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Growth and Physiological Responses of Four Plant Species to Different Sources of Particulate Matter

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ABSTRACT

Background and objective: Particulate matter (PM) has a serious impact on health. Recently, studies are conducted to reduce PM in an environmentally friendly way using plants. This study investigated the physiological responses of plants and their ability to remove PM by continuously spraying different PM sources (loam, fly ash, carbon black) to four native plant species, such as *Iris sanguinea*, *Pteris multifida*, *Vitis coignetiae*, and *Viburnum odoratissimum* var. *awabuki*.
Methods: The four plant species were randomly placed in four chambers, and 0.1 g of different PM was injected into each chamber twice a week. We measured chlorophyll, carotenoid, chlorophyll fluorescence (Fv/Fm), total leaf area, amount of leaf wax, PM10 (sPM10) and PM2.5 (sPM2.5) on the leaf surface, and PM10 (wPM10) and PM2.5 (wPM2.5) on the wax layer.
Results: For *I. sanguinea* and *V. coignetiae*, the sources of PM did not affect the growth response. *P. multifida* showed high chlorophyll a, b, total chlorophyll, and carotenoid content in carbon black as well as high Fv/Fm and total leaf area, thereby proving that carbon black helped plant growth. By PM sources, sPM10 showed a significant difference in three plant species, sPM2.5 in two plant species, and wPM10 in one plant species, indicating that sPM10 was most affected by PM sources.
Conclusion: Carbon black increased the leaf area by affecting the growth of *P. multifida*. This plant can be effectively used for PM reduction by increasing the adsorption area. *I. sanguinea* and *V. coignetiae* can be used as economical landscaping plants since they can grow regardless of PM sources.

Keywords: carbon black, fly ash, landscaping plants, loam, native plants, PM10, PM2.5

Introduction

Environmental pollution caused by industrialization and urbanization affects human health and has a negative influence on mortality and prevalence rates. In particular, each time the concentration of particulate matter (PM) increases by 10 $\mu g\ m^{-3}$, the mortality rates of all illnesses, cardiopulmonary diseases, and lung cancer increase significantly by 4, 6, and 8% respectively (Ebi and McGregor, 2008; Pope et al., 2002). To reduce the concentration of air pollutants, the fundamental solution would be to block or eliminate the sources, which is nearly impossible in the modern society. Thus, it is necessary to study methods to reduce the pollutants in an environmentally friendly way.

Atmospheric temperature, relative humidity, and wind velocity have a huge impact on air quality. Plants are also known to affect air quality. Areas without plants have poorer air quality than those with plants, and the quantity of pollutants

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detected from leaves planted in parks or suburbs is smaller than street trees growing in the city (Li et al., 2019; Ottelé et al., 2010). Plants in areas with poor air quality contribute greatly to reducing the quantity of air pollutants, but their survival may also be negatively affected by PM sources. Therefore, many studies are conducted to choose the optimal plant species suitable for sustainable air quality improvement and regional conditions with an excellent air purifying effect. Zhang et al. (2017) studied the relationship between leaf surface characteristics and PM capture capacity of various tree species for a year in Beijing to select the optimal plant species to use in air quality improvement. As a result, the TSP and PM10 capturing capacity of the leaves of *Pinus tabuliformis* and *Pinus bungeana*, which are needle-leaved trees, decreased at first but then increased over time, whereas *Salix matsudana*, *Acer truncatum*, and *Populus tomentosa*, which are broad-leaved trees, showed opposite results. Zhang et al. (2020) reported that PM capturing capacity of plants, air pollution tolerance index (APTI), and antioxidant systems can be used as indicators to select suitable plant species in green belt construction. Bui et al. (2021) compared the accumulative amount of PM and APTI with 11 species of woody plants and reported that *Pinus strobus* showed the highest PM accumulation and APTI, whereas *Cercis chinensis* showed the lowest.

Urbanization and industrialization are increasing the population staying indoors. Recently, the demand for green buildings is increasing due to the reduction of energy use and greenhouse gas emissions, and the evaluation items of green building certification systems include elements such as indoor pollutants (So and Cho, 2018). Plants serve as dust collector filters for air purification in addition to indoor landscaping, adsorbing and absorbing air pollutants and improving air quality in an environmentally friendly way. Park et al. (2008) conducted an experiment in which they removed formaldehyde using 6 species of ornamental plants and discovered that formaldehyde is removed actively during the day when there is photosynthesis. Moreover, a certain level of concentration that does not damage the plant may also help plant growth. Kim and Yoo (2011) used 3 species of plants such as *Deffenbachia*, *Ficus benjamina*, and *Chrysalidorcarpus lutescens* as well as fine gravel, sand, moss, and *Selaginella* as the pot covering materials to determine the effect on formaldehyde removal efficiency. As a result, the formaldehyde removal rate was highest in *Deffenbachia* regardless of the covering method, and in *Selaginella* for the covering material. Bang et al. (2013) compared PM10 concentrations in three environments such as the control without plants, indoor green walls, and the 'bio green wall system' with functionality and reported that PM10 concentrations decreased by 62% and 72%, respectively, in the general green wall and bio green wall system compared to the control without plants.

A study on PM reduction using plants analyzed the quantity and ingredients of PM sources absorbed and adsorbed on plant leaves, which are spontaneously generated yellow dust and pollutants caused by vehicles (Sgrigna, et al., 2020). In indoor or chamber experiments, cigarette smoke, mosquito coils, and test powder are used as PM sources (Jeong et al., 2020; 2021; Kwon and Park, 2017; 2018; Lee et al., 2015; Yoon et al., 2009; Yoon and Kim 2018). PM is comprised of various components such as carbon (carbon black, organic carbon, organism), ion (chlorine, nitric acid, sulfuric acid, ammonium, sodium, etc.), metal (lead, arsenic, cadmium, mercury, etc.), and polycyclic aromatic hydrocarbon, etc. (Dominici et al., 2015). Therefore, this study is conducted to examine the physiological response of plants toward sources of PM (loam, fly ash, carbon black) as well as PM removal capacity of 4 native plant species such as *Iris sanguinea*, *Pteris multifida*, *Vitis coignetiae*, and *Viburnum odoratissimum* var. *awabuki*.

Materials and Methods

Plant materials

For plant materials, we selected *I. sanguinea*, *P. multifida*, *V. coignetiaer*, and *V. odoratissimum* var. *awabuki* that were proven to have excellent PM reduction capacity in the studies by Kwon et al. (2020; 2021) (Table 1). Each plants were planted

Table 1. Plants used in the experiment

Species	Family	Korean name	Habit
Iris sanguinea	Iridaceae	붓꽃	Perennial herb
Pteris multifida	Pteridaceae	봉의꼬리	Evergreen fern
Vitis coignetiae	Vitaceae	머루	Deciduous vine
Viburnum odoratissimum var. *awabuki*	Caprifoliaceae	아왜나무	Evergreen small tree

in a plastic pot with a diameter of 15 cm using horticultural substrate (Wonjo Mix, Nongkyung, Korea) and grew in a greenhouse, and acclimated in a laboratory environment for 2 weeks.

Experiment method and data analysis

We randomly arranged total 12 pots, 3 pots of each plant, in the acrylic chamber (800 × 800 × 1000 mm, L × W × H) that modeled an indoor space. For photosynthesis of the plants, we installed an LED white light source panel over the acrylic chamber, and the amount of light at the very top of the plants was 75 μmol $m^{-2}s^{-1}$PPFD. We installed a fan on the upper part of the light source to reduce the heat from the light source over the chamber and covered the entire chamber with blackout curtains to minimize the effect of light from the outside. The indoor temperature was set at 25℃ using an air conditioner.

Three PM sources were used: fly ash (JIS Test Powders1 (JIS Z 8901) (Class 10), The Association of Powder Process Industry and Engineering, Japan), loam (JIS Test Powders1 (JIS Z 8901) (Class 11 KANTO (Japanese), The Association of Powder Process Industry and Engineering, Japan), and carbon black (JIS Test Powders1 (JIS Z 8901) (Class 12), The Association of Powder Process Industry and Engineering, Japan). We used the chamber without PM as the control. We put 0.1g of PM in the spray container set up at the center of the top part of the chamber, connected the silicone hose to the outside of the chamber, and sprayed it 5 times a minute using an air gun connected to the compressor, after which we concealed it to prevent inflow of outside air. We injected it twice a week for 90 days.

After injecting PM, we measured chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll (Tchl), carotenoid content, and chlorophyll fluorescence (Fv/Fm) 30 days after treatment (DAT), 60 DAT, and 90 DAT. To measure Chl a, Chl b, Tchl, and carotenoid, we froze the leaf samples with liquid nitrogen and crushed them, extracted supernatant using a centrifuge (Cef-6, DAIHAN, Korea) and measured absorbance at the wavelength of 470 nm, 646.8 nm, and 663.2 nm using a spectrophotometer (UV-1800, SHIMAZU, Japan). The measured values were calculated using the following Equation (1) according to the method by Lichtenthaler et al. (1987).

$$\begin{aligned} &\text{Chlorophyll a} = (12.25 \times A_{663.2} - 2.79 \times A_{646.8}) \\ &\text{Chlorophyll b} = (21.5 \times A_{646.8} - 5.1 \times A_{663.2}) \qquad (1) \\ &\text{Carotinoid} = (1000 \times A_{470} - 1.82 \times \text{Chl a} - 85.02 \times \text{Chl b}) / 198 \end{aligned}$$

Where, $A_{646.8}$, was absorbance at 646.8 nm and $A_{663.2}$, and A_{470} were absorbance at 663.2 and 470 nm, respectively.

Fv/Fm was measured repeatedly 9 times after 30 minutes of dark adaptation using a chlorophyll fluorometer (OS-30P+, Opti-Science, USA). After the experiment, we measured total leaf area, wax content, PM10 (sPM10) and PM2.5 (sPM2.5) on the leaf surface, and PM10 (wPM10) and PM2.5 (wPM2.5) on the wax layer. We measured PM10 and PM2.5 on the leaf surface and wax layer after the experiment using the method by Dzierżanowski et al. (2011). After PM exposure, we collected about 400 cm^2 of leaves from each pot and washed them in 250ml of distilled water, after which we filtered at least 100 μm of impurities using a standard screen, then filtered them one by one using 10-100 μm (Whatman No.91) and 2.5-10 μm (Whatman No.42) filter paper. We dried the filter paper in a dryer (HB-502M, Hanbaek Science, Korea) at 80°C and measured the weight using a analytical balance (AUW220D, SHIMADZU, Japan). The area of leaves used in the filtering process was measured using a leaf area meter (LI-3100C, LI-CO, USA). We divided the difference in weight before and after drying the filter paper by leaf area and calculated the amount of PM per unit area of each plant as $\mu g\ cm^{-2}$. We measured wax layer PM using the same method as the measurement of surface PM after dissolving the same leaves in chloroform. Wax content was measured by filtering all PM and then using the difference in weight before and after filtration of the remaining solution in the beaker. Leaf area was measured by measuring the area of all leaves overground with a leaf area meter (Li-3000A, LI-COR, USA) after the experiment.

Statistical analysis was conducted using SAS 9.3 (SAS Institute Inc., USA), and Duncan's multiple range test (DMRT) was conducted at a 5% significance level to determine the difference in means.

Results and Discussion

Only *P. multifida* showed a significant difference in Chl a, Chl b, Tchl, and carotenoid content depending on PM sources in 30 DAT, 60 DAT, and 90 DAT, while the other three plants did not show a significant difference (Fig. 1). Even though *I. sanguinea* had sufficient acclimation in the laboratory environment, all of Chl a, Chl b, Tchl, and carotenoid content decreased in 60 DAT and increased in 90 DAT in the control and PM sources treatment during the three-month experiment in the chamber, showing a V-shaped pattern. As a result of cultivating *P. multifida* with different concentrations of arsenic in the soil for phytoremediation, which is a biological treatment technology purifying heavy metal in soil, it was found that growth in 50 and 500 mg kg^{-1} treatments was similar to the non-treatment regardless of arsenic type; and as arsenic concentrations increased, growth decreased overall compared to non-treatment (Kwon et al., 2015). Chang and Lee (2005) evaluated tolerance to arsenic and reported that growth of *P. multifida* rather increased with low-concentration arsenic compared to non-treatment. In this study, *P. multifida* seems to show good growth conditions with high values of each measurement item in carbon black, whereas there was no difference with the control in fly ash and loam. *V. coignetiae* and *V. odoratissimum* var. *awabuki* showed a similar pattern of Chl a, Chl b, Tchl, and carotenoid with the control in 30 DAT, 60 DAT, and 90 DAT, showing no significant difference.

Chlorophyll fluorescence reaction shows the effect on environmental stress by nondestructively analyzing the variables detecting quantitative change in photosynthesis photons and the decrease in photosynthesis (Oh et al., 2014). *I. sanguinea* showed a V-shaped pattern in Fv/Fm over time as did in chlorophyll and carotenoid content regardless of PM sources (Fig. 1), indicating that acclimation takes at least a month. Łukowski et al. (2020) exposed three species of woody plants to PM collected from cement, construction sites, and roads, in which case Fv/Fm was significantly lower than the control. In this study, Fv/Fm of *I. sanguinea* and *V. coignetiae* did not show a significant difference depending on PM sources (Table 2). Fv/Fm of *V. odoratissimum* var. *awabuki* increased over time in the control, thereby not showing stress, but it decreased over time when carbon black was injected, showing the lowest value at 0.778 in 90 DAT. Therefore, carbon black helped the growth of *V. odoratissimum* var. *awabuki* up to 30 DAT but inhibited the growth after that. Fv/Fm of *P. multifida* was higher in carbon black and fly ash than the control in 30 DAT, and in carbon black and loam than the control in 60 DAT. There was no significant difference depending on

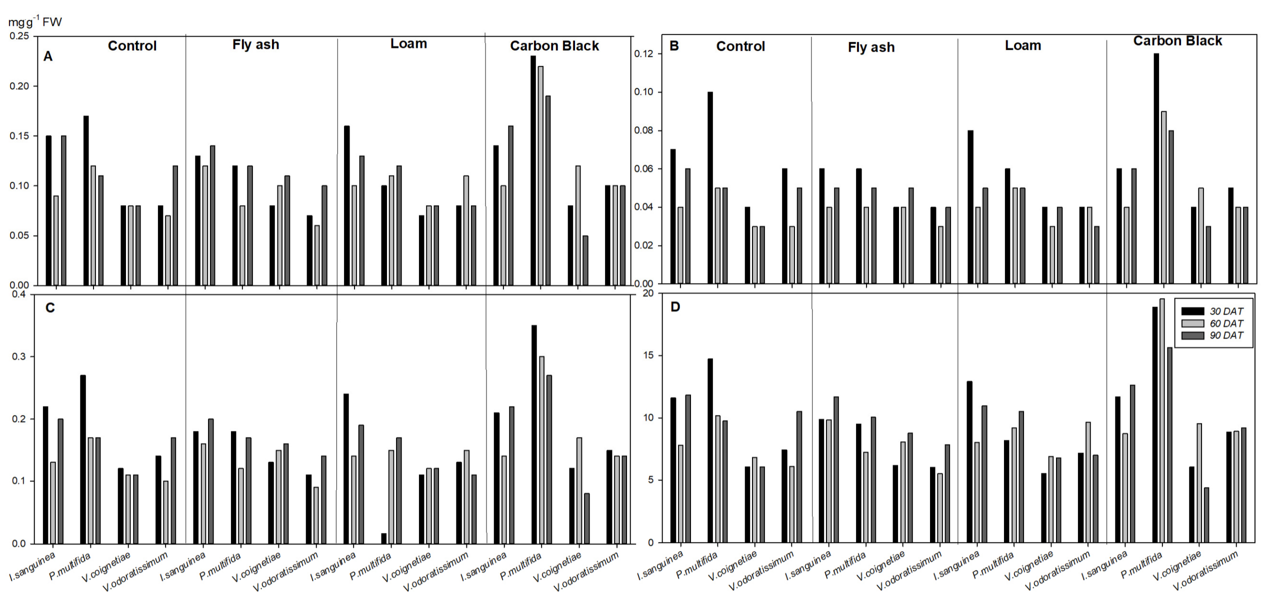

Fig. 1. Comparison of chlorophyll and carotenoid contents according to PM sources. A: Chl a, B: Chl b, C: Tchl, and D: carotenoid.

PM sources in 90 DAT. This is the same as the result that chlorophyll and carotenoid content of *P. multifida* were highest in 30 DAT in carbon black and decreased over time as shown in Fig. 1.

After the experiment, leaf area did not show a significant difference depending on PM sources in three plant species other than *P. multifida* (Table 3). As a result of continuous exposure to PM sources, *P. multifida* showed 2-3 times wider leaf area in carbon black compared to the control and other PM sources. This may have been affected by high chlorophyll and carotenoid content (Fig. 1) and high Fv/Fm (Table 2). However, *P. multifida* showed 2/3 survival rate in 90 DAT and carbon black. Growth may have been inhibited by watering the plant with only a certain amount of water despite the rapid increase in leaf area. Park et al. (2008) conducted an experiment on removing formaldehyde from ornamental plants and revealed that a certain level of concentration that does not damage the plant may rather have a positive effect on plant growth. Łukowski et al. (2020) compared shoot length in each PM with the control and discovered that *Quercus robur* did not show a significant difference by PM sources, whereas *Betula pendula* and *Tilia cordata* showed less growth in certain PM sources compared to the control, which indicates that PM sources may promote or inhibit growth, and thus it is necessary to experiment with various PM sources and plants. Wax content of each plant did not show a significant difference by plants and PM sources after the experiment. However, *I. sanguinea* showed about 2-3 times higher mean in the PM sources than the control,

Table 2. Comparison of chlorophyll fluorescence (Fv/Fm) of each plant according to PM sources

DAT	Species	Control	Fly ash	Loam	Carbon black	Significance
30	*I.sanguinea*	0.784 ± 0.01 a[z]	0.785 ± 0.01 a	0.785 ± 0.01 a	0.795 ± .0.01 a	ns
	P.multifida	0.790 ± 0.02 b	0.805 ± 0.01 ab	0.781 ± 0.04 b	0.825 ± 0.01 a	**
	V.coignetiae	0.777 ± 0.01 a	0.778 ± 0.01 a	0.770 ± 0.02 a	0.786 ± 0.02 a	ns
	V. odoratissimum var. *awabuki*	0.778 ± 0.01 c	0.797 ± 0.01 b	0.800 ± 0.01 b	0.809 ± 0.01 a	***
60	*I.sanguinea*	0.774 ± 0.02 a	0.772 ± 0.01 a	0.756 ± 0.03 a	0.760 ± 0.02 a	ns
	P.multifida	0.757 ± 0.02 b	0.774 ± 0.01 b	0.792 ± 0.03 a	0.794 ± 0.02 a	***
	V.coignetiae	0.769 ± 0.02 a	0.764 ± 0.04 a	0.762 ± 0.03 a	0.751 ± 0.05 a	ns
	V. odoratissimum var. *awabuki*	0.791 ± 0.01 b	0.789 ± 0.01 b	0.812 ± 0.02 a	0.778 ± .002 b	**
90	*I.sanguinea*	0.784 ± 0.02 a	0.787 ± 0.02 a	0.784 ± 0.02 a	0.797 ± 0.02 a	ns
	P.multifida	0.778 ± 0.01 a	0.763 ± 0.05 a	0.766 ± 0.02 a	0.783 ± 0.02 a	ns
	V.coignetiae	0.774 ± 0.02 ab	0.769 ± 0.02 b	0.764 ± 0.04 b	0.794 ± 0.02 a	ns
	V. odoratissimum var. *awabuki*	0.802 ± 0.01 a	0.787±0.01 bc	0.800 ± 0.01 ab	0.778 ± 0.02 c	*

[z]Different letters in the same row indicate significant difference according to Duncan's multiple range test, $p < .05$.
ns, *, **, and *** indicate no significance and significance at at $p < .05$, $p < .01$, and $p < .001$, respectively.

Table 3. Comparison of leaf area and wax content after the end of the experiment

Leaf characteristics	Plant species	Control	Fly ash	Loam	Carbon black	Significance
Leaf area (cm^2/pot)	*I.sanguinea*	257.0 a[z]	138.6 a	167.7 a	250.1 a	ns
	P.multifida	275.5 b	302.9 b	313.7 b	742.4 a	*
	V.coignetiae	134.5 a	116.6 a	126.1 a	168.5 a	ns
	V. odoratissimum var. *awabuki*	258.5 a	261.0 a	310.4 a	306.3 a	ns
Wax content (μg cm^{-2}/pot)	*I.sanguinea*	45.1 a	151.1 a	115.3 a	138.8 a	ns
	P.multifida	72.9 a	61.9 a	49.2 a	44.6 a	ns
	V.coignetiae	69.0 a	60.8 a	69.2 a	52.6 a	ns
	V. odoratissimum var. *awabuki*	146.3 a	142.7 a	133.3 a	175.3 a	ns

[z]Different letters in the same row indicate significant difference according to Duncan's multiple range test, $p < .05$.
ns, and * indicate no significance and significance at at $p < .05$, respectively.

and *V. odoratissimum* var. *awabuki* showed about 2-3 times higher wax content than the other three plant species.

We measured the PM per unit leaf area on the leaf surface (sPM10, sPM2.5) and PM on the wax layer (wPM10, wPM2.5) in 90 DAT (Table 4). sPM10 did not show a significant difference in only *P. multifida*, whereas in the other three plant species, it was the same as the control in carbon black and higher than the control in fly ash and loam. *P. multifida* did not show a significant difference in sPM10 by PM sources, but sPM2.5 showed a significant difference, mostly in loam. Łukowski et al. (2020) also revealed that *Quercus robur* did not show a difference in total PM depending on PM sources, and *Betula pendula* showed a significant difference only in cement out of three sources of PM (cement, construction, and roadside PM). *I. sanguinea* showed a significant difference in wPM10 by PM sources, whereas other wPM did not show a significant difference by PM sources. *I. sanguinea* showed a significant difference in wax content (Table 3) by PM sources, but the mean was 2-3 times higher in treatment, implying that wax content and wPM10 of *I. sanguinea* may have affected each other. In general, sPM is higher than wPM in many studies (Przybysz et al., 2014: Popek et al., 2017: Bui et al., 2021). However, in a study by Przybysz et al. (2014), wPM was higher than sPM in *Pinus sylvestris* in February when there is much rainfall, and there was more wax content than other seasons as well. *Hedera helix* showed high sPM at all times regardless of precipitation and also consistent wax content. Therefore, certain plants like *I. sanguinea* and *Pinus sylvestris* increase wax content and accumulate PM sources on the wax layer against non-hydrophilic PM sources that are not easily washed away with water.

Conclusion

This study examined physiological responses and PM removal capacity of four native plant species such as *I. sanguinea*, *P. multifida*, *V. coignetiae*, and *Viburnum odoratissimum* var. *awabuki* by constantly spraying different PM sources (loam, fly ash, carbon black). PM sources did not affect physiological responses of *I. sanguinea*, but wax content was 2-3 times higher in the PM sources compared to the control. The amount of

Table 4. The amount of particulate matter (PM) on the leaf surface and wax layer according to PM sources

PM	Species	The amount of PM (μg・cm^{-2})				Significance
		Control	Fly ash	Loam	Carbon black	
sPM10	*I.sanguinea*	13.1 ± 4.6 b[z]	44.3 ± 8.5 a	48.2 ± 9.5 a	10.8 ± 2.9 b	***
	P.multifida	57.9 ± 14.9 a	97.6 ± 38.4 a	83.1 ± 35.6 a	43.3 ± 24.2 a	ns
	V.coignetiae	19.8 ± 7.1 b	64.1 ± 14.6 a	75.7 ± 22.9 a	26.5 ± 16.3 b	**
	V. odoratissimum var. *awabuki*	20.0 ± 1.7 c	55.9 ± 4.5 a	49.8 ± 3.5 b	16.9 ± 1.6 c	***
sPM2.5	*I.sanguinea*	1.8 ± 1.0 a	24.8 ± 33.2 a	7.4 ± 1.2 a	4.8 ± 2.3 a	ns
	P.multifida	6.0 ± 2.1 b	9.4 ± 3.9 b	38.7 ± 0.3 a	5.7 ± 2.6 b	***
	V.coignetiae	1.8 ± 2.0 a	7.0 ± 1.1 a	11.3 ± 11.0 a	5.8 ± 2.5 a	ns
	V. odoratissimum var. *awabuki*	0.3 ± 0.4 b	4.8 ± 2.26 a	5.6 ± 1.5 a	4.3 ± 0.6 a	**
wPM10	*I.sanguinea*	13.5 ± 4.9 b	63.4 ± 11.8 a	70.2 ± 19.0 a	52.2 ± 33.0 a	*
	P.multifida	38.6 ± 8.4 a	45.7 ± 15.8 a	38.8 ± 2.3 a	28.5 ± 10.9 a	ns
	V.coignetiae	26.3 ± 20.1 a	34.3 ± 13.8 a	37.9 ± 18.0 a	23.1 ± 17.4 a	ns
	V. odoratissimum var. *awabuki*	8.1 ± 2.5 a	11.6 ± 7.2 a	6.7 ± 2.3 a	7.2 ± 3.7 a	ns
wPM2.5	*I.sanguinea*	2.8 ± 2.2 a	5.7 ± 1.5 a	2.6 ± 2.0 a	5.2 ± 2.2 a	ns
	P.multifida	1.5 ± 0.6 ab	1.6 ± 0.8 ab	4.0 ± 2.8 a	1.0 ± 0.1 b	ns
	V.coignetiae	6.9 ± 3.8 a	11.2 ± 4.1 a	15.1 ± 8.2 a	9.9 ± 8.2 a	ns
	V. odoratissimum var. *awabuki*	1.4 ± 0.7 b	1.8 ± 0.3 ab	2.6 ± 0.5 a	2.1 ± 0.4 ab	ns

[z] Different letters in the same row indicate significant difference according to Duncan's multiple range test, $p < .05$.
ns, *, **, and *** indicate no significance and significance at at $p < .05$, $p < .01$, and $p < .001$, respectively.

sPM10 was highest in fly ash and loam, whereas that of wPM10 was highest in all three PM sources. Therefore, *I. sanguinea* can be used effectively in removing PM10. *P. multifida* showed high Chl a, b, Tchl, and carotenoid content in carbon black in the 30 DAT, as well as high Fv/Fm and total leaf area after the experiment, thereby proving that carbon black helped plant growth. There was no significant difference in sPM10 and wPM depending on PM sources. However, sPM2.5 was high in fly ash and loam. Therefore, *P. multifida* can be used effectively in removing carbon black by planting it in areas with high carbon black concentration in the air. For *V. coignetiae*, PM sources did not affect growth, and there was no significant difference in PM amount except sPM10. However, it can be used as an economical landscaping tree since it can grow regardless of PM sources. *V. odoratissimum* var. *awabuki* showed lower Fv/Fm over time in the PM sources until 90 DAT, which shows that it must be observed longer. There was no significant difference in wPM, while sPM10 was highest in fly ash and loam. The amount of sPM2.5 was highest in all three PM sources, indicating that this plant is more effective in adsorption than absorption of PM.

Effective plants are selected by measuring the number of particles or weight, since there are limited PM sources that can be used as PM sources in PM removal experiments using plants. However, PM that are actually generated vary depending on the place, such as yellow dust, chemical plants, cement factories, and construction sites. Therefore, it is necessary to select effective plants based on characteristics of regional PM sources.

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