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Research article

Effects of roadside dust on biochemical properties of selected ornamental plants in Kathmandu Valley

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Abstract

Dust pollution is a major problem in cities of developing countries. The foliar surface of plants serves as a continual interface with the surrounding atmosphere, making it the primary recipient of dust particles. This inherent characteristic allows for assessing the ambient dust levels and the capacity of various plant species to intercept and alleviate it. This study aimed to investigate the efficiency of dust deposition among common roadside plant species and its effects on leaf biochemical properties, including pH, relative water content, and total chlorophyll content. Among the plant species studied, *Malvaviscus arboreus* exhibited the highest dust deposition on its leaf surface, while *Pyrostegia venusta* showed the lowest. The results revealed that the maximum dust deposition occurred during the post-monsoon season compared to the pre-monsoon season in all plant species. Dust deposition demonstrated significant positive correlations with relative water and ascorbic acid content, while its relationships with total chlorophyll levels and leaf extract pH were negative. This study suggests that certain roadside plant species can tolerate higher levels of dust pollution and thus can serve as effective natural filters, contributing to the mitigation of dust pollution in urban environments.

Keywords: Ascorbic acid, chlorophyll content, dust load, pH, relative water content.

Introduction

Airborne particulate matter (PM) encompasses a complex mixture of solid particles, gases, and liquid droplets (Davidson *et al.* 2005). Fine particulate matter (a collection of particles in the air that are 2.5 µm or less in diameter) is particularly worrisome due to its respirable nature, leading to adverse effects on human health and vegetation (Zhang *et al.* 2015). Road dust is an important source of PM and the most hazardous pollutant in urban areas because such dust contains toxic trace elements, among others (Gunawardana *et al.* 2012; Zhang *et al.* 2015). The increased dust deposition particularly affects vegetation along highways and roads affecting physiological and biochemical aspects of plant species. Dust deposition causes alterations in the pH and relative water content of plants and potentially impacts essential plant processes, such as photosynthesis, respiration, stomatal functioning, transpiration, and overall productivity (Ahmed and Quadir 1975; Farmer 1993; Joshi *et al.* 2009). Studies have shown that dust deposition on plants reduces chlorophyll content, increases ascorbic acid levels, and accelerates the process of senescence (Gavali *et al.* 2002).

Roadside vegetation plays a crucial role as a natural filter by capturing dust particles on leaf surfaces (Ahmed *et al.* 2009). This process significantly contributes to enhancing air quality. Leaves act as effective pollution receptors and can actively contribute to reducing airborne dust levels (Lorenzini *et al.* 2006; Sæbø *et al.* 2012). Various trees and shrubs, along with specific leaf traits, have been identified, which can serve as practical tools in air pollution biomonitoring and mitigating the increased urban dust pollution (Fusaro *et al.* 2021; Rodríguez-Santamaría *et al.* 2022; Steinparzer *et al.* 2023).

Dust pollution is a major problem in cities of developing countries. Many developed cities and nations, including London, UK (Meetham 1964), Russia (Novoderzhikina *et al.* 1969), and Ohio, USA (Dochinger 1980), have embraced the utilization of vegetation to combat dust pollution. Several researchers, such as Varshney and Mitra (1993), Rai and Panda (2014), and Devkota *et al.* (2023), have conducted studies on plants employed for biomonitoring dust loads. Vegetation along roadsides, comprising trees, shrubs, and dense hedges, has been found to play a crucial role in effectively mitigating the detrimental impact of gaseous and particulate pollutants (Ahmed *et al.* 2009).

The present study aimed to investigate how dust deposition affects the biochemical parameters, including pH, relative water content (RWC), and total chlorophyll content of roadside plants. The objective was to identify tolerant plant species that can potentially control the future impact of dust pollution. Additionally,

Figure 1. Map showing the six specific study sites in Kathmandu Valley.

Table 1. Common names, habits, and leaf characteristics of the plant species studied.

Plant species	Common name	Family	Nature	Leaf shape	Leaf surface/leaf lamina
Hibiscus rosa-sinensis L.	China rose	Malvaceae	Shrub	Ovate	Glabrous, flat
Jasminum multiflorum (Burm.f.) Andrews	Star jasmine	Oleaceae	Shrub	Ovate	Tomentose
Malvaviscus arboreus Cav.	Turk cap or sleeping hibiscus	Malvaceae	Shrub	Ovate-cordate	Pubescent, flat
Pyrostegia venusta (Ker.Gawl.) Miers	Flame vine/ orange trumpet vine	Bignoniaceae	Creeper/ climber	Ovate	Slightly smooth, slightly curled

the study also aimed to explore potential relationships between dust deposition and the biochemical parameters of plant leaves. The findings from this study can contribute to future research focused on mitigating dust pollution by selecting suitable plant species with tolerance capabilities. We analyzed the relationship between dust deposition and various physiological parameters in selected ornamental plant species commonly grown along the roadsides in the Kathmandu Valley.

Materials and methods

STUDY AREA

The research was conducted in the Kathmandu Valley, central Nepal. A preliminary survey was conducted, which identified six specific sites in the valley (Figure 1). These sites were categorized based on peak-hour traffic observations, resulting in the classification of two heavily polluted (Swoyambhu and Satdobato), two moderately polluted (Harisiddhi and Chobar), and two control (Tribhuvan University area and Godawari) sites. The study focused on analyzing the distribution of vegetation along roadsides in the selected sites.

PLANT SPECIES

In this study, four commonly occurring ornamental plant species of the Kathmandu Valley — *Hibiscus rosa-sinensis* L., *Jasminum multiflorum* (Burm.f.) Andrews, *Malvaviscus arboreus* Cav., and *Pyrostegia venusta* (Ker.Gawl.) Miers — were selected for detailed investigation. The morphological characters of the species included in the present study are presented in Table 1.

LEAF SAMPLING, ESTIMATION OF THE AMOUNT OF DUST, AND BIOCHEMICAL ANALYSIS

Plant species growing along the roadside were selected from March to May and October to November 2020. Ten fully matured leaves from each species were randomly collected to assess dust accumulation, chlorophyll content, relative water content, leaf extract pH, and ascorbic acid levels. The leaves were collected early in the morning from the lower branches (at a height of 2–4 m) and quickly transported to the laboratory in polythene bags kept in iceboxes for further analysis (Rai and Panda 2014).

Determination of dust amount: The following formula was used to calculate the amount of dust (Prajapati and Tripathy 2008).

$$W = \frac{W2 - W1}{A}$$

where, W = total amount of dust (g/m^2), W_1 = weight of leaf without dust, W_2 = weight of leaf with dust, and A = total leaf area in m^2.

Estimation of chlorophyll content: The spectrophotometric method of Arnon (1949) was followed for measuring chlorophyll content. Fresh leaves (0.25 g), taken in a clean mortar with 30 ml of 80% acetone, were finely ground and filtered. After filtration, the remaining tissues were again ground with 80% acetone and filtered. The final filtrate was adjusted to a total volume of 50 ml by adding 80% acetone. The optical density of the extract was measured using a spectrophotometer at 645 nm, 652 nm, and 663 nm against 80% acetone as a blank. The concentrations of chlorophyll a, chlorophyll b, and total chlorophyll were calculated using the following formulae (Arnon 1949):

$$\text{Chl. a (mg/g)} = [12.7(\text{OD}663) - 2.69(\text{OD}645)] \times \frac{v}{1000 \times W}$$

$$\text{Chl. b (mg/g)} = [22.9(\text{OD}645) - 4.68(\text{OD}663)] \times \frac{v}{1000 \times W}$$

$$\text{Total Chl. (mg/g)} = \frac{\text{OD}652 \times 1000}{34.5} \times \frac{v}{1000 \times W}$$

where, Chl. = chlorophyll, OD = optical density reading, V = volume of the acetone-chlorophyll extract, and W = fresh weight of the plant material.

Relative water content: The moisture content of plant material was expressed as relative water content (RWC). Fresh leaves were taken, washed with distilled water, and weighed. The leaves were then immersed in distilled water overnight, blotted dry, and their turgid weight was recorded. After this, the leaves were dried in an oven at 70^{0}C for 24 hours and reweighed to determine their dry weight. The relative water content was then calculated using the following formula (Tsega and Prasad 2014).

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Leaf extract pH: A sample of fresh leaves (1 g) was homogenized with 10 ml of distilled water. The pH of the resulting extract was then measured using a pH meter (Tsega and Prasad 2014).

Ascorbic acid content: A sample of fresh leaves (1 g) was extracted with 4 ml of oxalic acid-EDTA extracting solution, 1 ml of orthophosphoric acid, 1 ml of hydrochloric acid (5%), 2 ml of ammonium molybdate, and 3 ml of distilled water. The solution was then left to stand for 15 minutes, after which its absorbance was measured at 760 nm using a spectrophotometer. The ascorbic acid concentration in the sample was determined by extrapolating from a standard ascorbic acid curve (Tsega and Prasad 2014).

STATISTICAL ANALYSIS

The effects of seasons and sites with different pollution levels on dust load and biochemical properties of roadside plant species were assessed through the two-way analysis of variance. We compared the mean biochemical characteristics and dust load on leaf surfaces among plant species considering two-way interactions between plant species and seasons, seasons and sites, and sites and plant species. We performed Duncan's multiple range tests to assess the difference in the mean values of dust load and biochemical parameters among sites. We calculated Pearson correlation coefficients to measure the relationships between dust load and leaf biochemical parameters. All the analyses were performed using SPSS version 20 (IBM Corporation 2011).

Results

DUST ACCUMULATION

Dust accumulation on leaf surfaces significantly differed among plant species studied, between two seasons, and among different locations ($p<0.001$; Figure 2, Table 2). The highest mean dust load was found on the leaves of *Malvaviscus arboreus* (1.73 mg/cm^2), followed by *Jasminum multiflorum* (0.90 mg/cm^2), *Hibiscus rosa-sinensis* (0.54 mg/cm^2) and *Pyrostegia venusta* (0.51 mg/cm^2).

Plants from the polluted site showed the highest dust load than those from the moderately polluted and control sites (Table 2). For each species and site, dust deposition on the leaves varied with season, the high deposition occurred in the post-monsoon than in the pre-monsoon season. Dust deposition was found to be maximum in *Malvaviscus arboreus* (2.02 mg/cm^2) during the post-monsoon season, and minimum in *Pyrostegia venusta* (0.069 mg/cm^2) during the pre-monsoon season (Figure 2).

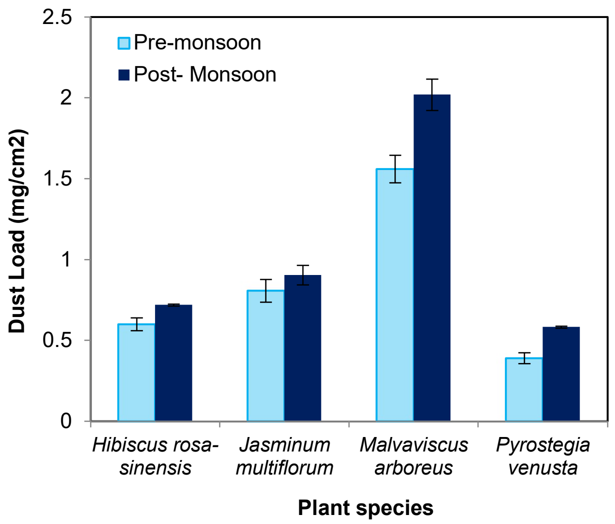

Figure 2. Dust load (mg/cm^2) in four roadside plant species during pre- and post-monsoon seasons.

TOTAL CHLOROPHYLL CONTENT

The leaf chlorophyll content varied significantly among the roadside plant species studied ($p<0.001$), the mean values of which had a range of 1.64–2.17 mg/g (Table 3). *Jasminum multiflorum*

Table 2. Dust accumulation on leaf surfaces (mg/cm^2) of four roadside plant species across three sites and two seasons.

Plant species	Highly polluted site (HPS)	Moderately polluted site (MPS)	Control site (CS)	Mean (species)
Hibiscus rosa-sinensis	1.20 ± 0.05^c	0.29 ± 0.06^b	0.13 ± 0.005^a	0.54 ± 0.05
Jasminum multiflorum	1.12 ± 0.02^c	0.23 ± 0.03^a	0.25 ± 0.006^a	0.90 ± 0.49
Malvaviscus arboreus	2.01 ± 0.93^c	1.26 ± 0.05^b	0.05 ± 0.02^a	1.73 ± 9.57
Pyrostegia venusta	1.13 ± 0.01^c	0.34 ± 0.03^b	0.089 ± 0.01^a	0.51 ± 0.016
Mean (location)	1.365 ± 0.25	0.505 ± 0.17	0.129 ± 0.01	
Plant spp.	<0.001	**Plant spp. × seasons**	0.181	
Seasons	<0.001	**Seasons × sites**	0.191	
Sites	<0.001	**Sites × plant spp.**	<0.001	

The values shown in the upper four rows in the table are mean ± S.D. (n = 20). The p-values shown in the last three rows are based on two-way ANOVA. The values in a row (among the upper four) followed by the same superscript letter indicate that the means are not significantly different among the study sites.

Table 3. Total leaf chlorophyll content (mg/g) in four roadside plant species across three sites and two seasons.

Plant species	Highly polluted site (HPS)	Moderately polluted site (MPS)	Control site (CS)	Mean (species)
Hibiscus rosa-sinensis	1.60 ± 0.15^a	1.70 ± 0.14^{ab}	1.82 ± 0.12^c	1.67 ± 0.14
Jasminum multiflorum	2.17 ± 0.25^{ab}	2.13 ± 0.22^a	2.22 ± 0.11^b	2.17 ± 0.20
Malvaviscus arboreus	1.93 ± 0.17^a	1.93 ± 0.16^a	2.09 ± 0.20^b	1.98 ± 0.19
Pyrostegia venusta	1.58 ± 0.12^a	1.65 ± 0.10^{ab}	1.71 ± 0.15^b	1.64 ± 0.14
Mean (location)	1.89 ± 0.31	1.90 ± 0.26	2.00 ± 0.27	
Plant spp.	<0.001	**Plant spp. × seasons**	0.674	
Seasons	<0.001	**Seasons × sites**	0.909	
Sites	<0.001	**Sites × plant spp.**	0.435	

The values shown in the upper four rows in the table are mean ± S.D. (n = 20). The p-values shown in the last three rows are based on two-way ANOVA. The values in a row (among the upper four) followed by the same superscript letter indicate that the means are not significantly different among the study sites.

Table 4. Leaf extract pH in four roadside plant species across three sites and two seasons.

Plant species	Highly polluted site (HPS)	Moderately polluted site (MPS)	Control site (CS)	Mean (species)
Hibiscus rosa-sinensis	6.55 ± 0.20^a	6.51 ± 0.20^a	6.92 ± 0.30^b	6.66 ± 0.23
Jasminum multiflorum	6.53 ± 0.23^a	6.69 ± 0.21^{ab}	7.43 ± 0.38^b	6.71 ± 0.48
Malvaviscus arboreus	6.53 ± 0.20^a	6.63 ± 0.23^b	6.97 ± 0.29^c	7.08 ± 0.31
Pyrostegia venusta	6.33 ± 0.32^a	6.48 ± 0.25^{ab}	6.75 ± 0.27^b	6.52 ± 0.32
Mean (location)	6.46 ± 0.26	6.60 ± 0.25	7.05 ± 0.42	
Plant spp.	<0.001	**Plant spp. × seasons**	0.1582	
Seasons	<0.001	**Seasons × sites**	0.909	
Sites	<0.001	**Sites × plant spp.**	0.435	

The values shown in the upper four rows in the table are mean ± S.D. (n = 20). The p-values shown in the last three rows are based on two-way ANOVA. The values in a row (among the upper four) followed by the same superscript letter indicate that the means are not significantly different among the study sites.

showed the highest chlorophyll content (2.17 ± 0.20 mg/g) among the studied species (Table 3), followed by *Malvaviscus arboreus* (1.98 ± 0.19 mg/g), *Hibiscus rosa-sinensis* (1.67 ± 0.14 mg/g), and *Pyrostegia venusta* (1.64 ± 0.14 mg/g). We also observed significant variation in total chlorophyll content between seasons (p<0.001). In all the species studied, the highest leaf chlorophyll content was observed in plants collected in the pre-monsoon than in the post-monsoon season (Figure 3). Among the plant species, *Jasminum multiflorum* had the highest total chlorophyll content (2.27 mg/g) in the pre-monsoon season, and *Pyrostegia venusta* exhibited the lowest value (1.57 mg/g) in the post-monsoon season.

Additionally, there was a significant variation in leaf chlorophyll content according to studied locations with different pollution levels (p<0.001). As shown in Table 3, plant species growing in highly polluted sites such as Swoyambhu and Satdobato exhibited the lowest total chlorophyll content in their leaf extracts. Species from the control sites like the Tribhuvan University (TU) area and Godawari (classified as the least polluted sites) had the highest leaf chlorophyll content.

LEAF EXTRACT PH

Leaf extract pH varied significantly (p<0.001) among plant species, between seasons, and at different locations (Table 4; Figure 4). The mean pH value ranged 6.52–7.08 (Table 4). The maximum pH of leaf extract (7.08) was recorded in *Malvaviscus arboreus*, while the minimum (6.52) was observed in *Pyrostegia venusta*. In all the species studied, a higher leaf extract pH was observed in plants collected in the post-monsoon than in the pre-monsoon season (Figure 4). *Malvaviscus arboreus* had the highest recorded pH of the leaf extract (7.68) in the post-monsoon season, and *Pyrostegia venusta* showed the lowest value (6.49) in the pre-monsoon season.

Moreover, plants collected from control sites like TU and Godawari showed a higher leaf extract pH (7.05), and those collected from polluted sites like Swoyambhu and Satdobato exhibited a lower pH value (6.46). *Malvaviscus arboreus* exhibited remarkable seasonal variation in leaf extract pH, whereas *Pyrostegia venusta* showed minimal fluctuation. These results indicated that leaf extracts from plants in polluted sites tended to be more acidic than those from control sites.

RELATIVE WATER CONTENT (RWC)

The value of RWC varied significantly (p<0.001) among species, between seasons, and among different locations with different pollution levels (Table 5). The mean RWC value ranged from 80.25% to 85.68% (Table 5). *Malvaviscus arboreus* showed the highest mean RWC (85.68%) and *Pyrostegia venusta* exhibited the lowest value (80.25%). RWC was lower in control sites such as Godawari and the TU area (81.20%) compared to polluted sites like Satdobato and Swoyambhu (85.67%). Higher RWC was observed in plants collected in the post-monsoon than in the pre-monsoon season (Figure 5).

ASCORBIC ACID CONTENT

There was a significant difference in ascorbic acid content among plant species (p<0.001), across locations (p<0.001), and between seasons (p = 0.001) (Table 6; Figure 6). Among plant species, the mean ascorbic acid content varied from 0.35 mg/g to 0.64 mg/g (Table 6) with *Malvaviscus arboreus* exhibiting the highest value and *Pyrostegia venusta* the lowest.

Plants growing on polluted sites such as Satdobato and Swoyambhu exhibited a higher ascorbic acid content (0.58 mg/g) than those from control sites such as Godawari and the TU area (0.47 mg/g). Ascorbic acid content was significantly higher in plants collected in the post-monsoon season than in the pre-monsoon season (Figure 6).

RELATIONSHIPS BETWEEN DUST LOAD AND LEAF BIOCHEMICAL PROPERTIES

A strong relationship was observed between dust load and leaf biochemical characteristics (Table 7). Dust load exhibited a positive relationship with relative water content and ascorbic acid content, but a negative relationship with leaf extract pH and total chlorophyll.

Discussion

DUST ACCUMULATION ON LEAF

Dust accumulation on plant species depends on weather conditions, wind direction and speed, pollution levels, and plant traits (Sæbø *et al.* 2012; Hassanen *et al.* 2016; Steinparzer *et al.* 2023). Among the plant traits, leaf shape, size, orientation, texture,

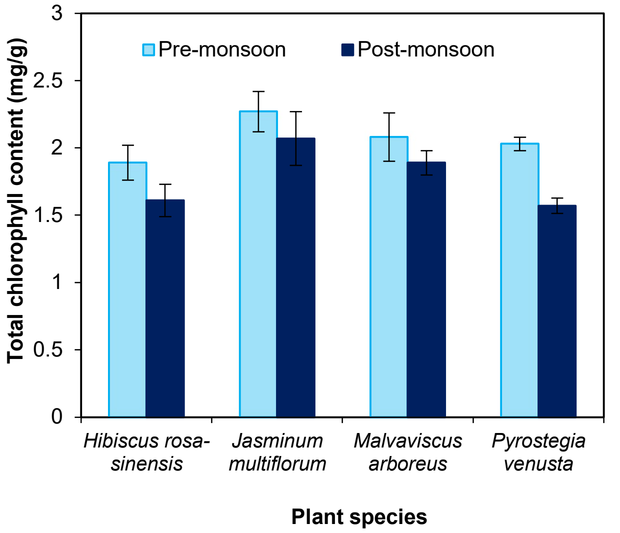

Figure 3. Leaf chlorophyll content (mg/g) in four roadside plant species during pre- and post-monsoon seasons.

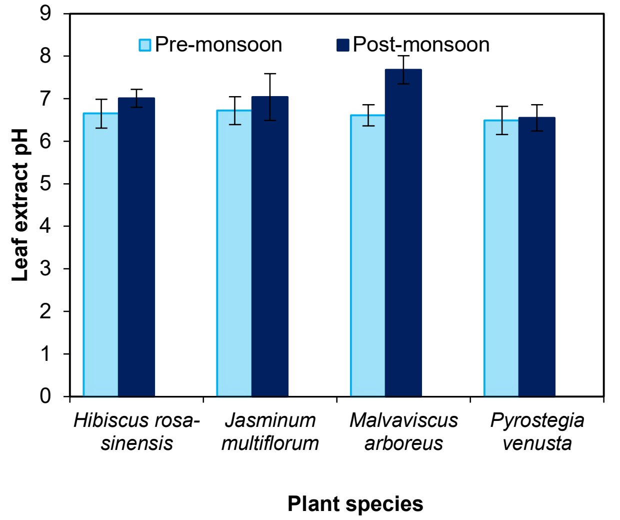

Figure 4. Leaf extract pH in four roadside plant species during pre- and post-monsoon seasons.

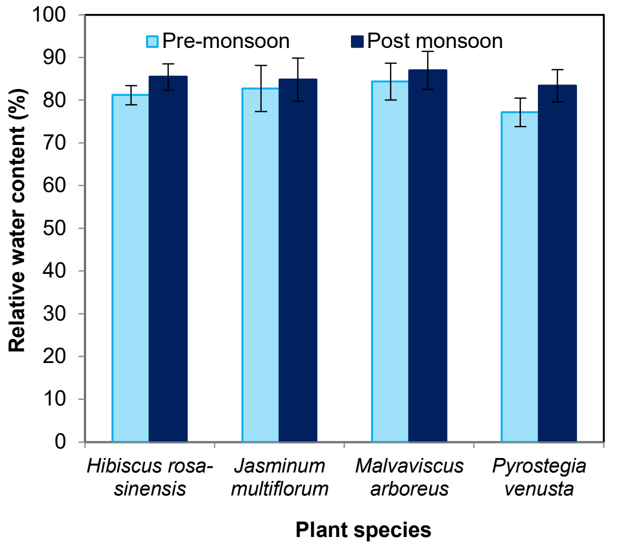

Figure 5. Leaf relative water content in four roadside plant species during pre- and post-monsoon seasons.

Table 5. Leaf relative water content (%) in four roadside plant species across three sites and two seasons.

Plant species	Highly polluted site (HPS)	Moderately polluted site (MPS)	Control site (CS)	Mean (species)
Hibiscus rosa-sinensis	84.21 ± 3.25[b]	82.31 ± 1.25[a]	82.01 ± 2.25[a]	82.84 ± 2.25
Jasminum multiflorum	86.87 ± 4.56[c]	83.27 ± 4.20[b]	81.11 ± 5.48[a]	83.75 ± 5.33
Malvaviscus arboreus	87.98 ± 3.16[c]	85.97 ± 5.20[b]	83.35 ± 4.20[a]	85.68 ± 3.03
Pyrostegia venusta	81.92 ± 5.25[b]	80.15 ± 4.53[b]	78.69 ± 3.74[a]	80.25 ± 4.74
Mean (location)	85.67 ± 5.26	82.89 ± 4.85	81.20 ± 5.01	
Plant spp.	<0.001	**Plant spp. × seasons**	0.025	
Seasons	<0.001	**Seasons × sites**	0.862	
Sites	<0.001	**Sites × plant spp.**	0.802	

The values shown in the upper four rows in the table are mean ± S.D. (n = 20). The p-values shown in the last three rows are based on two-way ANOVA. The values in a row (among the upper four) followed by the same superscript letter indicate that the means are not significantly different among the study sites.

Table 6. Leaf ascorbic acid content (mg/g) in four roadside plant species across three sites and two seasons.

Plant species	Highly polluted site (HPS)	Moderately polluted site (MPS)	Control site (CS)	Mean (species)
Hibiscus rosa-sinensis	0.58 ± 0.10[c]	0.42 ± 0.01[ab]	0.40 ± 0.01[a]	0.47 ± 0.04
Jasminum multiflorum	0.63 ± 0.04[c]	0.58 ± 0.03[b]	0.52 ± 0.06[a]	0.58 ± 0.06
Malvaviscus arboreus	0.69 ± 0.03[c]	0.64 ± 0.03[b]	0.59 ± 0.02[a]	0.64 ± 0.05
Pyrostegia venusta	0.43 ± 0.1[c]	0.32 ± 0.04[b]	0.304 ± 0.03[a]	0.35 ± 0.09
Mean (location)	0.58 ± 0.13	0.51 ± 0.14	0.47 ± 0.13	
Plant spp.	<0.001	**Plant spp. × seasons**	3.048	
Seasons	0.001	**Seasons × sites**	0.301	
Sites	<0.001	**Sites × plant spp.**	0.049	

The values shown in the upper four rows in the table are mean ± S.D. (n = 20). The p-values shown in the last three rows are based on two-way ANOVA. The values in a row (among the upper four) followed by the same superscript letter indicate that the means are not significantly different among the study sites.

hair and wax cover, and petiole length are important, which can alter the accumulation of particulate matter (Sæbø *et al.* 2012; Steinparzer *et al.* 2023). *Malvaviscus arboreus* showing the highest dust deposition may be related to its leaves with large surface area and rough texture compared to other plant species studied. Leaves with complex shapes and large circumferences have been reported to be more efficient in capturing particulate matter (Son *et al.* 2019). The relatively low dust deposition on the leaf surface of *Hibiscus rosa-sinensis* and *Jasminum multiflorum* may be due to their smooth surfaces and comparatively smaller circumferences compared to *Malvaviscus arboreus*. Additionally, the orientation and arrangement of leaves on the stem may contribute to less dust deposition. *Pyrostegia venusta* exhibiting the lowest dust accumulation may be due to its smaller-sized leaves with smooth surfaces. Although *Pyrostegia venusta* and *Malvaviscus arboreus* have similar leaf sizes, the length of their petioles may influence the amount of dust deposition, with *Pyrostegia venusta* having longer petioles that allow for greater leaf movement due to wind, reducing dust deposition. These findings are consistent with those of Vora and Bhatnagar (1986) and Soheili *et al.* (2023), who reported that leaf morphological characteristics play a role in dust deposition.

The highest dust deposition was observed in plants from polluted sites compared to those from moderately polluted and control sites. Polluted sites experience high vehicle movement, contributing to elevated dust levels in the air, which in turn increases dust deposition on leaves. These results are consistent with Samal and Santra (2002), who observed high dust loads near roadsides with more vehicular activity than control sites. The higher dust accumulation in the Satdobato site is due to ongoing road expansion during the study period.

Seasonal variations in leaf dust deposition were also evident in the study. Higher dust deposition in the post-monsoon than in the pre-monsoon season may be related to lower rainfall during the post-monsoon period. Furthermore, dust accumulation

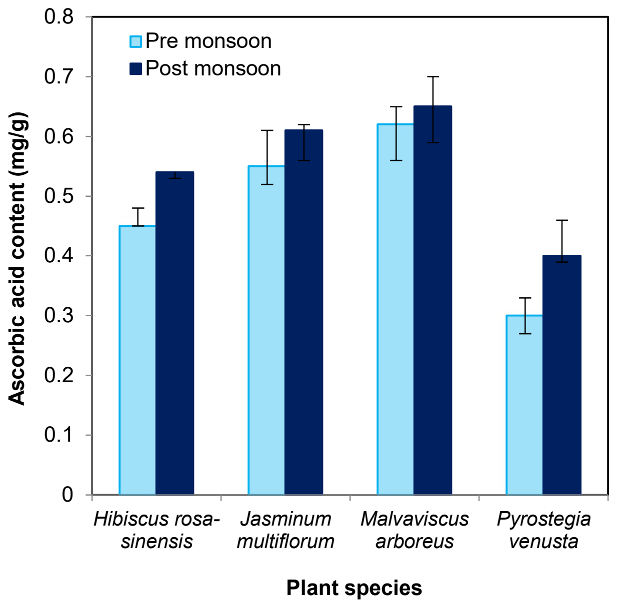

Figure 6. Leaf ascorbic acid content (mg/g) in four roadside plant species during pre- and post-monsoon seasons.

Table 7. Correlations of dust load with pH, relative water content (RWC), total chlorophyll content, and ascorbic acid content in four plant species.

Plant species	Correlation coefficients (*r*)			
	pH	Relative water content	Total chlorophyll	Ascorbic acid content
Hibiscus rosa-sinensis	-0.752	0.660	-0.996	0.852
Jasminum multiflorum	-0.898	0.656	-0.995	0.698
Malvaviscus arboreus	-0.758	0.682	-0.996	0.958
Pyrostegia venusta	-0.886	0.770	-0.999	0.986

during the post-monsoon season may also be facilitated by wet leaf surfaces from nighttime dew, gentle breezes, and foggy conditions that prevent particulate dispersion. In contrast, lower dust deposition in the pre-monsoon season may be due to rain washing away particulate matter and high wind speeds preventing significant dust accumulation (Prajapati and Tripathi 2008).

BIOCHEMICAL VARIATIONS

The total chlorophyll content significantly varies among plant species growing at different sites. All selected species exhibited their highest chlorophyll levels during the pre-monsoon season. The variability in chlorophyll content among species is likely to be influenced by dust particles. Dust accumulation causes significant damage to the photosynthetic apparatus (Prajapati and Tripathi 2008). Dust settling on leaf surfaces alters their optical properties, particularly reflectance in the visible and short-wave infrared radiation spectrum (Eller 1977; Keller and Lamprecht 1995). This reduces the amount of light available for photosynthesis.

An increase in dust load has been shown to have a decrease in chlorophyll content in plants (Prajapati and Tripathi 2008). Thus, reduced leaf chlorophyll content during the post-monsoon season is attributed to higher dust accumulation, which disrupts light intensity and lowers photosynthetic efficiency. In contrast, the higher chlorophyll content observed during the pre-monsoon season likely reflects minimal dust accumulation. Dust deposition may hinder gas diffusion between the leaf and the atmosphere by physically blocking the stomatal pores (Joshi and Swami 2009). The lower chlorophyll content is accountable for reduced photosynthesis (Joshi and Swami 2009).

The leaf extract pH significantly varied ($p<0.001$) among plant species and between seasons (Table 4). High pH value in post-monsoon season is related to the highest dust deposition. The high pH causes the dissolution of dust particles in the cell sap resulting in an alkaline condition (Naji *et al.* 2024). Among the studied species, *Malvaviscus arboreus* had the highest leaf extract pH indicating an alkaline condition due to the highest dust accumulation, and such condition may contribute to chlorophyll degradation (Prajapati and Tripathi 2008). *Pyrostegia venusta*, on the other hand, exhibited lower pH values, potentially due to acidic pollutants shifting cell sap pH toward acidity.

Relative water content (RWC) also exhibited significant seasonal variation. The higher RWC during the post-monsoon season is likely due to dust obstructing stomatal openings and reducing transpiration rates (Roy *et al.* 2024). Ascorbic acid content varied significantly ($p<0.001$) with pollution levels. The fluctuation in ascorbic acid content could be due to the plants' intrinsic ability to withstand stressful conditions (Zhang 2013; Xiao *et al.* 2021). The higher ascorbic acid content in plants signifies their tolerance to pollution (Akram *et al.* 2017). Elevated leaf ascorbic acid levels have been attributed to enhancements in the plant's defense mechanisms, which may vary among plant species (Cheng *et al.* 2007). The increased ascorbic acid levels in the leaves of *Malvaviscus arboreus* may reflect the species' greater adaptive capacity to endure pollution and other stressful conditions. These findings align with Zhang (2013), who documented enhanced adaptive phenotypic variation and stress tolerance in certain plant species. Elevated pollution levels near roadsides may stimulate the synthesis of ascorbic acid as part of the plant's defense mechanism (Cheng *et al.* 2007).

Conclusions

The results indicate that the accumulation of atmospheric dust on plants is influenced by species-specific traits such as height, leaf structure, orientation and arrangement, petiole length, and presence/absence of surface hairs. Plants exhibiting folded leaves with rough textures tend to collect more dust than those exhibiting flat leaves with smooth textures. Dust deposition affects leaf biochemical parameters, causing either an increase or decrease in their levels. The extent of the effect on leaf biochemical parameters depends on the chemical composition of the dust and the plant's dust tolerance ability. Biochemical responses such as variations in chlorophyll content, relative water content, pH, and ascorbic acid content suggest that certain plant species exhibit greater tolerance to dust pollution. Importantly, *M. arboreus* demonstrates greater efficiency in trapping dust with higher adaptive capabilities than the other species studied, indicating its potential as an effective natural dust filter.

The results suggest that roadside plants can function as effective natural filters for mitigating dust pollution in urban areas. Identifying plant species with greater tolerance to dust and pollution stress can help urban planners select suitable species for roadside plantations. Integrating these plants into urban landscapes can improve air quality and minimize the harmful effects of particulate matter on human health and ecosystems.

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