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Original Research

Air Pollution Mitigation Potential of Dominant Landscape Plants of an Urban Ecosystem (Lahore City) of Pakistan: An Air Pollution Tolerance Index (APTI) Assessment

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Abstract

Lahore, the second largest city of Pakistan with higher population and large industrial zones, is under tremendous environmental stress of increasing air pollution. Roadside plants can mitigate increasing pollution rate by serving as a natural sink. This research work was designed to evaluate the role of roadside plantation in pollution mitigation in an urban ecosystem of Lahore. In this urban ecosystem, three busiest roadsides i.e., Zafar Ali Road, Canal Road and Jail Road with heavy traffic flow and commonness of plants were selected as sampling sites. Air Pollution Tolerance Index (APTI) of the selected plants was calculated through chlorophyll content (mg/g), ascorbic acid content (mg/g), relative water content (%) and pH. At control sites, ascorbic acid ranges from 3.11±0.21 (*Cosmos sulphureus*) to 1.18±0.08 (*Tabarnaemontana divaricata*) while at polluted sites, it was found to range from 2.95±0.09 (*Cosmos sulphureus*) to 1.03±0.08 (*Tabarnaemontana divaricata*). Chlorophyll content ranged from 37.00 ±1.11 (*Ficus religiosa*) to 5.28±1.22 (*Hibiscus rosa sinensis*) at control sites, while at polluted sites, it ranged from 29.09±1.15 *(Ficus reliogiosa*) to 5.56±0.95 (*Tabarnaemontana divaricata).* At control sites, relative water content ranged from 198.76 ±2.45 (*Catharanthus roseus*) to 10.02±1.95 (*Tabarnaemontana divaricata*) while at polluted sites, it was found to range from 192.40±2.11 (*Catharanthus roseus*) to 9.50 ±1.18 (*Tabarnaemontana divaricata*). At control sites pH value ranged from 6.69±0.21 (*Catharanthus roseus*) to 5.04 ± 0.45 (*Alstonia scholaris*). At polluted sites, it ranged from 6.69±0.21 (*Catharanthus roseus)* to 5.42±0.48 (*Alstonia scholaris*). At control sites, APTI value varies from 28.45±0.21 (*Catharanthus roseus*) to 2.59±0.11 (*Tabarnaemontana divaricata*). While at

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polluted sites, APTI value ranges from 27.57±1.45 (*Catharanthus roseus)* to 2.18±1.33 (*Tabarnaemontana divaricata).* Calculated APTI values were correlated with ascorbic acid, chlorophyll, %relative water content and pH. Highly positive correlation was found between APTI and ascorbic acid with R^2 = 0.9183. While slightly positive correlation of APTI with chlorophyll and relative water content (R^2 = 0.3779 and 0.336 respectively) was found. This indicates towards their participation in strengthening plants' defense mechanism. This research work followed by statistical analyses evaluates the tolerance level of plants towards air pollution. This evaluation paves the way in screening out the tolerant plants for pollution abatement. In this research work, *Catharanthus roseus* and *Cosmos sulphureus* were found tolerant to air pollution having high APTI values while *Helianthus annuus*, *Ficus benjamina, Ficus religiosa*, *Hibiscus rosa-sinensis, Robinia pseudoacacia, Alstonia scholaris* and *Tabarnaemontana divaricata* was found sensitive to the air pollution.

Keywords: APTI (air pollution tolerance index), ascorbic acid content, chlorophyll content, relative water content, urban landscape ecosystem

Introduction

Lahore is at the top of the list due to its rapid increase in population which is resulting into high levels of atmospheric pollution among all cities of Pakistan. High number of particulates emitting from diesel and gasoline-based vehicles are predominating played their role in elevating the pollution in Lahore city [1]. From 2007 to 2011, contents of sulphur dioxide (SO_2) and particulate matter (PM) remains many times higher than air quality recommendations of World Health Organization [2]. Accompanying gaseous pollutants, elemental pollutants i.e., cadmium, lead and zinc were also found higher in concentrations. According to standards of World Health Organization (WHO), these elevated concentrations is found to be highly toxic for survival [3, 4]. Lahore ranks the second most polluted city after Delhi according to IQ Air Air Visual's live rankings [5]. Higher pollutant level destroys the quality of air of Lahore city. Annual economic loss in healthcare department costs more than 500 million dollars [6]. Rapid and unintended growth in industrialization and urbanization has elevated the atrocious quality of air, blemishing the environment. For fulfilling daily needs, fossil fuel combustion is adding many pollutants like CO_X, metals, NO_X, soot particles and SO_X in the atmosphere. The excessive use of vehicles and inferior quality fuel triggers the induction of ultrafine and toxic pollutants in the environment [7]. Anthropogenic activities caused by the intrusion of human beings has resulted in the destruction of the urban ecosystems especially over the last three decades, altering the constituents of the environment, up to such extent that they are usually found exceeded from the normal standard values resulting into a phenomenon of "Air Pollution". The main reason for elevated pollution rate in urban areas is the tremendous use of energy and unplanned concrete structure development to fulfill the daily needs of people. In cosmopolitan cities, the main cause of air pollution is excessive use of vehicles which are richest source of contaminants i.e., oxides of nitrogen, sulphates and particulate matter (PM_{10} and $PM_{2.5}$) along with flashy soot [8]. More importantly, the excessive use of vehicles and inferior fuel quality, triggers the induction of ultrafine toxic pollutants in the environment. Excessive emission of harmful gases from automobiles and vehicles along with diverse range of human activities have aggravated the issue of global warming i.e., causing threat to all living beings and the environment as well [9]. Pollutants emitted directly from the source are the primary pollutants i.e., oxides of carbon. While the pollutants formed in the atmosphere by chemical reactions are secondary pollutants i.e., ozone (O_3) [10]. These deleterious effects of these contaminants will be the major concern in future regarding human health, as population of the urban cities will be increased up to 70% till 2050 [11].

Deposition of dust and various other pollutants decreases the nutrient uptake, canopy covers and foliage density of plants. Increased concentration of pollutants i.e., CO_2, SO_2, NO_X and Ozone etc. elevates the atmospheric temperature which causes reduction in photosynthetic and enzymatic activities. Plants respond differently to different air pollutants i.e., some plants do not exhibit any physical change but some plants get harmed and bruised [12]. By using this course of action, plants terminate particulates and pollutants like SO_2, hydrogen fluoride (HF) and heavy metals from atmosphere and bring modification in germination of seeds, pedicle length, rate of photosynthesis and type of stomata. Some resistant plants adjust the alteration in the environment by causing a change in the pH, content of ascorbic acid, relative water and chlorophyll content. So, tolerant, and sensitive plant species can be used for developing green belts and to monitor air pollution respectively [13, 14]. Proliferation of ascorbic acid and depletion of chlorophyll causes a change in biochemical and physiological processes of plants which might lead to their death. Air pollutants absorbed in plants reduce the level of carotenoid and chlorophyll pigments decreasing their photosynthetic activity and yield [15]. Chlorophyll is an important component of photosynthetic activity of plants therefore change in level of chlorophyll, indicates the quality of air. Ascorbic acid acts as an antioxidant, controls division and expansion of cells and detoxifies harmful chemicals [16]. Ascorbic acid controls the aerobic metabolism and reactive oxygen production, protecting the plant from injury caused by oxidation during stressful circumstances. During stress conditions, the physiological activity of plants is sustained by content of water in leaves, indicating its association with level of pollution. Higher pH values enhance the glucose conversion into ascorbic acid which eventually increases the tolerance of plants against pollutants. Higher deposition of dust reduces the chlorophyll content while the relative water content balances the physiological activities under the conditions of stress i.e., higher rate of transpiration and pollution. However, pH level of plants is related to the extent and type of pollutants reacting with water and forming variable solutions having distinct pH values [17].

Plants, through their metabolic activity, eliminate pollutants from their surroundings and raise the quality of air. Plants recycle important nutrients like oxygen and carbon, which is clear evidence of their participation in ecological maintenance of ecosystem. Plants play their role in mitigating air pollution by providing a sink for absorption of pollutants. Green belts ease the pollution reduction by absorbing and checking the dust flow [18]. The development of green belts in big cities can contribute in mitigating the pollution but this plantation should not be executed without proper scrutiny and knowledge of its filtering effect towards pollution. According to some studies, *Tamarindus indicus* is an effective absorbent of particulates because of its small leaves comparing to the plants having large leaves. Deciduous trees are less effective in filtering pollutants as compared to evergreen trees. A list of trees was suggested for plantation in urban areas, as 25% mitigation of air pollution was observed in these plants in Singapore. Those trees were *Azadirachta indica, Syzygium cumini, Cassia fistula, Polyalthia alba, Delonix regia, Lagerstroemia indica, Ficus religiosa* and *Jacaranda mimosifolia* [19]. *Plantago lanceolata* and *Taraxacum officianle* deposit heavy metals on their leaf surfaces, therefore, suggested as active bioindicators [20]. APTI determines the role of plants in reducing air pollution by measuring its level of tolerance to particulate matter. Sensitive plant species play their role as bio-indicators while tolerant plant species act as sink for pollutants or particulates.

Due to increasing survival needs, the excessive usage of vehicles, industry and power plants has raised the emissions and level of particulate matter in air. Recently, heavy smog was experienced in Lahore city because of intense amount of polluting emissions from the industries resulting in death of large number of people due to lack of control and protective measures [21]. Diesel, non-renewable hydrocarbons, and Compressed Natural Gas (CNG) based vehicles exalts greenhouse gas of about 13.5% in big cities like Lahore. Dependence and increased usage of personal vehicles has emanated excessive fuel consumption, turbulent traffic density, increased fossil fuel consumption and air pollution.

Plants in different environments exhibit diverse range of responses and activities. They markedly vary in the degree of executing the process of photosynthesis, stomata regulation, respiration, and various enzymatic, metabolic, and biochemical processes [22]. This variation in physiological and biochemical attributes aids in determining the sensitivity and tolerance of plants of various air pollutants. Parameters like content of ascorbic acid, chlorophyll, relative water and pH are measured in leaves of various plants to calculate their Air Pollution Tolerance Index (APTI) which narrates about the sensitive and tolerant behavior of plants towards air pollution [23, 24]. APTI value differs indifferent plant species. Various research workers around the world gave importance to the issue of air pollution around the cosmopolitan cities and the role of the plants in its mitigation, which is cited in the following lines. The role of urban forest in sequestering the air pollution cannot be ruled out as twenty nine tree species were tested for their APTI and API in Varanasi urban forest of India. Out of these 59 tree species 12 trees were selected as excellent (02) emitted, very good (04) and good 06 [25]. These pollutants also effect the growth, yield and quality of grain in various crop fields (mung bean, peas and wheat). It was observed that gaseous pollutants effect was tremendous in polluted site, low in less polluted site and below the standards in control sites. In polluted site, pollution cause injuries in crop, decreased biomass, leaf area and height [26]. The impact of vehicular exhaust was studied on invader (exotic) weed species of Pakistan i.e., *Parthenium hysterophorus* at two busiest roads of Pakistan. Studies revealed reduction in stomatal conductance resulting in low values of transpiration rate and photosynthetic rate in plant samples of the polluted sites [27]. While APTI of twenty five tree species were determined in Talkotra industrial zone of India in which trees were also assessed for their dust capturing potential as biomonitors. Among these plants *Moinga oleifera* showed highest potential of dust accumulation. Among tree species six were found tolerant towards air pollution and one as sensitive [28]. Moreover, API, APTI And heavy metal accumulation index was determined in two tropical forests of India. One was taken as control site (Bhallavpur Wildlife Sanctuary) and the other as polluted site (Bajora Forest). In these forests four tree species were selected i.e., *Acaccia auriculiformis*, *Azadirachta indica*, *Eucalyptus globulus* and *Shorea robusta*. Results indicated that air pollution significantly affects the physicochemical attributes of the tree plants of the polluted tropical forest as compared to the control one [29]. Categorization of the road avenue trees for development of green belts and their pollution mitigation potential is the future of urban development. For this purpose, nine plant species were selected in Beijing for determining their dust capturing potential, morpho-chemical attributes and APTI. It was observed that plants with high capturing capacity of particulate matter showed greater levels of oxidative stress [30]. Role of plants in mitigating air pollution, providing cooling effect in tropical urban environments is studied in central Bangkok (Thailand). Total 21 species were selected to determine the air and soil temperature reduction, APTI And API. Among these species it was observed that species of both deciduous and evergreen habitat were good at providing the cooling effect, but they showed variable results in their tolerance potential of air pollution [31]. By considering the ever-increasing ambient pollution levels and the most polluted city of the world (Lahore), this research work was executed to calculate the APTI value of various landscape plant species, so the tolerant plant species would be suggested to plant in urban developing areas for mitigating air pollution while plant species sensitive to pollutants would be utilized as bio-indicators in highly polluted areas [32].

Materials and Methods

Study Site

Three roads of Lahore city were selected to ascertain the effects of pollution in the atmosphere on plantation along the sides of roads. The roads selected were Zafar Ali Road, Canal Road and Jail Road due to heavy loads of the traffic and associated pollution with them in an urban ecosystem of Lahore, while the control samples were taken from nearby parks away from the roadsides (less polluted sites). The selected roads also had highest number of landscape plants along roadsides and their sampling was performed in triplicates while taking their GPS coordinates as shown in Fig. 1.

Floristic Composition

Field survey of three selected roads was conducted to know about the plant diversity of the study site. A survey of selected roads was conducted and then their floristic composition was prepared. Annual and perennial plants were then identified with the available literature [33-35]. Later, plants were selected, based on commonness and evenness of the plants on each road and their sampling was done during months of spring season in which the plants were in their maximum stage of growth.

Design of Experiment

Whole experimental work was carried out following the completely random design because selected plant species were collected from three different selected sites depending on their availability. Selected plants

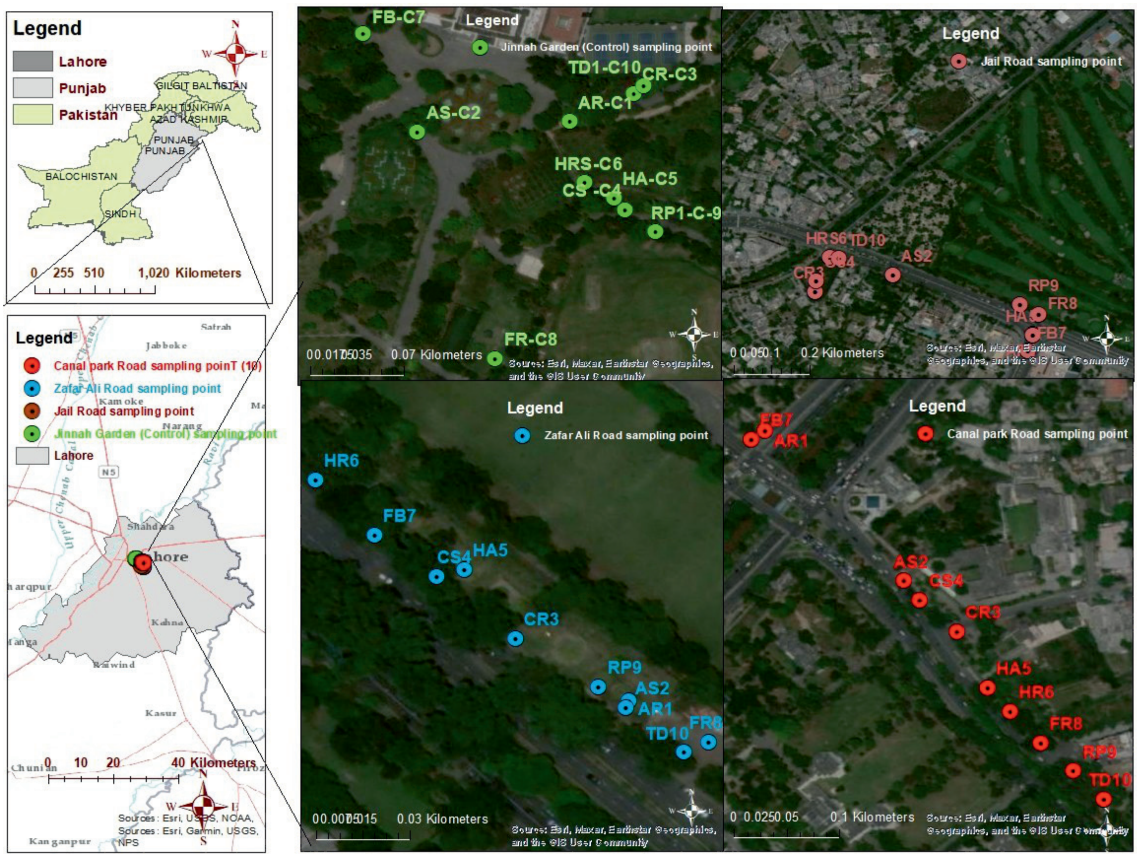

Fig. 1. Study area with sampling sites (GPS Coordinates).

from three different sites were collected in replicates. Three replicates of each plant species were collected. For the measurement of Air Pollution Tolerance Index (APTI), different physio-chemical measurements and analysis were performed. Fresh mature leaves of control (less polluted) and sample plants were collected at peak rush time of day.

Ascorbic Acid, Chlorophyll Content, Relative Water Content and pH

Method used for calculating the content of ascorbic acid was presented by Keller & Schwager in 1977 [36]. Absorbance of plant extract and blank was calculated. Blank was prepared by first preparing 5 ml DCPIP solution then mixing1ml of extracting solution with a single drop of ascorbic acid in the test tube. Absorbance of blank at 520 nm using spectrophotometer was determined. 2 g fresh leaves were grinded with 20 ml of extracting solution by using pestle and mortar. Leaves were completely homogenized with extraction solution. This extract was then filtered in conical flask by using Whatman filter paper No. 1. This extract was centrifuged for fifteen minutes at 6000 rpm. In the eppendorph tubes, 2 layers were formed. 1 layer should be separated as 1 layer was pallet. 1ml supernatant was taken out and poured in test tube and mixed with 5 ml 2, 6-DCPIP solution, due to which pink colored solution was observed. At 520 nm of wavelength, its absorbance was noted using spectrophotometer. Absorbance of pink solution is represented as Es. After noting the absorbance,1drop of 1% ascorbic acid was added in it to de-color the solution. Absorbance of this bleached solution was noted using spectrophotometer at 520 nm. This absorbance was denoted as Et. Collected plant specimens from three different roads for determining ascorbic acid content were treated in the same way. Ascorbic acid content of selected plant species was calculated by using Eq (1).

$$\text{Ascorbic Acid Content (mg/g)} = [Eo - (Es - Et) \text{ x } V] / W \text{ x } V1 \text{ x } 1000 \quad (1)$$

Where, Eo = Absorbance of blank, Es = Absorbance of pink solution, Et = Absorbance of bleached solution, W = Fresh weight of leaves, V = Volume of Mixture, V1 = Volume of Supernatant.

For calculation of chlorophyll content of plant species, acetone extraction method of Singh et al. (1991) [37] was used. Fresh leaves weighing 2 g were crushed and grinded with 20 ml of 80% acetone using pestle and mortar. Extract was filtered in the conical flask using Whattman filter paper and its absorbance at 645 nm and 663 nm was noted. This method was used for all the collected samples of selected sites and applied the following formula to calculate content of chlorophyll in the plant's species. Chlorophyll content of the plant species was calculated by using Eq. (2).

$$\text{Chlorophyll a (mg/g) fresh weight} = (A663 \times 0.0127 + A645 \times 0.00269) \times 10 \times 50$$
$$\text{Chlorophyll b (mg/g) fresh weight} = (A645 \times 0.0229 + A663 \times 0.00468) \times 10 \times 50$$
$$\text{Total Chlorophyll (mg/g) fresh weight} = (A663 \times 0.0202 + A645 \times 0.00802) \times 10 \times 50 \quad (2)$$

where, A663 = Absorbance at 663 nm and A645 = Absorbance at 645 nm

For determining the water content of plants, method described by Sivakumaran & Hall in 1978 was used [38]. Following this method, standard fresh weight of leaves was noted and then soaked in 250 ml of distilled water for a period of 24 hours. After, 24 hours, leaves were taken out of water and dried completely by using a filter paper and then weighed again. This measured weight is their saturated weight. After noting their weight, leaves were kept in oven for 24 hours at 71 degree Celsius and then weighed again to note their dried weight. All the collected samples from different sites were treated in the same way to calculate their relative water content. Relative water content was calculated by using the Equation (3)

$$\text{Relative water content (\%)} = \text{Fresh Weight} - \text{Dry Weight} \times 100/\text{Saturated Weight} - \text{Dry Weight} \quad (3)$$

For determining the pH of leaf extracts method used was described by Das & Pascal in 2010 [39]. Following this method, 1 g fresh leaves were weighed and then grinded using pestle and mortar in 50 ml of distilled water. Its extract was filtered in conical flask using filter paper and its pH was noted using pH meter.

APTI

Using method of Singh & Rao (1983) [40], Air Pollution Tolerance Index (APTI) of collected plants from selected sites was calculated using the Eq. (4).

$$\text{Air Pollution Tolerance Index (APTI)} = [A (T+P) + R] /10 \quad (4)$$

where, A = Ascorbic Acid Content (mg/g), T = Total Chlorophyll Content (mg/g), P = pH of leaf Extract, R = Relative Water Content of Leaf (%).

Results and Discussions

This research work was executed by determining the four basic variables i.e., Ascorbic Acid Content, Total Chlorophyll Content, % Relative Water Content and pH of the control and roadside plant samples and detailed site survey was executed to prepare floristic composition. Total number of 1974 plants were recorded. 10 dominant and common plants present

Table 1. Taxonomic illustration of selected plants in urban ecosystem of Lahore (Pakistan).

S. No.	Scientific Name	Family	Common Name	Habit
1.	*Alcea rosea*	Malvaceae	Hollyhock	Biennial Shrub
2.	*Alstonia scholaris*	Apocynaceae	Blackboard or Devil tree	Perennial, Evergreen Large Trees
3.	*Cathranthus roseus*	Apocynaceae	Graveyard Plant or Old Maid	Annual, Sometimes Perennial Shrub and tree
4.	*Cosmos sulphureus*	Asteraceae	Yellow Cosmos	Annual Herb
5.	*Helianthus annuus*	Asteraceae	Sunflower	Annual Herb
6.	*Hibiscus rosa-sinensis*	Malvaceae	Chinese Hibiscus	Evergreen Shrub
7.	*Ficus benjamina*	Moraceae	Weeping Fig	Perennial, evergreen shrub or tree
8.	*Ficus religiosa*	Moraceae	Peepal	Perennial and deciduous tree
9.	*Robinia pseudoacacia*	Fabaceae	Black Locust	Perennial and evergreen tree
10.	*Tabernaemontana divaricata*	Apocynaceae	Pinwheel Flower	Perennial and evergreen shrub

at all study sites were selected for this research work. These most planted plants of the urban landscape on the three busiest roads were *Alcea rosea, Alstonia scholaris, Catharanthus roseus*, *Cosmos sulphureus, Ficus benjamina, Ficus religiosa, Helianthus annuus, Hibiscus rosa-sinensis, Robinia pseudoacacia* and *Tabarnaemontana divaricata* were selected for analysis of physiochemical characters. The selected plant species along with their local name and habit is given in Table 1. Air pollution tolerance and sensitivity of plants was calculated by holding the fact of drastic effects of air pollution on atmosphere and vegetation of Lahore city.

Physiochemical Analyses of Plant Species

In *Alcea rosea* ascorbic acid content was 1.75 (mg/g), chlorophyll content was 16.2 (mg/g) was found in experimental plant samples while, in control samples, the ascorbic acid content and chlorophyll content was 1.82 (mg/g) and 10.53 (mg/g) respectively. While calculations for % RWC resulted in value of 66.16 at polluted site while its control value was 68.46. pH value was 6.43 which was higher than control value of 6.29. Calculations and physiochemical assessment of these parameters showed mean APTI value of 10.57 while control value calculated was 11.12 (Table 2).

In *Alstonia scholaris* ascorbic acid content was determined as 1.62 (mg/g) in plants of polluted roadside plants as compared to the values of the control plant samples (less polluted) i.e., 1.68 (mg/g). Lower chlorophyll content was recorded in experimental samples as 9.01 (mg/g) as compared to control i.e., 10.53 (mg/g). While calculations for % RWC resulted in low value of 28.90 at polluted site while its control value was 30.12. pH value was found to be 5.42 which was higher than control value of 5.04. Calculations showed mean APTI value of 5.19 while control value calculated was 5.62 (Table 2).

In *Catharanthus roseus* higher ascorbic acid content and chlorophyll content was observed as 2.39 (mg/g) and 28.8 (mg/g) respectively in plants of polluted sites which was found higher in concentration as compared to control samples. %RWC resulted in value of 192.4 at polluted site while its control value was 198.76. pH value was found to be 6.06 and 6.69 at polluted site and control respectively. APTI value was calculated as 27.57 for plant samples of polluted site as compared to the control value i.e., 28.45 (Table 2).

In *Cosmos sulphureus* ascorbic acid content was 2.95 (mg/g), chlorophyll content was 26.97 (mg/g) was found in experimental samples as compared to control that was recorded as 3.11 (mg/g) and 27.45 (mg/g) respectively. %RWC resulted in lower content at polluted site (105.13) as compared to the higher amounts (107.71) of water content in control samples. pH value was found to be 5.80 which was higher than control value of 5.46. APTI value was calculated higher in control samples as 21.01 compared to the experimental samples as 20.70 (Table 2).

In *Helianthus annuus* ascorbic acid content was found 2.29 (mg/g), chlorophyll content was 15.24 (mg/g) in experimental plant samples as compared to control samples that was 2.41 and 16.43 respectively. % RWC resulted in lower value (114.33) at polluted site while its control value was 118.29. pH value was found to be 6.69 which was higher than control value of 6.34. APTI value was calculated as 16.45 for experimental samples while control value was 17.31 (Table 2).

In *Hibiscus rosa-sinensis* lower ascorbic acid content and chlorophyll content was observed as 1.67 and 5.1 (mg/g) in roadside plant samples which was found lower as compared to the control sample values. % RWC resulted in low value of 38.9 at polluted site while its control value was 40.12. pH value was found to be 6.51 which was higher than control value of 6.04. APTI value in experimental samples was calculated 5.82 while in control value was 5.99 (Table 2).

Table 2. Comparative analysis (Control vs Experimental) of Air Pollution Tolerance Index of selected species of urban landscape of Lahore city

S. No	Plant Species	Ascorbic Acid Content (mg/g)		Total Chlorophyll Content (mg/g)	Relative Water Content (%)			pH		Air Pollution Tolerance Index (APTI)	
		*Cont.	*Exp.	*Cont.	*Exp.	*Cont.	*Exp.	*Cont.	*Exp.	*Cont.	*Exp.
1	*Alea rosea*	1.82 ±0.09	1.75 ±0.18	17.20 ±0.21	16.20± 0.75	68.46 ±1.22	66.16± 1.28	6.29 ±0.98	6.43 ±0.45	11.12 ±0.11	10.57 ±0.45
2	*Alstonia scholaris*	1.68 ±0.11	1.62 ±0.11	10.53 ±0.11	9.01 ±0.81	30.12 ±1.19	28.90± 1.95	5.04 ±0.45	5.42 ±0.48	5.62 ±0.13	5.22 ±0.88
3	*Catharanthus roseus*	2.39 ±0.13	2.23 ±0.12	29.20 ±1.12	28.80± 1.12	198.76± 2.45	192.40± 2.11	6.69 ±0.21	6.06 ±0.51	28.45 ±0.21	27.57 ±1.45
4	*Cosmos Sulphureus*	3.11 ±0.21	2.95 ±0.09	27.45 ±1.13	26.97± 1.13	107.71± 1.98	105.13± 1.98	5.46 ±0.98	5.80 ±0.43	21.01 ±0.23	20.70 ±1.98
5	*Helianthus annuus*	2.41 ±0.06	2.29 ±0.08	16.43 ±1.41	15.24± 0.98	118.29± 1.57	114.33± 1.45	6.34 ±0.12	6.69 ±0.48	17.31 ±0.41	16.45 ±0.95
6	*Hibiscus rosa sinensis*	1.75 ±0.09	1.67 ±0.15	5.28 ±1.22	5.10 ±1.01	40.12 ±1.25	38.90± 2.95	6.04 ±0.13	6.51 ±0.45	5.99 ±0.45	5.82 ±1.45
7	*Ficus benjamina*	2.93 ±0.17	2.85 ±0.16	12.77 ±1.25	12.05± 1.11	42.12 ±1.23	53.00± 2.98	6.01 ±0.55	6.47 ±0.46	9.71 ±0.25	10.57 ±1.98
8	*Ficus religiosa*	1.95 ±0.11	1.82 ±0.17	37.00 ±1.11	29.09± 1.15	18.99 ±1.19	18.10± 1.15	5.14 ±0.45	5.45 ±0.18	10.11 ±0.15	8.10 ±1.11
9	*Robinia pseudoacacia*	1.78 ±0.13	1.72 ±0.21	18.71 ±1.21	12.33± 1.07	26.12 ±1.25	22.30± 2.12	5.04 ±0.23	5.60 ±0.21	6.83 ±0.35	5.42 ±1.22
10	*Tabarnaemontana divaricata*	1.18 ±0.08	1.03 ±0.08	7.52 ±1.19	5.56 ±0.95	10.02 ±1.95	9.50 ±1.18	6.01 ±0.48	6.40 ±0.19	2.59 ±0.11	2.18 ±1.33

In *Ficus benjamina* ascorbic acid content was 2.85 (mg/g), chlorophyll content was 12.05 (mg/g) in experimental samples of plants while values for these parameters were observed slightly high in control samples i.e., 2.93 and 12.77 respectively. % RWC resulted in high value of 53 at polluted site indicating its tolerance towards air pollution while its control value was 42.12. pH value was found to be 6.47which was higher than control value of 6.01. APTI value of experimental plants was 10.57 as compared to the control value that was 9.71 (Table 2).

In *Ficus religiosa* higher ascorbic acid content was found as 1.82 (mg/g) and chlorophyll content as 29.09 (mg/g) in roadside plant samples while values for both the parameters were found slightly higher as 1.95 and 37.00 (mg/g) respectively. % RWC resulted in low value of 18.20 at polluted sites while its control value was 18.99. pH value was found to be 5.45 and 5.14 at polluted and control sites respectively. APTI calculated for experimental plants was 8.10 as compared to control samples that was 10.11 (Table 2).

In *Robinia pseudoacacia* ascorbic acid content was 1.72 (mg/g) in experimental plant samples and chlorophyll content of 12.33 (mg/g), while ascorbic acid content was 1.78 (mg/g) in control samples and 18.71 (mg/g) was total chlorophyll content. % RWC resulted was low (22.3) at polluted site while its control value was higher (26.12). pH value was found to be 5.60 which was higher than control value of 5.04, while 5.42 APTI value was calculated in experimental plants and 6.83 in control samples (Table 2).

In *Tabarnaemontana divaricata* had higher ascorbic acid content as 1.03 (mg/g) and lower chlorophyll content was observed as 5.56 (mg/g) in roadside plant samples while it was 1.18 and 7.52 (mg/g) for both the parameters respectively. While calculations for % RWC resulted in value of 9.5 at polluted site while its control value was 10.02. pH value was found 6.4 which was higher than control value of 6.01. 2.18 APTI value was calculated for experimental plants while 2.59 APTI was calculated for control samples as shown in (Table 2).

It was found that air pollution tolerant plant was *Catharanthus roseus* having APTI value 27.01 followed by *Cosmos sulphureus* with 20.18 APTI value, *Helianthus annuus* with 16.45, *Alcea rosea* and *Ficus benjamina* with 10.57 APTI value each, *Ficus religiosa* with 8.09, *Hibiscus rosa-sinensis* had 5.82, *Robinia pseudoacacia* with 5.31, *Alstonia scholaris* with 5.19 and *Tabarnaemontana divaricata* with 2.18 ATPI values. So, selected plants are tolerant to air pollution in the order as*: Catharanthus roseus> Cosmos sulphureus> Helianthus annuus> Ficus benjamina> Alcea rosea> Ficus religiosa> Hibiscus rosa-sinensis> Robinia pseudoacacia> Alstonia scholaris>Tabarnaemontana divaricata* (Table 2).

Plants are either tolerant or sensitive to the pollutants present in the air and this mode of action and response of plants towards air pollution can be determined by calculating their APTI value. Value of Air Pollution Tolerance Index of plants can be determined by calculating the content of ascorbic acid, chlorophyll, pH and water present in the leaves of plants. By conducting several surveys, three busiest roads with dense and heavy traffic were selected for execution of this research work.

Fig. 2. illustrates the correlation of APTI with four physicochemical parameters i.e., ascorbic acid, chlorophyll, relative water content and pH. In Fig. 2a) highly positive correlation between APTI and ascorbic acid was found which represents the plants' strong defense mechanism to combat air pollution. Fig. 2(b, c) represent a positive correlation of APTI with relative water content and chlorophyll with R^2 values of 0.336 and 0.3379 respectively. In Fig. 2d) slightly positive correlation of APTI with pH values was found having R^2 value of 0.0018. Higher R^2 values highlights the major role of ascorbic acid in plants to face stressed and challenging conditions. Positive values of R^2 for chlorophyll and relative water content and slightly positive values for pH indicates their significance in maintaining the resilience of plants. This statistical analysis proves the participation of all four physicochemical parameters in building up the defense mechanism of plants against pollutants present in air. Moreover, comparative analyses of all these parameters were performed with respect to both experimental and control as shown in Figs 3-7.

Plants having low ascorbic acid content are sensitive to the pollutants of air while plants having high ascorbic acid content exhibits tolerance towards air pollution [41]. In this research work higher ascorbic acid content was found in *Alstonia scholaris* (1.62±0.11), *Ficus religiosa* (1.82±0.17) *Catharanthus roseus* (2.23±0.12) and *Cosmos sulphureus* (2.95± 0.09) while lower content of ascorbic acid was found in *Helianthus annuus* (2.29±0.08) and *Hibiscus rosa-sinensis* (1.67±0.15). Ascorbic acid fixes carbon in photosynthesis and have strong reducing ability due to which, it plays a vital role in protection and defense of plants and regulation of various physiological and metabolic processes. Thus, contributing to provide the resistance against culminating pressure of air pollution on plants [42,43]. While the emissions related to vehicular exhausts showed the lower concentrations of the chlorophyll contents in plant samples of polluted sites [44]. Accumulation of sulphates in the plant cells synthesizes hydrogen and oxygen peroxide which is restricted by the elevated levels of ascorbic acid content in plants. This increased ascorbic acid content restricts the deterioration to the fixation of CO_2 and chlorophyll activation. In this research work it was found that *Ficus religiosa*, *Robinia pseudoacacia, Catharanthus roseus* and *Cosmos sulphureus* have high chlorophyll content which indicates its resistance towards air pollution. *Alstonia scholaris* and *Tabarnaemontana*

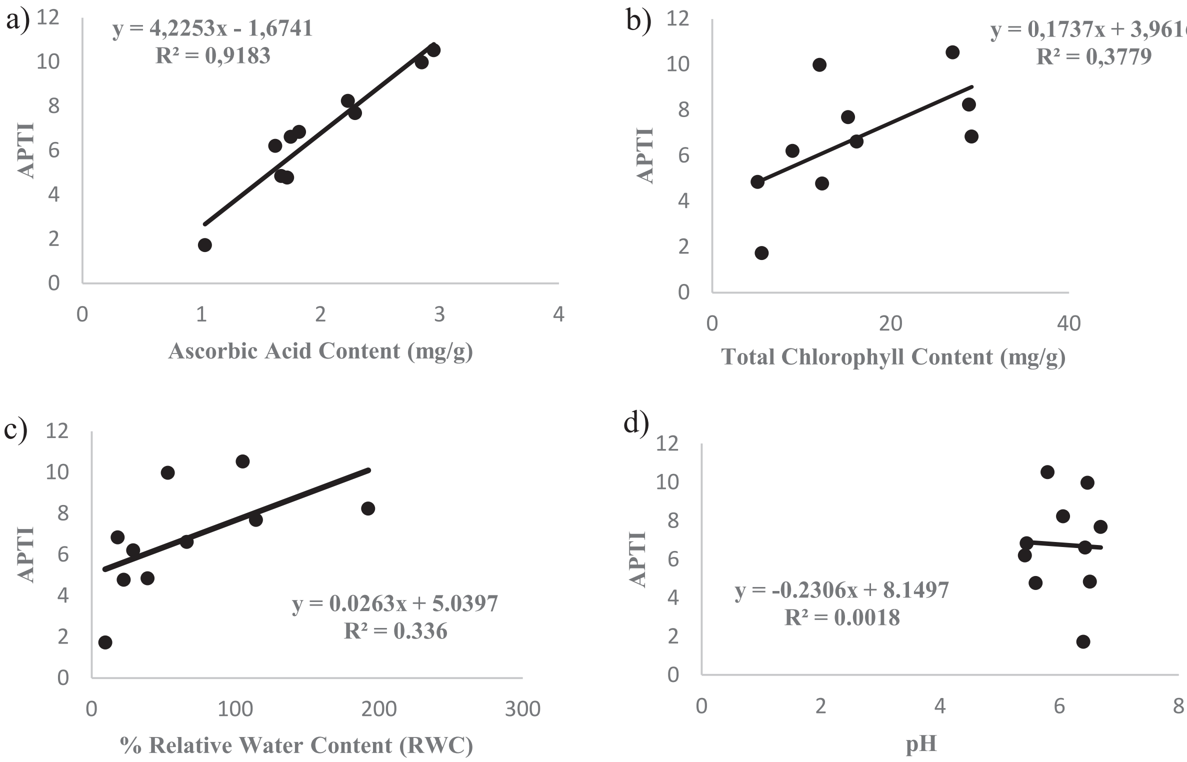

Fig. 2. a) Trends of ascorbic acid content (mg/g), b) total chlorophyll content (mg/g), c) % relative water content (%RWC) and d) pH in selected plant species.

divaricata exhibited least chlorophyll content which according to Aguiar-Silva showed their sensitivity towards air pollution [46]. Zhang et al. found that the plants with higher chlorophyll content were resistant towards elevated pollution rate. Ascorbic acid content in the chloroplast of the plant body dictates about the amount of chlorophyll present [47]. However, chlorophyll content present in the plant body varies by the variable number of pollutants present in the cells of that plant. Such contents help the plant to develop the resistance mechanism of the plant against air pollutants [48,49]. In this research work it was found that elevated level of water content was found in *Alcea rosea, Helianthus annuus* and *Cosmos sulphureus* while *Tabarnaemontana divaricata* had lowest water content in their plant body. In highly polluted areas, plants restrict the process of transpiration form maintaining the balance of physiological activities of plants. Pollutants decreased the level of relative water content in plants and affect the rate and process of transpiration rate of plants [50,51]. In this research work, calculated pH value for selected species was found in the range of 5.42-6.69. *Tabarnaemontana divaricata* showed the lowest value of pH while *Helianthus annuus* showed highest value of pH. Plants having low values of pH are vulnerable to air pollution [52]. While the plants having elevated pH values are resistant to air pollution. Conversion of hexose sugar into the ascorbic acid is due to the elevated levels of pH [53]. Plants absorb nitrogen oxide and sulphur dioxide due to the high

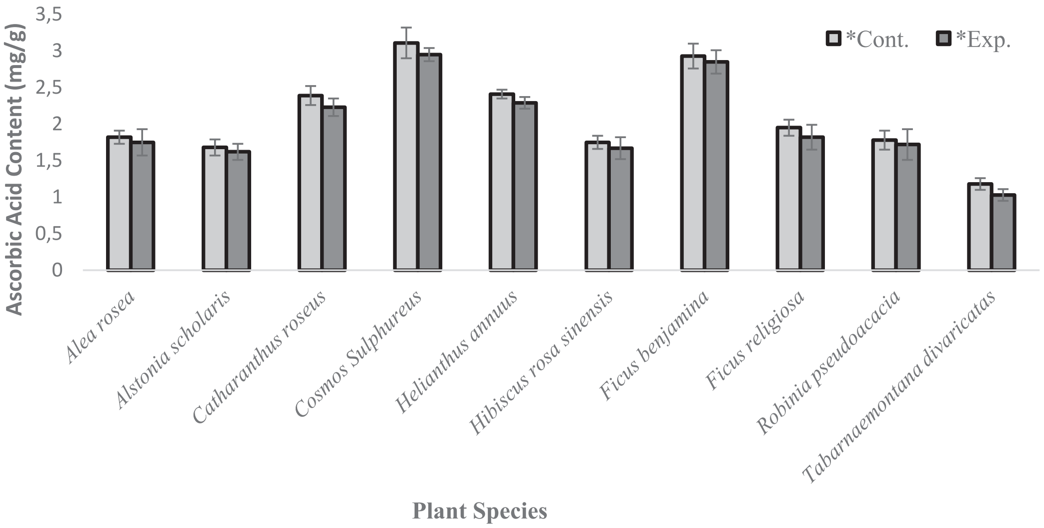

Fig. 3. Comparative Analysis (*Control vs *Experimental) of Ascorbic Acid Content (mg/g) of selected species of urban landscape of Lahore City.

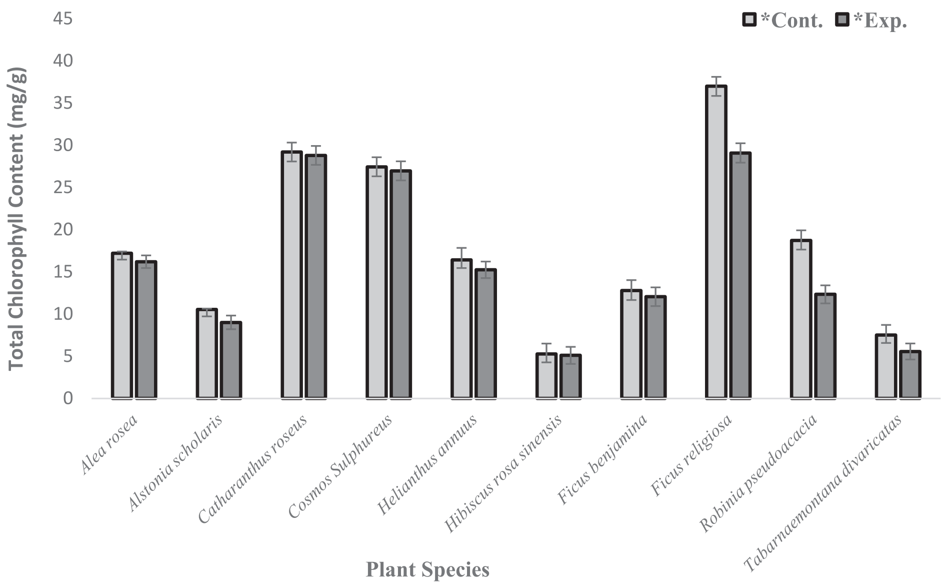

Fig. 4. Comparative Analysis (*Control vs *Experimental) of Chlorophyll Content (mg/g) of selected species of urban landscape of Lahore City.

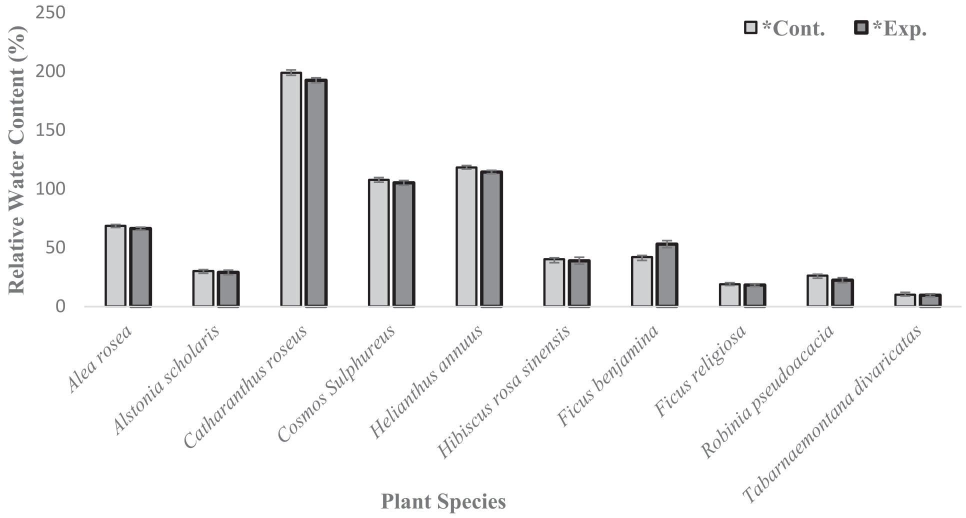

Fig. 5. Comparative Analysis (*Control vs *Experimental) of Relative Water Content (%) of selected species of urban landscape of Lahore City.

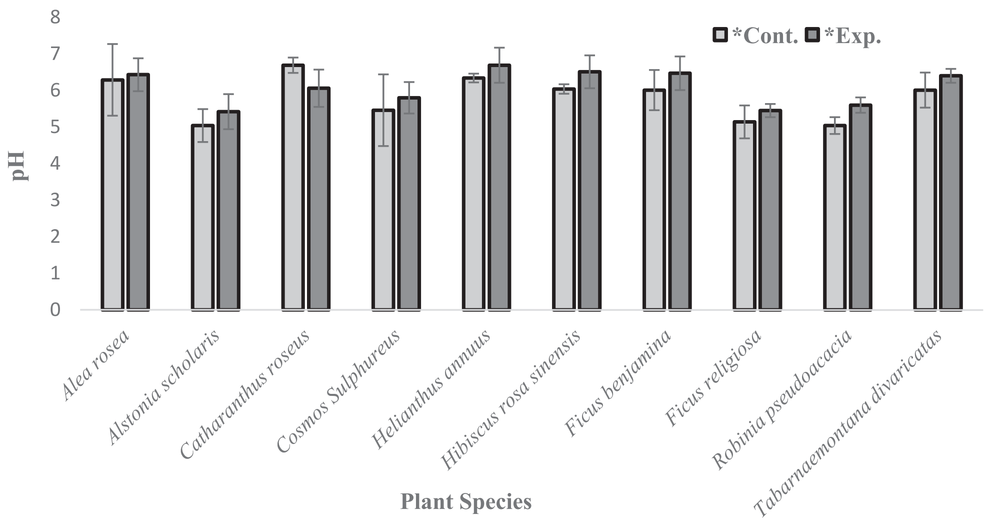

Fig. 6. Comparative Analysis (*Control vs *Experimental) of pH of selected species of urban landscape of Lahore City.

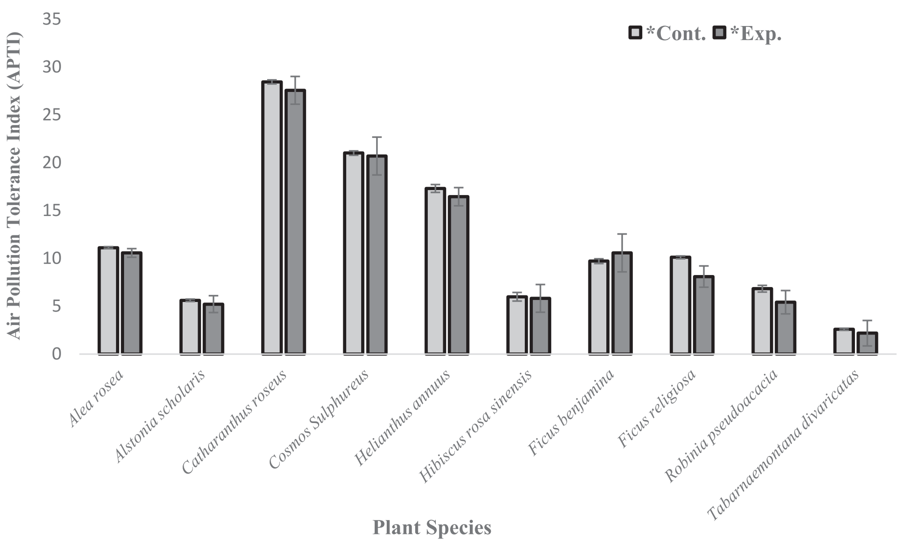

Fig. 7. Comparative Analysis of Air Pollution Tolerance Index (APTI) between *Control and *Experimental.

value of pH of leaves. Values of Air Pollution Tolerance Index (APTI) are calculated by measuring the four parameters of Ascorbic acid, chlorophyll, relative water content and pH. By calculating and putting the observed values in their respective formulas, APTI of all selected plants was calculated and *Catharanthus roseus* and *Cosmos sulphureus* showed highest values of APTI indicating its resistance towards air pollution. While *Tabarnaemontana divaricata* showed the lowest value of APTI. Several research workers showed that the evergreen plants are more tolerant to air pollution because they filter the pollutants more efficiently. Hazarika et al. through their studies suggest that the plants having values of APTI lesser than 1 are very sensitive, while plants having APTI values between 1-16, 17-29 and 30-300 are sensitive, intermediate, and tolerant respectively [54]. In this research work APTI value was calculated for the selected species and it ranges from 2.18-27.57. In this research work, some of the plant species were found as sensitive while some as tolerant and intermediately tolerant to air pollutants [55, 56]. So, by thoroughly studying and executing the entire research work, it can be said that response of plants towards air pollutants varies by varying the sites of plants selection and types of pollutants absorbed by the plant body depends on its sensitive and tolerant behavior. Rai et al. said that APTI is the main attribute of plants to cope up with the stress of pollution. Elevating the level of physiochemical characters i.e., ascorbic acid, pH, relative water content and leaf chlorophyll enables the plant to naturally adjust the absorption of variable air pollutants and cope up with the air pollution [57, 58].

Conclusion

Densely busy roads with heavy traffic loads in Lahore city creates negative affect on the health of people and on growth and diversity of vegetation present on the adjacent sides of roads. Increasing rate of urbanization and vehicular ejections induces detrimental changes in the physiology and morphology of plants. Continuous subjection of plants to air pollution causes a change in their chlorophyll content, ascorbic acid content, water content and pH. By measuring the variations in these parameters, Air Pollution Tolerance Index (APTI) of plants are calculated which indicates about the sensitive and tolerant behavior of plants to Air Pollution. In this research work, results of many of the plants give indications towards their sensitive nature. *Catharanthus roseus, Cosmos sulphureus, Helianthus annuus* and *Ficus benjamina* having higher APTI values of 27.57±1.45, 20.70±1.98, 16.45±0.95 and 10.57±1.98 respectively were found to be tolerant towards air pollutants while *Robinia pseudoacacia, Alstonia scholaris* and *Tabarnaemontana divaricata* were found to be sensitive towards air pollutants having lower APTI values of 5.42±1.22, 10.57±0.45 and 2.18±1.33 respectively. As Lahore is one of the busiest cities of Pakistan with high traffic and pollution rate, so, resistant and tolerant plants should be grown in the urban areas for mitigating the continuously elevating pollution in the city. This strategy can be executed by making plantation of resistant plants as a compulsory section of urban planning for best results.

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Conflict of Interest

The authors declare no conflict of interest.

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