Impact factor assessment of the uptake and accumulation of polycyclic aromatic hydrocarbons by plant leaves: Morphological characteristics have the greatest impact

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HIGHLIGHTS

- Eight plant leaves significantly differ in their ability to uptake and adsorb PAHs.
- Morphology and physiological characteristics have greater impact than adsorption.
- Retention of particulate PAHs on leaf is a valid way to reduce atmospheric PAHs.
- HMW PAHs reserved by leaves are mainly affected by wax content and adsorption.

GRAPHICAL ABSTRACT
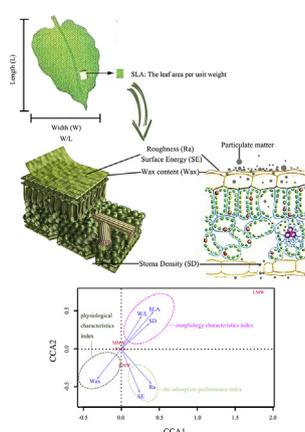
ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) have toxic, teratogenic, mutagenic and carcinogenic effects on living organisms. Plants can function as pollutant bioindicators and bioaccumulators due to their wide surface distribution and specific responses to atmospheric pollutants. However, various plants exhibit significant differences in their capacities to accumulate PAHs. At present, research has mainly focused on the effects of leaf morphology and physiological characteristics, and few studies have evaluated the effects of the leaf surface on PAH accumulation. We aimed to assess the factors impacting the uptake and accumulation of PAHs by leaves. We selected 8 common tree species in Shanghai, China, and used supercritical fluid extraction technology to determine the content of PAHs in their leaves. Specific measurements of leaf area, width/length, wax content, and stomatal density were applied to index the morphological and physiological characteristics; surface roughness, surface free energy, polar components, and dispersion components were compiled into an adsorption performance index. Principal component analysis (PCA) and canonical correlation analysis (CCA) were used to assess the effects of

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Physiological characteristics
Surface adsorption

different leaf characteristics on PAH accumulation. We found that the mean concentrations of ΣPAHs ranged from 300 to 2000 ng·g^{-1} and that the proportions of different benzene rings were significantly different among the different tree species. Leaf morphology and physiological characteristics had more significant effects compared to surface adsorption. CCA showed a significant negative correlation between leaf morphological characteristics and wax content, but had no significant correlation with surface adsorption. Low-molecular-weight PAHs were found to be mainly affected by the morphological characteristics, while medium- and high-molecular-weight PAHs were influenced by wax content and adsorption. Our conclusions provide a theoretical basis for the establishment of a reliable plant atmosphere-monitoring system and a method for screening tree species with strong PAH adsorption capacity.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are hydrocarbon compounds consisting of 2–7 condensed aromatic rings. High-molecular-weight (HMW) PAHs, in particular, are known for their toxic, teratogenic, mutagenic, and carcinogenic effects on living organisms (Capozzi et al., 2017; Cheruiyot et al., 2015; Di Palma et al., 2016; Kodnik et al., 2015). PAHs are derived from a broad range of natural and especially anthropogenic sources, such as traffic and industrial activity, through the combustion of oil, wood, and other organic materials (Krzebietke et al., 2018). PAHs and their derivatives comprise over 400 compounds, 16 of which are listed as priority pollutants by the US Environmental Protection Agency (US EPA) because of their hazardous nature. Recently, research on air pollution has focused on biomonitoring—an appropriate means to detect and monitor air pollution effects on organisms. In particular, plants, due to their wide surface distribution and specific responses, can function as pollutant bioindicators and bioaccumulators (Augusto et al., 2015; Capozzi et al., 2017; Odabasi et al., 2015; Rodriguez et al., 2012). Tree leaves are very efficient at trapping PAHs and therefore play a special role in reducing the level of respirable fine particulates that cause serious human diseases (De Nicola et al., 2011; Rauert and Harner, 2016).

Different types of plant leaves have different physicochemical properties and thus significantly differ in their ability to adsorb PAHs. Therefore, many studies have focused on the effects of leaf morphology and physiological characteristics on PAH accumulation. Some scholars believe that gaseous PAHs can transfer into the mesophyll directly by molecular diffusion. Accordingly, the stomatal density (SD) is positively correlated with the content of PAHs in leaves, which is an important pathway for the adsorption of PAHs by leaves (Desalme et al., 2013; Dias et al., 2016; Elisa Terzaghi et al., 2013). Leaf wax content (Wax) is considered to be another important factor affecting PAH adsorption (Prajapati and Tripathi, 2008). The adsorption efficiency of plant leaves for particulate PAHs mainly depends on the 1-octanol/water partition coefficient (K_{ow}). The wax/water partition coefficient of PAHs ranges from 104.1 to 107.6, which is equivalent to or even higher than K_{ow}, indicating that the waxy layer has a high ability to adsorb PAHs and promotes PAH absorption. However, leaf wax can mostly retain organic pollutants, including PAHs, preventing them from entering the leaves and affecting plant growth (Li et al., 2010; Wild et al., 2010). Many studies have also discussed the effects of specific leaf area (SLA) and width/length (W/L): a significant negative correlation between the content of PAHs and SLA has been observed. SLA determines blade thickness. It is generally believed that the larger the SLA is, the thinner the plant blade. SLA affects the wax of the leaves, which in turn affects the content and distribution of PAHs in the leaves of plants (Howsam et al., 2001; Terzaghi et al., 2015).

Compared with broadleaf plants and their influencing factors, typical pollutant bioindicators and bioaccumulators, such as mosses and conifers, have been favored by many researchers (Nascimbene et al., 2014; Protano et al., 2014; Van der Wat and Forbes, 2015); it remains difficult to make direct comparisons between studies because of data heterogeneity among the results. Moreover, existing studies have explored the

influence of plant leaf morphology and their waxy layers but have not considered the surface adsorption characteristics of plant leaves, such as the surface roughness (Ra) and surface free energy (SE), which can reflect the liquid and solid substances in the atmosphere. In summary, the uptake and accumulation of PAHs by plant leaves is affected by many factors, and the correlations between and contributions of these different factors remain to be explored.

We selected 8 common landscaping tree species in Shanghai, China, and used supercritical fluid extraction (SFE) technology to determine the content of PAHs in plant leaves without washing the specimens. SLA, W/L, Wax, and SD were used as indexes of the morphological and physiological characteristics of plant leaves, and Ra, SE, polar components (Pol), and dispersion components (Dis) were used as the adsorption performance index. Principal component analysis (PCA) and canonical correlation analysis (CCA) were used to assess the effects of different leaf characteristics on the uptake and accumulation of PAHs.

In particular, we attempted to answer the following questions:

a) What is the correlation between each characteristic factor of each tree species?
b) Which key factor affects the uptake and accumulation of PAHs by plant leaves in the context of morphological, physiological, and adsorption characteristics?
c) How does each leaf characteristic factor affect the uptake and accumulation of PAHs?

2. Materials and methods

2.1. Sample collection

Sabina chinensis, *Cedrus deodara*, *Magnolia grandiflora*, *Metasequoia glyptostroboides*, *Ginkgo biloba*, *Cinnamomum camphora*, *Salix babylonica* and *Platanus acerifolia* were selected as representatives of the common greening species in Shanghai, including evergreen and deciduous tree species as well as coniferous and broadleaf tree species. The sampling time was controlled within 2 h of June 4th, 2018, on the fifth day after a 60-mm rainfall, which is the most vigorous season for plants to grow in Shanghai. All samples were collected in Wujing Park, which is located in the suburbs of Shanghai and has very rich diversity in tree species.

At each site, the leaves were sampled from heights of 3–5 m above the ground using pruning shears, taking approximately five branches from different directions (N, S, E, W) of three mature and healthy trees (10–20 years old), with a distance of at least 100 m between each sampled tree. Then, a large number (50–100 pieces) of mature and healthy leaves were taken by hand from the branches and combined into one homogeneous sample; care was taken to minimize tactile contact with the leaf surfaces. For each species, 3 parallel samples were collected, and all samples were transferred to the laboratory using polyethylene bags. No samples were rinsed with pure water, and all samples were shattered and stored at −18 °C in polyethylene bags until analysis.

2.2. Parameter detection

W/L was directly determined using ImageJ software (Version 1.46, National Institutes of Health, USA).

SLA was calculated as follows (Chaturvedi et al., 2013):

$$SLA(cm^2/g) = \frac{S(cm^2)}{DW(g)}$$

where *SLA* is the specific leaf area, *S* is the leaf area, and *DW* is the dry weight of leaves.

Wax determination was performed as described earlier (Ardenghi et al., 2017). Based on our experimental needs, we explored the best extraction time for 8 plants. Specifically, as the extraction time is extended, the wax from the leaves is gradually removed, and their uneven structure becomes obvious. When a certain extraction time is reached, the structure will not change with the addition of more time, indicating the best point for wax extraction. Based on the results, adjusted extraction times were as follows: *S. chinensis:* 2 min, *C. deodara:* 2 min, *M. grandiflora:* 5 min, *M. glyptostroboides:* 10 min, *G. biloba:* 5 min, *C. camphora:* 20 min, *S. babylonica:* 20 min, and *P. acerifolia:* 5 min. After the extraction was confirmed, the wax was observed under a scanning electron microscope (Mira3 (SEM) & Aztec X-Max (EDS), CZ), and the pores were clearly visible.

SD: After extracting wax from the leaves of each tree species, the results were observed and recorded using electron microscopy (Mira3 (SEM) & Aztec X-Max (EDS), CZ) (Yang et al., 2017).

Ra was measured using an atomic force microscope (Dimension Icon & FastScan Bio, USA) as previously described (Nairn and Forster, 2017), and the roughness of the blade was expressed by the surface roughness.

SE, Dis, and Pol: The contact angles of deionized water, ethylene glycol, and DMF on the paraxial and abaxial surfaces of plant leaves were measured as previously described. Using the internationally accepted Owens–Wendt–Rabel–Kaelble (OWRK) method and Young's equation, SE and components (polar and dispersive force components) of the paraxial and abaxial surfaces of each leaf blade were calculated (Wuytack et al., 2013).

2.3. PAH extraction, purification, and analysis

At present, traditional extraction methods such as ultrasonic extraction technology and rapid and efficient extraction technology are used to extract PAHs from leaves. Different extraction techniques have different advantages and disadvantages (Capozzi et al., 2017; Murakami et al., 2012; Papa et al., 2012). SFE techniques, which have been widely used in atmosphere and soil sciences (Achten et al., 2011; Bartolomé Ortega et al., 2017), can efficiently extract PAHs in a short period of time. However, due to the large amount of pigments and impurities in plant leaves, the application of this method on plant leaves is still rare, and related parameters remain to be explored. We investigated the applicable parameters and used SFE to accurately determine the uptake and accumulation of PAHs by plant leaves.

For each sample, approximately 5 g of fresh leaves was used for each extraction, and a duplicate extraction was made simultaneously. The SFE cell was first packed with 2 g of anhydrous sodium sulfate and 5 g of 60–100 mesh silica gel; then, the exact weight of whole needles was loaded. Standard perdeuterated naphthalene-d_8, phenanthrene-d_{10}, acenaphthene-d_{10}, chrysene-d_{12}, and perylene-d_{12} at a concentration of 2 μg·g^{-1}, 250 μL each, were spiked into the sample as internal standards. The cell was connected to the SFE system for extraction.

An ISCO syringe pump (260 D; Lincoln, NE) was used to deliver CO_2 and to maintain the pressure. A two-stage extraction was conducted. The first stage was approximately 15 min of static extraction at an oven temperature of 180 °C and a pressure of 350 atm. After the static extraction, the temperature was decreased to 110 °C, and the dynamic extraction was started. Hexane was added as a cosolvent. The extract

or effluent was collected in 5 mL of dichloromethane in a 30-mL vial, and the flow rate was controlled with an outlet valve at approximately 4 mL·min^{-1}. The extraction was stopped after approximately 30 min.

The extracted samples were purified with silica–alumina column solid-phase extraction cartridges, as previously reported (Yang et al., 2017). Finally, the PAH elution was concentrated to 0.5 mL for GC/MS analysis.

Purified extractions were analyzed using GC–MS (GC/MS, Agilent 7890 A/5977 A, USA), with parameter settings as previously reported (Fellet et al., 2016).

2.4. Quality control and quality assurance

To verify the feasibility of this method, we performed one procedural blank and one spike blank (a standard mixture of 16 PAHs prioritized by the US EPA and 5 deuterated PAHs spiked into the solvent) for every 7 samples by carrying out the same experimental procedure. The target compounds were below the detection limit in procedural blanks. The average recoveries of 16 PAHs in spiked blanks ranged from 69% to 112%, and the experimental results were all corrected by recovery. The relative standard deviation of the parallel samples was below 20%. Thus, the experimental data in our study were reliable.

2.5. Statistical analysis

All statistical analyses were conducted in R 3.5.0, and the significance level was set to 0.05. First, the experimental variables were analyzed for correlation, and the independent variables with significant influence on the dependent variables were filtered. Considering the influence of only a single factor is obviously incomplete and ignores the contribution of different factors. Then, PCA was used to reduce the dimensionality of the independent variables, and linear regression was employed to explore the factors that had the greatest influence on the dependent variables. By using CCA, the relationship between multiple sets of variables was explained in general.

3. Results

3.1. ΣPAH concentrations in leaves of different tree species

ΣPAH concentrations varied in leaves of different tree species (Table 1). Some PAHs had the same characteristic ions, but their peaks were difficult to distinguish, so they were categorized as one group. The mean concentrations of ΣPAHs ranged from 300 to 2000 ng·g^{-1}, of which 343.60 ± 8.30 ng·g^{-1} for *P. acerifolia* was the lowest. The highest was 1974.50 ± 123.18 ng·g^{-1} for *S. chinensis*. This result was consistent with some studies (Dias et al., 2016; Ratola et al., 2011).

3.2. Difference in the proportion of PAHs with different benzene rings

The proportions of different benzene rings were significantly different among the leaves of different tree species (Fig. 1). This ratio was similar to previous studies (Dias et al., 2016; Ravindra et al., 2008). In general, the substance profiles were dominated by medium-molecular-weight (MMW) PAHs, accounting for 70%–90%, and this fraction was much higher than that of the nonvolatile high-molecular-weight (HMW) PAHs, ranging from 10% to 30%; the low-molecular-weight (LMW) PAHs content in the leaves of different tree species was extremely low. PAHs exhibit different physical and chemical properties, likely due to the different vapor pressures of the compounds. The LMW PAHs mainly exist in gaseous form, but their stability is poor and they are easily degraded (Ravindra et al., 2008). Moreover, it is difficult for leaves to accumulate HMW PAHs, which mainly exist as particles in the atmosphere (Tretiach et al., 2011; Xinhui et al., 2004).

Table 1
ΣPAHs concentrations in the leaves of 8 species (ng·g^{-1}).

	S. chinensis	C. deodara	M. grandiflora	M. glyptostroboides	C. camphora	G. biloba	S. babylonica	P. acerifolia
Naphthalene	1.18 ± 0.26	0.06 ± 0.02	1.81 ± 0.12	0.78 ± 0.03	0.06 ± 0.00	0.23 ± 0.20	6.50 ± 4.26	8.80 ± 3.29
Acenaphthylene	36.55 ± 3.03	19.11 ± 6.49	268.61 ± 7.20	69.54 ± 2.39	19.11 ± 3.36	178.18 ± 10.92	112.96 ± 6.44	12.36 ± 4.64
Acenaphthene	901.09 ± 21.31	13.13 ± 1.38	12.27 ± 1.59	12.76 ± 5.12	13.13 ± 2.59	21.07 ± 8.07	18.85 ± 2.42	25.11 ± 2.05
Fluorene	432.32 ± 49.63	24.05 ± 7.30	81.08 ± 22.92	10.00 ± 2.61	24.05 ± 8,65	108.08 ± 9.33	95.30 ± 0.52	20.99 ± 0.62
Phenanthrene + Anthracene	13.83 ± 1.84	180.57 ± 20.57	163.16 ± 4.21	102.51 ± 18.05	180.57 ± 37.31	120.00 ± 7.65	62.36 ± 14.05	32.62 ± 1.29
Fluoranthene	20.76 ± 0.23	69.65 ± 7.09	122.91 ± 6.32	317.77 ± 96.17	69.65 ± 6.91	39.02 ± 3.20	62.43 ± 31.83	154.30 ± 5.14
Pyrene	16.30 ± 3.60	42.29 ± 3.53	89.34 ± 18.92	18.96 ± 3.42	42.29 ± 6.91	3.53 ± 1.89	2.63 ± 0.72	4.24 ± 0.06
Chrysene+Benzo(a)anthracene	63.07 ± 15.28	65.81 ± 2.90	7.06 ± 0.71	19.69 ± 5.23	65.81 ± 1.44	3.41 ± 1.75	1.34 ± 0.16	4.12 ± 1.93
Benzo(b)fluoranthene + Benzo(a)pyrene + Benzo(k)fluoranthene	29.85 ± 0.94	3.61 ± 0.50	5.39 ± 1.88	5.47 ± 0.59	3.61 ± 0.41	10.96 ± 1.34	41.66 ± 4.07	11.05 ± 0.56
Indeno(1,2,3-cd)pyrene + Benzo(ghi)perylene	49.85 ± 4.52	22.92 ± 7.81	1.56 ± 0.01	5.81 ± 0.26	22.92 ± 3.64	12.96 ± 4.41	26.18 ± 5.12	6.23 ± 5.30
Dibenz(a,h)anthracene	409.69 ± 10.19	157.36 ± 39.52	204.08 ± 22.47	49.89 ± 6.89	157.36 ± 4.38	80.41 ± 8.82	48.57 ± 7.68	63.79 ± 32.62
ΣPAHs	1974.50 ± 123.18 [a]	598.56 ± 16.55 [b]	957.26 ± 12.49 [c]	613.18 ± 107.29 [d]	598.56 ± 10.29 [d]	577.86 ± 31.25 [de]	478.78 ± 6.53 [de]	343.60 ± 8.30 [e]

Note: Different letters indicate significant differences (P < .05).

3.3. Factors influencing ∑PAH in the leaves of different tree species

To explore the correlation between various characteristic factors of the leaf, we performed a correlation coefficient matrix (Fig. 2) for the SLA, W/L, SD, Ra, Wax, SE, Pol, and Dis.

∑PAHs adsorbed by plant leaves was significantly negatively correlated with SLA, W/L, and SD, whereas ∑PAHs was significantly positively correlated with Wax (Fig. 2). Additionally, there was an obvious collinearity between different characteristics of plant leaves. However, considering the influence of only a single factor is obviously incomplete and ignores the contribution of different factors in the uptake and accumulation of PAHs by plant leaves. Therefore, after preliminary judgment of the correlation between variables, PCA was used to classify each factor and reduce the principal components.

After PCA (Fig. 3), three principal components were obtained with a cumulative contribution rate of 93.52%. The first principal component (F1) mainly characterized the leaf morphology and physiological characteristics, loaded with the following characteristic factors: SLA, W/L, SD, and Wax. F1 could effectively explain 55.87% of the change in all characteristic factors. The larger the SLA of the blade was, the larger the leaf area per unit weight; in other words, the thinner the blade was, the higher the SD and the lower the Wax. The second principal component (F2) was dominated by Ra, which could explain 24.23% of all characteristic factors, reflecting the ability of the leaf surface to retain particulate matter. The third (F3) was mainly based on SE, which could explain 13.42% of all characteristic factors and characterized the ability of leaves to adsorb polar and nonpolar substances.
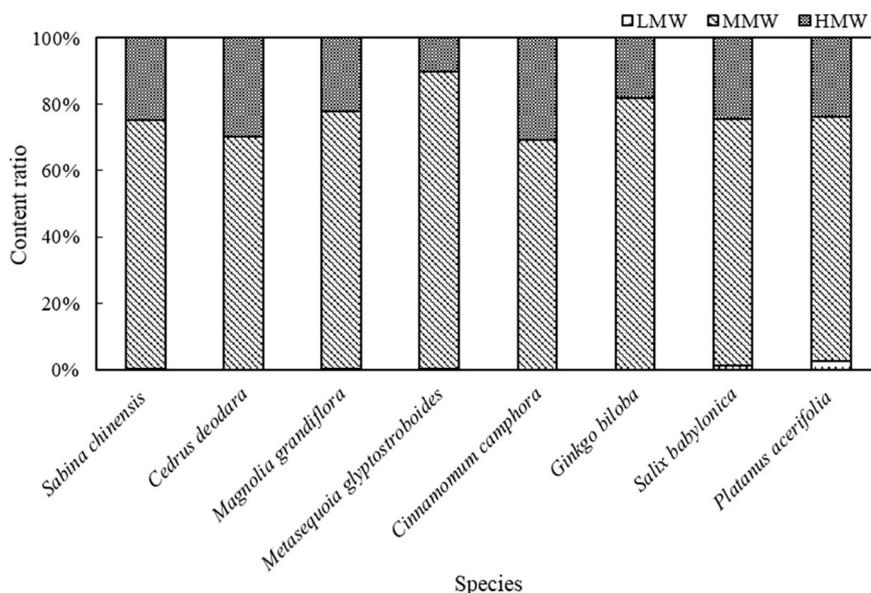

Fig. 1. Content ratios of different-ring PAHs in the leaves of 8 typical landscaping tree species in Shanghai.
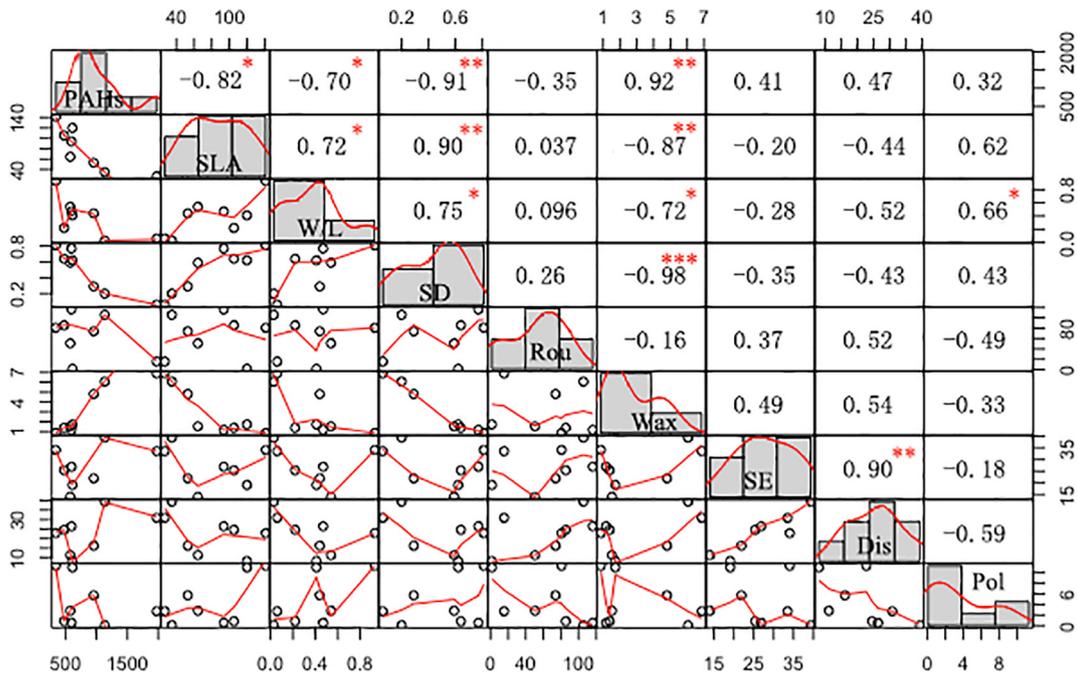
Fig. 2. Factor correlation analysis matrix of various characteristic factors. ***: P < .001 **: P < .01 *: P < .05.

After dividing the plant leaf features into 3 principal components, the principal components become independent of one another, and $\sum$PAHs in the leaves can be linearly transformed:

$$PAHs^{\#} = -5.641 \times F1 - 2.593 \times F2 + 1.417 \times F3.$$

[#]:Standardized data.

Turning into the original variable:

$$PAHs^{\#} = -2.55SLA^{\#} - 2.32\,W/L^{\#} - 3.29SD^{\#} - 1.67Rou^{\#} + 3.31Wax^{\#} + 0.30SE^{\#} + 1.32Dis^{\#} - 0.30Pol^{\#}.$$
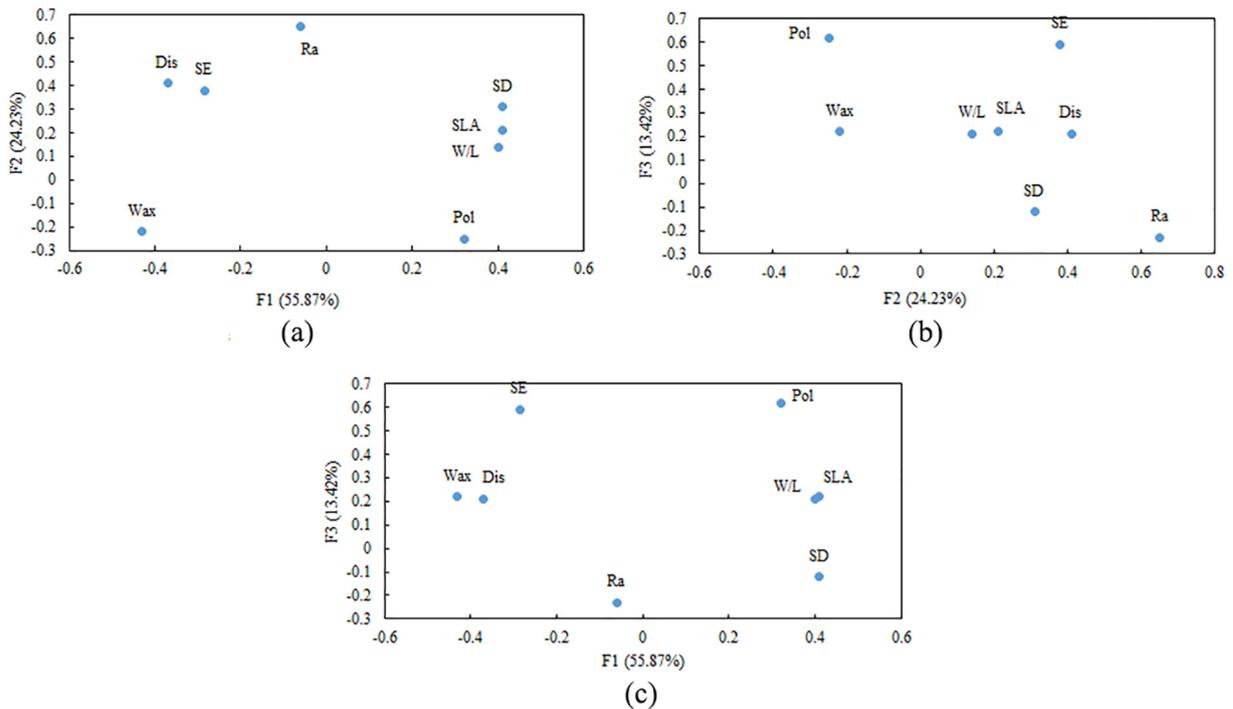
[#]:Standardized data.

Fig. 3. Principal component analysis (PCA) for 8 variables of 8 tree species (n = 16). (a) projection of the variables on PCA1 and PCA2; (b) projection of the variables on PCA2 and PCA3; (c) projection of the variables on PCA1 and PCA3.

4. Discussion

In the present study, we found that ΣPAHs in the leaves was seriously affected by F1—that is, leaf morphology and physiological characteristics. ΣPAHs was negatively correlated with SLA, W/L, and SD and positively correlated with Wax, which was consistent with the preliminary determination of the correlation (Fig. 2). However, this result is contrary to some studies (Barber et al., 2004; Dias et al., 2016). It has been reported that a relative balance exists between PAHs in leaves and PAHs in the atmosphere (Barber et al., 2004). PAHs are volatile and evaporate from the leaves because of the high temperatures in spring and summer, whereas notable condensation phenomena are caused by low temperatures in fall and winter (Nakajima et al., 1995). The stomata of the leaves are critical organs for the exchange between plant leaves and the external environment, which directly affects the content and distribution characteristics of the leaves. Our sampling time was summer, and the temperature was high: the stomata were fully open, and considerable quantities of PAHs were volatilized from the leaves into the atmosphere. Therefore, the PAHs in the leaves were negatively correlated with the leaf SD.

Leaf W/L was another important factor affecting the accumulation of PAHs. Tree species with large W/L (such as broadleaf tree species) have a strong ability to intercept dewdrops and are heavily washed, resulting in low PAH accumulation. Wax is the structural material of the outermost layer of the surface layer of plant leaves, with numerous lipid substances, and PAHs are organic compounds with similar solubility characteristics. Thus, a large number of PAHs cannot migrate from cuticles to interior leaf constituents due to the low penetration ability and high adsorption capacity of the cuticles (Kim et al., 2014; Moeckel et al., 2008). Therefore, PAHs in leaves are positively correlated with leaf Wax. The SLA of the leaves mainly affects the thickness of the leaf wax layer. Generally, the thicker the leaves are, the thicker the waxy layers and the more strongly the PAHs are retained (Kim et al., 2014).

F2 with Ra as the main factor and F3 with SE as the main factor also significantly affected the adsorption of PAHs. These two major components mainly determined the PAH retention in the granular state on the blade surface. After the PAHs adsorbed in the particles settle to the surface of the leaves, redistribution occurs. Some of the particles may fall off with the epidermis or may be removed from the surface of the blade under the influence of external meteorological conditions, such as heavy rainfall and wind erosion, and may be released back to the atmosphere. The remaining particle-bound PAHs are embedded in the surface of the blade and are less likely to return back to the atmosphere once they enter the inner tissue (Kaupp et al., 2010). Therefore, while discussing the contribution of plants to the sedimentation of PAHs in the environment, one should consider the retention of particulate PAHs on the surfaces of the leaves as an essential means to reduce PAHs in the atmosphere.

PCA did not adequately demonstrate the correlation among different features. There were large differences in the physical and chemical properties of PAHs with different benzene rings. As such, considering only one indicator for ∑PAHs would be insufficient. Therefore, we used CCA to classify different leaf feature factors and reflect the relationship between multiple groups of variables in general (Fig. 4).

The leaf characteristics were divided into 3 groups (Fig. 4). SLA, W/L, and SD were grouped, which characterized the morphological characteristics of plant leaves. Wax was one group, reflecting the internal retention of the leaves, which was significantly negatively correlated with the former group. SE and Ra constituted one group, reflecting the ability of the leaf surface to adsorb and retain particulate matter, and their group was not significantly correlated with the former 2 groups.

The content of PAHs with different benzene rings in plant leaves was also affected by different factors. LMW PAHs were mainly affected by the leaf morphological characteristics, but due to their low vapor pressure, they easily decomposed in the atmosphere. Therefore, the content of LMW PAHs adsorbed by the leaves was extremely low, and their
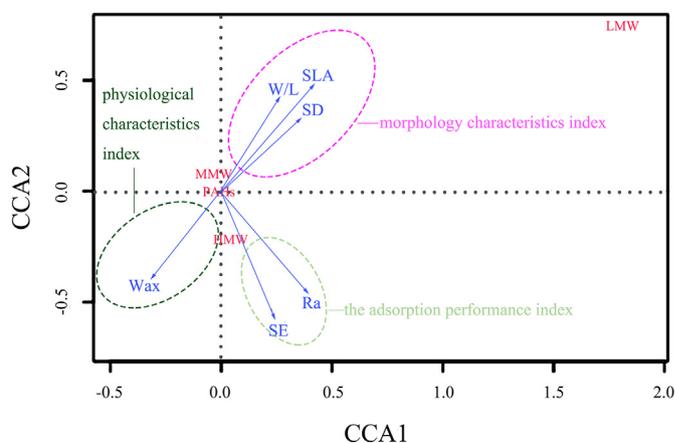

Fig. 4. Canonical correlation analysis (CCA) for various characteristic factors based on the PAHs contents in plant leaves: the leaf characteristics were divided into three groups.

contribution to the total amount of PAHs adsorbed was thus relatively small. MMW PAHs were affected by the morphological characteristics of the first group (positively) and the Wax of the second group (negatively). MMW PAHs enter the blade through the pores and are then blocked by the wax layer. HMW PAHs were mainly affected by the second group of Wax and the third group of SE and Ra. HMW PAHs are mostly adsorbed in the particulate matter. After the particulate matter in the atmosphere contacts the blade, it is first held by the surface of the blade, which is related to the Ra and SE of the surface. Among them, HMW PAHs will resolve during the contact with the leaves and will be released from the particles and migrate to the stratum corneum of the plant leaves. Some of them are absorbed and fixed by fatty substances (such as keratin and wax) in the stratum corneum; others can pass through the stratum corneum and continue to spread into the interior of the leaves (Liu et al., 2006; Riederer et al., 2002). On the whole, LMW PAHs are mainly affected by the morphological characteristics of plant leaves, whereas MMW and HMW PAHs are mainly affected by the wax content and adsorption.

5. Conclusions

In this study, we evaluated the effects of different leaf characteristics on their ability to accumulate PAHs. We found that the mean concentrations of ΣPAHs ranged from 300 to 2000 ng·g^{-1} and that the proportions of different benzene rings were significantly different. The PAH content in coniferous species represented by *S. chinensis* and *C. deodara* was significantly higher than that in broadleaf species. The substance profiles were dominated by MMW PAHs, followed by HMW PAHs; the LMW PAHs content was extremely low.

The factors affecting the uptake and accumulation of PAHs can be divided into 3 main components. Compared with adsorption, the morphology and physiological characteristics of leaves (mainly SLA, SD, and Wax) had a more significant effect. However, the contribution of the surface of the blade to the adsorption of PAHs cannot be ignored, either. CCA showed a significant negative correlation between morphological characteristics and wax content but had no significant correlation with leaf surface adsorption. LMW PAHs were mainly affected by leaf morphological characteristics, whereas MMW and HMW PAHs were mainly affected by wax content and adsorption. Our conclusions provide a theoretical basis for the establishment of a reliable plant-based atmospheric monitoring system and a method for screening tree species with strong PAH adsorption capacity. In the future, we will study additional tree species and verify our experimental conclusions. We would also like to expand the study area to explore whether differences exist in the factors affecting the accumulation of PAHs in different regions under different pollution levels.

Acknowledgements

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