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Using indoor plants as biomonitors for detection of toxic metals by tobacco smoke

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Abstract

Clean air is an indispensable resource for modern world. Many people are indifferent to the seriousness of air pollution or have only recently realized the problem. The air pollution continues deteriorating with several emissions every year on global scale. Beside various sources, tobacco smoke has caused the indoor air pollution. One of the most important of these factors is smoking. Especially indoor air pollution occurs depending on tobacco use. Exposure to cigarette smoke is recognized as the most significant health problem in indoor air. The study aims to evaluate the toxic metal accumulation due to tobacco smoke indoors by using some indoor ornamental plants. In this study, *Dieffenbachia amoena*, *Dracena marginata*, *Ficus elastica*, *Spathiphyllum wallisii*, and *Yucca massengena* were used houseplants as biomonitors. Accumulation of some toxic metals can be easily seen in indoor plants. Cadmium (Cd), chrome (Cr), and lead (Pb) were selected that high emissions from tobacco smoke. They were determined by taking the leaves of the plant species and analyzed with inductively coupled plasma-optical emission spectrometry (ICP-OES). The Cd, Cr, and Pb concentrations (Pb > Cr > Cd) were higher with tobacco than non-tobacco in all species. The results showed that *Spathiphyllum wallisii* was selected to be most suitable as biomonitor.

Keywords Indoor air pollution · Biomonitors · Toxic metals · Indoor plants · Tobacco use

Introduction

Among the environmental pollutants, air pollutants are more dangerous and it will probably become more tangle (Amegah and Agyei-Mensah 2017; Dávila-Román et al. 2021). According to World Health Organization (WHO), 90% of the world population breathes polluted air which is responsible for the deaths of approximately 7 million people each year (WHO 2018; Tarín-Carrasco et al. 2021; Zacarias et al. 2021). Air pollutants are occurring due to unplanned urbanization, industrial emissions, fossil fuel use, and tobacco smoke (Ozturk et al. 2021; Singh et al. 2021). They have adverse effects on the ecosystem and the ozone layer (de Vries 2021; Liao et al. 2021; Rai et al. 2021). Indoor air pollutants are very important that are very severe for human and plants health at high concentrations (Brilli et al. 2018; Sevik et al. 2018). They can cause some disorders such as stroke, lung cancer, and heart disease (Turnock et al. 2016). According to the U.S. Environmental Protection Agency (US EPA), indoor air is more polluted up to 100 times than outdoor air (Mason et al. 2000; Wood et al. 2006; Caselli et al. 2009; Yoon et al. 2011). Since people spend most of their time in indoor areas, it has been observed that the effect of indoor air on human health is much more than the outside air (Brown et al. 2010). Indoor air pollutants are about 1000 times more likely to infect the lungs (Pérez-Padilla et al. 2010; Wallner et al. 2012). It is reported that air pollution, which is defined as the most important environmental cause of death globally, has caused an estimated 3.8–4.3 million premature deaths every year in the last decade (Chen and Kan 2008; Hiscock et al. 2012). Children under 5 and women make up an estimated 60% of premature deaths associated with indoor air pollution (Guxens et al. 2018; de Bont et al. 2019; Brumberg and Karr 2021).

Tobacco smoke is among the primary pollutants (carcinogenic in humans) for indoor air that exposure to smoke is a serious health issue (Cavalcante et al. 2017; Yim et al. 2021). Globally, one out of every ten deaths is derived from

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tobacco use (Corsello and Stefania La Grutta 2014). Also, more than eight million people die annually due to addiction to tobacco products (Bialous and Sarna 2016). The annual cost of tobacco use is more than $1 trillion to the world economy (Acharya et al. 2016; Gulland 2017). Cigarettes, which have such a large market, contain more than 7000 completely unidentified components, including toxins and carcinogens (Böhlandt et al. 2012; Venugopal et al. 2021). The main ones among them are toxic metals arsenic (As), cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) in smoke content. From a toxicological perspective, it is rich in many lipophilic toxic substances, mutagens, carcinogens, and many chemical compounds such as nicotine and heavy metals (Ferlay et al. 2018; Isinkaralar 2020). Many studies reported that heavy metals are associated with the toxicity of tobacco (Gallart-Mateu et al. 2021; Dahlawi et al.2021). These elements that are toxic metals have shown cancer mortality and especially lung cancer (Ndokiari et al. 2021). In addition, if it is intensely exposed to mainstream smoke, it leads up to various types of cancers such as breast, urinary bladder, prostate, endometrium, and pancreas (Adams et al. 2012). Elton-Marshall et al. (2010) reported that Chinese cigarettes have high levels of toxic metals (As, Cd, Pb, and Cr) higher than Canada tobaccos. O'Connor et al. (2010) exhibited that averaging values of As, Cd, and Pb were 0.82 µg/g, 3.21 µg/g, and 2.65 µg/g, respectively. Piadé et al. (2015) analyzed Ar, Cd, and Pb levels for 568 tobacco filters. They found mean values as 256 ng/g, 898 ng/g, and 466 ng/g, respectively. These values were considerably higher than limit values. In this study, it focuses on Cd, Pb, and Cr that Cd is a non-essential element and the International Agency for Research on Cancer is classified as Group 1 human carcinogen (IARC 2012). The Pb can cause some health problems such as neurological and kidney disorders and high blood pressure due to it easily accumulates in the human body at long-term exposure to high concentrations (Chen et al. 2021). The Cr is a very serious carcinogen when it is oxidized from trivalent (Cr^{+3}) to hexavalent (Cr^{+6}) (Majhi et al. 2021). It readily aggregates in the human cells and forms cancer types like other high toxicity elements (Minkina et al. 2021). In addition to these toxic elements is nicotine that affects many physiological systems, including the peripheral nervous system, central nervous system, cardiovascular system, gastrointestinal system, and exocrine glands (Tweed et al. 2012). Both passive and direct exposure to tobacco use can trigger the progression of many diseases, not only in target organs but also in a wide variety of vital organs (Warner and Warltier 2006). Non-smokers are also at risk due to inhalation in the group defined as passive smokers due to exposure to this smoke (Avino et al. 2018; Woo et al. 2021). Passive smokers' exposure can cause detrimental effects on vascular homeostasis, respiratory failure, heart disease, chronic obstructive pulmonary disease (COPD) in the general population (Du et al. 2020). It can be extremely harmful, mainly for children who are exposed to cigarette smoke (Chao et al. 2018). It is one of the most critical risk factors for chronic lung and cardiovascular system diseases, including cancer (Benowitz et al. 2018; Noormohammadi et al. 2020). Due to gender differences, women are more affected by cigarette smoke with other health risks such as stillbirth, cervical cancer, and fatal diseases during pregnancy (Tsuji et al. 2017). According to WHO (2017), more than 1 million non-smokers are affected by tobacco smoke. Therefore, smoking is a severe health problem globally for active smokers and individuals exposed to cigarette smoke (Green and Turner 2017; Li et al. 2020). Thus, a number of searches have emerged to help reduce the undesirable impact of tobacco use.

Plant species can be used as biological biomonitoring for various elements including heavy and toxic metals (Werdel et al. 2021). They have a physicochemical structure which have been a successful method for monitoring the long-term concentrations of air pollutants. Determination of heavy metal concentration in plants and organs can give important information about heavy metal pollution (Sobhanardakani et al. 2018; Cetin et al. 2021). The heavy metal uptake of the species varies depending on several factors that the plant organ is an essential factor (Wang et al. 2021). It has been determined that different heavy metals are held more intensely by various organs of plants (Boquete et al. 2021). Among these organs, leaves are the most affected organs by heavy metals in the air pollution. Particulate matter also attaches to various organs of plants such as hairy leaves or bark (Hatami-Manesh et al. 2021). Because leaves are the organs with air entry and exit through their stomata, and they interact with air the most. Heavy metal uptake from leaves varies depending on metals' physical and chemical properties, forms, the morphology of organs, surface area, surface texture, and the habitus of the plant, exposure time to heavy metals, environmental conditions, and gas exchange (Shahid et al. 2017). In addition, biomonitoring is a sustainable method, as the collection of leaves does not harm the plant. Therefore, many studies have been conducted on the determination of heavy metal concentrations in the leaves of deciduous plants (Isinkaralar et al. 2017; Sobhanardakani 2017; Koç 2021). In studies on plants grown in the same environment, it is stated that heavy metal concentrations vary significantly based on species, and this difference can be tens of times between some species (Turkyilmaz et al. 2019). However, the accumulation of toxic metals may vary considerably on the basis of plant species and plant organ (Gorena et al. 2020). In order to monitor each pollutant, plant species and organ must be determined separately due to several pollutants can enter the plant body from root or leaf uptake (Karacocuk et al. 2021). The leaves and organs are most affected by heavy metal and toxic metal pollution in the air. Indoor plants are the best biomonitors for indoor air monitoring. So there are many ornamental plants used for both decorative and hobby purposes (in homes, offices, schools, etc.). Some of these can easily absorb various elements from the indoor air. The best example of these plant species is *Dieffenbachia amoena* which is a perennial evergreen plant originating from tropical America, growing up to 3 m tall (Henny et al. 2009). The leaves are thick, large (6–23 cm), lanceolate, long petiolate, dark green. However, the leaves of cultivars used indoors are creamy 75 yellow on green. It grows in semi-shade places that do not receive direct sunlight and in hot climates. *Dracena marginata* is a perennial plant originating from tropical Africa, 50–100 cm tall. The leaves are 20–30 cm, narrow, striped, pointed, brownish-dark brown, and the middle part is glossy dark green. The flowers are in the form of a cluster on a long stalk, yellowish-cream colored (Bertero et al. 2020). *Ficus elastica*, also known as the Indian rubber tree throughout the world, is an evergreen plant of tropical Asian origin grown for rubber (Augustus and Seiler 2011). It is grown as an ornamental plant worldwide and can be grown outdoors in frost-free regions. *Spathiphyllum wallisii* is also known as white sails, a perennial, underground stem, evergreen herbaceous plant (Pavlović et al. 2019). Its leaves are bright green with long stems coming out from the bottom, and its homeland is Colombia. The flowers are lanceolate, spoon-shaped on a long stalk, first green, then white, and after a while turn green again. The last species is *Yucca massengena*, one of the most used as indoor houseplants, whose homeland is the America and its upright leaves and durability (Chen et al. 2020; Susanto et al. 2020; Tkachenko et al. 2020). This study aimed to determine the toxic metal accumulation level of Cd, Cr, and Pb in *Dieffenbachia amoena*, *Dracena marginata*, *Ficus elastica*, *Spathiphyllum wallisii*, and *Yucca massengena* from tobacco use in indoor areas.

Materials and methods

Sampling

In this study, the most preferred indoor ornamental plants were used for tobacco use from indoor air. They were collected from seven residences' smoking areas in Kastamonu province, Turkey. The common feature of all of them is that they can easily and abundantly consume cigarettes indoors. All leaf samples were selected for exposure to tobacco smoke in residences. They were taken from plants that have been in a continuous tobacco (at least 10 per day) for more than 3 months (periodically ventilated with fresh air). To make comparisons, leaf samples were taken from plants grown in a non-tobacco use (references site).

Sample preparation and analysis

All species were divided into two groups as washed and unwashed. After the washing process, it was brought to specific dimensions and left to dry for 1 month in room conditions (not receive sunlight and any heat source). Then, leaf samples were taken into glass tubes (all samples were protected from moisture). The leaf samples were powder as 0.5 g by ball mill grinding. Then, 6 ml nitric acid (65% HNO_3 from Merck, Germany) and 2 ml hydrogen peroxide (30% H_2O_2 from Merck, Germany) were mixed in teflon microwave tubes for leaf sample digestion then were begun to microwave burning (Ethos One, Milestone). The dried samples were analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES from Spectroblue, Spectro GmbH, Kleve, Germany).

Statistical analysis

The obtained data were subjected to analysis of variance homogeneity using an ANOVA parametric test and Duncan multiple range test was applied and interpreted for factors with at least 95% confidence level ($p < 0.05$) with the SPSS 22.0 (Statistical Package for the Social Sciences, IBM) package program. In addition, abbreviations have been given to the species as *Dieffenbachia amoena* (DF), *Dracena marginata* (DR), *Ficus elastic* (KC), *Spathiphyllum wallisii* (SP), and *Yucca massengena* (YC).

Results and discussion

The analysis of the study determined which type is the most suitable for biomonitoring the concentration of Cd, Cr, and Pb in the tobacco. Also the washing process was carried out for particulate matter adhering to the plants. The amount and structure of particulate matter affect the chemical structure of plants. This interaction happens in several different ways that the washing process decreases the concentration values of some heavy metals. It is related to whether the particulate matter removed from the surface by the washing process is contaminated with heavy metals.

Levels of Cd, Cr, and Pb concentrations in the species

The changes of the Cd, Cr, and Pb concentrations were evaluated for all species in terms of concentration level. They were separately determined average values based on species in Table 1.

Table 1 Variation of Cd, Cr, and Pb concentrations (ppb) by species

Species	Cd	Cr	Pb
DF	320.9 b	843 ab	5239.8 a
DR	187.8 a	1070 b	4210 a
KC	296.2 ab	628 a	6975.4 b
SP	292.8 ab	847.2 ab	3579.4 a
YC	536.7 c	701 a	8059.9 b
F-value	12,924**	2676**	9491**

The lower letters indicate the statistical differences among different species.

Level of significance **: $p < 0.01$

Table 2 Change of Cd, Cr, and Pb concentrations (ppb) according to usage (use or not)

Element	Non-smoking		Smoking		*F*-value
	Washed	Unwashed	Washed	Unwashed	
Cd	261.9	355.1	356	334.4	105**
Cr	721.3	878.8	920.6	750.7	0.98**
Pb	4364.8	5800.7	6709.4	5576.6	2.11**

Level of significance **: $p < 0.01$

The highest concentrations in YC were obtained as 536.7 ppb for Cd while the highest value in Cr and Pb acquired in DR as 1070 ppb and 4210 ppb. It is seen that the variation of Cd, Cr, and Pb concentrations based on species is significant at a 99% confidence level ($p < 0.01$). When the mean values and the groups formed as a result of Duncan's test are examined, it is seen that the concentrations of different elements in each species are at higher levels.

Levels of Cd, Cr, and Pb concentrations in the tobacco use

The change of Cd, Cr, and Pb concentrations was singly evaluated for each element based on the tobacco situation (use or not). They were assessed independently as washed and unwashed leaves. Also to examine the initial concentration, it was checked in the non-tobacco. It was considered environments that obtained data for the average concentrations and the *F*-value. The ANOVA and Duncan test results are given as the groups in Table 2.

It is seen that the change of Cd, Cr, and Pb (not statistically significant), which is the subject of the study, was based on the wash or unwashed tobacco use.

Species, washing, and tobacco use relationship for Cd concentration

Table 3 shows the average values and statistical analysis results regarding the variation of Cd concentration depending on the tobacco and washing conditions in different species.

The variation based on both species and habitat in all cases is statistically significant at the 99% confidence level. When the mean values and the groups formed due to Duncan's test results. When the species were examined that the DR has the lowest value as 64.3 ppb and the highest value was 703.8 ppb in unwashed samples for tobacco smoking. When the SP values are examined, its value in non-tobacco areas was 78.2 ppb, while this value increased to 403.4 ppb in tobacco areas. The KC was shown similar feature that increased from 150.8 to 510.7 ppb. It is seen that the changes based on the tobacco zone in all species are statistically significant ($p < 0.001$). There is a significant difference between the values obtained in non-tobacco and tobacco areas. In DF, KC, SP, absorbed concentrations enhanced with tobacco than non-tobacco. However, there is no statistically significant difference between the washed and unwashed leaves in tobacco. According to these values, it can be assumed that the most suitable species for biomonitoring Cd concentration are DF and SP.

Table 3 Variation of Cd (ppb) concentration

Species	Non-smoking		Smoking		*F*-value
	Washed	Unwashed	Washed	Unwashed	
DF	202.1 Ac	275.6 Ba	283.5 Bb	522.2 Ce	2910.1***
DR	174.6 Bb	321.Db	191.3 Ca	64.3 Aa	1267.7***
KC	150.8 Ab	287.6 Ca	510.7 De	235.7 Bb	5280.2***
SP	78.2 Aa	291.8 Ba	403.4 Cd	397.8 Cc	261.1***
YC	703.8 Dd	599.8 Cc	391.1 Ac	452.1 Bd	319.3***
F-value	887.18***	486.12***	3629.6***	1500.7***	

Uppercase letters represent horizontal direction, Lowercase letters represent vertical directions

Level of significance ***: $p < 0.001$

Species, washing, and tobacco use relationship for Cr concentration

The average values state that statistical analysis results revealed relationship between the variation of Cr concentration and tobacco status in Table 4. The washing case is changed concentration in different species.

The variation of Cr concentration based on species was statistically significant at a 99.9% confidence level both in tobacco and non-tobacco areas. As a result of the Duncan test results, it is seen that Cr concentration forms two groups occurred (i) KC, SP, and YC, (ii) DF—DR in washed leaves in the non-tobacco. The species were generated into three groups DR—KC, DF—SP, and YC in the non-smoke. However, all species were organized in a separate group in tobacco. The lowest average concentrations were derived from the KC as 586.5 ppb, while the highest average concentrations were gained from DR as 2162.8 ppb. The lowest values were obtained in YC as 380.4 ppb and in DR as 502.2 ppb although the highest values were obtained in SP as 1149.4 ppb and in DF as 1118.7 ppb for the tobacco use with unwashed leaves. It was determined that the change of the Cr concentration based on the tobacco users in all species was statistically significant ($p < 0.001$). When the mean values and the groups formed as a result of the Duncan test are examined, it is seen that the Cr concentration is irregularly distributed in all species. It is noteworthy that all of the values obtained from the unwashed leaves in DF, KC, and SP were higher than the values obtained from the washed leaves. Based on these values, it can be assumed that DR and SP are the most suitable biomonitors for Cr concentration.

Table 4 Variation of Cr (ppb) concentration

Species	Non-smoking		Smoking		*F*-value
	Washed	Unwashed	Washed	Unwashed	
DF	800 Bb	922.4 Cb	531 Aa	1118.7 Dd	1315.8***
DR	913 Cb	702.2 Ba	2162.8 De	502.2 Ab	3783.4***
KC	622.2 Aa	700. 6 Ba	586.5 Ab	602.6 Ac	22.6***
SP	647.2 Aa	903.5 Bb	688.6 Ad	1149.4 Ce	265.3***
YC	624. Ba	1165.2 Cc	634.3 Bc	380.4 Aa	702***
F-value	132.7***	256.9***	2404.4***	2227.8***	

Uppercase letters represent horizontal direction, Lowercase letters represent vertical directions

Level of significance ***: $p < 0.001$

Species, washing, and tobacco use relationship for Pb concentration

The average values of Pb concentration are expensed tobacco and washing conditions in different species in Table 5.

The variation of Pb concentration based on species was significant at a 99.9% confidence level in tobacco use. It is observed that the Pb concentration varies between 2102.1 ppb (SP) and 8646.4 ppb (YC) in the washed leaves although it has shown an alteration between 3514.6 ppb (SP) and 7465.6 ppb (DR) in the unwashed leaves in the non-tobacco. In other condition, the Pb concentrations were exhibited as ranged from 3427 ppb (DF) to 11,878.8 ppb (KC) in washed leave, while it was determined that they ranged from 1373.1 ppb (DR) to 8812.2 ppb (DF) in unwashed leaves in tobacco. As with other elements, it is seen that the variation of Pb concentration based on the tobacco use is statistically significant in all species. When the mean values and the groups formed due to the Duncan test are examined, it can be assumed that the Pb concentration is irregularly distributed in species other than SP. Therefore, it can be said that the most suitable type for monitoring Pb concentration is SP. However, it seems that the YC type is quite well both tobacco and non-tobacco as range from 6874.4 to 7723.4 ppb.

Similarly, it has been emphasized that heavy metals can vary significantly on several species in many studies (Turkyilmaz et al. 2018; Cetin et al. 2019). Also tobacco is an essential source of many heavy metals, especially Cd and Pb. It is estimated that the amount of Cd inhaled resulting from smoking many cigarettes from different brands is around 1.40–2.70 µg (Janaydeh et al. 2019). This value was calculated as 1.32–2.64 µg for UK cigarettes and 1.54–3.08 µg

Table 5 Variation of Pb (ppb) concentration

Species	Non-smoking		Smoking		*F*-value
	Washed	Unwashed	Washed	Unwashed	
DF	4162.1 Bc	4557.8 Cb	3427 Aa	8812.2 De	1296.4***
DR	2668.9 Bb	7465.6 De	5332.4 Cc	1373.1 Aa	2473.1***
KC	4244.6 Ac	6591.4 Cc	11,878.8 De	5186.8 Bc	2549.5***
SP	2102.1 Aa	3514.6 Ba	3913.4 Bb	4787.8 Cb	54.3***
YC	8646.4 Cd	6874.4 Ad	8995.6 Dd	7723.4 Bd	150.2***
F-value	394.17***	809.72***	1608.2***	1815.12***	

Uppercase letters represent horizontal direction, Lowercase letters represent vertical directions

Level of significance ***: $p < 0.001$

for Korean cigarettes (Ashraf, 2012). Massadeh et al. (2005) was determined that the Cd concentration was 2.64 µg/g and the Pb concentration was 2.67 µg/g in cigarettes produced in Jordan. Ashraf (2012) stated that the number of heavy metals in cigarettes can vary to a large extent. In one study, the heavy metal amounts in cigarettes made in China were about three times the amount of heavy metals found in brands made in Canada. It has been determined that an average of 2.0% and 5.8% of Cd and Pb in cigarettes pass into main smoke, respectively. It was calculated that the amount of Cd contained in 20 cigarettes that passed into the main smoke ranged from 0.48 to 0.22 and 0.78 µg on average, and the estimated Pb amount in the streaming smoke was 2.4 µg on average. It is generally accepted that the Cd concentration in cigarettes varies between 1 and 3 µg/g and the Pb concentration varies between 1 and 2 µg/g. The Cd and Pb concentrations in filter cigarettes have been reported to be 1.7 and 2.4 µg/g. Tobacco smoking is the most important source of Cd exposure in the general population. On average, cigarettes contain 1–2 µg of Cd. It can be estimated that a person who smokes 20 cigarettes a day takes in about 1 µg of Cd per day. For comparison, it can be said that the concentration of Cd in ambient air is usually below 5 ng/m^3, and in most cases, less than 0.01 µg of Cd from the air is absorbed daily in the lungs. Tobacco grown on soils with higher Pb and Cd levels have correspondingly higher levels in the tobacco lamina. Therefore, cigarette brands with similar tar distributions may contain different levels of heavy and toxic metals depending on where the tobacco is grown and whether it is filtered or not. The study was conducted in Saudi Arabia; the amount of Pb inhaled from a pack of 20 cigarettes of the brands examined is estimated to be 1.98–3.37 µg and this value is approximately four times higher than that of UK cigarettes (0.22–0.65 µg), and from Korea (3.5 times higher). It is estimated that smoking 20 cigarettes a day results in 2–4 µg of Cd and 1–5 µg of Pb or even more (Massadeh et al. 2005; Ashraf 2012). It is stated that the differences between heavy metal concentrations in cigarettes vary depending on the heavy metal content in the soil where the tobacco is grown, the type of tobacco, growing conditions, and the tobacco processing process. After all, tobacco is also a plant, and it is known that almost all the morphological, anatomical, structural, and physiological characteristics of plants are shaped under the interaction of genetic structure and environmental conditions (light, temperature, and precipitation) (Aricak et al. 2019; Sert et al. 2019). In the studies about using different plant species as biomonitors, it is stated that plant structure is also shaped by the 264 effects such as genetic structure, soil nutrient content, edaphic factors, soil structure, and climatic factors (Cetin et al. 2020; Savas et al. 2021). Sevik et al. (2019) determined that the Ni concentration level in the leaves of *Fraxinus excelsior*, *Acer platanoides*, and *Aesculus hippocastanum* collected from traffic areas, respectively, were 1504.8 ppb, 1050.6 ppb, and 36,845.6 ppb. Turkyilmaz et al. (2020) determined that while the average Cd concentration was 4737 ppb in *Sophora japonica*, it was 84,935 ppb in *Salix babylonica*, 14,084 ppm in *Salix babylonica*, and 1540 ppm in *Aesculus hippocastanum.* Generally, heavy and toxic metals in tobacco use are higher than in the non-tobacco use in all plant species.

Conclusion

The aim of the study was to analyze the Cd, Cr, and Pb concentrations from tobacco use in five different indoor plants. The highest Cd and Pb concentrations were obtained in the YC species while the Cr concentration was proved in DR species. In the evaluations made according to the mean values based on the tobacco use, it was determined that the changes in Cd, Cr, and Pb were not at a statistically significant level ($p > 0.05$). However, instead of interpreting according to average values, it is thought that it would be more accurate to evaluate the changes in Cd, Cr, and Pb concentrations separately in different species depending on the tobacco and washing conditions. As a result of the evaluations made in this way, it was determined that the Cd and Cr concentrations in SP and DF species were higher in tobacco use than the values obtained in the non-tobacco. Because of the differences in the structures of the species, it creates different stress levels such as drought, frost, radiation and pollution, hormone applications, shading, irrigation, and fertilization. Therefore, it is inevitable that the chemical structure of the plant will change depending on tobacco use. One of the factors affecting is precipitation in plants of particulate matter that is contaminated with heavy and toxic metals, some volatile organic compounds due to the rate of penetration smoke. It can be easily accumulating in plant leaves via transferring to all cells. Therefore, developmental irregularities are seen that show high concentrations of heavy metals in their cells by tobacco areas. Therefore, the washing process of leaves to remove particulate matters was carried out in order to get a much more precise result in this study. The main purpose of this is to determine the amount absorbed after cleaning the particles adhering to the plant. As a result of the study, it was determined that the highest Cd and Cr values were obtained in the unwashed leaves in DF and SP with tobacco, while the Cr values were higher in the unwashed leaves in DF, KC, and SP than in the washed leaves. The DF and SP are the most suitable species for monitoring Cd concentration, and SP is the most suitable species for monitoring Pb and Cr elements. As a conclusion, the SP is recommendable for tobacco areas as biomonitors that the most suitable species have successful absorption performance of Cd, Cr, and Pb.

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Author contribution Wasem Esmael Omer Ghoma: raw material collection, processing analysis, interpretation. Hakan Sevik: thesis supervisor, processing analysis, interpretation. Kaan Isinkaralar: conceptualization, software, writing original draft, data curation, formal analysis and review and editing.

Data availability All data generated or analyzed during this study are included in this published article.

Not applicable.

Declarations

Ethics approval. Not applicable.

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