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RESEARCH ARTICLE

The morphological structure of leaves and the dust-retaining capability of afforested plants in urban Guangzhou, South China

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Abstract
Purpose Air pollution is a serious health problem throughout the world, exacerbating a wide range of respiratory and vascular illnesses in urban areas. The mass artificial plantation is very helpful to absorb dust and reduce pollution for conservation of the urban environment. The foliar surface of plants is an important receptor of atmospheric pollutants. Therefore, selection of suitable plant species for urban environment is very important.
Methods The dust-retaining capability of urban trees in Guangzhou was determined at four different types of urban area, and the morphological traits of their leaves such as wax, cuticle, stomata, and trichomes were observed under a scanning electron microscope.
Results It was determined that the dust-retaining capability of any given tree species is significantly different in the same place. Of the four studied tree species in the industrial area (IA) and commercial/traffic areas (CTA) type urban areas, the highest amounts of dust removed by *Mangifera indica* Linn was 12.723 and 1.482 g/m^2, respectively. However, in contrast, the equivalent maxima for *Bauhinia blakeana* is only 2.682 g/m^2 and 0.720 g/m^2, respectively. Different plant species have different leaf morphology. The leaf of *M. indica* has deep grooves and high stomata density which are in favor of dust-retained, and thus, their dust-retained capability is stronger, while *B. blakeana* has the cells and epicuticular wax with its stomata arranging regularly, resulting in poor dust catching capability. Leaf size was also shown to be related to dust capture for the four studied tree species.
Conclusions The dust removal capacity of individual tree species should be taken into account in the management of greening plantation in and around an urban area. It was also shown that temporal variation in dust accumulation occurred over the 28-day observation period and this was discussed. Furthermore, spatial contrasts in dust accumulation were evidenced by the data. This reflected the differing pollution loadings of the four urban-type areas. The highest amount of dust accumulation was associated with the industrial area in which shipyard and steelworks occurred whilst the lowest dust accumulation was associated with the grounds of the University which was the control area.

Keywords Morphological features · Foliar dust retention · Trees · Leaf area · Urban Guangzhou

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1 Introduction

Air pollution is a major environmental issue in many cities throughout the world, with particulate pollution being a matter of great concern due to its adverse effect on human health (e.g., influenza, streptococcosis, tuberculosis, rhinovirus and adenovirus infections, eye irritation, respiratory, pneumococcal pneumonia, heart disease, cardiovascular disease, and so on) and the environment (Smith 1977; Nowak et al. 2006; Qiu et al. 2009; Ratnesh et al. 2009; Rai et al.

2010). The report of the World Health Organization, which looked at vehicular emissions of particulates in three European countries, revealed that more people were killed prematurely by the effects of these pollutants than through car accidents (WHO 1999). Trees can intercept atmospheric particles and absorb various gaseous pollutants (including CO_2 sequestration, sulfur dioxide (SO_2), nitrogen dioxide (NO_2)). Vegetated greenbelts have been shown to effectively block dust and filter suspended particles in urban areas (Cavanagh et al. 2009; Wang 2011). Many studies indicate that urban trees have a positive influence on air quality. For example, according to Cavanagh (2008) trees currently remove around 300 t of air pollutants annually from Christchurch, New Zealand. McDonald et al. (2007) estimated that trees currently remove around 4 % of the primary PM_{10} in the West Midlands and 3 % in Glasgow annually, in the United Kingdom. Yang et al. (2005) estimated that trees removed a total of 1,261.4 t of pollutants from the air in Beijing, with a net reduction of 772 t of PM_{10} over a year. Some particles may be absorbed into the tree but most are retained on the plant surface. However, some particles will be re-suspended, but others will be washed off (particularly soluble particulates) or fall to the ground in association with leaves or twigs. Re-suspension of fine particulates is less likely as they are more easily embedded within the leaf boundary layer (Nilsson et al. 2011). To abate the impact of pollutants in urban areas, environmentalists/decision-makers have long been emphasizing the need for a perennial green envelope requiring large-scale afforestation in and around industrial areas and alongside roads (Liu et al. 2008). Afforestation can be applied as a pollution mitigation tool in a variety of urban settings such as industrial areas, housing developments, at historical sites, along highways and protected areas.

It is well documented that plants can effectively adsorb and reduce particulates in the air by capturing the airborne particulate matter such as foliar dust, hydrogen fluoride, SO_2, some compounds of photochemical reactions, and heavy metals such as mercury (Hg) and lead (Pb) from the air on their leaves (Lin 1976; Freer-Smith et al. 1997; Brack 2002; Liu et al. 2008). Plants remove air pollutants by three means: absorption by the leaves, deposition of particulates and aerosols over leaf surfaces, and fallout of particulates on the leeward side of the vegetation (Rawat and Banerjee 1996; Chai et al. 2002). The dust-retention abilities of vegetation depend on several factors, such as the type of tree canopy, leaf and branch density and leaf morphology (roughness, trichomes and concave/convex, etc.), as well as prevailing meteorological conditions (Prusty et al. 2005; Qiu et al. 2009; Rai et al. 2010; Wang et al. 2010). Additionally, leaf orientation and the sessile or semi-sessile nature of leaves play important roles in dust deposition and this is because they determine the surface that is available for dust deposition. Air movement easily disturbs leaves with thin lamina, smooth surfaces, and long petioles. Consequently, such leaves can hold lesser amounts of dust while thick leaves with rough surfaces or hairs on the surface and short petioles can hold relatively large amounts of dust and hence are better collectors of dust (Prusty et al. 2005).

Research quantifying the capturing capacity of individual plant species in urban areas has only received limited attention. The studies cited above that are from China are mainly in the North of the country. In addition studies of the cities of Harbin, Qingdao and Xi' an, conducted by Li and Liu (2008) and Wang et al. (2010) are also located geographically in the North of China. Guangzhou is one of the biggest cities and a major political, industrial and economic center in South China with an area of 7434 km^2 and a population of over 12.7 million. With rapid economic development, the environmental quality of Guangzhou has severely deteriorated. There are few reports on dust removal from the atmosphere by afforested plants in either Guangzhou or South China, and the current study examines the capacity of dust removal by afforested trees in Guangzhou. The objectives of this study are to observe the dust-retention process of individual afforested tree species in different urban areas of Guangzhou and measure the capacity of dust removal of individual tree species. In addition, the morphological structure of leaves will be described and analysis of the relationship between the morphology of the leaf surface and the dust-capturing capability of different plant species will be studied. The study will help to understand the role of trees in decreasing atmospheric dust pollution in a major urban area in South China.

2 Material and methods

2.1 Sampling

Sampling sites Four types of urban area have been identified as being characteristic of urban Guangzhou, namely, industrial areas (IA), residential area (RA), commercial/traffic areas (CTA) and a control area. In each of these urban-type areas, the location of which is shown in Fig. 1, trees were sampled. Trees along major thoroughfares, six residential areas, adjacent to a shipyard and steelworks and on a university campus were sampled.

Species sampled Four species of tree, namely, *Ficus virens* var. *sublanceolata*, *Ficus microcarpa*, *Bauhinia blakeana* and *Mangifera indica*—account for nearly 42 % of landscaping trees in the built-up zone of the city. Therefore, these four species were selected for sampling.

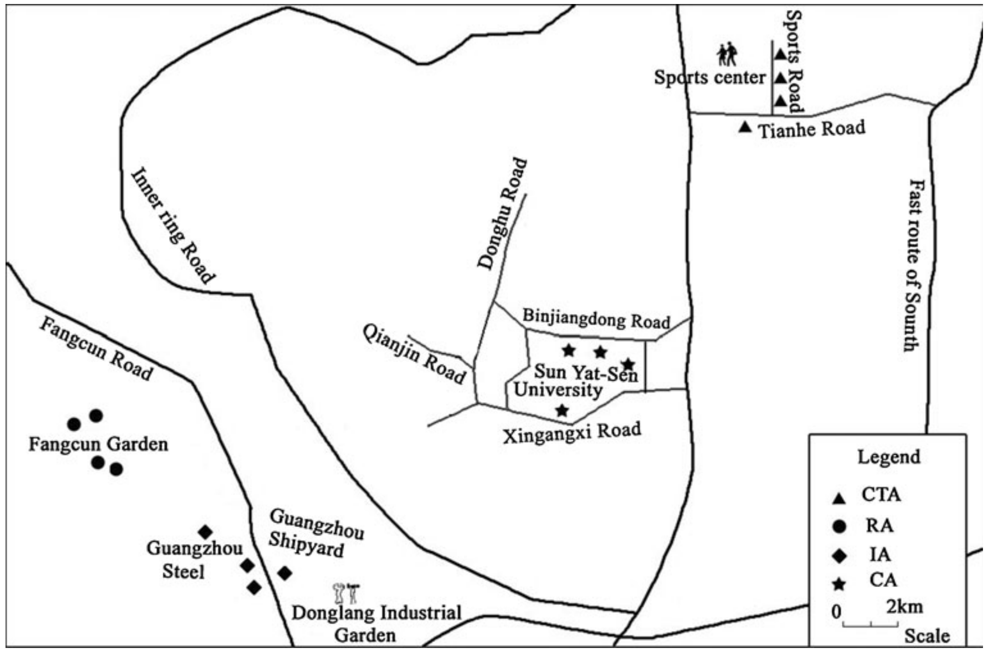

Fig. 1 Locations of Sampling Sites in urban Guangzhou (where CTA, RA, IA, CA in legend represent the commercial/traffic area, the residential area, the industrial area and the control area, respectively).

Sampling methods Generally, precipitation of more than 15 mm can wash the dust off the leaves whilst a wind speed stronger than17 m/s can also remove dust from the surface of leaves, thereby beginning a new dust release-retention cycle for the trees (Zhao et al. 2002). The four species of trees in IA, CTA, RA and CA were sampled seven times during the period October to December 2010 and sampling began in October, 4 days after a period of heavy rain (rainfall 17 mm or more) and strong wind (max. gust wind speed=15 m/s). Sampling continued at 4-day intervals up to 28 days giving a temporal sequence of samples obtained 4, 8, 12, 16, 20, 24, and 28 days after the period of heavy rain and strong wind (which minimized dust stored on the leaves). On any given sampling day, for each tree species in each area (CTA, RA, IA, and CA) five trees were selected for sampling. From each tree mature and healthy leaves were collected from N, W, S, and E facing aspects at a height of 5 m above the ground. The leaves were cut from the plant with clean scissors with the operative wearing polyethylene gloves (Qiu et al. 2009). A sample of around 100 g was collected from each tree and then bulked to give a total of 500 g per tree species per sampling site (five trees times 100 g). The bulk sample of leaves were collected in polyethylene bags and returned to the laboratory. A total of 112 samples were collected for analysis of foliar dust which equates to 4 tree species times 4 sampling areas times 7 sampling days.

2.2 Sample pre-treatment

Upon return to the laboratory, the sampled leaves were immersed in distilled water for 20 min and an ultrasonic cleaning instrument (KQ5200) was applied to separate the attached dust on those leaves (Chen et al. 2003). After 20 min, the leaves were carefully taken out of the distilled water by tweezers. The distilled water was filtered through a dried, pre-weighed filter-paper, whose weight was written as D_1. The filter-paper was subsequently dried for 4 h at 85 °C, and then weighed and recorded as D_2. The difference between the two weights was the weight of dust on the sampled leaves. The area of leaves used to obtain the dust was measured after weighing and then written as S.

$$M = (D_2 - D_1)/S \quad (1)$$

The above Eq. 1 gives the amount of dust removed from leaves (g/m^2), and S was the area of leaves (m^2).

The determination method of the area of leaves for any given sample was as follows. For each tree species, a drill-punch (φ=1 cm) was used to obtain a small ‘disc’ of leaf material with a known area. Multiple ‘discs’ of known leaf area were collected and weighed. This enabled an empirical relationship to be established between leaf area and weight. Consequently, the weight of any leaf sampled could be used to obtain the area of the leaf. An empirical weight versus leaf area relationship was established for each tree species. The leaf area of the collected samples was recorded as S.

2.3 Scanning electron microscopy of the leaves

A scanning electron microscope was used to obtain information on the characteristics of the leaf surfaces of the urban trees. The method used was as follows: small strips (about 1 cm^2) were trimmed from areas between the margin and midrib of leaves, fixed in glutaraldehyde for 4 h (0.2 mol/L phosphate buffer/

25 % glutaraldehyde/double distilled water, 5:1:4), cleaned four times by 0.1 M phosphate buffer, dehydrated through an ethanol series (from 30 % to absolute), replaced with iso-amyl acetate two times, and then dried in a critical point drier using liquid CO_2 at 1,075 psi and 31.4 °C pressure and temperature, respectively. Two pieces of leaf (about 0.5 cm^2) were cut from the dried strips and mounted on stubs, with double-sided adhesive tape, taking care to expose adaxial and abaxial surfaces side by side on the same stub. The specimens were coated with a thin conductive film of gold, in an ion sputter coater (PELCO-SC-7). Coated specimens were examined and photographed under a field emission scanning electron microscope (JSM-6330F, Japan) at an accelerating voltage of 15 kV, at the magnification range of ×400–2,000.

2.4 Data analysis

SPSS 17.0 was applied to carry out the Tukey test determining the significance of treatment means at $P<0.05$. Most graphs were constructed using Excel 2007 and origin 8.5.

3 Results

3.1 The dust-retention process in different urban areas

The amount of dust retained on the leaves of the four tree species in the four types of urban area in Guangzhou are shown in Fig. 2. It can be seen from Fig. 2 that for all four tree species the amount of dust collected in the IA greatly exceeded that held on leaves in the other types of urban area in Guangzhou. The dust removed from the atmosphere by *M. indica* illustrates this point with values of 0.591, 1.190, 1.482, and 12.723 g/m^2, respectively for CA, RA, CTA and IA. For three species, *M. indica*, *F. microcarpa*, and *B. blakeana* the rank order dust accumulation by area was IA > CTA > RA > CA. For *F. virens*, the rank order

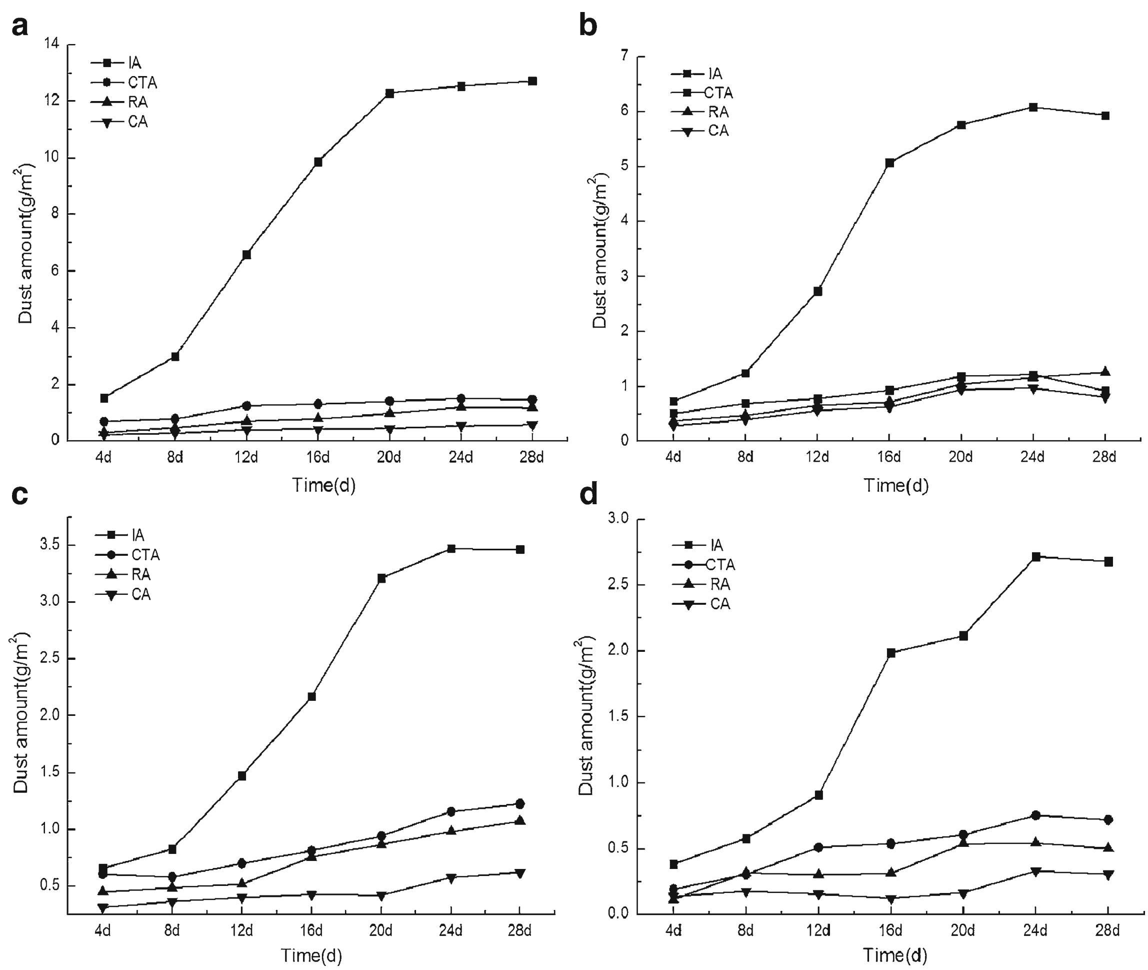

Fig. 2 The dust-retention process of *M. indica*, *F. virens*, *F. microcarpa*, *B. blakeana*. **a** The dust-retention amount of *M. indica* in different urban areas. **b** The dust-retention amount of *F. virens* in different urban areas. **c** The dust-retention amount of *F. microcarpa* in different urban areas. **d** The dust-retention amount of *B. blakeana* in different urban areas

was IA > RA > CTA > CA. All four species exhibited the lowest dust accumulation in the CA.

In terms of temporal patterns of accumulation Figs. 2 and 3 show that the amount of dust retained on the four species of tree increased with time in all four types of urban area. However, Figs. 2 and 3 reveal that for the period of 8 days to 20/24 days in the IA, a much higher accumulation of dust occurred in comparison to the other three types of urban area. The amount of dust in any given urban area is shown in Fig. 3 and it reveals that temporal trends of dust capture were most consistent in the IA (Fig. 3a), with a high accumulation up to 20 days and then a plateau, suggesting saturation of the storage capacity for all four species in this area. For the RA, with the exception of *B. blakeana*, the other three tree species evidence linear accumulation with time up to the cessation of observations at 28 days. The CTA and CA also exhibit accumulation with time and show same evidence of storage being full at 24 days. The Tukey HSD analysis showed no significant difference in the amount of dust retention between 24 and 28 days in all of the urban areas (p=0.985>0.05 and p=0.989>0.05). This suggests that the amount of dust retained approached or reached a maximum within 24 days after a period of heavy rain and then changed little until presumably another heavy rain or wind event began a new cycle.

3.2 The dust-retention process of different plant species

Using all the data from the four types of urban area in Guangzhou there is a significant difference in dust capture between *M. indica* and *B. blakeana*, both of which significantly differ from the two other species (*F. virens* and *F. microcarpa*) with a test statistic for the Tukey test of p=0.007<0.01. Moreover, at each of the four type areas, the data presented in Fig. 3 reveals considerable variation in the amount of dust retained on the leaves of the four tree species. For example, in the IA type area a maxima of 12.723 g/m^2 was recorded on *M. indica* whilst a minimum of 2.682 g/m^2 was observed on *B. blakeana*: the maxima being 4.74 times the minima. Regarding the CTA, a maximum of 1.482 g/m^2 were recorded on *M. indica* which was 2.06 times higher than the minimum of

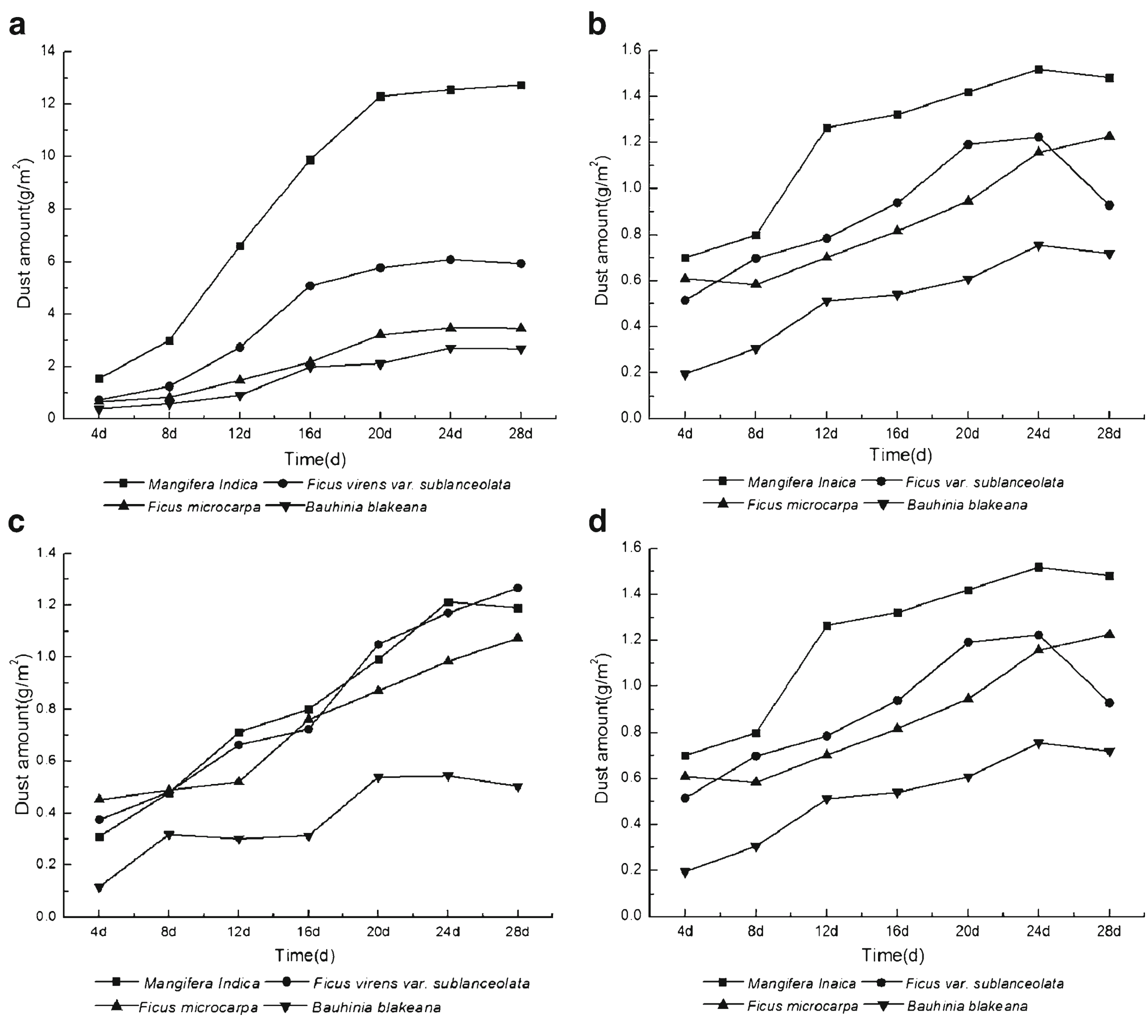

Fig. 3 The dust-retention process of different species in the same place

0.720 g/m^2 recorded on the *B. blakeana*. In the urban-type areas of RA and CA, there is also a range of dust capture by the different tree species, but in contrast to the IA and CTA type areas the maximum capture was always by *F. virens* and the minima by *B. blakeana*. Indeed the data presented in Fig. 3 reveals that of the four tree species used in this study *B. blakeana* recorded the lowest amount of dust in all four urban-type areas in Guangzhou.

Regarding temporal patterns of accumulation Fig. 3a reveals that in the IA urban-type zone the four tree species exhibit a similar pattern with a limited increase in dust amount after 20 days. In the RA urban-type area, with the exception of *B. blakeana*, the other species exhibit a linear rate of accumulation up to the end of monitoring at 28 days (Fig. 3c). A broadly linear pattern of accumulation is also evidence in Fig. 3b for the CTA urban area, although *F. virens* did evidence a decline in dust between 24 and 28 days. In the control area, two tree species, *F. microcarpa* and *M. indica*, exhibited very similar temporal patterns of dust accumulation whilst *F. virens* and *B. blakeana* exhibited varying temporal accumulation (Fig. 3d), however, both exhibited a decrease in dust content at the end of the measurement period.

3.3 Morphological structure characteristics of leaf of different plant species

In Table 1 is presented the surface structural properties of the four tree species used in this study. In terms of leaf shape, Table 1 reveals that *M. indica*, *F. microcarpa*, and *B. blakeana* had distinctive leaf shapes. *F. virens* had oval or ellipse leaf forms, the latter shape overlapping with *F. microcarpa*.

In the scanning electron microscopy (SEM) study, epicuticular wax was observed in granular from (*M. indica* and *F. virens*, Fig. 4a,b) or it could be in the form of a crust (*B. blakeana*, Fig. 4d). Cuticle surfaces of the studied plants are either wrinkled (*M. indica,* Fig. 4e) or smooth (*B. blakeana* and *F. microcarpa*, Fig. 4d, g). Stomata of most of the species under study were either globose, elevated, or slightly sunken and only in *F. microcarpa* are they generally hidden in crypts (Fig. 4c). In the plant of *F. virens*, the stomata were smaller in size, their frequency was higher, and in almost all cases they were level with epidermal cells. Glandular trichomes are observed in *B. blakeana* (Fig. 4d), where it is typically elongate, uniseriate, and multicellular.

3.4 Effect of leaf surface structure on the dust removed amount: evidence from SEM

SEM images of the leaf surface structure of the four tree species are presented in Fig. 4. The stomata density of *M. indica* is 51 under the 400 times magnification. The dust removal capacity of *M. indica* is the strongest, and the glandular is reticular shaped (Fig. 4a,e). Therefore, this leaf structure facilitates the capture of dust. The stomata density of *F. microcarpa* is 17 under the 400 times magnification (Fig. 4c). The dust removal amount of *F. microcarpa* was influenced by irregular convexities on its surface. Only in *F. virens* is the stomata closed and the stomatal density is higher than the other three tree species. From Fig. 4f, the morphological characteristics of *F. virens* shows a visible groove in the leaf. Glandular trichomes are observed in *B. blakeana* (Fig. 4d), where they are typically elongate, uniseriate and multicellular. The surface of *B. blakeana* has crystalline waxes. The structure and morphology of epicuticular waxes is a reliable indicator of plant health, and an important function of the epicuticular wax is to increase the efficiency of stomatal functioning and to reduce leaf water loss (Fig. 4h).

4 Discussion

4.1 Comparison of the dust-retention amounts per unit leaf area

Previous studies have shown that dust-retention capability has variance among different species. Dust-retention capability of keynote trees in Fuzhou as follows: *M. indica*>*F. microcarpa*>*Cinnamomum camphora*>*B. blakeana*; and dust-retention capability of keynote trees in Xiamen as

Table 1 Surface structural properties of the four species of urban tree

No.	Tree species	Shape of leaf	The average of leaf area (cm^2)	Epicuticular wax	Cuticle	Stomata	Trichomes
1	*M. indica*	Lanceolate	76.89	Granular	Wrinkled, sometimes papillose	Globose, slightly sunken	NR
2	*F. virens*	Oval or ellipse	65.30	Granular	Disorganized and wrinkled	Size almost half	NR
3	*F. microcarpa*	Ellipse	15.95	Inconspicuous	Smooth	Stomata in crypts	NR
4	*B. blakeana*	Palmate, almost circular	156.86	Crystal and crust	Smooth	Walls not well defined	Slender, multicellular acute tipped

NR not recorded

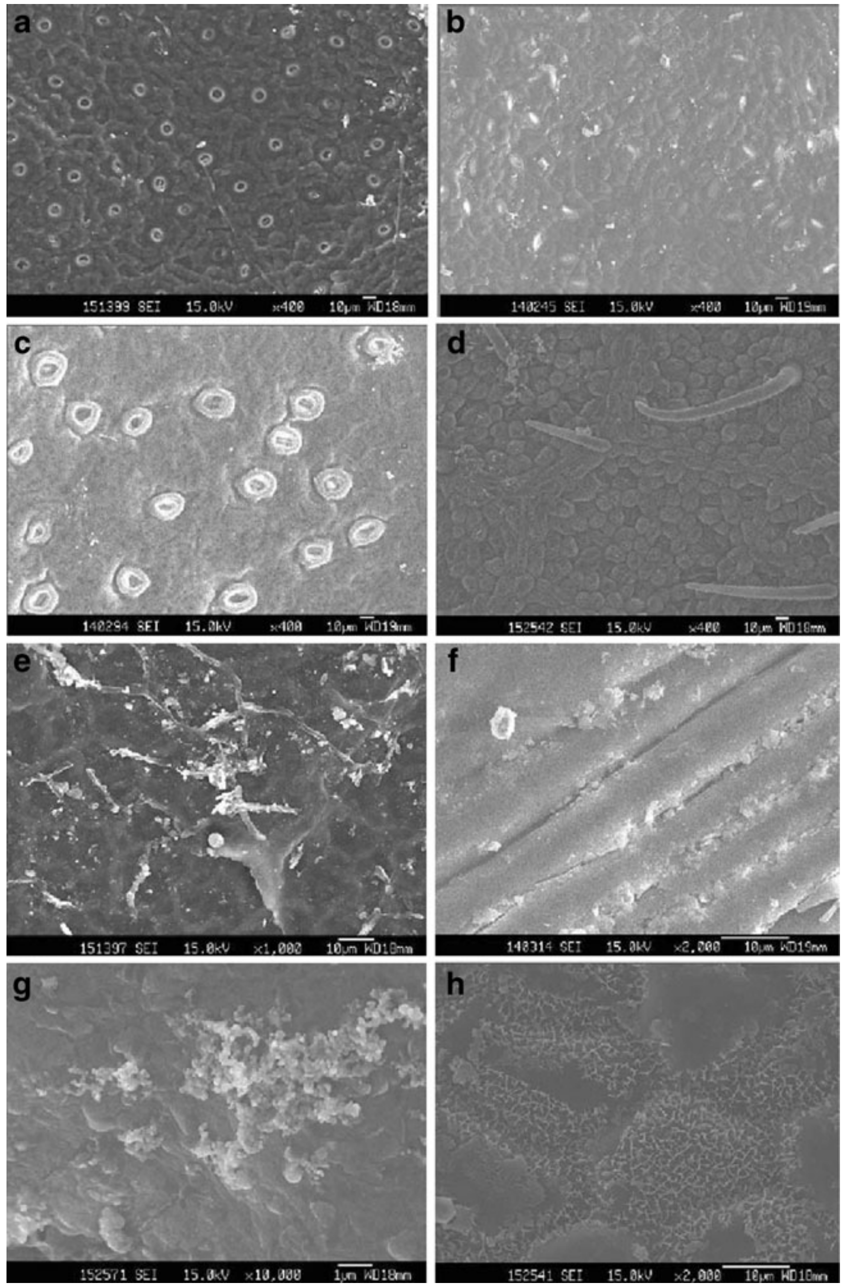

Fig. 4 Scanning electron micrographs of leaves surface: **a** *M. indica*, showing a glandular and stomata. **b** *F. virens*, showing almost closed stomata frequency. **c** *F. microcarpa*, showing a clear stomata. **d** *B. blakeana*, showing an elongated trichome and stomata. **e** *M. indica*, showing a reticular shaped. **f** *F. virens*, showing a deep groove. **g** *F. microcarpa*, showing a irregular convex. **h** *Bauhinia blakeana*, showing normal epicuticular wax

follows: *M. indica*>*Winchia calophylla*>*Ficus altissima*>*B. blakeana* (Cai 2010). In a study conducted in and around Brighton, Sussex, England, Beckett et al. (2000b) show that fine particulate material captured on tree foliage varied with species. Of the five tree species compared, Corsican Pine was the most effective at capturing fine particulates. For the broad-leaf species, at the most polluted site at Withdean Park, maple accumulated most fine particulates. In a study of foliar dust retention along two major highways in Taiwan, Wang (2011) compared ten woody plants at each of two highways. At National Highway no. 1, the highest dust retention on leaves was observed for *Acacia confusa* and *Terminalia boivinii*. The greatest amount of dust retained on leaves was on *Casuarina equisetifolia* and *Pittosporum tobira* along National Highway no. 3. At both study sites, Wang (2011) demonstrates that dust retention on leaves varied considerably between species.

The data from this study in urban Guangzhou indicate that the leaves of different tree species have varying abilities of dust retention. The literature provides additional evidence of variation between species for dust capture by leaves. This variation between species may need to be considered in terms of the selection of tree species for planting programs in urban areas. However, as noted by Yang et al. (2005), tree species and leaf morphology are only two factors that influence air pollution removal ability by trees. Others include the dimensions, growth rate, air pollution tolerance and

BVOC/pollen emission potential, for example. Yang et al. (2005) also identify the need to consider the general suitability of a tree species for the urban environment.

In this study, the maximum amount of dust retained 28 days after a rain event in IA was 12.723 g/m^2 of leaf area for *M. indica*, which was much different from the 2.682 g/m^2 of leaf area observed for *B. blakeana*, a difference of 4.74 times. Under different dust pollution status, as reflected by the four types of urban area, the amount of dust removed by the four urban tree species showed much difference (Fig. 2). With the increasing pollution intensity, the amount of dust removed increased for each sampled species and was at a maximum in the IA. Under less polluted condition (the CA), the dust removed amount is the lowest of the four types of urban area used in this study. To illustrate this point further, for *F. virens*, the difference between the less and heavily polluted conditions is nearly 5.114 g/m^2 24 days after the rainfall. Because the study area (IA) is located in the steelworks and shipyard in Guangzhou, where the particulate matter pollution is serious, so that urban trees in this area have to withstand greater atmospheric pollution loading on the environment, and the foliar dust-retention capacity of trees in this area is obviously high. Other studies have also shown that for the same urban trees under different pollution intensity, the dust removed amount also shows much difference (Liu et al. 2008). This study also showed that the amounts of dust retained on plants were markedly higher in Guangzhou compared to previous studies in a range of cities in China, and this is likely to reflect a higher concentration of dust particles in the atmosphere. In fact, the air quality in Guangzhou has improved in recent years, but it is difficult to bring about a large improvement in a short time. Hence, dust retention, or capture, amounts by leaves on trees in urban Guangzhou are comparatively high.

4.2 Relationship between foliar dust retention and time

Studies have shown that foliar retention and adsorption of dust were subjected to the impact of time, but that the specific time variation depended on the different species and different ambient conditions (Guo et al. 2010). Other reviews have suggested that there was a linear regression relationship between dust capacity and time (Jiang et al. 2003; Gao et al. 2007). The research by Nowak et al. (2000) showed that the dust detention functions of plant varied significantly with the change of season.

The temporal characteristics of dust retention by the four tree species in the four types of urban area in Guangzhou have been documented. Figs. 2 and 3 graphically present the data by urban-type area and species, respectively. As suggested previously, dust accumulation on tree leaves in the IA was noticeably higher for all four species compared to the other areas and Fig. 3a suggests a plateau for all four species after 20 days which may be indicative of saturation of the storage capacity. This is at least partly supported by the fact that in the other three urban-type areas some tree species exhibit approximately linear accumulation patterns up to 28 days. See in Fig. 3, for example, *F. microcarpa* in CTA, *F. sublanceolota* and *F. microcarpa* in the RA, and *F. microcarpa* and *M. indica* in the CA. This approximately linear accumulation pattern for these species is similar to the work of Jiang et al. (2003) and Gao et al. (2007) who have reported a linear regression relationship between dust capacity and time. In terms of temporal accumulation, it is of interest that Fig. 3 reveals that in two urban-type areas, CTA and CA, *F. sublanceolota* exhibits an obvious decline in dust storage between days 24 and 28. This may reflect the leaf properties outlined in Table 1. Table 1 reveals that epicuticular wax is inconspicuous on this species compared to the other three species used in this study and Beckett et al. (1998) have indicated that sticky surfaces on leaves and bark enhances particle uptake by trees. The temporal pattern of accumulation in urban Guangzhou illustrated in Figs. 2 and 3 also illustrates the fact that shortly after rainfall, dust accumulation is comparatively low (4 and 8 day observations), in part because the rainfall has washed the dust out of the air, however, with the drying out of both the atmosphere and the urban surface after the cessation of rainfall more dust is present in the urban atmosphere and hence the dust amount captured by urban leaves increases after the 8 days observation in Fig. 3.

4.3 Plant morphologic characteristics and dust-retention properties

Under identical climatic conditions, urban trees display different dust-retention abilities depending on tree canopy structure, branch density, leaf inclination angle, as well as factors such as leaf morphologic structure characteristics and leaf area (Qiu et al. 2009). The difference of dust capacity between plant species is also determined by foliar morphology characteristics (including the degree of roughness, shape and amount of trichome in upper and lower epidermis of leaves) (Chai et al. 2002). For instance, research has shown that fly ash particles are more easily adsorbed by those leaves with a high surface roughness, leaf hairs, ditch or raphe, mucilage or oil, and those with short petiole (Freer-Smith et al. 1997). The study of Li and Liu (2008) showed that a rough or wrinkled surface, cell arrangement, intensive cilia on the foliar surface could affect the dust removal ability of different species.

The results of this study show that the dust-retention abilities of the four sampled trees decreased in the following order: *M. indica*>*F. virens*>*F. microcarpa*>*B. blakeana*, which roughly follows their decreasing single leaf size ($p < 0.05$). For the four tree species, dust-retention amount increases with the increase of the number of stomata, suggesting that stomata and guard cell more easily absorb dust (Fig. 4a; Table 1). *F. virens* which has a wrinkled form of cuticle and deep grooves which easily detained the dust (Fig. 4b, f). Nevertheless, for *B. blakeana*, which despite having trichomes, had the smallest dust removal capacity of the four studied species; it is leaf size that is critical in controlling dust removal from the atmosphere: *B. blakeana* had the largest leaf size of the trees studied in urban Guangzhou, while the dust-retention amount per unit leaf area was the smallest (Table 1). Meanwhile, *B. blakeana*, which has an epicuticular wax, does not easily absorb dust (Fig. 4h). The different surface morphology of plant leaves have direct effects on the dust removal capacity. Specifically, leaf surfaces with grooves or trichomes have a higher capability of dust retention, while leaves with a smooth surface have a lower capacity for dust retention. This study provides further evidence of the role played by leaf characteristics in controlling dust accumulation on the leaf surface. As noted by Li Haimei (2008), the research on quantification of leaf surface structure/morphology and its association with dust removal need to be further developed.

5 Conclusions

Urban trees have an important role in dust detention in urban areas and this study in the major urban area of Guangzhou, located in the SE of China is an important addition to the literature as most previous studies in China have been carried out in cities in Northern China. In this study, in general, the amount of dust retained per unit leaf area of the four sampled species decreased in the order of *M. indica>F. virens>F. microcarpa>B. blakeana*. This suggests that the dust removal capacity varies between species and there have been comparatively few studies undertaking species specific comparisons in the literature. This variation between species may reflect the nature of the leaves including size, morphology, presence of trichomes, a smooth or wrinkled surface, the presence of wax or a sticky surface, and so forth. Therefore, urban-greening plans needs to take into account of plant species and their dust removal properties. Figures 2 and 3 demonstrate temporal variation in dust accumulation over the 28-day study period and this has been discussed. There is also evidence that atmospheric loading may cause spatial variation in the amount of dust retained on trees. For example, the polluted IA area exhibited the highest amounts of dust capture of the four types of urban area sampled in this study, while the comparatively clean CA had the lowest rates of dust capture. The dust removal demonstrated by the trees in this study provide further evidence of the ability of trees to help in improving the urban environment in terms of public health.

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