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Individual effects of trichomes and leaf morphology on $PM_{2.5}$ dry deposition velocity: A variable-control approach using species from the same family or genus☆

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ABSTRACT

Urban green infrastructure is closely linked to the alleviation of pollution from atmospheric particulate matter. Although particle deposition has been shown to depend on leaf characteristics, the findings from earlier studies are sometimes ambiguous due to the lack of controlling variables. In this study, we investigated the impact of leaf morphological characteristics on $PM_{2.5}$ dry deposition velocity by employing a control-variable approach. We focused on four indices: trichome density, petiole length, aspect ratio (width-to-length ratio), and fractal deviation. For each index, tree species were chosen from the same family or genus to minimize the influence of other factors and make a group of treatments for an individual index. The dry deposition velocities of $PM_{2.5}$ were determined through application of an indirect method. The results revealed that the presence of leaf trichomes had a positive effect on $PM_{2.5}$ dry deposition velocity, and a higher trichome density also led to a greater particle deposition velocity. Lower leaf aspect ratio, shorter petioles, and higher leaf fractal deviation were associated with greater $PM_{2.5}$ dry deposition velocity. The control-variable approach allows to investigate the correlation between deposition velocity and a certain leaf characteristic independently while minimizing the effects of others. Thus, our study can clarify how a single leaf characteristic affects particle deposition velocity, and expound its potential mechanism more scientifically than the published studies. Our research points out the importance of controlling variables, and also provides ideas for future researches on related factors to be found. Meanwhile the results would help provide insight into design improvements or adaptive management for the alleviation of air pollution.

1. Introduction

Particulate matter (PM) is a complex aggregation, and the pollution caused by it is hazardous to human health and environment (Brown et al., 2013; Deng et al., 2019; Kim et al., 2015; Samek et al., 2018). Particulate alleviation by foliar is being extensively studied for its surfaces can act as natural receptors for particulates, which can help intercept them from the atmospheric environment (Rai and Panda, 2014; Zhang et al., 2020). Thus, urban forests are considered to play the role of natural and biological filters in combating airborne PM (Beckett et al., 1998; Beckett et al., 2000; Willis et al., 2017; Yin et al., 2020; Zhang et al., 2019a,b). Some studies have also demonstrated that plants can deteriorate air quality by emitting substances (e.g., biogenic volatile organic compounds (Kumar et al., 2019)) and cause harm to human health, such as asthma (Eisenman et al., 2019; Tong et al., 2015; Xing and Brimblecombe, 2019).

Because of the variations in leaf biological traits, especially between different families or genera, many studies have evaluated the

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interactions between particle deposition and leaf characteristics and reported their beneficial effects. Leonard at al. (2016) found leaf hairs enable the accumulation of significantly more particles (ϕ < 100 μm). The presence of leaf hairs increases the surface roughness of leaves, which can enhance the particle deposition velocity (Weerakkody et al., 2018b; Zhang et al., 2019a,b). On the contrary, Perini et al. (2017) found that leaf hairs removed a lower amount of PM.

Fractal deviation, a measure of the irregularity of an object, is widely used in leaf identification (Backes et al., 2009) and taxonomic analysis (Rossatto et al., 2011). Räsänen et al. (2013) studied the particle capture efficiency of *Pinus sylvestris*, *Betula pendula*, *Betula pubescens*, and *Tilia vulgaris*, and found that a smaller leaf size led to a higher efficiency of particle capture. Weerakkody et al. (2018a) also came to the same conclusion. However, Son et al. (2019) found that the removed amount of PM did not differ depending on the size of leaves, but in terms of the shape of leaves. Zhao et al. (2019) also pointed out that the amount of PM collected on leaves varies with leaf shapes, and a leaf with a complex shape exhibited a greater potential to capture particles (Weerakkody et al., 2017).

The aforementioned studies investigated two major influential aspects of particle deposition in different tree species: trichomes and shape characteristics. However, in some of these studies, investigations of the relationship between a specific factor and deposition velocity may neglect the influences of other factors due to the lack of controlling variables. Therefore, it is necessary to apply a set of treatments for a certain characteristic under natural conditions and control other irrelevant variables to verify the influence of the characteristic on particle deposition.

In this study, we selected 17 tree species and focused on four leaf characteristics: trichome density, aspect ratio, petiole length, and leaf fractal deviation. Plants were chosen from the same family or genus, thus ensuring that all differences observed would be related to the research context, for the investigation of the influence of each individual characteristic and for the formation of a group of treatments at different levels. The dry deposition velocities were determined by a newly invented indirect method. This study examined the relationship between $PM_{2.5}$ deposition and leaf morphological characteristics through application of a control-variable approach. Understanding the leaf morphological characteristics responsible for particle deposition may provide insight into design improvements or adaptive management techniques for the alleviation of air pollution.

This article aimed to answer the following questions:

- Do leaf trichome density, petiole length, aspect ratio, and fractal deviation affect $PM_{2.5}$ dry deposition velocity (V_d)?
- Compared with non-control-variable approach, why does control-variable approach explain better the relationship between V_d and leaf characteristics?

2. Material and methods

2.1. Sample collection

In this study, 17 tree species were chosen as materials (the studied characteristics and corresponding tree species are presented in Table 1). Leaf samples were collected from a plant nursery on Minhang Campus, Shanghai Jiao Tong University (Fig. 1). The trees selected were mature, with steady and healthy growth, and the leaves used in the experiment were gathered from outer canopies at approximately 2/3 of the tree height. We chose three trees of the same species, and each tree was used for one replication of the experiment. Approximately 30–50 broad leaves were collected from each tree. Leaves were washed at least three times with deionized water and dried in a fume cupboard.

2.2. Variables controlling

1) *Lindera glauca* and *Cinnamommum camphora* from Lauraceae family were selected to study the effect of epidermal hairs on V_d. The selected leaf areas of *L. glauca* and *C. camphora* were in the range of 22–26 cm^2, and the petiole length was approximately 2.5–3.0 cm. However, *L. glauca* leaves have epidermal hairs on both sides but *C. camphora* leaves have none.
2) Trichomes are a type of epidermal hair prevalent in *Elaeagnus*, constituting one of its critical plesiomorphic characteristics. However, some interspecies differences exist in trichome density. Therefore, we selected *E. multiflora*, *E. Pungens* 'Aurea', *E. macrophylla*, *E. pungens,* and *E. glabra* as tested species to see if trichome density affects V_d.
3) *Acer truncatum* was selected to study whether petiole length can affect the $PM_{2.5}$ V_d because it has a natural gradient of petiole length according to the position of the branches, and the differences are unaffected by the growth stages of the leaves. Therefore, we used leaves of *A. truncatum* with different petiole lengths to verify the relationship between petiole length and V_d. We picked leaves with a similar shape and leaf area of 30–40 cm^2 and divided them into three groups according to

Table 1
Tree species chosen for the study.

Family	Genus	Species	Target characteristics	Sample description
Lauraceae	*Lindera*	*L. glauca*	presence of epidermal hairs	Leaf area 22–26 cm^2; petiole length 2.5–3.0 cm; same aspect ratio
	Cinnamomum	*C. camphora*		
Elaeagnaceae	*Elaeagnus*	*E. multiflora*	trichome density	Leaf area 12–15 cm^2; petiole length 0.8–1.2 cm; same aspect ratio
		E. pungens		
		E. glabra		
		E. Pungens 'Aurea'		
		E. macrophylla		
Sapindaceae	*Acer*	*A. truncatum*	petiole length	Leaf area 30–40 cm^2; same aspect ratio
Fagaceae	*Quercus*	*Q. nuttallii*	aspect ratio	Leaf length 11–12 cm^2; petiole length 2.3–2.7 cm
		Q. shumardii		
Sapindaceae	*Acer*	*A. buergerianum*	fractal deviation	Leaf area 20–30 cm^2 (except *A. amplum*: 100 cm^2); petiole length 3–5 cm
		A. truncatum		
		A. coriaceifolium		
		A. palmatum		
		A. palmatum 'Dissecrum'		
		A. negundo		
		A. tataricum subsp. *ginnala*		
		A. amplum		

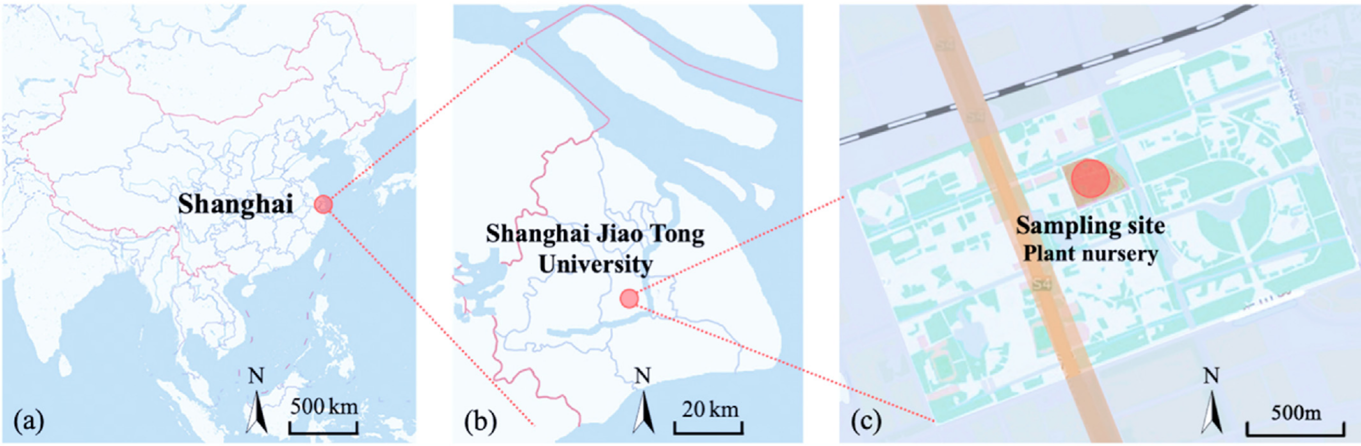


Fig. 1. Study area and sampling site(a) Shanghai, China; (b) Shanghai Jiao Tong University; (c) Plant nursery.

petiole length: *A. truncatum*-1, from the outer canopy (10.7302 cm); *A. truncatum*-2, from the middle canopy (5.9147 cm); and *A. truncatum*-3, from the inner canopy (4.1449 cm).

4) *Q. nuttallii* and *Q. shumardii* were selected to investigate how the leaf aspect ratio can affect V_d. They have similar morphological characteristics except for leaf width. The leaf length of both leaves is in the range of 11–12 cm, and the petiole length is approximately 2.3–2.7 cm, but the leaves of *Q. nuttallii* are wider than those of *Q. shumardii.*
5) *Acer* species are widely used in gardens, and their leaf shapes are very rich. In this study, eight *Acer* species were selected: *A. palmatum* leaves are pinnately divided to have seven lobes; *A. coriaceifolium* have integrifolious leaves with no lobes; *A. buergerianum* and *A. tataricum* subsp. *ginnala* usually have leaves that deeply lobed with incised margins; *A. truncatum* leaves are integrifolious and often pentalobed; *A. negundo* leaves are divided into three leaflets, each of which is integrifolious; and *A. amplum* leaves are larger, with a length of 10–18 cm and width of 9–16 cm. Because of the large interspecies variation in leaf shape, fractal deviation was used in this study. The petiole length and aspect ratio of the leaves from the different tree species used were kept as equal as possible.

2.3. Determination of $PM_{2.5}$ V_d

An indirect method (Yin et al., 2019) was used to determine the $PM_{2.5}$ V_d in an artificial smog chamber. The indirect method is suitable for measuring the V_d of small-scale plants under controlled environmental conditions. We first studied the attenuation pattern of $PM_{2.5}$ in an empty smog chamber. The concentration of $PM_{2.5}$ was exponentially attenuated over time (control curve in Fig. 2). Next, the leaves were placed in the smog chamber, and the concentration of $PM_{2.5}$ was exponentially attenuated, but this time more quickly than when the leaves were not present (test curve in Fig. 2).

On the basis of the slight differences in attenuation rates, the calculation of V_d was derived as Equation (1):

$$V_d(t) = (e^j - e^k)\cdot\frac{V}{LA} \tag{1}$$

where j is the attenuation rate constant of the $PM_{2.5}$ concentration in the empty smog chamber and $j = -0.0010618\ s^{-1}$. This constant is fixed owing to the invariance property of the empty smog chamber. Moreover, k is the attenuation rate constant of $PM_{2.5}$ concentration in the smog chamber with leaves inside and changes according to the leaf areas and properties. LA is the total leaf area of the tested species, and V is the volume of the smog chamber, which is 0.4 m^3.

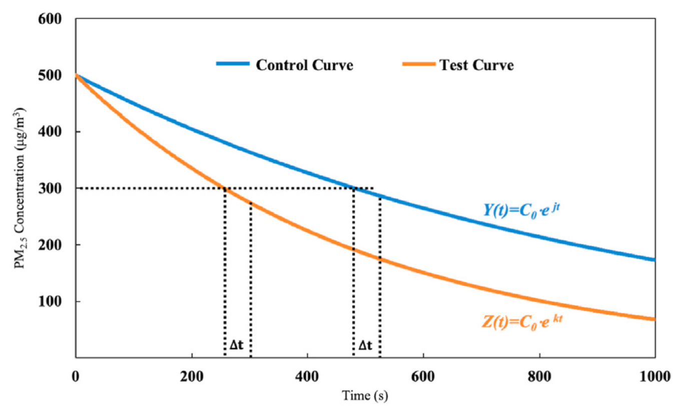


Fig. 2. Exponential decay curves of $PM_{2.5}$ concentration in a smog chamber with (test curve) and without leaves (control curve).

j and k were determined as follows:

1) The washed and dried leaves were fixed with clips in the smog chamber. For each tree species, the angle was adjusted according to its natural growth state to simulate the growth environment with the highest possible accuracy.
2) The smog chamber was filled with nitrogen and then deflated using an air pump, allowing the $PM_{2.5}$ concentration to drop to 10 $\mu g/m^3$. Diamond powder was then injected into the smog chamber to keep the initial concentration of $PM_{2.5}$ at approximately 400 $\mu g/m^3$.
3) The concentration of $PM_{2.5}$ in the smog chamber was monitored with an aerosol spectrometer (Grimm11-R; Grimm Aerosol Technik, Germany), and data were recorded every 6 s. Each test lasted 3000 s.
4) Through data fitting, the value of the attenuation constant k was obtained.
5) Similarly, the value of the attenuation constant j with no leaves in the smog chamber was also obtained.
6) Each tree species was subjected to three replications.

2.4. Trichome density

Leaves were first dried in a lyophilizer for 24 h and then cut into squares (0.5 × 0.5 cm^2). Each sample was sputter coated with gold for 60 s and evaluated through scanning electron microscopy (Sirion 200; FEI, USA). Three images of each species were captured as replications. Trichome density was calculated using the following equation:

$$TD\ (mm^{-2}) = N\ /\ S \tag{2}$$

where *TD* is trichome density, *N* is the number of trichomes, and *S* is the leaf area (mm^2).

2.5. Petiole length, aspect ratio, and fractal deviation

Petiole length, aspect ratio, and fractal deviation were selected as representative shape characteristics that have a great influence on dry deposition. These three indices were acquired using Win-FOLIA (WinFOLIA Pro 2016, Regent Instruments Inc., Canada). The leaves, after determination of V_d, were placed in a scanner, and the software displayed the results directly. Three replications were performed, with 20–30 leaves per replication.

2.6. Data processing

One-way analysis of variance, Duncan multiple comparisons and regression analysis were employed using SPSS (version 25). One-way analysis of variance and Duncan multiple comparisons were used to identify significant differences in V_d, and regression analysis was used to investigate the correlation between V_d and leaf traits chosen in this study. Images presented were processed using Microsoft Excel (2019, version 16.32).

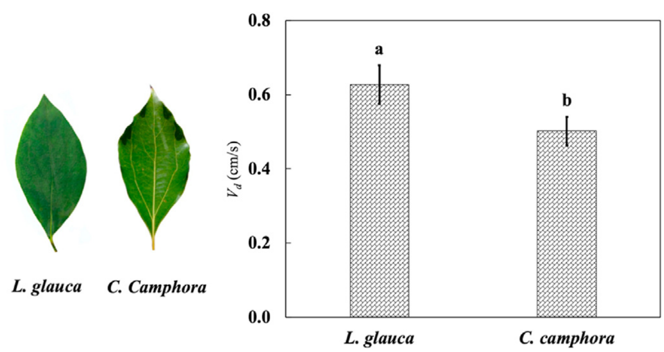


Fig. 3. V_d of *L. glauca* and *C. camphora*. Significant differences in V_d were indicated with different letters (significant level $\alpha = 0.05$, P = 0.028).

3. Results

3.1. Presence of epidermal hairs and $PM_{2.5}$ V_d

Fig. 3 displays that with the presence of epidermal hairs, particles deposition velocity on *L. glauca* leaves (0.627 ± 0.0512 cm/s) is higher than the one on *C. camphora* leaves (0.502 ± 0.039 cm/s) which have no epidermal hairs on either side.

3.2. Trichome density and $PM_{2.5}$ V_d

Through scanning electron microscopy, we counted the trichomes to obtain the trichome density (Table 2). The trichome density and V_d results of five species of *Elaeagnus* are shown in Fig. 4. The ranking of these species in terms of particle deposition velocity was as follows: *E. multiflora* (2.687 ± 0.221 cm/s) > *E. Pungens* 'Aurea' (2.538 ± 0.146 cm/s) > *E. macrophylla* (1.831 ± 0.167 cm/s) > *E. pungens* (1.535 ± 0.139 cm/s) > *E. glabra* (0.992 ± 0.112 cm/s).

After the determination of trichome density, the relationship between V_d and trichome density was studied. The results of regression analysis (Fig. 5) indicated that an increased trichome density can enhance the particle deposition velocity.

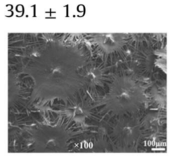
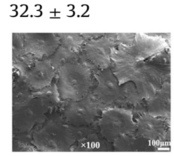
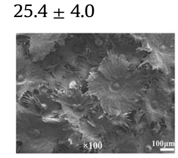
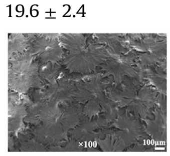
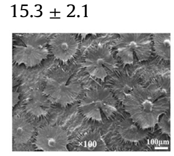
3.3. Petiole length and $PM_{2.5}$ V_d

The V_d of *A. truncatum* with the average petiole length of 10.7302 cm was 0.229 ± 0.011 cm/s, those with the average petiole length of 5.9147 cm had the V_d of 0.343 ± 0.013 cm/s, and the shortest petiole length (4.1449 cm) led to the biggest V_d (0.367 ± 0.006 cm/s). The results of the regression analysis between different petiole lengths of *A. truncatum* and $PM_{2.5}$ V_d are presented in Fig. 6. A longer petiole leads to a lower particle deposition velocity.

3.4. Aspect ratio and $PM_{2.5}$ V_d

The V_d of *Q. shumardii* was 1.185 ± 0.038 cm/s, and that of *Q. nuttallii* was 0.602 ± 0.057 cm/s (Fig. 7). This indicates that compared with the *Q.nuttallii* leaves of higher aspect ratio, those with a lower aspect ratio (*Q. shumardii*) can enhance the particle

Table 2
Scanning images and trichome densities of the five *Elaeagnus* species.

	E. Pungens 'Aurea'	E. multiflora	E. pungens
Trichome density (mm^{-2})	39.1 ± 1.9	32.3 ± 3.2	25.4 ± 4.0
Scanning image			
	E. macrophylla	*E. glabra*	
Trichome density (mm^{-2})	19.6 ± 2.4	15.3 ± 2.1	
Scanning image			

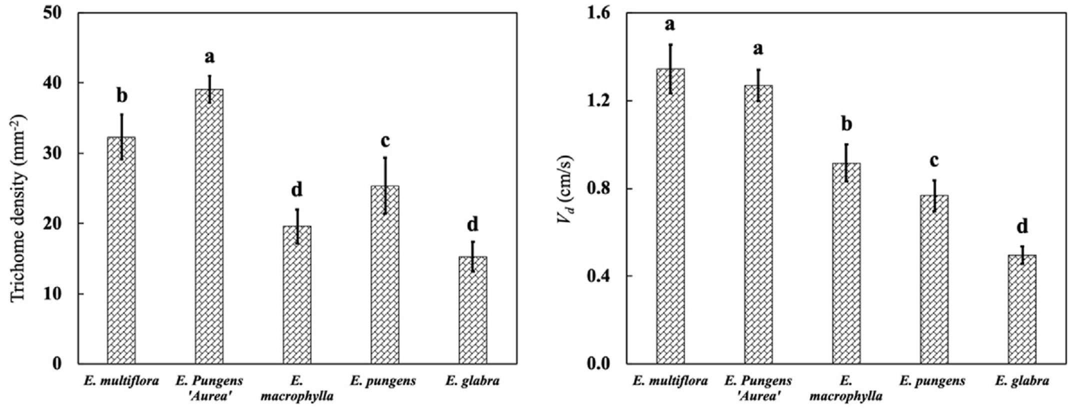


Fig. 4. Trichome density and V_d of *E. multiflora*, *E. Pungens* 'Aurea', *E. macrophylla*, *E. pungens*, and *E. glabra* Significant differences in trichome densities and V_d were indicated with different letters (significant level $\alpha = 0.05$, $P < 0.001$).

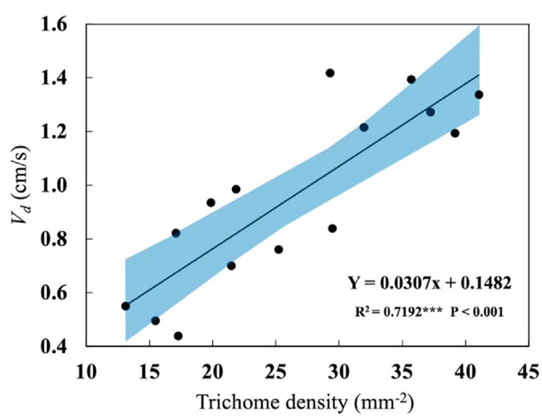


Fig. 5. Regression analysis of V_d and trichome density. The shaded area represents the fitted line of 95% confidence interval.

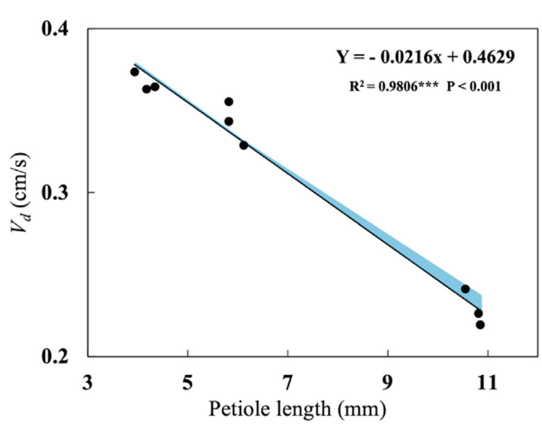


Fig. 6. Regression analysis of the V_d and petiole length of *A. truncatum* The shaded area represents the fitted line of 95% confidence interval.

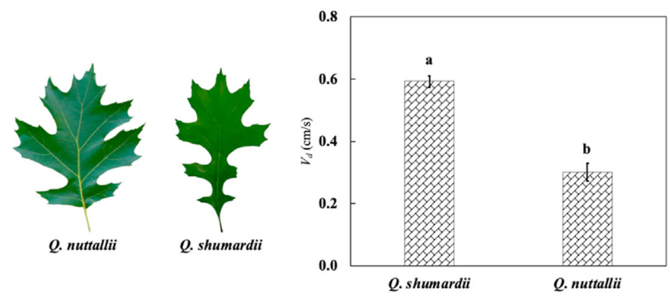


Fig. 7. V_d of *Q. shumardii* and *Q. nuttallii* Significant differences in V_d were indicated with different letters (significant level $\alpha = 0.05$, $P < 0.001$).

deposition velocity (significance level $\alpha = 0.05$; $P < 0.001$).

3.5. Fractal deviation and $PM_{2.5}$ V_d

The leaf fractal deviation and V_d values of eight species of *Acer* are shown in Table 3, and the significant differences are shown in Fig. 8. The results of regression analysis of $PM_{2.5}$ V_d and leaf fractal deviation are displayed in Fig. 9. A positive linear correlation was noted between $PM_{2.5}$ V_d and leaf fractal deviation.

4. Discussion

4.1. Effect of the presence of epidermal hairs and its density on $PM_{2.5}$ V_d

Epidermal hairs are the first point of contact between leaves and particles (Zhang et al., 2019a,b). Weerakkody et al. (2018a) examined the particles captured by four different species and found that more particles were retained in the presence of trichomes than on glossy smooth surfaces. Our study comes to the same conclusions. Also, trichomes play a crucial role in leaf water relations by affecting leaf wettability, droplet retention, and leaf water uptake (Bickford, 2016). Fernández et al., 2011 found that the removal of trichomes from the surface of peaches increased the polar component of surface free energy from 3.8% to 23.6%, leading to a higher dehydration rate.

Moreover, trichomes, as a type of leaf projection can increase the complexity of leaf micromorphology not only in two dimensions but also in three dimensions. They increase the surface area for particle capture and fix the particles to reduce resuspension. Hence, we investigated the resuspension rates of different trichome densities according to the method used by Pullman (2009). We found that resuspension rate and trichome density shared a negative correlation (Table 4), which can eventually affect deposition velocity.

Thus, more trichomes may lead to greater potential for particle deposition (Leonard et al., 2016; Räsänen et al., 2013; Speak et al., 2012), and our findings supported this argument and also helped

Table 3
Scanning images, fractal deviation of the eight *Acer* species and their V_d.

	A. palmatum 'Dissecrum'	A. palmatum	A. buergerianum	A. truncatum
Fractal deviation	0.0102 ± 0.0004	0.0060 ± 0.0004	0.0039 ± 0.0003	0.0036 ± 0.0003
Scanning image				
$PM_{2.5}$ V_d (cm/s)	0.734 ± 0.144	0.702 ± 0.190	0.501 ± 0.029	0.229 ± 0.011
	A. tataricum subsp. *ginnala*	*A. negundo*	*A. coriaceifolium*	*A. amplum*
Fractal deviation	0.0034 ± 0.0002	0.0025 ± 0.0002	0.0023 ± 0.0001	0.0019 ± 0.0004
Scanning image				
$PM_{2.5}$ V_d (cm/s)	0.323 ± 0.154	0.281 ± 0.013	0.530 ± 0.070	0.218 ± 0.015

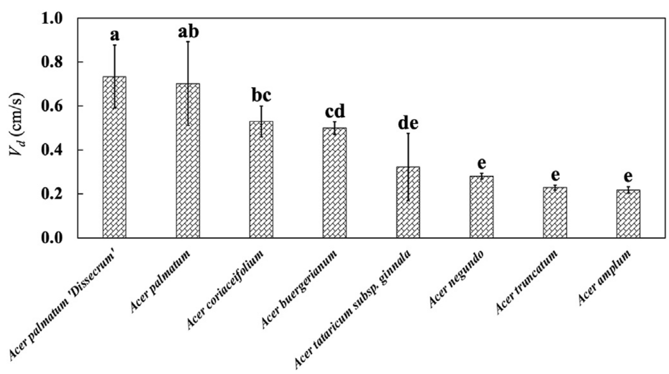


Fig. 8. V_d of eight *Acer* species Significant differences in V_d were indicated with different letters (significant level $\alpha = 0.05$, $P < 0.001$).

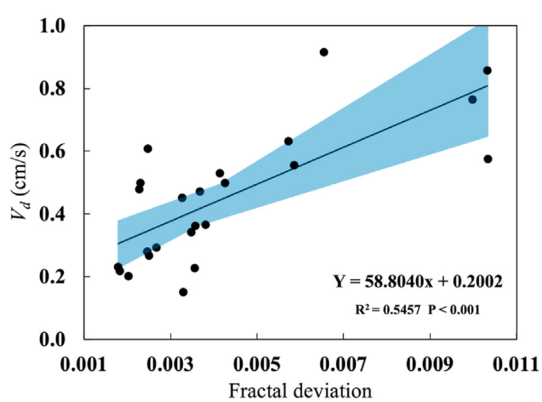


Fig. 9. Regression analysis of V_d fractal deviation of eight *Acer* species The shaded area represents the fitted line of 95% confidence interval.

Table 4
Different trichome densities and petiole lengths and their corresponding resuspension rates.

Species	Resuspension rate (%)	Correlation
E. Pungens 'Aurea'	3.92 ± 1.29	−0.896**
E. multiflora	8.83 ± 3.95	P < 0.001
E. pungens	14.98 ± 1.05	
E. macrophylla	11.47 ± 3.28	
E. glabra	20.78 ± 4.01	
A. truncatum (petiole length 10 cm)	15.51 ± 5.42	0.840**
A. truncatum (petiole length 6 cm)	6.76 ± 2.79	P < 0.005
A. truncatum (petiole length 4 cm)	5.08 ± 1.45	

Note: ** means that the significant level is 0.01.

clarify the conflicting argument between Perini et al. (2017) and Weerakkody et al. (2018b).

4.2. Effect of petiole length on $PM_{2.5}$ V_d

Petiole length can be a crude estimate of potential leaf movement (Anten et al., 2010; Poorter, 2009) and it is also a key factor that can affect particle deposition (Warren, 2015). Our study found that the petiole length and V_d share a negative correlation. This is possibly because a shorter petiole may reduce leaf movement in a windy environment and thereby enhance the velocity of particle deposition (Prusty et al., 2005). By contrast, a longer petiole enables leaves to flutter and causes resuspension (Leonard et al., 2016). We also briefly checked the relationship between petiole length and resuspension rate, and found that they shared a positive correlation (Table 4). Furthermore, Zajączkowska et al. (2015) concluded that trichomes can serve as a reservoir of hydrostatic pressure, which is necessary to ensure that petioles remain in a prestressed state and that the dehydration of trichomes can slow down or prevent leaf reorientation.

4.3. Effect of aspect ratio on $PM_{2.5}$ V_d

Our results showed that a lower leaf aspect ratio can have an impact on enhancing V_d. This helped make clear the debate between Weerakkody et al. (2018a) and Son et al. (2019). Leaf formation reflects its adaptation to the surrounding environment, especially under extreme conditions. Leaf local temperature increases with the square root of the distance from the edge (Vogel, 2009). The narrower, shallower or pinnate leaves help to reduce the convective dissipation, reduce the temperature difference between the leaf surface and the environment, and make the particle attachment more stable. In addition to the temperature-dependent convection at the edge of the leaf, a wider shape also reduces the leaf stability (Leonard et al., 2016). Early studies have implied that narrow-leaved species have better particle-capturing capacity (Freer-Smith et al., 2005; Weerakkody et al., 2017, 2018a). Our results are consistent with this.

4.4. Effect of fractal deviation on $PM_{2.5}$ V_d

Fractal deviation can help describe a leaf shape (Kulkarni et al., 2013), and the larger the fractal deviation, the more complex the leaf shape, resulting in a larger circumference and thus making the leaf more likely to come into contact with particles in the air (Weerakkody et al., 2018b). Also, because of the turbulence caused by leaf resistance to airflow (ff_et_al_2009" title = "bib16">Petroff

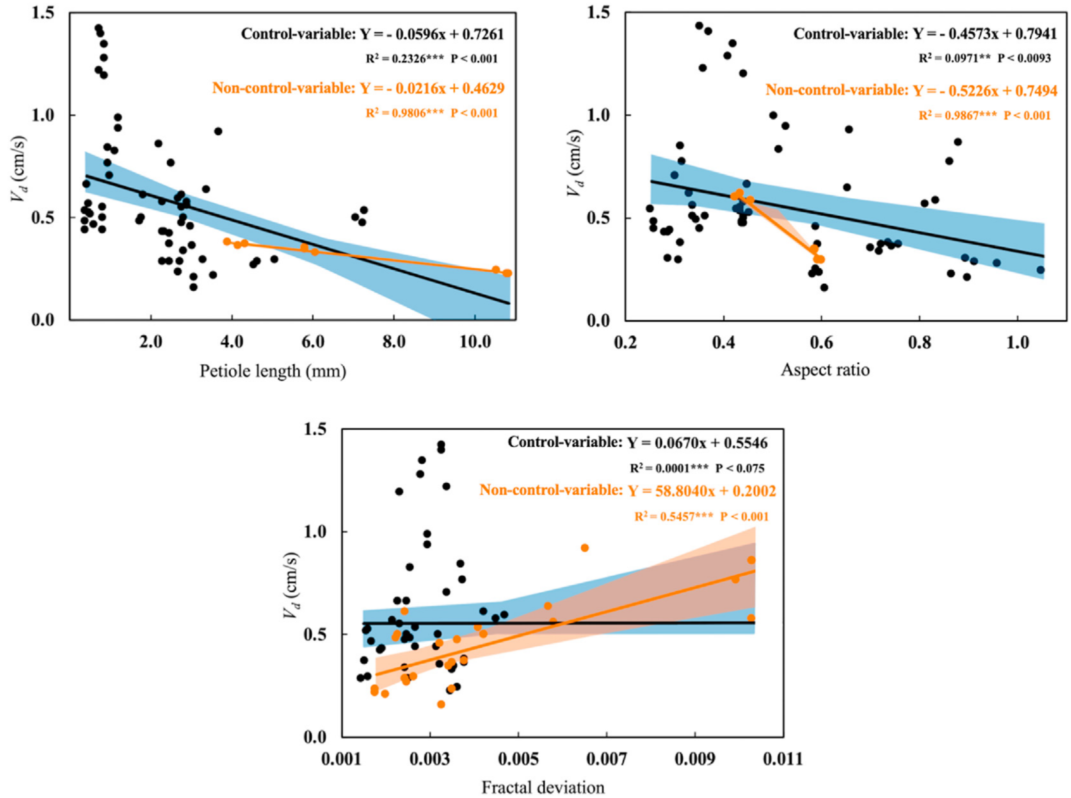


Fig. 10. Regression analysis of V_d and petiole length, aspect ratio and fractal deviation of all the tested tree species The shaded area represents the fitted line of 95% confidence interval.

et al., 2009), the particles are mainly concentrated at the tips and along the edges of the leaves (Weerakkody et al., 2018a); thus, leaves with a larger fractal deviation are more suitable for PM accumulation.

On the basis of the results obtained by investigating trees from the same family or genus, we speculated whether the results will differ when trichome density, aspect ratio, petiole length and fractal deviation are studied, regardless of their family or genus. Therefore, we compared the results between two methods.

As shown in Fig. 10, the results of linear regression between control-variable approach and all the tested species (non-control-variable) differ. It's shown that the correlations between V_d and fractal deviation vary between the methods we used. Through control-variable approach, we found a positive correlation between them (P-value < 0.001), while no correlation (P-value = 0.075 > 0.05) was found using all the tested species, but the correlation between V_d and petiole length (or V_d and aspect ratio) was close, regardless of using control-variable approach or all the tested species. The P-values of both methods are less than 0.001 and the R^2-values are reasonable. The results shown above revealed that the uncertainty caused by not using control-variable approach, such as the studies on trichomes (Perini et al., 2017; Weerakkody et al., 2018b) and leaf shapes (Son et al., 2019; Weerakkody et al., 2018a).

The relationship between leaf characteristics and V_d can be clarified scientifically when control-variable approach is applied. The influences of trichomes (Räsänen et al., 2013; Zhang et al., 2019a,b), petiole length (Leonard et al., 2016; Warren, 2015), leaf shape (Freer-Smith et al., 2005), leaf size (Räsänen et al., 2013) and fractal deviation (this study) can all affect V_d, it's imperative to use control-variable approach to help understand the relationship between V_d and a certain leaf trait while minimizing some other influencing factors. Species from the same family or genus share similar leaf traits, which is a good way to use as a control-variable approach.

In real situations, PM dry deposition velocity can be not only affected by one single morphological characteristic, but also can be influenced by the togetherness of several leaf characteristics. And some factors may be so influential that they may diminish the effect of other factors, thus interfering with our judgment of the results. Therefore, this paper only focused on the effect of the single variable. Also, some external factors, such as meteorological conditions or environmental pollution status, can have an impact on leaves' ability of retaining aerosol particles. Leaf morphological characteristics, PM concentration and meteorological conditions are all crucial to the deposition process. Field tests can be conducted, founded on the conclusions from this study, and investigate how meteorological conditions and environmental pollution status affect particle deposition in practical terms. However, our findings can offer a beneficial suggestion for species selection to optimize vegetation arrangements to filter particles and alleviate air pollution.

5. Conclusions

Leaf morphological characteristics influence the particle deposition velocity. Tree species from the same family or genus were selected to study how trichome density, petiole length, aspect ratio, and fractal deviation individually affect $PM_{2.5}$ V_d by using a control-variable approach.

The presence of leaf trichomes enables the interception of more particles from the environment, and more the trichomes are, more particles can be retained on leaves. The petiole length is also a key factor for affecting V_d. A longer petiole leads to a weaker $PM_{2.5}$ V_d.

Moreover, leaves with a higher fractal deviation (lobed or pinnate, etc.) can also enhance $PM_{2.5}$ V_d.

Our study findings were based on the species from the same family or genus as a control-variable approach. It investigated the impact of one factor independently, while minimizing the impact of other characteristics, which is often ignored in the past experiments. This method allowed us to fathom the relationship between particle deposition velocity and a certain leaf trait. Future studies should figure out more influencing factors using control-variable approach as we proposed. This study can serve as a reference for the design of future experiments for determining the factors influencing V_d.

Credit author statement

Xuyi Zhang: Conceptualization, Methodology, Writing – original draft, Junyao Lyu: Methodology, Investigation, Formal analysis, and Writing, Yuxiao Zeng: Investigation, Reviewing and Editing, Ningxiao Sun: Methodology and Investigation, Chunjiang Liu: Resources, Reviewing and Editing, Shan Yin: Writing – review & editing, and Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2020.116385.

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