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# Relationship of leaf physiognomies of four broad-leaved plant species with their potential for particle seizing from the roadsides of Quetta city

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**Key words:** Quetta city, Traffic flow, Leaf roughness, Seasonal variation, Particulate matter.

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## Abstract

In this study, the influence of leaf surface features of different native plant species on dust particle capture from the road side of Quetta city. The topography of leaf surfaces influences their ability for dust particle capture. Particulate matter capturing capacity of a given plant species, dust in and outside the plant shelter at ground level was collected by using standard formulas and statistical analysis was done by using analysis of variance (ANOVA). Results demonstrated that per unit area of the leaf, total suspended particles (TSP) captured by the broad-leaved tree were in the order of *Vitis vinifera* (grape) > *Helianthus annuus* (sunflower) > *Morus alba* (*white mulberry)* > *Prunus armeniaca* (apricot). There was significant season-wise variation in particulate matter-capturing capacities of leaves, with higher capturing capacities in spring and summer seasons and lower in the autumn season. Leaf surface micro-roughness had a significant positive correlation with the particle-density settled on surfaces of leaves. However, the main factors that affected leaf adsorptive capacity were the number of stomata, the thickness of epi-cuticular wax and the surface morphology of the cuticle over time. The flow of traffic had also a positive correlation with dust fall on leaf surfaces. So the research conclude that leaf surface topography of all study plant species showed a significant correlation with the density of PM on leaf surface throughout the study period.

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## Introduction

Tree plants play a substantial role in attenuating urban pollution through the capture of dust particles (particulate matter) by leaves (Liu *et al.,* 2013). The retention capacity of leaves for particulate matter (PM) from the air depends on size of leaf, roughness of leaf surface, trichome length, density of stomata, phyllotaxy, length of petioles and canopy structure and height of trees (Liu *et al.,* 2013; Leghari *et al.,* 2019; Li *et al.,* 2019; Sgrigna *et al.,* 2020). Urban trees play a significant role in improving air quality. For instance, a study in Guangzhou, China by Liu *et al.,* (2013) revealed that annually, the vegetation of urban areas can retain 8012.9 tons of dust. Likewise, the study by Yang *et al.,* (2005) demonstrated that per year reduction of dust by trees from the air in Beijing, China was by 772 tons PM10µm. Speak *et al.,* (2012) reported that the per year capture capacities for $PM_{10}$ of *Agrostis stolonifera* (creeping bench grass), ribwort plantain *Plantago lanceolata* (ribwort plantain), *Festuca rubra* (red fescue), and Sedum album (sedum) along Oxford Road corridor, Manchester were 1.81 g $m^{-2}$ $yr^{-1}$, 3.21 g $m^{-2}$ $yr^{-1}$, 0.49 $m^{-2}$ $yr^{-1}$ and 0.42 $m^{-2}$ $yr^{-1}$ respectively.

Rapid urbanization and industrialization have resulted in increased air pollution and PM in air causes serious health issues in urban environments (Amann *et al.,* 2013; Ysebaert *et al.,* 2021). Road dust contains a small amount of clay and minerals and a high amount of different metals (Beckett *et al.,* 2000).

In urban areas, vehicles are the main source of dust generation; while, poor road infrastructure further aggravates this situation. Therefore, roadside plantation of trees is important to control PM urban pollution (Ysebaert *et al.,* 2021). However, plant leaf capability for dust accumulation varies and depends on phyllotaxy, the surface geometry of leaves, cuticular and epidermal features, pubescence of leaf, canopy and plant height (Chaturvedi *et al.,* 2013). Adaptive traits of roadside plant species have also been observed and are more visible in plants along the sides of roads with poor infrastructure and more running vehicles. The study of Mughal *et al.,* (2018) demonstrated that roadside plant species had significant variation in morpho-physiological characteristics as compared to control site plants.

The population and number of vehicles in Quetta (international metropolitan) of Pakistan have increased rapidly. The population of Quetta in 2019 was approximately 1.001 million and in 2020 it was 1.1 million, which is a 2.8% increase in just one year.

The number of motor vehicles in 2019 was reported as 0.8 million. Therefore, because of a high rate of traffic-generated dust along with high wind storms, the atmosphere of Quetta city is highly polluted (Leghari *et al.,* 2013).

The main objective of this study was to find out the relationship between dust particle seizing capacities and leaf surface physiognomies of 4 tree species that were grown along the roadsides of Quetta city.

## Materials and Methods

*Study site*

This study was performed in Quetta city, which is the capital of the province Balochistan, Pakistan. This city is at an elevation of 1676-1900 meters above sea level. The climate of this city is the Mediterranean, which receives most of the precipitations in spring and winter while the summer season occasionally (once in few years) receives rainfall. Per annual rainfall is less than 250 mm.

The month of June and July are the warmest and the maximum temperature is 35°C and 40°C respectively. The coldest month is January and the average maximum and minimum temperatures in this month are around 11°C and -3°C respectively (Ghani *et al.,* unpublished data).

*Plant selection and sample collection*

This study was performed in spring, summer and autumn in 2020, once a month from March to November. Four plant species with different life forms (herbaceous, shrubs and tree) were selected.

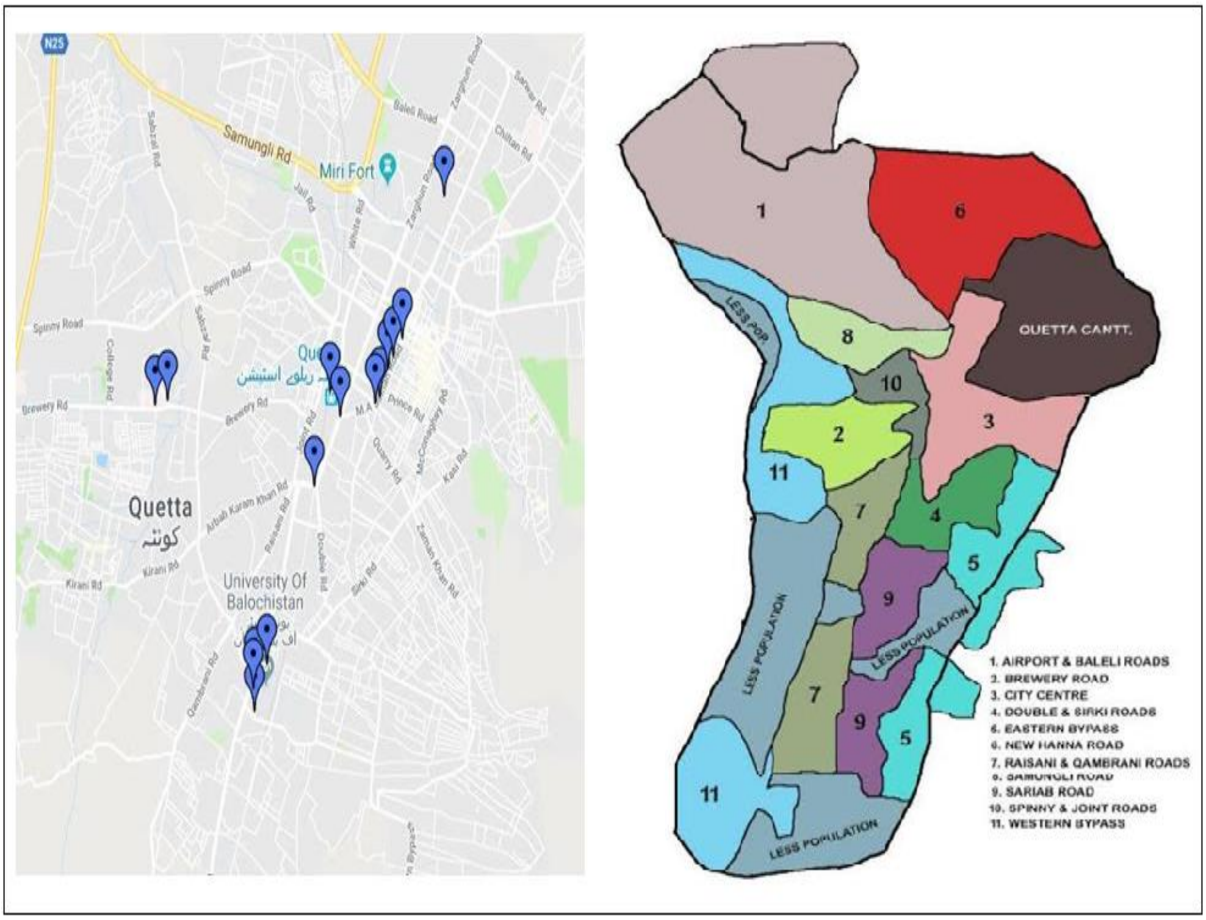


**Fig. 1.** Google map of study area.

The plants were *Morus alba* L. (herbaceous plant species) *Vitis vinifera* L. (grapes of creeping shrub) *Helianthus annuus* (herbaceous plant) and *Prunus armeniaca* (tree species). One plant from each study species was selected. 10 leaves of each plant species were selected for analysis; therefore, a total of 40 leaves were used for analysis every month during the study period. The leaves were tagged with orange thread to make them visualize. The dorsal surface of leaves was cleaned from dust with a fine brush. After 24 h, dust from leaves was collected carefully on tracing paper (pre-weighed). Thereafter, leaves were separated from twigs and further analysis was done in the laboratory. The leaf area was measured by tracing leaves on paper (Vora and Bhatnagar, 1986).

The dust collected from leaves was weighed using an electrical mono-pan balance (Dhona 100 DS). The amount of dust was calculated using the following equation;

$$W = (W2 – W1)\ A \qquad (1)$$

Where W is concentration of dust (mg cm$^{-2}$ leaf area$^{-1}$), W1 and W2 are initial and final weight of paper with dust respectively, A is leaf area (cm$^2$).

*Dust fall on plant leaves*

The efficiency of leaf for particle removal from the air was measured in 0.5 m high, 0.5 m wide and 1 m in the length wind tunnel. Several leaves with branches of the test species were freshly plucked up on sampling day. Leaves with their branches were laid flat to ensure that air stream passed through them. Using wind speed of 20 m s$^{-1}$, leaf capacity for PM capture was assessed by dividing the cumulative amount of PM collected from all leaves by the number of leaves. The concentration of room air aerosol was approximately 10 m$^3$. At first, leaves were placed in the wind tunnel followed by the passing of air that did not contain PM, through the wind tunnel via a plenum that had several openings. Thereafter, the fan was switched on at a wind speed of 20 m s$^{-1}$, to blow leaves in the tunnel for approximately 10 min for all

PM on the leaf surfaces to become suspended in the tunnel. Yaoyao, (2015) reported that wind of 20 m $s^{-1}$ speed and duration of approximately 10 minutes can remove > 85% PM from leaves. In the last, the concentration of PM of the tunnel air was measured by using Dustmate (Turnkey, UK). The concentration of PM per unit area of the leaf of study plant species was calculated using the formula of Bing *et al.,* (2015).

$$Mi = \sum_{1}^{n} \frac{mij}{si} \qquad (2)$$

Where $M$ is captured PM by leaf area (μg/$cm^2$), $i$ is a given tree species, $j$ is the types of PM, $n$ are replications (3 replicates), $S$ is leaf area ($cm^2$), and $mij$ is mass of TSP, PM10μm and PM2.5μm (μg). To measure particulate matter capturing capacity of a given plant species, dust in and outside the plant shelter at ground level was collected and the fallowing formula was used;

DCCP = DCOPS – DCIPS (3)

Where DCCP is cust capturing capacity of Plant, DCOPS is dust collected outside the plant shelter/canopy and DCIPS is dust collected inside plant shelter/canopy.

*Statistical analysis*

Differences between treatments were measured using analysis of variance (ANOVA), whereas differences between treatment means were analyzed by the least significance difference (LSD) test. Correlation analysis was performed to analyze the relationship of concentration of PM on leaf surfaces with morphological traits of leaves and with traffic flow.

## Results

*Dust fall on plant leaves and total suspended particulate matters during different seasons in the study area*

The season-wise variation in dust capture on plant leaves and total suspended particulate matters in the study area are presented in Tables 1 and 2. Our results demonstrate that all plants showed highest dust deposition capacity (0.14 mg/$cm^2$/leaf area) in summer followed by autumn (0.13 mg $cm^{-2}$ leaf $area^{-1}$) and lowest (0.08 mg $cm^{-2}$ leaf $area^{-1}$) in spring season.

Similarly, the highest TSP (13.0 μg $cm^{-2}$) was noted during summer followed by autumn (12.7 μg $cm^{-2}$) and lowest (9.3 μg $cm^{-2}$) in the spring season respectively (Table 2). One way ANOVA showed significant differences in the accumulation of dust on leaf surfaces among the plant species.

The relation between traffic flows, dust accumulation on plant leaves and total suspended particulate matter near the sampling sites are presented in Table 2. Results indicated that as traffic flow (833.3-1004.3) increased the rate of dust fall also increased by 0.08-0.14 μg $cm^{-2}$ leaf $area^{-1}$ respectively.

**Table 1.** Traffic flow and average dust density on leaves and on the study sites during study period.

| Seasons | Average Number of vehicles per hour on 3 study site | | | | | | | | | | Dust density (mg $cm^{-2}$ $leaf^{-1}$) | | | | TSP (μg/$cm^2$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Two wheeler | | | Three wheeler | | | Four and more wheeler Average vehicle/hr | | | | | | | | | | | |
| | Site 1 | Site 2 | Site 3 | Site 1 | Site 2 | Site 3 | Site 1 | Site 2 | Site 3 | Ave. | Site 1 | Site 2 | Site 3 | Ave. | Site 1 | Site 2 | Site 3 | Ave. |
| Spring | 528 | 505 | 490 | 212 | 203 | 197 | 132 | 120 | 113 | 833.3 | 0.09 | 0.06 | 0.08 | 0.08 | 11 | 8 | 9 | 9.3 |
| Summer | 656 | 611 | 581 | 227 | 190 | 195 | 203 | 170 | 161 | 1004 | 0.18 | 0.11 | 0.12 | 0.14 | 16 | 12 | 11 | 13.0 |
| Autumn | 637 | 603 | 590 | 251 | 220 | 228 | 186 | 170 | 128 | 998.0 | 0.17 | 0.10 | 0.13 | 0.13 | 17 | 10 | 11 | 12.7 |

TSP; Total suspended particulate matters at 3-4m above the ground, Dust load is the average of four plant for 24-h average.

The correlation coefficient showed that there was a highly significant relationship ($r$ = 0.91-0.95%) between dust accumulation on plant leaves and total suspended particulate matters in study sites (Table 1&2).

*Relationship between leaf roughness and total particles captured*

The roughness of leaves of study plant species was measured for both dorsal and ventral sides. The roughness of leaves had a positive correlation with the concentration of adsorbed dust ($P<0.05$, Table 3). The degree of roughness of both sides of leaves was in the order; *Vitis vinifera* L. (256.42 nm) > *Helianthus annuus* (127.10 nm) > *Morus alba* L. (102.47 nm) > *Prunus armeniaca* (081.66 nm). The leaf surface roughness of test plant species had a significant positive correlation ($r$ = 0.85-0.95; $P < 0.05$; Table 3) with total particles captured per unit leaf area. Results showed significant variation in dust collected under and outside the plants' shelter.

The amount of dust collected under and outside the plant shelter ranged 4.34-9.35. µg $hr^{-1}$ and 13.11-13.74 µg $hr^{-1}$, respectively (Table 4).

**Table 2.** Traffic flow and correlation coefficient between average dust density on plant leaves and TSP in study sites during study period.

| Seasons | Average No of Vehicle/hr | TSP (µg/$cm^2$) | Dust density (mg/$cm^2$/leaf area) | *r* |
|---|---|---|---|---|
| Spring | 833.3 ± 19.14 | 09.33 ± 1.53 | 0.08 | 0.94* |
| Summer | 1004.3 ± 24.27 | 13.00 ± 2.65 | 0.14 | 0.95* |
| Autumn | 998.0 ± 37.75 | 12.70 ± 3.79 | 0.13 | 0.91* |

*indicates significant level at $P<0.05$.

*Temporal Variation in the Particulate Matter Capture-Capacity of study plant Species*

Results presented in Table 5 and Fig. 2 indicate a temporal difference in PM capture-capacity of leaves of study plant species; while, average dust capturing capacity during the monitoring period was ranged (1.5 – 3.6 µg $cm^{-2}$ $leaf^{-1}$) (Fig. 2). Maximum dust (total particulate maters) absorptions by *Vitis vinifera* fallowed by *Helianthus annuus, Morus alba* and *Prunus armeniaca* (3.7, 3.2, 2.8 and 2.5 µg $cm^{-2}$ $leaf^{-1}$, respectively) in August and minimum in March and September (2.4, 2.0, 1.6 and 1.3 µg $cm^{-2}$ $leaf^{-1}$, respectively). *Vitis vinifera* L. showed maximum which followed by *Helianthus annuus*, *Morus alba* L., and the minimum was for *Prunus armeniaca*. During the study period (March 2019 - October 2019), the PM capturing capacity of broad leaves was greater than that of the less broad leaves.

**Table 3.** Correlation analysis between roughness and total particles captured on leaves of test plant species. * $P < 0.05$.

| Plant species | Roughness (nm) | Total particles captured (µg/$cm^2$/leaf area) | *R* | Significance |
|---|---|---|---|---|
| *Vitis vinifera* L. | 256.42 ±21.2 | 6.35 ±1.21 | 0.95 | * |
| *Helianthus annuus* | 127.10 ±18.4 | 5.51 ±0.44 | 0.94 | * |
| *Morus alba* L. | 102.47 ±15.7 | 3.02 ±0.75 | 0.91 | * |
| *Prunus armeniaca* | 081.66 ±07.5 | 2.10 ±1.33 | 0.85 | * |

The *V. vinifera* L. had the highest capturing capacity; whereas, *P. armeniaca* showed the weakest capacity. However, a significant temporal difference between species for TSP capture-capacity was observed ($P < 0.05$). Capturing capacity was found minimum in March to April and reached its maximum from September to October and gradually increase was after May (Table 5).

**Table 4.** Average dust capture-capacity of study plant species under and outside the plant shelter at ground level during study period (* $P < 0.01$).

| Plant species | Amount of dust collected under the plant shelter (µg/hr) | Amount of dust collected outside the plant shelter (µg/hr) | Significance |
|---|---|---|---|
| Vitis vinifera L | 4.34 | 13.74 | * |
| Morus alba L. | 6.10 | 13.24 | * |
| Prunus armeniaca | 6.22 | 13.55 | * |
| Helianthus annuus | 8.51 | 13.11 | * |

*Surface Morphological Structures of investigation Plant Leaves*

The leaf capture-capacity for PM was closely related to the surface roughness of leaves; this factor and other morphological traits significantly contributed to the capture-capacity of leaves in all seasons (Table 6 and Fig. 3). The surfaces of *M. alba* and *P. armeniaca* showed obvious grooves.

**Table 5.** Average ± SD total particulate matter (TPM) (μg/cm²/leaf area) captured by different plant species during study period.

| Months | TPM captured by different Plant Species | | | | Significant difference |
|---|---|---|---|---|---|
| | *Prunus armeniaca* | *Morus alba* L. | *Helianthus annuus* | *Vitis vinifera* L. | |
| March | 1.3 ±0.04 | 1.5 ±0.05 | 2.0 ±0.06 | 2.4 ±0.05 | * |
| April | 1.5 ±0.06 | 1.7 ±0.06 | 2.4 ±0.07 | 2.8 ±0.03 | * |
| May | 1.7 ±0.07 | 1.7 ±0.08 | 2.5 ±0.08 | 3.2 ±0.01 | * |
| June | 2.3 ±0.10 | 2.5 ±0.11 | 2.7 ±0.10 | 3.4 ±0.12 | * |
| July | 2.4 ±0.11 | 2.6 ±0.13 | 3.0 ±0.13 | 3.6 ±0.14 | * |
| August | 2.5 ±0.13 | 2.8 ±0.16 | 3.2 ±0.14 | 3.7 ±0.16 | * |
| September | 1.6 ±0.14 | 1.7 ±0.18 | 2.5 ±0.16 | 3.0 ±0.16 | * |
| October | 1.6 ±0.14 | 1.6 ±0.17 | 2.3 ±0.17 | 2.8 ±0.17 | * |
| November | 1.5 ±0.13 | 1.7 ±0.15 | 2.6 ±0.15 | 2.9 ±0.15 | * |

The concentration of PM captured by test plant species. The 2-way ANOVA showed significant difference between species and are presented with * ($P<0.05$).

The arrangement density of stomata and the thickness of epicuticular wax of *M. alba* were higher than those of *P. armeniaca,* and *H. annuus*. The stomata of *P. armeniaca* were arranged vertically and were circular and showed an irregular capturing pattern of PM on it. This kind of structure helps PM settle close to the stomata; therefore, the dust gets concentrated on the stomata (Fig. 3).

**Table 6.** Leaf Surface structural properties of the plant species under investigation during spring season.

| Season | Plant species | Epicuticular Wax | Cuticle | Epidermis | Stomata | Closed stomata/cm² (%) | Injured/damage stomata /cm² |
|---|---|---|---|---|---|---|---|
| *Spring* | *Morus alba L.* | Granular | Less waxy and wavy | Ordinary dust laden | low frequency and low dust filled | 4% | 3% |
| | *Vitis vinifera L* | Crystal | Wavy | More dust laden | low frequency and dust filled | 5% | 6% |
| | *Helianthus annuus* | Granular | Wavy and less waxy | More dust laden | high frequency and dust filled | 7% | 8% |
| | *Prunus armeniaca* | Oval | Less waxy | Mediate dust laden | Moderate frequency and partially filled | 3% | 6% |
| *Summer* | *Morus alba L.* | Granular | Medium waxy & Disorganize | additional dust laden | high frequency and excessive dust filled | 8% | 11% |
| | *Vitis vinifera L* | Crystal | Disorganize | modest dust laden | moderate frequency but dust filled | 7% | 10% |
| | *Helianthus annuus* | Granular | Disorganize | inflated dust laden | high frequency and more dust filled | 9% | 11% |
| | *Prunus armeniaca* | Oval | Disorganize | elevated dust laden | high frequency and dust filled | 6% | 8% |
| *Autumn* | *Morus alba L.* | Grainy | Highly waxy and Wavy | little dust laden | low frequency and dust filled | 7% | 12% |
| | *Vitis vinifera L* | Limpid | Disorganize | average dust laden | moderate frequency but dust filled | 8% | 11% |
| | *Helianthus annuus* | Granulated | Wavy | dust laden | high frequency and dust filled | 10% | 12% |
| | *Prunus armeniaca* | Ovoid | Disorganize | more dust laden | high frequency and dust filled | 7% | 9% |

The *P. armeniaca* leaves had waxes on leaf surface, irregular surface texture, had sheets and no obvious pubescence. The *P. armeniaca* had oval stomata, larger as compared to *H. annuus*; however, leaves of *P. armeniaca* had a smooth texture around stomata than other plant species. Therefore, it had captured less particulate matter than other species. The *M. alba* leaves had a smooth surface, low density of stomata, no wax and no epidermal cilium. The *V. vinifera* leaves had a smooth epidermis with no secretions, stomata were small, embedded and surrounded by corneum that covered protuberances.

The texture was wavy, granular with ornamentation of shallow mesh, no glands and epidermal pubescence. The *H. annuus* leaves had parallel and radial arrangement stomata, with shallow ridges and honeycomb trench organizations with an irregular but distinct texture. Its cuticle had less waxy and wavy texture with a more dust-laden epidermis (Table 6).

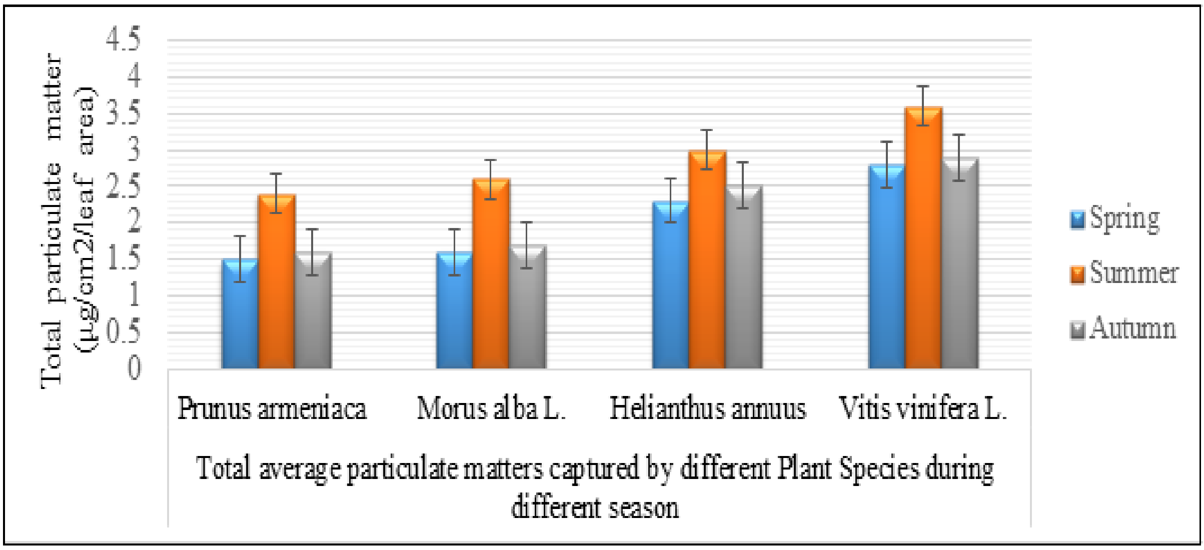


**Fig. 2.** Average total particulate matter (TPM) captured by different plant species during different seasons (µg/cm²/leaf area).

**Discussion**

The absorption of PM by study plant species reached their maximum in August (3.7, 3.2, 2.8 and 2.5 µg/cm²/leaf, respectively) and was minimum in March and September (2.4, 2.0, 1.5 and 1.3 µg/cm², respectively). This variation can be due to seasonal variation in wind velocity, as winter days were observed from August to September in Quetta city more than the rest of the study time. Due to strong winds, less PM gets settled on the surface of leaves. March received high rainfall, like wind, raindrops may wash particulate matter and result in less PM on leaves. The PM capture-capacity of leaves slightly varied between species, which may be because of the variation in the micro-morphological structure of leaf surfaces of plant species (Zheng *et al.,* 2005; Mitchell *et al.,* 2010; Zhang *et al.,* 2017; Sgrigna *et al.,* 2020). Zhang *et al.,* (2017) found that PM capture-capacity of broad-leaved tree species had a strong positive relationship with the roughness of leaf surfaces ($r$ = 0.85-0.94). The observation of Zhang *et al.,* (2017) is an endorsement of our study results. In our study, for all study plant species, the difference in PM capture-capacity of the leaves was significantly affected by surface morphology such as structure and number of stomata, the thickness of epicuticular wax and roughness of epidermis. The grooves and ridges of epidermis cells and other features e.g. cell peaks, recesses and valleys determined the roughness of leaf surfaces as was also found by Zhao, *et al.,* (2013) and Hailong *et al.,* (2012). In this study, roughness of leaf surfaces had a significant correlation with the amount of PM captured on leaf surfaces overtime for all study species. We also observed that the roughness of leaf surfaces of broad-leaved species is greater than the leaves of less broad-leaved species. Furthermore, surface roughness was directly proportional to the capture capacity of leaves for PM. Our results are consistent with the findings of Zhang *et al.,* (2017) for broad-leaved plant species; however, this observation was not found for coniferous trees (Wang *et al.,* 2013).

The retention of PM in leaves is not only affected by morphological features of leaf surface but also by other factors such as rainfall and wind speed. There are several empirical pieces of evidences, which demonstrate that the amount of PM on leaf surfaces was influenced by rainfall. This is because rainfall washes away PM from surfaces of leaves; however, the amount of rain that can substantially influence this process for the leaves of a given plant species remains unraveled (Rai *et al.,* 2010; Huixia, 2012). Furthermore, it also needs to be evaluated the potential influences of retention of PM on plant health, because when the amount of PM on leaf surface reaches a certain level, it affects respiration, transpiration and photosynthesis (Tomašević *et al.,* 2005; Paoletti *et al.,* 2011; Wang, *et al.,* 2015; Rai , 2016; Zhang *et al.,* 2017).

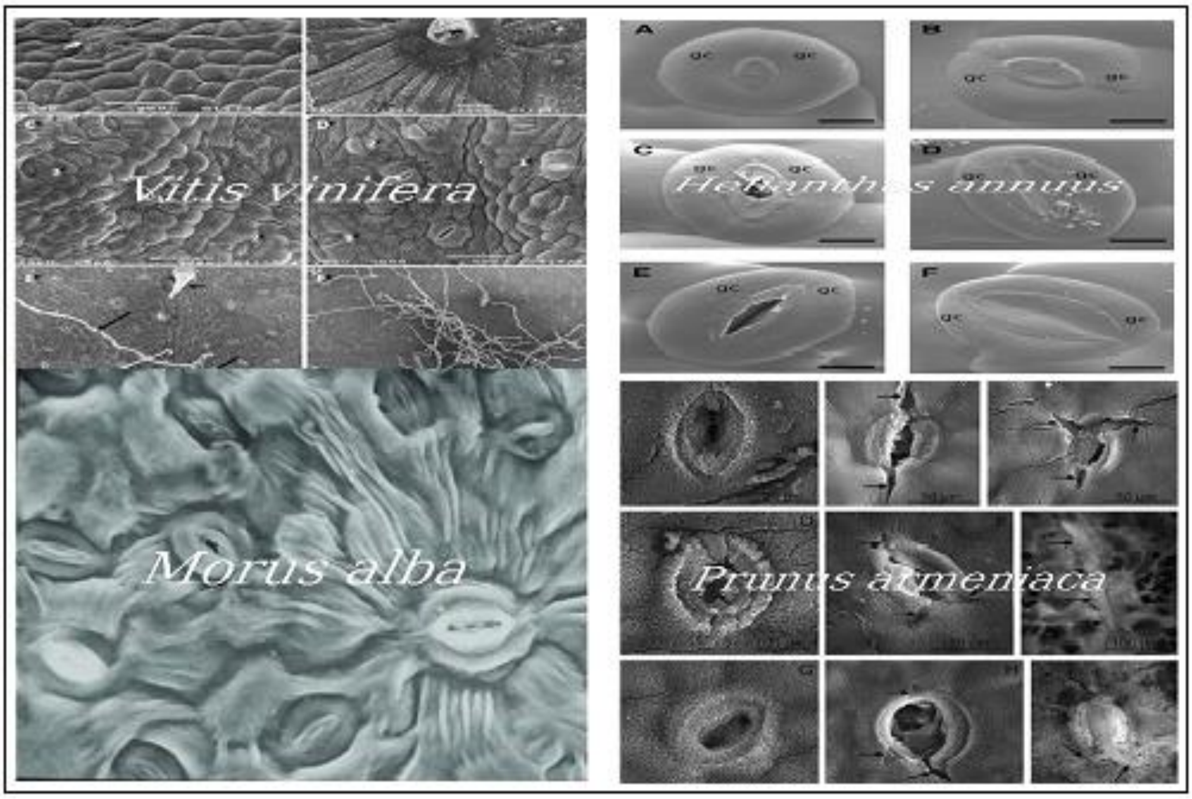


**Fig. 3.** Leaf stomatal structure of different plant species under investigated, (A): *V. vinefera* (B) *H. annuus* (C):*M. alba* (D): *P. armeniaca*.

**Conclusion**

We conclude that leaf surface topography of all study plant species showed a significant correlation with the density of PM on leaf surface throughout the study period. The main factors affecting PM capture capacities of leaves were the number of stomata, amount of epi-cuticular wax and the properties of cuticle in different seasons. Besides leaf roughness, the flow of traffic had also a positive correlation with dust fall.

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