



Comparison of the rate of certain trace metals accumulation in indoor plants for smoking and non-smoking areas

Wasem Esmael Omer Ghoma¹ · Hakan Sevik² · Kaan Isinkaralar²

Received: 2 January 2023 / Accepted: 16 May 2023 / Published online: 25 May 2023
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2023

Abstract

Tobacco smoke causes to release severe toxic metals into the environment. It is recognized as the most significant issue in indoor air quality. Pollution and toxic substances in smoke quickly spread and penetrate the indoor environment. Environmental tobacco smoke is responsible for lowering indoor air quality. There is much evidence that poor air quality occurs with inadequate ventilation conditions in indoor environments. The plants have been observed to absorb the smoke in the environment into their own body like a sponge. The plant species in this study can be used easily in almost every office, home, or other indoor areas. Using indoor plants is very beneficial in biomonitoring and absorbing these trace metals. Some indoor plants have shown successful performance as biomonitors for health-damaging pollutants. The study aims to determine the concentration of three trace metals (Cu, Co, and Ni) using five indoor ornamentals frequently used in smoking areas, namely *D. amoena*, *D. marginata*, *F. elastica*, *S. wallisii*, and *Y. massengena*. The Ni uptake and its accumulation in *S. wallisii*, and *Y. massengena* increased in correlation with smoke areas. However, the rate of accumulation of Co and Cu was found to be independent due to consideration of the environmental emissions. Consequently, our results suggest that *F. elastica* is more resistant to smoking, whereas *S. wallisii* would be a better choice as a biomonitoring plant of tobacco smoke.

Keywords Air exchange rate, Biomonitoring · Indoor air control · Smoking indicator · Ventilation

Introduction

Tobacco smoking became the most significant contributor to ambient pollution that causes low indoor air quality (IAQ) worldwide (Obore et al. 2020; Blount et al. 2021; Rajagopalan and Goodman 2021; Isinkaralar 2023). People spend their time in closed areas such as houses, offices, cafes, and restaurants with limited ventilation due to gaseous emissions in the indoor environment. They are affected much more than the non-smoke areas (Persily 2015; Rostami et al. 2021). The main factor in the decrease in IAQ is the

non-ventilated or limited-ventilated environments. Tobacco and its derivatives, such as cigarettes and water pipes, have been considered one of the most harmful indoor air pollution pollutants. Indoor plants are adversely affected by tobacco smoke (Rumchey et al. 2017). Although most countries prohibit cigarettes and their products, which have a license to use tobacco, there are permits in close areas (Fix et al. 2019). The various absorption abilities of plants in closed areas as biomonitors have been beneficial due to the exposure to many pollutants in the IAQ. Due to tobacco use, indoor plants have different toxic elements and have been exposed to contaminants (Forster et al. 2018). Therefore, observing the IAQ primarily emanating from its source is necessary.

The indoor air pollutants have increased with several indoor activities because they have been released from many sources and accumulated at different levels. A primary concern stems from cigarette smoke contains more than 7000 chemicals in the gas or particulate phase (WHO 2021). Moreover, cigarette smoke is an aerosol containing thousands of chemicals. Ninety-two to ninety-five percent of mainstream smoke, including 0.3–3.3 billion particles at 1 mL, are in the gas phase (Singh et al. 2022). The average

Responsible Editor: Philippe Garrigues

✉ Kaan Isinkaralar
kisinkaralar@kastamonu.edu.tr

¹ Institute of Science, Department of Material Science and Engineering, Kastamonu University, 37150 Kastamonu, Türkiye

² Department of Environmental Engineering, Faculty of Engineering and Architecture, Kastamonu University, 37150 Kastamonu, Türkiye

particle diameter is 0.2–0.5 mm, and this size is also breathable (Schilling et al. 2021). Cigarette smoke is pharmacologically active, and it causes antigenic, cytotoxic, mutagenic, and carcinogenic damage in humans. The gas phase pollutants contain carcinogens such as acrolein and acrylonitrile, hydrocyanic acid and acetaldehyde, nitrogen oxides and carbon monoxide (Hoh et al. 2012; Janaydeh et al. 2019; Kollati and Mohapatra 2021). More than 8 million people pass away annually from tobacco addiction, and 8 million people may lose their lives this century due to smoking (Peprah et al. 2021). Also, more than 480,000 deaths yearly and more than 41,000 deaths from second-hand smoking exposure in the USA (Kim et al. 2019; Orri et al. 2021; Welker 2021).

Moreover, passive smoking leads to many diseases and premature deaths in children and adults (Vanker et al. 2017; Ghosh and Mukherji 2021). Also, it has been associated with various health impacts such as sudden infant death syndrome, acute respiratory infections, ear problems, risk of severe asthma, and slow lung development detected in passive smoker children (Pan et al. 2015; Cho 2020; Lelieveld et al. 2020; Neuburger 2021). Toxic substances caused by smoking are spread throughout the environment, and non-smokers have penetrated the respiratory system (Palazzi et al. 2019; Rice et al. 2020). Numerous studies have been accomplished on the smoking effects and discussed the relationship between exposure and biomonitoring results (Abdullah et al. 2017; Lin et al. 2017; Wani et al. 2018; Rajfur et al. 2018; Tan et al. 2018; Chen et al. 2021). Although trace metal concentrations were analyzed from cigarettes and tobacco, biomonitoring studies of toxic metal pollution are quite limited (Arıcak et al. 2020; Świsłowski et al. 2022). Many plant studies have been conducted on biomonitoring for toxic metal pollution from tobacco smoke (Vimercati et al. 2016; Kumakli et al. 2017). Indoors, plants are subject to several IAQ, smoke, and water availability stresses. It, therefore, plays a vital role in the absorption of many toxic metals. However, some research shows that the ability to absorb elements in some ornamental species that grow in smoky areas leads to the degradation of their leaves (Viana et al. 2011; Benson et al. 2017; Gushit et al. 2022). The adverse effect of tobacco smoke has been highly demonstrated on the indoor plant due to cause degradation properties and composition of leaves. Notably, tobacco smoke has been widely used for analyzing toxic and essential heavy metals using plants. The determination of the capacities of the plants used is in parallel with the absorption of metals in the indoor air. Tobacco product dissimilarities in terms of species and indoor plants may serve for both considering air pollution impression and diagnosing potential biomonitoring species.

The most frequently used plant species as indoor ornamental plants in almost all parts of the world, especially in Europe, are *Dieffenbachia amoena*, *Dracena marginata*,

Ficus elastica, *Spathiphyllum wallisii*, and *Yucca massengena*. They are also known as decorative species extensively used indoors because they have left much different from the natural vegetation. They have other leaf structures in shape or color, making them visually valuable because they are often used indoors. Another reason these plants can be used indoors is that they do not encounter frost and cold air in their natural distribution area. They are significantly damaged by frost outside their natural distribution area, and they can be grown indoors because they are not exposed to frost damage. In the selection of the species used, their widespread presence in the indoor environment has been the main reason for preference. Recent studies of the literature have found evidence that tobacco smoke indoors may show the accumulation of certain metals such as arsenic (Ar), cadmium (Cd), chromium (Cr), lead (Pb), beryllium (Be), and polonium (Po). However, there is actually a lack of knowledge about the accumulation of cobalt (Co), copper (Cu), and nickel (Ni) in ornamental plants. This work aims to determine the deposition of Co, Cu, and Ni on the leaves of indoor ornamental plants *D. marginata*, *Y. massengena*, *F. elastica*, *S. wallisii*, and *D. amoena*.

Materials and methods

Plant materials and preparation

The species subject of this study is *Dieffenbachia amoena*, *Dracena marginata*, *Ficus elastica*, *Spathiphyllum wallisii*, and *Yucca massengena*, which are naturally spread in tropical and subtropical regions. They were placed in smoking areas (SA) and non-smoking areas (NSA as reference points) to determine the effect of cigarette smoke. A total of 10 smoke areas were selected on these areas keeping around 1 m of the distance between the smoke zone. Three non-smoking indoor areas were chosen as reference points and indoor sunlight is more limited. In our previous work, we extensively explained through leaves, including under control environment (Ghoma et al. 2022). They have almost the same age and grow under the same conditions. Indoor air parameters for a non-controlled condition (SA), such as room temperature (21.67 ± 3.28 °C), window opening ratios of 21–49% depend on outdoor temperature, and smoking frequency (defined as > 8 cigarettes per smokers) were continuously controlled and recorded periodically by regulating the frequency of the supply air volume controller. Cigarettes, tobacco use, and hookah smoke occur intensely in the ambient air. Also, the ventilation rate at night was investigated based on smoke concentration while the ventilation rate is only for at least 10-min intervals in the morning when no one is inside. In addition, to understand more clearly how much is absorbed from

the smoke, species with the same age and characteristics were collected from an indoor environment that can be considered as a reference point. For a controlled condition (NSA), doors and windows were closed for at least 8 h without mechanical ventilation. A controlled process was monitored to ensure that the dimensions and diameters of the leaves ($n = 250$) collected for sampling were the same and environmentally controlled. In order to maintain the impact of the particles on the leaf on the analysis results, it was first prepared for analysis without washing. Then, to reduce the impact of contaminants or particles sticking to it, it was washed many times with pure warm water and dried at room temperature until the moisture was gone.

Analyses of total toxic metals

Species ready for analysis were first put in glass containers in a controlled oven and kept at 50 °C for about two weeks (until the moisture inside was removed) without being exposed to any pollutant effects from outside and indoor air. Each sample was taken in a polytetrafluoroethylene (PTFE) vessel and weighed before and after drying. After drying, it was converted into a smaller particle form in a ring mill and placed in the vessel at 0.45 ± 0.05 g. Into the beakers, respectively (i) 3 mL hydrochloric acid (38 wt% HCl), (ii) 6 mL nitric acid (72 wt% HNO₃), (iii) 2 mL hydrogen fluoride (49 wt% HF), (iv) pressurized mixer until it reaches a paste-like consistency. (iv) Then, it was conducted in a microwave digestion machine until 180 °C at 25 min, (v) HClO₄ was then added to the cooled samples to the vessels to remove HF and acid digestion successfully, and (vi) drying leaves are done with 105 °C for the evaporation of excess water in the containers. After 30 min, it was filtered through filter paper and analyzed by inductively coupled plasma optical emission spectrometry to the concentrations of Co, Cu, and Ni trace elements present (ICP-OES, Spectroblue, Germany). The results were verified by comparing them with the analysis of certified reference material for quality control of the degradation process.

Statistical analysis

The data was collected after several experiments with smoking frequency, type of indoor species, and ventilation period by smoking. One-way ANOVA was used by least significance was applied to statistically significant differences between control samples with a confidence interval of 95%. Duncan's test determined homogeneity groups between elements by IBM SPSS analytical software version 22.0 for Windows.

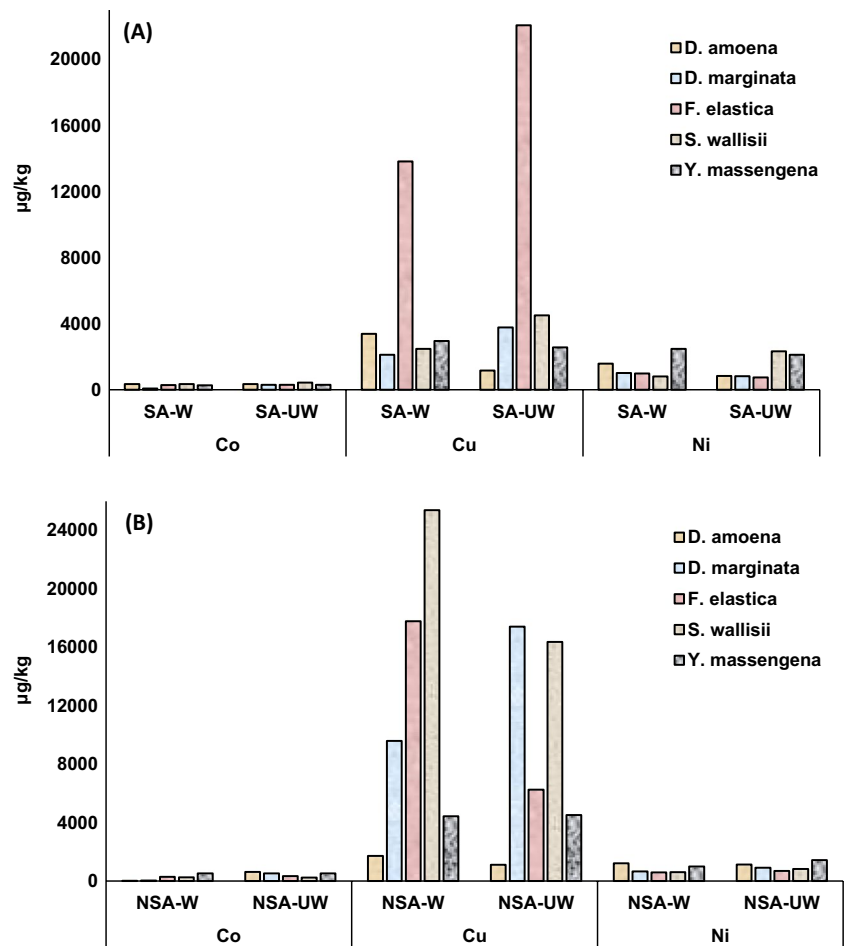
Results and discussion

A total of 250 leaves were evaluated for Co, Cu, and Ni contamination in species. The leaf deposition ensured sustainable monitoring of the increasing amount of Co, Cu, and Ni metals. They examine the degree of Co, Cu, and Ni regarding human and environmental health. The ease of using leaves is not only due to the cost-effectiveness and feasibility of identifying pollutants based on species and environment. Statistical analysis showed that trace metal change was evaluated separately for each component. The washed leaves (W) and unwashed leaves (UW) in the non-smoke area (NSA) and smoke area (SA) were considered individual results, and the F value was obtained from the ANOVA and Duncan test. All results show that the change of Co, Cu, and Ni metals in all environments was statistically significant, with a 99.9% confidence level ($p < 0.001$) in Fig. 1.

The Co concentration ranged from 26.5 µg/kg in the W of *D. amoena* to 520.7 µg/kg in the NSA of *Y. massengena*, while it ranged from 242.4 µg/kg in the UW of *S. wallisii* to 623.3 µg/kg in *D. amoena*. Duncan's test results are remarkable: the lowest value was obtained in the NSA-W and the highest in the NSA-UW of *D. amoena*. The lowest average scores were obtained in *D. amoena* and *D. marginata* of NSA-W, while it was attained in SA-W of *D. marginata*. On the contrary, the highest importance was accepted in the SA of *S. wallisii*. However, the Co concentration is more regularly distributed in *S. wallisii* than others due to the same group of NSA-W and NSA-UW. In SA, the concentrations range was analyzed *D. marginata* as 73.8 to 348.3 µg/kg in W of *D. amoena*. In comparison, the Co concentration was shown to score similarly in the UW of *F. elastica* range from 300 to 430.9 µg/kg of *S. wallisii*. According to Co concentration, the most suitable specie is in S4 for monitoring accumulation level. In all species except *S. wallisii*, Co concentrations in NSA-UW were higher than NSA-W, although in all species except *D. amoena*—*Y. massengena* were higher in UW than in W in SA. In general, Cu concentrations were not influenced by cigarette smoke and are thought to depend on other conditions in all types. Further analysis exhibits the Co, Cu, and Ni concentration (µg/kg) biomarkers for washing conditions in different species in Fig. 2.

Based on Fig. 2, the minimum amount acquired in the NSA with 1120 µg/kg of UW, and 1730 µg/kg of W, although the top record in the NSA was 25,390 µg/kg and 17,420 µg/kg of W and UW. In SA-W, the lowest value was obtained at S2 with 2116.6 µg/kg, while the highest was achieved at *F. elastica* with 13,820 µg/kg. Conversely, in SA-UW, 1163.3 µg/kg was found in *D. amoena* as the least; for all that, 22,066.6 µg/kg was

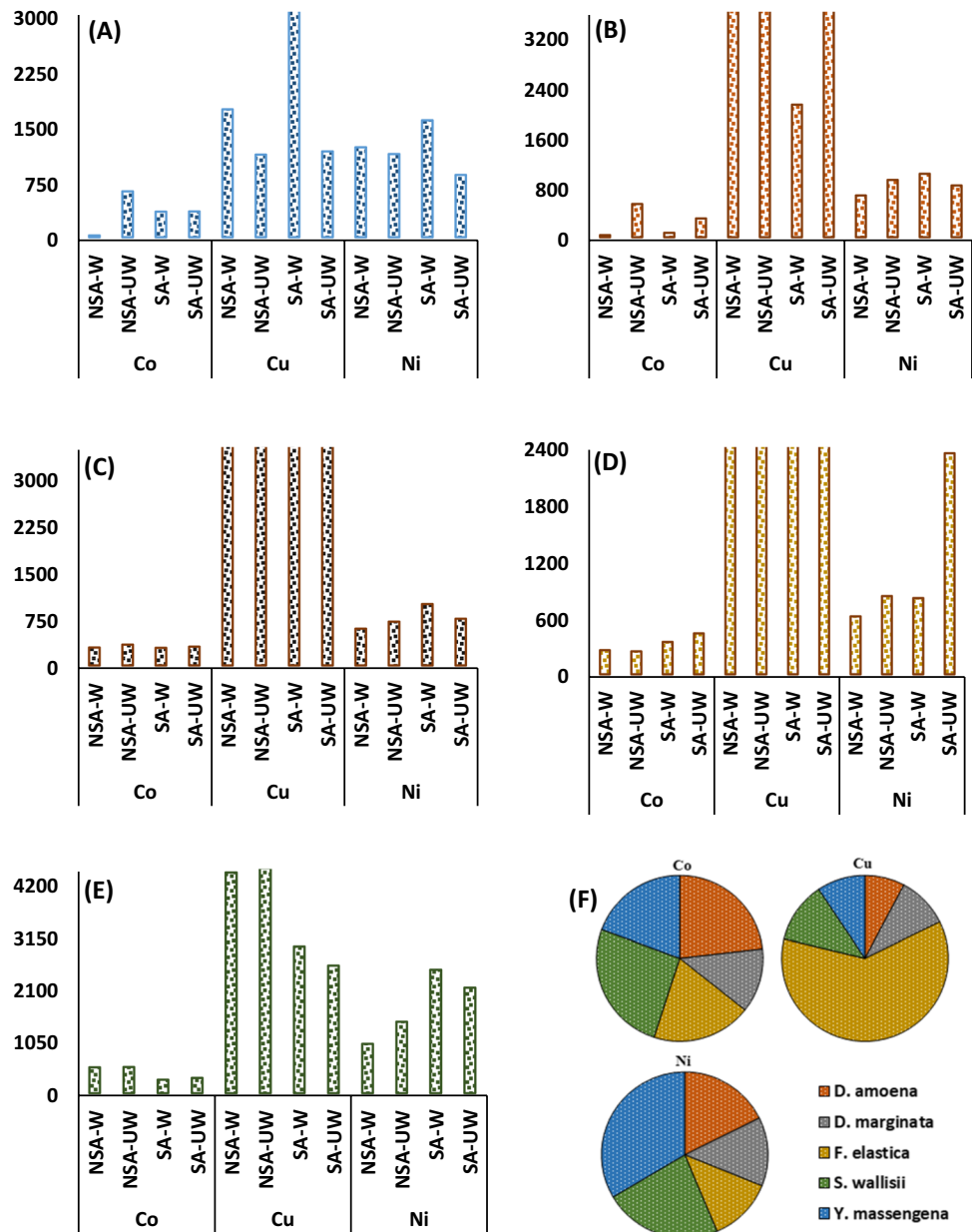
Fig. 1 Comparison of the total accumulation ($\mu\text{g}/\text{kg}$) in leaves under **A** the SA and **B** the NSA



attained in *F. elastica*. In all species except *D. marginata* and *Y. massengena*, Cu concentrations in NSA-UW are higher than NSA-W, whereas in all species except *D. amoena*—*Y. massengena* are higher in W than in UW in SA. Cu concentrations in several types except *Y. massengena* are generally higher in SA than in NSA. The mean concentration ranged from 590 $\mu\text{g}/\text{kg}$ of S3 to 1219.4 $\mu\text{g}/\text{kg}$ in NSA-W of *D. amoena*, even though the redundancy level was between 701.4 $\mu\text{g}/\text{kg}$ (*F. elastica*) and 1435.5 $\mu\text{g}/\text{kg}$ (*Y. massengena*) in NSA-UW. Smoking has changed as SA; the lowest value in W was obtained at 804.7 $\mu\text{g}/\text{kg}$, although this amount was increased to 2482.4 $\mu\text{g}/\text{kg}$ of *Y. massengena*. Correspondingly, it was gained in *F. elastica* with 746.9 $\mu\text{g}/\text{kg}$, and the highest value was gotten in *S. wallisii* with 2336.6 $\mu\text{g}/\text{kg}$. In all species except *D. amoena*, Ni concentrations in NSA-UW are higher than NSA-W, although in all species except *S. wallisii* are higher in W than in UW in SA. Ni concentrations in all types except *D. amoena* are generally higher in SA than in NSA.

Decorative plants can live with low light conditions as they naturally spread in the under-forest flora of the natural distribution area. The goal in designing and remediating IAQ focuses on providing healthful and relieving indoor ambient. Many plants are impressive and included in the absorption mission for IAQ. Given that many plants grown indoors are frequently preferred indoors for many reasons, such as helping to increase air quality, adding esthetic value to the environment, and contributing to biocomfort by increasing the humidity of the environment and the plants. Studies show that indoor plants reduce trace metal concentration from the indoor air by accumulating metals (Wood et al. 2006; Sánchez-Soberón et al. 2015; Torpy et al. 2017). Tobacco burning constitutes particulate matter, PAH, and heavy metals related to increased smoke density and other indoor conditions, such as inefficient ventilation. This usually leads to excessively high toxic concentrations in the surroundings of the smoke areas. Numerous studies were conducted to control indoor air quality, contributing to harmful metals (Salomone et al. 2017; Mannan and Al-Ghamdi 2021; Istanbullu

Fig. 2 Comparison of the metal accumulation ($\mu\text{g}/\text{kg}$) with SA and NSA in **A** *D. amoena*, **B** *D. marginata*, **C** *F. elastica*, **D** *S. wallisii*, **E** *Y. massengena*, and **F** distribution for a total accumulation



et al. 2023). Trace metals can get into the plant body by being absorbed by the plant root from the ground or by the plant leaves and stem directly from the atmosphere (Lajayer et al. 2017; Luo et al. 2019; Isinkaralar et al. 2022). Inadequate data exist to constitute an explicit association between tobacco smoke and all toxic metals in plants. However, plant leaves are the organs that interact with and interact with the air the most. Air enters through stomata in leaves and can be taken into the leaf structure with metals in the air. In order to conduct bioassays in *D. amoena*, *D. marginata*, *F. elastica*, *S. wallisii*, and *Y. massengena* are selected to investigate Co, Cu, and Ni deposition with extensive leaf areas. It is known that Co, Cu, and Ni adhere to atmospheric particulate matter, which moves, dry deposition, and accumulate with

particles. In our study, it was determined that they gathered with Co, Cu, and Ni. The fact that these species have a large leaf surface causes them to be exposed to tobacco smoke in a closed environment. It causes them to come into contact with pollutants with several toxic metals for a long time. Various researchers have associated many toxic metals derived from tobacco smoke. Few of these studies have accounted for ornamental plants, which may confound relationships between absorption rates and physicochemical properties. Therefore, this research intends to find other toxic metals (Co, Cu, and Ni) that can directly or indirectly enter the plant body via either the symplast or the apoplast. They can restrict metal uptake by precipitating or forming complexes in the rhizospheric region.

Continuously smoking activities are significantly associated with releasing air pollutants and reacting them at room temperature under UV light. In our study, Co, Cu, and Ni concentrations have been generated without ventilation, sometimes in daylight and sometimes under room lighting for long hours. Although there was limited evidence of Co, Cu, and Ni deposition on plants in this study, Ni accumulation levels were higher in tobacco species. It indicates that the investigation results still suggest storage, even after biomonitoring for the Ni levels that may arise from various burning tobacco products. Some scholars have already studied that the smoke gases from conventional tobacco and waterpipe are caused to varying concentrations of toxic metals and harmful particles (Hörmann et al. 2018; Liao et al. 2019). Although some metals like Co were deposited lower than Cu and Ni, researchers concluded that further monitoring is necessary. Cu and Ni variations could also be due to atmospheric Cu and Ni exposure and may be influenced by differences in uptake plant indexes. Nevertheless, this is the case with smoke exposed to other toxic metals; it deposits quickly on in-door species. Arain et al. (2015) investigated As and Cd levels in tobacco smoke and showed that their content might vary by tobacco plants grown on agricultural soil. Panhwar et al. (2016) analyzed to assess exposure to Al and Cd in cigarette tobacco. These toxic metals have been released into the environment and can potentially harm humans. Jain's study (2016) showed that the tobacco use questionnaire between 2005 and 2012 was for males and females. This study searched the variability in the u-SCN, u-P8, and u-NO₃ by several factors such as age, gender, race/ethnicity, and passive and active smoking. It is performed that active smoking was connected with a higher adjusted grade of u-SCN. A strong positive correlation was found between smoking and toxic elements by Campo et al. (2016), Barn et al. (2018), and Cai et al. (2019).

Few studies have extensively assessed several harmful elements for indoor air quality as biomarkers (Budaniya and Rai 2022). Researchers have reported a large amount of trace metal due to tobacco smoke correlated with several toxic metals (Chiwocha et al. 2009; Sawidis et al. 2012; Arfaenia et al. 2022). Brill et al. (2018) demonstrated evidence via indoor plants for reducing indoor air pollutants from CO, CO₂, VOCs, formaldehyde, several hydrocarbons, and PAHs. Plants can absorb them as a low-cost method by their stomata. So far, most ornamental plants are used to clean indoor air as high performance. In the previous studies to evaluate plant smoke exposure, several toxic compounds and metals accumulate in their tissue and leaves. Although, their report stated that the accumulation of metal pollutants has been observed in several plants by researchers (Yayla et al. 2022; Sulhan et al. 2022; Isinkaralar 2022a, 2022b, 2022c).

There is growing evidence that absorption rates in plants may have different consequences. Although it is unclear how and where they are contaminated, it is interesting that many contaminants have been monitored in the smoke environment due to various experiments. When the smoke rate is

high, toxic metals are efficiently removed and can directly depress the leaves, reflected in more growth decomposition. Several studies have demonstrated that plants are common biomarkers in smoke areas. About two or three decades later, ornamental plants suggested that all air contaminants need to be addressed, not just toxic metals from tobacco smoke. So far, although increasing research has made an effort to associate trace and toxic metals from burning tobacco on plants, the deposition is inconsistent partly due to several indoor states. However, the overall capacity of plant-based air pollution removal in natural conditions is unknown. Our findings assist the hypothesis of “absorption by plants” trace elements as a primary cause of tobacco smoke. Further studies on bioindicator-plants toxic metals are needed for IAQ.

Conclusion

We found that the biochemical accumulation of *D. marginata*, *Y. massengena*, *F. elastica*, *S. wallisii*, and *D. amoena* was studied in response to tobacco smoke. The study compared five potential biomonitor plants for their absorbed level. Trace metals significantly absorbed all the metals in species. A comparative analysis of their absorption approach has been made under the same conditions. Our study also proposed the absorption levels and average amounts of Co, Cu, and Ni elements as selected metals in plants' leaves. All species absorb high amounts of toxic metals from the indoor air depending on their morphological characteristics. Following Ni accumulation in leaves was positively correlated with smoke, although Co and Cu were not the only tobacco source. Co and Cu concentrations showed an independent increasing or decreasing trend in species, but the reasonable increase was in *S. wallisii*, and *Y. massengena*. The deposition trend of *F. elastica* was also recorded as pollutant-resistant to smoke compared to metal concentration, however, *S. wallisii* was found to be significantly absorbed by the Ni deposition. Thus, *S. wallisii* is a better biomonitor of Ni metal than *Y. massengena*. Hence, a possible correlation of other toxic metals will be a promising study for biomonitoring that can measure the concentration of different metals in the selected environment in future studies.

Acknowledgements This study is produced from the MSc thesis titled as “Change of heavy metal concentrations in some indoor plants depends on smoking” conducted at Kastamonu University, Institute of Science, Department of Material Science and Engineering.

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 and materials will be available upon reasonable request.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

- Abdullah P, Costanian C, Khanlou N, Tamim H (2017) Prevalence and characteristics of waterpipe smoking in Canada: results from the Canadian Tobacco Use Monitoring Survey. *Public Health* 148:102–108. <https://doi.org/10.1016/j.puhe.2017.03.007>
- Arain MB, Kazi TG, Baig JA, Afridi HI, Brehman KD, Panhwar H, Arain SS (2015) Co-exposure of arsenic and cadmium through drinking water and tobacco smoking: risk assessment on kidney dysfunction. *Environ Sci Pollut Res* 22:350–357. <https://doi.org/10.1007/s11356-014-3339-0>
- Arfaenia H, Masjedi MR, Jafari AJ, Ahmadi E (2022) Urinary level of heavy metals in people working in smoking cafés. *Environ Res* 207:112110. <https://doi.org/10.1016/j.envres.2021.112110>
- Aricak B, Cetin M, Erdem R, Sevik H, Cometen H (2020) The usability of Scotch pine (*Pinus sylvestris*) as a bi-omonitor for traffic-originated heavy metal concentrations in Turkey. *Polish J Environ Stud* 29(2). <https://doi.org/10.15244/pjoes/109244>
- Barn P, Gombojav E, Ochir C, Laagan B, Beejin B, Naidan G, Boldbaatar B, Galsuren J, Byambaa T, Janes C, Janssen PA, Lanphear BP, Takaro TK, Venners SA, Webster GM, Yuchi W, Palmer CD, Parsons PJ, Roh YM, Allen RW (2018) The effect of portable HEPA filter air cleaners on indoor PM_{2.5} concentrations and second hand tobacco smoke exposure among pregnant women in Ulaanbaatar, Mongolia: the UGAAR randomized controlled trial. *Sci Total Environ* 615:1379–1389. <https://doi.org/10.1016/j.scitoenv.2017.09.291>
- Benson NU, Anake WU, Adedapo AE, Fred-Ahmadu OH, Ayejuyo OO (2017) Toxic metals in cigarettes and human health risk assessment associated with inhalation exposure. *Environ Monit Assess* 189:1–17. <https://doi.org/10.1007/s10661-017-6348-x>
- Blount RJ, Phan H, Trinh T, Dang H, Merrifield C, Zavala M, Zabner J, Comellas AP, Stapleton EM, Segal MR, Balmes J, Nhung NV, Nahid P (2021) Indoor air pollution and susceptibility to tuberculosis infection in urban Vietnamese children. *Am J Respir Crit Care Med* 204(10):1211–1221. <https://doi.org/10.1164/rccm.202101-0136OC>
- Brilli F, Fares S, Ghirardo A, de Visser P, Calatayud V, Muñoz A, Annesi-Maesano I, Sebastiani F, Alivernini A, Varriale V, Menghini F (2018) Plants for sustainable improvement of indoor air quality. *Trends Plant Sci* 23(6):507–512. <https://doi.org/10.1016/j.tplants.2018.03.004>
- Budaniya M, Rai AC (2022) Effectiveness of plants for passive removal of particulate matter is low in the indoor environment. *Build Environ* 222:109384. <https://doi.org/10.1016/j.buildenv.2022.109384>
- Cai H, Xie P, Zeng W, Zhai Z, Zhou W, Tang Z (2019) Root-specific expression of rice OsHMA3 reduces shoot cadmium accumulation in transgenic tobacco. *Mol Breeding* 39(3):49. <https://doi.org/10.1007/s11032-019-0964-9>
- Campo L, Polledri E, Bechtold P, Gatti G, Ranzi A, Lauriola P, Goldoni CA, Bertazzi PA, Fustinoni S (2016) Determinants of active and environmental exposure to tobacco smoke and upper reference value of urinary cotinine in not exposed individuals. *Environ Res* 148:154–163. <https://doi.org/10.1016/j.envres.2016.03.029>
- Chen S, Yao Q, Chen X, Liu J, Chen D, Ou T, Liu J, Dong Z, Zheng Z, Fang K (2021) Tree-ring recorded variations of 10 heavy metal elements over the past 168 years in southeastern China. *Elem Sci Anth* 9(1):00075. <https://doi.org/10.1525/elementa.2020.20.00075>
- Chiwocha SDS, Dixon KW, Flematti GR, Ghisalberti EL, Merritt DJ, Nelson DC, Riseborough JAM, Smith SM, Stevens JC (2009) KARRIKINS: a new family of plant growth regulators in smoke. *Plant Sci* 177:252–256. <https://doi.org/10.1016/j.plantsci.2009.06.007>
- Cho JH (2020) Detection of smoking in indoor environment using machine learning. *Appl Sci* 10(24):8912. <https://doi.org/10.3390/app10248912>
- Fix BV, Smith D, O'Connor R, Heckman BW, Willemsen MC, Cummings M, Fong G (2019) Cannabis use among a nationally representative cross-sectional sample of smokers and non-smokers in the Netherlands: results from the 2015 ITC Netherlands Gold Magic Survey. *BMJ Open* 9(3):E024497. <https://doi.org/10.1136/bmjopen-2018-024497>
- Forster M, McAughy J, Prasad K, Mavropoulou E, Proctor C (2018) Assessment of tobacco heating product THP1. 0. Part 4: Characterisation of indoor air quality and odour. *Regul Toxicol Pharmacol* 93:34–51. <https://doi.org/10.1016/j.yrtph.2017.09.017>
- Ghoma WEO, Sevik H, Isinkaralar K (2022) Using indoor plants as biomonitors for detection of toxic metals by tobacco smoke. *Air Qual Atmos Health* 15(3):415–424. <https://doi.org/10.1007/s11869-021-01146-z>
- Ghosh P, Mukherji S (2021) Environmental contamination by heterocyclic Polynuclear aromatic hydrocarbons and their microbial degradation. *Bioresour Technol* 341:125860. <https://doi.org/10.1016/j.biortech.2021.125860>
- Gushit JS, Mohammed SU, Moda HM (2022) Indoor air quality monitoring and characterization of airborne workstations pollutants within detergent production plant. *Toxics* 10(8):419. <https://doi.org/10.3390/toxics10080419>
- Hoh E, Hunt RN, Quintana PJ, Zakarian JM, Chatfield DA, Wittry BC, Rodriguez E, Matt GE (2012) Environmental tobacco smoke as a source of polycyclic aromatic hydrocarbons in settled household dust. *Environ Sci Technol* 46(7):4174–4183. <https://doi.org/10.1021/es300267g>
- Hörmann V, Brenske KR, Ulrichs C (2018) Assessment of filtration efficiency and physiological responses of selected plant species to indoor air pollutants (toluene and 2-ethylhexanol) under chamber conditions. *Environ Sci Pollut Res* 25(1):447–458. <https://doi.org/10.1007/s11356-017-0453-9>
- Isinkaralar K (2022a) The large-scale period of atmospheric trace metal deposition to urban landscape trees as a biomonitor. *Bio-mass Conversion and Biorefinery* 1–10. <https://doi.org/10.1007/s13399-022-02796-4>
- Isinkaralar K (2022b) Atmospheric deposition of Pb and Cd in the *Cedrus atlantica* for environmental biomonitoring. *Landscape Ecol Eng* 18:341–350. <https://doi.org/10.1007/s11355-022-00503-z>
- Isinkaralar K (2022c) Temporal variability of trace metal evidence in *cupressus arizonica*, *platanus orientalis*, and *robinia pseudoacacia* as pollution-resistant species at an industrial site. *Water Air Soil Pollut* 233(7):250. <https://doi.org/10.1007/s11270-022-05743-1>
- Isinkaralar O (2023) Bioclimatic comfort in urban planning and modeling spatial change during 2020–2100 according to climate change scenarios in Kocaeli, Türkiye. *Int J Environ Sci Technol*. <https://doi.org/10.1007/s13762-023-04992-9>
- Isinkaralar K, Koç İ, Kuzmina NA, Menshchikov SL, Erdem R, Aricak B (2022) Determination of heavy metal levels using *betula pendula* roth. under various soil contamination in Southern Urals,

- Russia. *International J Environ Sci Technol* 19(12):12593–12604. <https://doi.org/10.1007/s13762-022-04586-x>
- Istanbullu SN, Sevik H, Isinkaralar K, Isinkaralar O (2023) Spatial distribution of heavy metal contamination in road dust samples from an urban environment in Samsun, Türkiye. *Bull Environ Contam Toxicol* 110(4):78. <https://doi.org/10.1007/s00128-023-03720-w>
- Jain RB (2016) Trends and variability in the levels of urinary thiocyanate, perchlorate, and nitrate by age, gender, race/ethnicity, smoking status, and exposure to environmental tobacco smoke over 2005–2012. *Sci Total Environ* 557:221–230. <https://doi.org/10.1016/j.scitotenv.2016.03.064>
- Janaydeh M, Ismail A, Zulkifli SZ, Omar H (2019) Toxic heavy metal (Pb and Cd) content in tobacco cigarette brands in Selangor state Peninsular Malaysia. *Environ Monit Assess* 191(10):1–8. <https://doi.org/10.1007/s10661-019-7755-y>
- Kim BJ, Kang JG, Kim JH, Seo DC, Sung KC, Kim BS, Kang JH (2019) Association between second-hand smoke exposure and hypertension in 106,268 Korean self-reported never-smokers verified by cotinine. *J Clin Med* 8(8):1238. <https://doi.org/10.3390/jcm8081238>
- Kollati PR, Mohapatra SS (2021) The combined chemical and mechanical modifications of cigarette: a novel methodology to reduce harmful effects. *Environ Sci Pollut Res* 28:67343–67361. <https://doi.org/10.1007/s11356-021-14659-y>
- Kumakli H, A'ja VD, McDaniel K, Mehari TF, Stephenson J, Maple L, Crawford Z, Macemore CL, Babyak CM, Fakayode SO (2017) Environmental biomonitoring of essential and toxic elements in human scalp hair using accelerated microwave-assisted sample digestion and inductively coupled plasma optical emission spectroscopy. *Chemosphere* 174:708–715. <https://doi.org/10.1016/j.chemosphere.2017.02.032>
- Lajayer BA, Ghorbanpour M, Nikabadi S (2017) Heavy metals in contaminated environment: destiny of secondary metabolite biosynthesis, oxidative status and phytoextraction in medicinal plants. *Ecotoxicol Environ Saf* 145:377–390. <https://doi.org/10.1016/j.ecoenv.2017.07.035>
- Lielieveld J, Pozzer A, Pöschl U, Fnais M, Münzel HAT (2020) Loss of life expectancy from air pollution compared to other risk factors: a worldwide perspective. *Cardiovasc Res* 116(11):1910–1917. <https://doi.org/10.1093/cvr/cvaa025>
- Liao J, Ye W, Pillarisetti A, Clasen TF (2019) Modeling the impact of an indoor air filter on air pollution exposure reduction and associated mortality in Urban Delhi household. *Int J Environ Res Public Health* 16(8):1391. <https://doi.org/10.3390/ijerph16081391>
- Lin B, Huangfu Y, Lima N, Jobson B, Kirk M, O'Keefe P, Pressley SN, Walden V, Lamb B, Cook DJ (2017) Analyzing the relationship between human behavior and indoor air quality. *J Sens Actuator Netw* 6(3):13. <https://doi.org/10.3390/jsan6030013>
- Luo X, Bing H, Luo Z, Wang Y, Jin L (2019) Impacts of atmospheric particulate matter pollution on environmental biogeochemistry of trace metals in soil-plant system: a review. *Environmental Pollution*, 255, 113138. <https://doi.org/10.1016/j.envpol.2019.113138>
- Mannan M, Al-Ghamdi SG (2021) Indoor air quality in buildings: a comprehensive review on the factors influencing air pollution in residential and commercial structure. *Int J Environ Res Public Health* 18(6):3276. <https://doi.org/10.3390/ijerph18063276>
- Neuberger M (2021) Tobacco and alternative nicotine products and their regulation. *Regulatory Toxicology* 1127–1151. https://doi.org/10.1007/978-3-030-57499-4_124
- Obore N, Kawuki J, Guan J, Papabathini SS, Wang L (2020) Association between indoor air pollution, tobacco smoke and tuberculosis: an updated systematic review and meta-analysis. *Public Health* 187:24–35. <https://doi.org/10.1016/j.puhe.2020.07.031>
- Orri M, Séguin JR, Castellanos-Ryan N, Tremblay RE, Côté SM, Turecki G, Geoffroy MC (2021) A genetically informed study on the association of cannabis, alcohol, and tobacco smoking with suicide attempt. *Mol Psychiatry* 26(9):5061–5070. <https://doi.org/10.1038/s41380-020-0785-6>
- Palazzi P, Hardy EM, Appenzeller BM (2019) Biomonitoring of children exposure to urban pollution and environmental tobacco smoke with hair analysis—a pilot study on children living in Paris and Yeu Island, France. *Sci Total Environ* 665:864–872. <https://doi.org/10.1016/j.scitotenv.2019.02.177>
- Pan A, Wang Y, Talaei M, Hu FB, Wu T (2015) Relation of active, passive, and quitting smoking with incident type 2 diabetes: a systematic review and meta-analysis. *Lancet Diabetes Endocrinol* 3(12):958–967. [https://doi.org/10.1016/S2213-8587\(15\)00316-2](https://doi.org/10.1016/S2213-8587(15)00316-2)
- Panhwar AH, Kazi TG, Afridi HI, Arain SA, Arain MS, Brahman KD, Arain SS (2016) Correlation of cadmium and aluminum in blood samples of kidney disorder patients with drinking water and tobacco smoking: related health risk. *Environ Geochem Health* 38:265–274. <https://doi.org/10.1007/s10653-015-9715-y>
- Peprah E, Armstrong-Hough M, Cook SH, Mukasa B, Taylor JY, Xu H et al (2021) An emerging systemic of smoking and cardiopulmonary diseases in people living with HIV in Africa. *Int J Environ Res Public Health* 18(6):3111. <https://doi.org/10.3390/ijerph18063111>
- Persily A (2015) Challenges in developing ventilation and indoor air quality standards: the story of ASHRAE Standard 62. *Build Environ* 91:61–69. <https://doi.org/10.1016/j.buildenv.2015.02.026>
- Rajagopalan P, Goodman N (2021) Improving the indoor air quality of residential buildings during bushfire smoke events. *Climate* 9(2):32. <https://doi.org/10.3390/cli9020032>
- Rajfur M, Świsłowski P, Nowaini F, Śmiechowicz B (2018) Mosses as biomonitor of air pollution with analytes originating from tobacco smoke. *Chemistry-Didactics-Ecology-Metrology*, 23(NR 1–2), 127–136. <https://doi.org/10.1515/cdem-2018-0008>
- Rice JL, McGrath-Morrow SA, Collaco JM (2020) Indoor air pollution sources and respiratory symptoms in bronchopulmonary dysplasia. *J Pediatr* 222:85–90. <https://doi.org/10.1016/j.jpeds.2020.03.010>
- Rostami R, Kalan ME, Ghaffari HR, Saranjam B, Ward KD, Ghobadi H, Poureshgh Y, Fazlzadeh M (2021) Characteristics and health risk assessment of heavy metals in indoor air of waterpipe cafés. *Building and Environment*, 190, 107557. <https://doi.org/10.1016/j.buildenv.2020.107557>
- Rumchev K, Zhao Y, Spickett J (2017) Health risk assessment of indoor air quality, socioeconomic and house characteristics on respiratory health among women and children of Tirupur, South India. *Int J Environ Res Public Health* 14(4):429. <https://doi.org/10.3390/ijerph14040429>
- Salamone F, Belussi L, Danza L, Galanos T, Ghellere M, Meroni I (2017) Design and development of a wearable wireless system to control indoor air quality and indoor lighting quality. *Sensors* 17(5):1021. <https://doi.org/10.3390/s17051021>
- Sánchez-Soberón F, Mari M, Kumar V, Rovira J, Nadal M, Schuhmacher M (2015) An approach to assess the Particulate Matter exposure for the population living around a cement plant: modeling indoor air and particle deposition in the respiratory tract. *Environ Res* 143:10–18. <https://doi.org/10.1016/j.envres.2015.09.008>
- Sawidis T, Krystallidis P, Veros D, Chettri M (2012) A study of air pollution with heavy metals in Athens city and Attica basin using evergreen trees as biological indicators. *Biol Trace Elem Res* 148(3):396–408. <https://doi.org/10.1007/s12011-012-9378-9>
- Schilling K, Gentner DR, Wilen L, Medina A, Buehler C, Perez-Lorenzo LJ, Godri-Pollitt KJ, Bergemann R, Bernardo N, Peccia J, Wilczynski V, Lattanza L (2021) An accessible method for screening aerosol filtration identifies poor-performing commercial masks and respirators. *J Exposure Sci Environ Epidemiol* 31(6):943–952. <https://doi.org/10.1038/s41370-020-0258-7>

- Singh A, Upadhyay A, Singh J, Singh AK, Gautam DNS, Singh NK (2022) Ayurvedic strategy to achieve sustainable development goal 3: management of cancer (Arbuda). *Agriculture Issues and Policies* 141
- Sulhan OF, Sevik H, Isinkaralar K (2022) Assessment of Cr and Zn deposition on *Picea pungens* Engelm. in urban air of Ankara, Türkiye. *Environ Dev Sustain* 1–20. <https://doi.org/10.1007/s10668-022-02647-2>
- Świsłowski P, Śmiechowicz B, Rajfur M (2022) Effects of tobacco smoke on indoor air quality: the use of mosses in biomonitoring. *J Environ Health Sci Eng* 20(1):485–493. <https://doi.org/10.1007/s40201-022-00794-2>
- Tan J, Zhang X, Wang W, Yin P, Guo X, Zhou M (2018) Smoking, blood pressure, and cardiovascular disease mortality in a large cohort of Chinese men with 15 years follow-up. *Int J Environ Res Public Health* 15(5):1026. <https://doi.org/10.3390/ijerph15051026>
- Torpy FR, Zavattaro M, Irga PJ (2017) Green wall technology for the phytoremediation of indoor air: a system for the reduction of high CO₂ concentrations. *Air Qual Atmos Health* 10(5):575–585. <https://doi.org/10.1007/s11869-016-0452-x>
- Vanker A, Barnett W, Workman L, Nduru PM, Sly PD, Gie RP, Zar HJ (2017) Early-life exposure to in-door air pollution or tobacco smoke and lower respiratory tract illness and wheezing in African infants: a longitudinal birth cohort study. *The Lancet Planetary Health* 1(8):e328–e336. [https://doi.org/10.1016/S2542-5196\(17\)30134-1](https://doi.org/10.1016/S2542-5196(17)30134-1)
- Viana GFDS, Garcia KS, Menezes-Filho JA (2011) Assessment of carcinogenic heavy metal levels in Brazilian cigarettes. *Environ Monit Assess* 181:255–265. <https://doi.org/10.1007/s10661-010-1827-3>
- Vimercati L, Baldassarre A, Gatti MF, Gagliardi T, Serinelli M, Maria LD, Caputi A, Dirodi AA, Galise I, Cuccaro F, Assennato G (2016) Non-occupational exposure to heavy metals of the residents of an industrial area and biomonitoring. *Environ Monit Assess* 188(12):673. <https://doi.org/10.1007/s10661-016-5693-5>
- Wani W, Masoodi KZ, Zaid A, Wani SH, Shah F, Meena VS, Wani SA, Mosa KA (2018) Engineering plants for heavy metal stress tolerance. *Rendiconti Lincei Scienze Fisiche e Naturali* 29(3):709–723. <https://doi.org/10.1007/s12210-018-0702-y>
- Welker M (2021) Indonesia's cigarette culture wars: contesting tobacco regulations in the postcolony. *Comp Stud Soc Hist* 63(4):911–947. <https://doi.org/10.1017/S0010417521000293>
- Wood RA, Burchett MD, Alquezar R, Orwell RL, Tarran J, Torpy F (2006) The potted-plant microcosm substantially reduces indoor air VOC pollution: I. Office field-study. *Water, Air, and Soil Pollution*, 175(1), 163–180. <https://doi.org/10.1007/s11270-006-9124-z>
- World Health Organization (2021) WHO global air quality guidelines: particulate matter (PM_{2.5} and PM₁₀), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide
- Yayla EE, Sevik H, Isinkaralar K (2022) Detection of landscape species as a low-cost biomonitoring study: Cr, Mn, and Zn pollution in an urban air quality. *Environ Monit Assess* 194(10):687. <https://doi.org/10.1007/s10661-022-10356-6>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.