in the air are high-priority research topics. Heavy metals can accumulate within various organs of plants grown in an environment with an increased level of heavy metal pollution. The metal analyses on these organs can provide insight into the heavy metal pollution in the air. In the present study, the concentrations of aluminum (Al), one of the most important heavy metals, were determined in the different organs of five plant species grown in regions with different traffic densities. Remarkable changes were observed in the Al concentrations in all the organs of species, which were examined here by organ and traffic density. The highest values were obtained from the organs of plants grown in no-traffic regions.

DOI: 10.15376/biores.18.1.792-803

Keywords: Heavy metal; Air pollution; Biomonitor; Aluminum; Al

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INTRODUCTION

The increase in the global population to nearly 8 billion and the advancements in technology together with the Industrial Revolution over the last century have caused an excessive use of natural resources (Shahid *et al*. 2017; Koç 2021). During this process, the increasing use of almost all the natural resources and the release of minerals into nature, which were processed and used as raw materials in the industry, resulted in excessive pollution of the air (Turkyilmaz *et al*. 2020; Savas *et al*. 2021), water (Ucun Ozel *et al*. 2020), and soil (Bayraktar *et al*. 2019). Because anthropogenic activities are the main reasons for the pollution, the level of pollution further increases in urban areas, where the population intensity in a unit area is much higher (Maslennikov *et al*. 2015; Cesur *et al*. 2021).

Air pollution, especially in urban areas, is a critical problem (Cetin *et al*. 2021). The World Health Organization (WHO) reports that 90% of the global population is breathing polluted air, and the air pollution can cause severe medical problems, such as stroke, lung cancer, and cardiac diseases, leading to the death of approximately 7 million people annually (Jo *et al*. 2020; Ghoma *et al.* 2022). Moreover, because it alters the composition of the atmosphere, air pollution has additional direct and indirect adverse effects on the ecosystem on earth (Koç 2021; Varol *et al*. 2021).

Air pollution has various components, such as particulate materials and CO_2 (Elsunousi *et al*. 2021). Among these components, heavy metals are the most important and dangerous ones. Heavy metals can be toxic and lethal for living organisms even when at low concentrations. It is known that As, Pb, Cd, Cr, and Hg are among the most toxic and harmful heavy metals (Shahid *et al*. 2017; Turkyilmaz *et al*. 2020). Furthermore, the elements that are necessary as a micronutrient for living organisms, such as Cu, Zn, Mn, Fe, Cr, and Ni, but these can be harmful when at high concentrations (Sevik *et al*. 2019).

Aluminum (Al), which is one of the elements that are necessary as a nutrient for organisms, is among the most abundant elements. It is a soft and lightweight metal and is used in several toothpaste brands, food boxes, aluminum foil, antacids used for the stomach, cigarette filters, several salts and cheeses, and antiperspirant deodorants, and is widely released from the industrial facilities where it is used as raw material. Within the body, Al accumulates in the liver and brain tissues the most, and it can cause liver damage, loss of appetite, muscle pains, and psychosis. Moreover, excessive intake of Al can result in memory disorder (Shahid *et al*. 2017; Sencard 2021).

Because heavy metals pose a considerable threat to human and environmental health, it is essential to monitor heavy metal pollution. The most frequently used method to monitor heavy metal pollution in the air is biomonitors (Alaqouri *et al*. 2020a, 2020b; Aricak *et al*. 2020). The present study aims to determine the most suitable biomonitor plant and organ to be used in monitoring heavy metal pollution in the air. For this purpose, it was aimed to determine the change of Al concentration in leaf, branch, and wood samples of four plant species by the traffic density.

EXPERIMENTAL

Materials

The organs (leaf, bark, and wood) used in this study were collected from high-traffic areas with continuous vehicle traffic (TRH), low-traffic areas with a low level of vehicle traffic (TRL), and no-traffic areas (TRNFor this purpose, samples were collected from the city center of Samsun as the region with high traffic, the district of 19 Mayıs as the region with low traffic, and the rural neighborhoods of the district of 19 Mayıs, which is far from the center, as the area where there is no traffic (Fig. 1).

Within the scope of this study, the samples were collected from *Robinia pseudoacacia* (RPs), *Platanus orientalis* (POr), *Acer negundo* (ANg), *Ulmus minor* (UMn), and *Nerium oleander* (NOe), among the plants grown for landscaping purposes in city centers. The samples were collected from Samsun city, Türkiye by cutting from the last-year shoot at the end of the vegetation season. The study was carried out in three replications. They were then taken to the laboratory and divided into organs.

Fig. 1. Pictures of high, low, and no traffic areas (from left to right) of the study area

Methods

Half of the leaves and barks were washed, and the washed leaf samples were labeled with "WLF", non-washed leaf with "UWLF", washed bark with "WB", non-washed bark with "UWB", and wood with "WO". In the process of washing, first, the needles, branches, and barks were washed with water; after that, one-third of a large glass was filled up with water and the pieces were put into the glass. The washing was performed by shaking the jar powerfully for several minutes, and then, the process was repeated 3 times until the water was completely clear. This process was repeated 3 times with pure water, with the aim of completely removing particulate matter adhering to the organs. Then, the washed samples were spread on paper towels, and excess water was removed by lightly pressing with the help of paper towels (Cetin *et al.* 2020).

The labeled samples were kept in ambient room conditions until they became air-dry without being exposed to direct sunlight for two weeks after pre-treatment. Then, they were dried in an oven at 45 °C for two weeks. The dried plant samples were put in a grinder to turn them into powder. Amounts of 0.5 g were weighed and put into tubes designed for microwave use; 10 mL 65% HNO_3 was added to the samples. The prepared samples were then burned in a microwave device at 280 PSI pressure and 180 °C for 20 min. After the procedures are completed, the tubes are removed from the microwave and left to cool at room temperature. They were completed to 50 mL by adding deionized water on the cooling samples. After the prepared samples were filtered through filter paper, they were read in ICP-OES device at the appropriate wavelengths (Karacocuk *et al.* 2022).

Aluminum analyses were performed on these five organ groups by making use of ICP-OES (Spectro, Kleve, Germany) device and the method used by Sevik *et al.* (2020a, 2020b). The data obtained were subjected to variance analysis and Duncan's test conducted with SPSS package software (SPSS, IBM, v.20, Armonk, NY, USA).

RESULTS

The change of Al concentrations by species and traffic density is presented in Table 1. Examining the change of Al (ppm) concentration by species shows that there was no statistically significant difference between species in TRL areas. In addition, the Al concentration changes in Rps, POr, and ANg species at different traffic densities were statistically non-significant. The change of Al concentration by organ and traffic density is presented in Table 2.

Table 1. Al (ppm) Concentration as Affected by Species and Traffic Density

Species	TRN	TRL	TRH	F Value
RPs	34,700 ab	21,800	9490 ab	1.756 ns
POr	17,200 ab	11,000	19,700 b	1.087 ns
ANg	8880 a	12,800	18,600 b	1.842 ns
UMn	46,500 bB	34,500 AB	6850 aA	4.138*
NOe	48,000 bB	22,500 AB	4430 aA	4.380*
F Value	2.549*	1.385 ns	3.089*	

Note: ns: non-significant; *: p-value less than 0.05; **: p-value less than 0.01; ***: p-value less than 0.001; lowercase letters refer to the vertical direction, whereas uppercase letters refer to the horizontal direction (Entries with no following letters were not in the same statistical group with any other entry.)

Table 2. Al (ppm) Concentration as Affected by Organ and Traffic Density

Organ	TRN	TRL	TRH	F Value
WLF	22,500 B	1660 aA	10,100 abA	7.886**
UWLF	35,700 B	1120 aA	118 aA	4.318*
WB	40,200	23,700 b	18,200 bc	1.284 ns
UWB	34,600	51,100 c	22,100 c	2.565 ns
WO	22,400	15,100 ab	8600 ab	2.738 ns
F Value	0.501 ns	10.770***	5.263**	

Note: ns: non-significant; *: p-value less than 0.05; **: p-value less than 0.01; ***: p-value less than 0.001; lowercase letters refer to the vertical direction, whereas uppercase letters refer to the horizontal direction (Entries with no following letters were not in the same statistical group with any other entry.)

Considering the change by organ, the change in Al concentration in TRN areas was statistically non-significant. Only the changes in WLF and UWLF organs at different traffic densities were statistically significant. Within the scope of this study, the changes of Al concentration by species and organ were examined together with the traffic density, and the results are presented in Table 3.

As a result of variance analysis, the changes in Al concentrations by organ and species at all the traffic densities as well as the changes by organ in all species were statistically significant. Table 3 shows that the highest three values were observed in TRN areas. The highest values were UWLF organ (154972.26 ppm) in NOe species, WB organ (137807.33 ppm) in Umn species, and UWB organ (114014.40 ppm) in RPs species.

Table 3. Al (ppm) Concentration as Affected by Species, Organ, and Traffic Density

Species	Organ	TRN	TRL	TRH	F Value
RPs	WLF	27.8 aA	57.7 aB	229 abC	93291.610***
	UWLF	36.9 aA	136 aC	44.4 aB	29367.689***
	WB	57,000 kB	107 aA	31.1 aA	7485.333***
	UWB	114,000 nC	101,000 B	34,500 kA	78825.481***
	WO	2550 bA	7700 dB	12,700 fC	4472.736***
POr	WLF	28,500 iC	57.0 aA	14,000 gB	2972.438***
	UWLF	82.0 aA	4170 bC	135 abB	37024.034***
	WB	5860 cA	11,500 eB	50,200 nC	13656.790***
	UWB	45,300 jC	12,100 eA	34,000 jB	67234.089***
	WO	6390 cB	27,400 iC	90.4 abA	297725.070***
Ang	WLF	11,000 deB	57.1 aA	134 abA	2093.350***
	UWLF	10900 deB	124 aA	333 bA	366.689***
	WB	113 aA	14800 fB	40,500 lC	48173.732***
	UWB	306 aA	25,300 hB	42,000 mC	51500.958***
	WO	22,100 hB	23,900 gC	10,000 eA	19546.531***
UMn	WLF	118,000 efB	8000 dA	29,400 iC	278.281***
	UWLF	12,500 fgB	27.7 aA	34.93 aA	3350***
	WB	138,000 oC	84,400 kB	41.80 aA	16,000***
	UWB	174 aA	75,400 jB	25.33 aA	97,600***
	WO	70,200 mB	4910 cA	4768.16 cA	147,000***
NOe	WLF	60,900 lC	131 aA	6559.20 dB	8,910***
	UWLF	155,000 pB	150 aA	40.93 aA	341,000***
	WB	115 aA	7660 dB	40.13 aA	26,400***
	UWB	13,400 gB	92,800 lC	29.50 aA	94,200***
	WO	10,500 dA	11,600 eB	15,500 hC	602***
F Value		36789.589***	14,900***	21568.325**	

Note: **: p-value less than 0.01; ***: p-value less than 0.001; Lowercase letters refer to the vertical direction, whereas uppercase letters refer to the horizontal direction

DISCUSSION

Environmental pollution is one of the most important problems worldwide. The studies performed on this subject focus on monitoring both the pollution and the solution. These studies include those examining the removal of pollutants from waters using different treatments (Tunçsiper 2017), using pollutant wastes in construction (Bayraktar 2019), and the reduction of pollutants in soil by using phyto-mediation practices (Arıkan and Bağdatlı 2021). However, no effective method to reduce air pollution has been developed. It is known that the plants are useful in reducing any type of air pollution (Bachurina and Zalesov 2020). Moreover, previous studies reported that plants accumulate heavy metals in different organs (Karacocuk *et al*. 2022). However, for the plants to be used effectively in reducing the heavy metal pollution in the air, it is necessary to determine which plants intensely accumulate which heavy metals and in which of their organs (Sevik *et al*. 2019).

The present study aimed to determine the change of Al concentration by species, organ, and washing status depending on the traffic density. The results showed that Al concentrations remarkably changed in all the organs of species examined here by organ and by traffic density. Because of the effects of heavy metals on human and environmental health, many studies were performed on the change of heavy metal concentration in different organs of plants. However, the studies concentrate mainly on elements such as Pb, Co, Ni, Cd, and Cr (Aricak *et al*. 2019; Cesur 2021). Additionally, it is known that Al examined here is important for organisms and the plants that have high potential to accumulate Al are of toxic effect and can cause muscle pains, psychosis, and even memory disorders among humans (Shahid *et al*. 2017; Okut 2019; Sencard 2021).

The accumulation of heavy metals in plants is influenced by various factors. The most important one among these factors is the plant species (Turkyilmaz *et al*. 2018; Karacocuk *et al.* 2022). Furthermore, in parallel with the results achieved here, the Al concentration may differ between different organs of the same species (Cetin *et al*. 2020). In a previous study, Hmeer (2020) reported that Al concentration in leaf, wood, and bark samples of four different species varied between 2.32 ppm and 466.7 ppm, and there was more than a 200-times difference between the lowest and highest values. Savaş (2021) determined that Al concentrations in the *Cedrus atlantica* plant were at the highest level in wood, followed by inner bark and outer bark, and Al concentration in outer bark can exceed 20,000 ppm. Gözüdeli (2021), in a study on *Abies nordmanniana*, determined that Al concentration ranged between 14.0 ppm and 626.7 ppm in needles and between 9.0 ppm and 785.7 ppm in woods.

Many studies reported that different heavy metals are retained in different organs of different species at different levels (Sevik *et al*. 2020a). It depends on the anatomic structure of the plant and the mutual interaction between the plant and heavy metal (Skripal'schikova *et al*. 2016). As well as any other phenotypic characteristic, plant metabolism is shaped by the mutual interaction between genetic structure (Yigit *et al*. 2016) and environmental conditions (Cetin *et al*. 2018; Yigit *et al*. 2021). Hence, many factors, including the genetic structure affecting the plant metabolism (Hrivnák *et al*. 2017), stress level (Sevik and Cetin 2015; Ozel *et al*. 2021a, 2021b), plant origin (Imren *et al*. 2021), hormone treatment (Topacoglu *et al*. 2016), pesticide application and fertilization that alters the edaphic and climatic factors (Canto *et al*. 2020), and shadowing (Agudelo-Castañeda *et al*. 2018) may affect the intake of heavy metal in plants and, consequently, the heavy metal concentration. Heavy metal accumulation process in plants is closely related to plant anatomical structure, and there is a significant relationship between the entry of heavy metals into the plant structure, especially air humidity and rainfall (Cetin *et al.* 2021; Isinkaralar *et al.* 2022a,b). In plant leaves, stomata control the entry of CO_2 and water vapor, and they are the organ with the highest potential to detect heavy metal accumulation in leaves. The size and density of stomata are significantly affected by environmental conditions. Especially in the morning, the concentration of heavy metals increases with the exhaust gases released during peak traffic. At the same time, the amount of moisture in the air reaches its highest value with the effect of the terrestrial climate. As a result of the combination of these two effects, heavy metals adhere to the surface of leaves, and the concentration of heavy metals increases in the leaves (Turkyilmaz *et al.* 2020). In addition, environmental factors directly affect plant growth (Özel *et al.* 2022; Varol *et al.* 2022), and there is a significant relationship between plant growth and heavy metal uptake. Therefore, the absorption of heavy metals into the plant and its accumulation in organs is relative (Savas *et al.* 2021; Cesur *et al.* 2022).

The process of heavy metal accumulation in plant organs also depends on factors such as physical and chemical characteristics, the form of metals, morphology, surface area, texture of plant organ, plant habitat, and heavy metal exposure time (Sevik *et al*. 2019; Karacocuk *et al*. 2022).

Heavy metals can accumulate in the plant body by being absorbed by the root, from the air *via* the leaves, and entering the stem parts directly (Cesur *et al.*, 2022). Some of the heavy metal content in the plant indeed originates from the soil (Cetin *et al.* 2022a,b). Acid accumulation has the potential to influence atmospheric heavy metal deposition, but it also significantly contributes to heavy metal deposition in tree rings and passive absorptions of active Al^{+3} by the roots (Turkyilmaz *et al.* 2019). However, it should be accepted that the amounts of Al in the soil are limited and consumed in a short time, and the amount of metal absorbed from these regions is limited as the tree roots go deeper. For this, the soil-borne heavy metal accumulation is ignored (Key *et al.* 2022).

Within the scope of this study, it was additionally determined that there can be remarkable differences between washed and non-washed organs in terms of Al concentration. It was reported that industrial facilities and traffic are the most important sources of heavy metals (Isinkaralar *et al.* 2022c), and after being released from the source, heavy metals can be transported to very far points, primarily through the air (Turkyilmaz *et al*. 2020). This process mainly occurs through the adhesion of heavy metals to particle matter (Shahid *et al*. 2017). Hence, it was emphasized that heavy metal concentration in the organs, such as bark, which have structures suitable for particle matter to adhere to, varies depending on the amount of particle matter and the contamination by heavy metals (Cesur *et al*. 2021; Ghoma *et al*. 2022).

CONCLUSIONS

1. The results achieved here showed that Al concentrations were remarkably different for both species and organs. Because non-washed organs and barks can be intensely affected by the particle materials in the air, they should not be used in monitoring the Al concentrations in the air. Given the results, it can be stated that the organs showing the change of concentration by traffic density best were the washed leaves and woods of *Robinia pseudoacacia*. However, because the use of wood is not a sustainable method, the most suitable organ to be used in monitoring the Al concentration in the air is the washed leaves of *Robinia pseudoacacia*.
2. In conclusion, there were remarkable differences between the Al concentrations obtained. The heavy metal concentration change in plants was a result of a complex mechanism depending on the mutual interaction between many factors. Moreover, this mechanism has not been completely revealed yet. Hence, future comprehensive studies to be performed on this subject are recommended.

ACKNOWLEDGMENTS

The work was carried out within the framework of the state task of the Bursa Technical University Faculty of Forestry, Bartin University, Faculty of Forestry, Kastamonu University, Faculty of Engineering and Architecture, Türkiye and the Botanical Garden of the Russian Academy of Sciences, Ural Branch: Institute Botanic Garden, Russia.

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Article submitted: April 24, 2022; Peer review completed: July 30, 2022; Revised version received: November 21, 2022; Accepted: November 22, 2022; Published: December 1, 2022.
DOI: 10.15376/biores.18.1.792-803