



Effect of air pollution on photosynthetic efficiency of roadside plants: A Review

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Abstract

Air pollution generated from vehicular exhaust emissions has become a serious environmental problem affecting the physiological and biochemical functioning of roadside vegetation worldwide. Roadside plants are continuously exposed to harmful pollutants such as particulate matter, nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), hydrocarbons, and heavy metals, which significantly influence their photosynthetic efficiency and overall health. The present review summarizes recent findings regarding the impact of vehicular air pollution on photosynthetic performance, physiological responses, biochemical adaptations, and anatomical changes in roadside plants. Various studies have demonstrated that exposure to polluted environments leads to considerable reduction in chlorophyll content, stomatal conductance, transpiration rate, carbon dioxide assimilation, and photosynthetic efficiency due to deposition of particulate matter and toxic pollutants on leaf surfaces. In response to pollution stress, plants exhibit several adaptive mechanisms including increased accumulation of proline, ascorbic acid, soluble sugars, antioxidant enzymes, wax deposition, and enhanced water use efficiency. Morphological and anatomical modifications such as increased leaf thickness, stomatal alterations, epidermal changes, and vascular tissue modifications have also been frequently reported in polluted roadside plants. The review further highlights species-specific variability in tolerance to vehicular pollution, where plants such as *Mangifera indica*, *Azadirachta indica*, *Ficus religiosa*, *Polyalthia longifolia*, and *Alstonia scholaris* demonstrated comparatively higher tolerance and pollutant-removal potential. Several researchers have used Air Pollution Tolerance Index (APTI) and associated physiological parameters as reliable indicators for identifying pollution-tolerant species suitable for urban plantation and green belt development. Overall, the review emphasizes the dual role of roadside vegetation as both sufferers and mitigators of air pollution, since these plants experience physiological stress while simultaneously contributing to air purification, particulate trapping, heavy metal detoxification, and maintenance of urban ecological balance.

Keywords: Vehicular air pollution, roadside vegetation, photosynthetic efficiency, physiological responses, biochemical adaptations, particulate matter

Introduction

Air pollution is one of the most serious environmental problems associated with rapid urbanization, industrialization, and increasing vehicular traffic across the world. Automobiles release a wide range of harmful pollutants into the atmosphere, including particulate matter (PM_{2.5} and PM₁₀), nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO), hydrocarbons, and heavy metals such as lead, cadmium, and zinc. These pollutants adversely affect not only human health but also plant growth, productivity, and ecosystem stability. Roadside plants remain continuously exposed to these toxic pollutants and therefore act as important biological indicators of environmental pollution. The deposition of particulate matter and toxic gases on leaf surfaces interferes with stomatal functioning, gaseous exchange, chlorophyll biosynthesis, and photosynthetic processes, ultimately reducing plant growth and physiological efficiency. Several studies have demonstrated that vehicular air pollution causes significant alterations in chlorophyll content, photosynthetic rate, transpiration, stomatal conductance, and biochemical composition of roadside vegetation.

Despite the harmful effects of air pollution, roadside plants play a crucial ecological role in mitigating environmental contamination by trapping dust particles, absorbing gaseous pollutants, accumulating heavy metals, and improving urban microclimate conditions. Plants exposed to polluted environments often develop various adaptive and defense mechanisms such as increased production of proline,

ascorbic acid, soluble sugars, antioxidant enzymes, wax deposition, and enhanced water use efficiency to tolerate stress conditions. In addition to physiological and biochemical responses, several morphological and anatomical modifications including increased leaf thickness, stomatal alterations, epidermal changes, and vascular tissue modifications have also been reported in polluted roadside plants. Different plant species show varying levels of tolerance to air pollution, and therefore parameters such as Air Pollution Tolerance Index (APTI) have been widely used to identify pollution-tolerant species suitable for urban plantation and green belt development. In this context, the present review focuses on the effects of vehicular air pollution on photosynthetic efficiency and associated physiological, biochemical, and anatomical responses of roadside plants while highlighting their important role in environmental pollution mitigation and sustainable urban ecosystem management.

Related Studies

In a recent study by Matsumoto *et al.*, (2022) ^[12], the researchers evaluated the effect of air pollution by automobile gas exhaust on photosynthetic functions of different roadside tree species in Kyoto city, Japan. Nitrogen monoxide and nitrogen dioxide were found to be the major gases contributing to vehicular air pollution. The results of the study indicated differential species-specific pattern in the photosynthetic efficiency of different plants to vehicular exhaust gases. The highest decline in

photosynthetic efficiency of plants at high traffic sites was observed in case of *Rhododendron pulchrum*, *Rhaphiolepis indica*, and *Prunus yedoensis*.

In another recent study by Robert Popek *et al.*, (2021), the researchers investigated the effect of particulate matter on the deposition on foliage as well as photosynthetic efficiency of seven different plant species belonging to three different categories- shrubs (3), trees (3) and climber (1). The analysis was performed for different plant varieties growing in two different geographical locations (centre and suburbs of Warsaw), which differed from each other in terms of concentration of particulate matter in the air. The results indicated increased accumulation of waxes and particulate matter on leaves of plants growing in polluted areas. The deposition of waxes and particulate matter was highest in leaves of *P. opulifolius* in comparison to *S. sorbifolia* owing to difference in leaf structure and morphology.

Another study by Ahmad *et al.*, (2018) [1] investigated the effect of Pb²⁺ pollution released from exhaust gases of vehicles on photosynthetic efficiency and plant water relations of roadside plant growing on Motorway (M-2) and G.T. road. The study was performed in plants growing at variable geographical distance from the main road.

Plants growing in close proximity to the main road showed higher decrease in photosynthetic efficiency, stomatal conductance and rate of transpiration in comparison to plants growing at 50 m distance from the main road.

In a study by Uka *et al.*, (2021) [24], the researchers analyzed the effect of vehicular pollution on content of photosynthetic pigments in roadside plants belonging to four different species, namely, *Terminalia catappa*, *Mangifera indica*, *Ficus platyphylla* and *Polyalthia longifolia*. For this study, two major sites were selected, Kwame Nkrumah University of Science and Technology Campus was used as the control site whereas another site overflowing with heavy vehicular traffic, namely Kumasi Metropolis, was selected as the polluted site. The leaves of all the plant species were evaluated for the photosynthetic pigments, whose concentration was correlated with the presence of heavy metals (Pb, Cu, Cd and zinc) in plant leaves. The accumulation of heavy metals in plant leaves was assessed using a parameter termed as metal accumulation index (MAI). In complete contrast to the chlorophyll, the highest decline in carotenoid content was observed in case of *Terminalia catappa* (31.58%) while the lowest decrease was found in case of *Polyalthia longifolia* (16.67%). In direct correlation with the content of photosynthetic pigments, leaves of plant grown in polluted site displayed higher accumulation of heavy metals including Cu, Pb, Zn and Cd. The highest heavy metal accumulation index was observed in *Mangifera indica* (5.35) while the second highest values of MAI were seen in case of *Polyalthia longifolia* (4.30). The findings highlighted in this study depict a clear correlation between the level of photosynthetic pigments in plant leaves, the heavy metal accumulation as well as the vehicular pollution.

A recent study by Kazi *et al.*, (2021) [9] evaluated the hazardous effect of air pollution from vehicular exhaust gases on roadside plants in Pune city. The study focused on the effect of different sized particulate matter (PM₁₀ and PM_{2.5} as well as gases like sulphur dioxide and nitrogen dioxide) on the morphology of *Polyalthia longifolia* and *Ficus racemosa* in Shivajinagar and Pashan area of Pune.

The results indicated higher pollution level in Shivajinagar area in comparison to Pashan area. The presence of polluted area in the Shivajinagar area led to greater decline in photosynthetic efficiency of the plants in that area, evident from higher level of air pollution tolerance index (APTI) in polluted areas. Additionally, the study highlights the crucial role of both the plant species, namely, *Ficus racemosa* & *Polyalthia longifolia*, for amelioration of air quality in both Shivajinagar and Pashan area at the expense of decline in photosynthetic efficiency of both the plants.

A recent study by Iqbal *et al.*, (2019) [7] demonstrated the effect of air pollution on chlorophyll content of four different roadside tree species viz. *Azadirachta indica* L., *Conocarpus erectus* L., *Guaiacum officinale* L. and *Eucalyptus*. The results indicated significant alteration in the level of chlorophyll a, b and total chlorophyll a+b in leaves of all the four plant species growing in polluted areas in comparison to the ones growing in control areas. The lowest amount of chlorophyll a, b as well as total chlorophyll a+b was found in leaves of plants growing in Quaidabad site, where heavy vehicular traffic is present. Therefore, the study highlighted the crucial role of vehicular air pollution in reduction of chlorophyll content and photosynthetic retardation in roadside plants while also highlighting the pivotal role of roadside plants in ameliorating the air quality and acting as sink to absorb harmful toxicants from the exhaust gases released by vehicles.

A study by Joshi *et al.*, (2009) [8] analyzed the effect of vehicular emissions on photosynthetic efficiency of six different plants species, namely, *Mangifera indica* L., *Tectona grandis* Linn.f., *Shorea robusta* Gaertn.f., *Holoptelea integrifolia* (Roxb.) Planch, *Eucalyptus citridora* Hook. Syn. and *Mallotus philippinensis* Muell-Arg. The results indicated decline in chlorophyll a, b and total chlorophyll a+b in leaves of plants growing in polluted areas.

Holoptelea integrifolia (Roxb.) displayed the maximum reduction in total chlorophyll content of leaves, with percentage decline amounting to 48.73%. In contrast to this, lowest decline in total chlorophyll content of leaves was observed in case of *Mallotus philippinensis* Muell-Arg, with percentage decline amounting to 17.84%. Therefore, the study highlighted deleterious effect of vehicular air pollution in deterioration of chlorophyll and carotenoid content of leaves of roadside plants.

In a study by Geeta *et al.*, (2014), the researchers showed the detrimental effect of air pollution from vehicular exhaust gases on chlorophyll content of three different plant species, belonging to *Polyalthia longifolia*, *Thevetia nerifolia* and *Alstonia scholaris*. For the study purpose, the plant species were collected from three different areas of Jamshedpur city, which differed from each other in terms of vehicular traffic and air quality index. The areas selected for this purpose belonged to three different categories, namely, industrial, commercial and residential localities. The results indicated significant decline in chlorophyll content of *Polyalthia longifolia* while moderate insignificant decline in chlorophyll content of *Alstonia scholaris* was observed in the same area. Therefore, out of all the three studied plant species, maximum susceptibility to air pollution was found in case of *Polyalthia longifolia*, followed by *Alstonia scholaris* and *Thevetia nerifolia*.

A study by Celiktas *et al.*, (2019) [5] demonstrated the hazardous effects of vehicular exhaust gases like CO₂

(carbon dioxide), HC (hydrocarbons), and NO (nitrogen oxides) on physiological processes in plants including photosynthesis and stomatal conductance, both of which are important determinants of crop yield. Both total soluble sugar as well as proline are indicators of plant stress and a consequent increase in their levels in leaves of plants growing in polluted region is indicative of plant adaptation and tolerance to the environmental stress.

In a recent study, Singh, (2021) ^[21] studied the effects of vehicular air pollution on physiological, morphological, and biochemical characteristics of *A. scholaris* planted on roadsides. The results of the study indicated that exposure of plants to polluted environment led to increase in leaf thickness, dust load flux, local cooling created by canopy, water use efficiency, proline, ascorbic acid, pH, soluble sugar and heavy metal accumulation in plant leaves.

In a recent study by Ogagaoghene *et al.*, (2017) ^[14], the researchers investigated the effect of air pollution caused by vehicular exhaust gases on four different biochemical parameters such as pH, ascorbic acid, proline and soluble sugar. The results of the study showed a gradual increase in all the parameters (ascorbic acid and proline) in leaves of plants growing in polluted environment with decrease in pH value and soluble sugar. However, different results were obtained in case of *Musa paradisiaca* L. and *Manihot esculenta*, which is reflective of different behavior in plants when exposed to same kind of stressful conditions.

A recent study by Shaukat *et al.*, studied the hazardous effect of air pollution by exhaust gases of vehicles on different roadside plants in Karachi, Pakistan. For this, different parameters including ascorbic acid, total chlorophyll content, pH and relative water content of leaves was measured to calculate the air pollution tolerance index (APTI) of the plant species. As per the results of the study, the plants growing in polluted areas were found to contain partially as well as completely clogged stomata. In addition to this, the plants growing in polluted sites were found to contain higher level of free amino acids. The study concluded with a message that alleviation of air pollution in the city would require planting of tolerant tree species with higher APTI.

In a recent study, Turfan *et al.*, (2019) ^[23] investigated the effect of air pollution induced by exhaust gases of vehicles on different physiological and biochemical parameters of *Prunus laurocerasus* L. in Kastamonu city. For this, leaf samples of plants growing in two different regions were selected, that included leaves from plants growing in Salpazarı region with heavy traffic and polluted air and plants growing in Kışla park region with low traffic and unpolluted air. In addition to this, plants growing in lightly polluted areas were found to have higher activity of APX and lower activity of hydrogen peroxide. Therefore, the study pointed towards air pollution tolerance ability of plants and highlighted their ameliorative role in controlling air pollution.

In a study by Sen *et al.*, (2017) ^[16], the researchers analyzed the effect of air pollution on ten species of plants growing in University of Burdwan during the pre-monsoon and post-monsoon seasons. The study investigated the effect of primary air pollutants on physiological and biochemical attributes of plants. The results of the study indicated that pre-monsoon season was marked by higher concentration of different parameters in plants such as proline content, pH, relative water holding capacity, photosynthetic rate, and

respiration rate in comparison to the post monsoon season. However, certain parameters such as total chlorophyll, ascorbic acid, sugar, and conductivity were higher during the post monsoon season in comparison to pre-monsoon season. Also, the study reported lower concentration of air pollutant gases such as sulfur oxide (SO_x), nitrogen oxide (NO_x), and suspended particulate matter (SPM) in atmosphere during the post monsoon season in comparison to pre-monsoon.

A recent study by Tak *et al.*, (2020) ^[22] analysed the effect of air pollution on overall physiological and biochemical characteristics of plants cultivated on roadsides in Thane, India. For this, the researchers selected four different species of plants, namely, *Alstonia scholaris*, *Cassia siamea*, *Ficus religiosa* and *Mangifera indica* from two sites differing from each other in terms of pollution level. The presence of higher water content in plants at the polluted site is a measure of the tolerance capacity of plants to different stressful conditions. In addition to the water capacity, the plants growing in polluted sites were found to accumulate higher level of ascorbic acid, which is indicator of the plant stress and helps the plant in overcoming stressful situations. The study also reported decreased stomatal efficiency in plants growing in polluted areas, which maybe attributed to deposition of dust and waxy cuticle on the surface of the leaves. In addition, the plants growing in polluted environment were found to accumulate higher concentration of the stress marker proline.

In a recent study, Singh *et al.*, (2021) ^[21] investigated the effect of air pollution released from exhaust gases of vehicles on health and physiological parameters of roadside plantation while also highlighting the crucial ameliorative role of roadside plantation in alleviating air pollution. For this study, the researchers analyzed the effect of air pollutants on two important roadside tree species, namely, *Grevillea robusta* and *Mangifera indica* in Uttarakhand. Furthermore, the ability of trees to tolerate air pollution due to vehicular exhaust gases was measured by using various attributes such as However, the plant species in polluted sites displayed lower carbon dioxide assimilation efficiency, leading to decreased photosynthetic efficiency in comparison to control plants.

In another study by Anjum *et al.*, (2021) ^[4], the researchers analyzed the effect of air pollutants on different physico-chemical characteristics of two plant species, namely, *Nerium oleander* and *Ricinus communis* cultivated on two different roads in Pakistan- from Faisalabad to Okara (R-1) and Okara to Lahore (R-2) roads. For this, the researchers analyzed different parameters of plant species growing at two different locations- the polluted site (in close proximity to the road) and the control site (50 mtr away from the road). The analyzed parameters included, photosynthetic pigments, photosynthetic rate, transpiration rate and total soluble proteins. Moreover, the plants growing in polluted sites on the roadsides were found to accumulate higher level of proline amino acid, which is indicative of triggering of stress responsive pathways in plants leading them to stress tolerance and resistance.

Another study by Khalid *et al.*, (2019) ^[10] analysed the effect of vehicular exhaust gases on physiological and biochemical responses of two different plant species, namely, *Datura alba* and *Ricinus communis* growing on the roadside of Punjab, Pakistan. For this, the researchers analyzed different parameters of plant species, growing at

two different geographical locations, polluted (growing in close proximity to the main road) and control (50 mtr away from main road). Furthermore, the plants growing in polluted site were also found to showcase increased internal CO₂ concentration and water use efficiency. In addition to this, plants growing in polluted sites were found to exhibit reduction in total soluble protein content coupled with increased activity of antioxidant enzymes; which is indicative of the triggering of plant antioxidant system under stressful conditions. Therefore, the results of the study suggest that *Ricinus communis* is better adapter for its ameliorative role in alleviation of air pollution occurring because of vehicular exhaust gases.

In another consecutive study by Singh *et al.*, (2022) ^[19], the researchers investigated the effect of different concentrations of foliar particulate matter on physico-chemical parameters of different plants such as *Mangifera indica* and *Psidium guajava*), semi-evergreen (*Ficus religiosa* and *Azadirachta indica*), and deciduous (*Dalbergia sissoo*) over a period of 2 years. The analysed parameters included: Physiological parameters (P_n, g_s, Ci, E, and WUE), nutrient stoichiometry (C: N) in different plant parts, and their allocation pattern for five macro- (C, N, K, Mg, Ca) and five (Zn, Ni, Mn, Cu, Fe) micro-elements. Two different concentrations of particulate matter were used for this study that included an ambient concentration as control and a higher concentration as the polluted condition.

The results of the study highlighted following findings:

- Increase in foliar deposition of particulate matter led to significant decline in the photosynthetic rate of all the tested plant species.
- The leaves of plant growing in polluted sites were found to showcase higher variability in C, N, K, Mg, and Zn levels with slight decline in ratio of C/N in mature leaves.
- Based on the results of the nutrient stoichiometry, it was inferred that plants belonging to the deciduous category showcased higher tolerance in comparison to other plants.
- The study also reported higher nutrient allocation in foliage as compared to branch in evergreen trees.

Another study conducted by Singh *et al.*, (2020) ^[20] investigated the adaptation and mitigation potential of different plant species, in alleviation of vehicular exhaust gases induced air pollution. Furthermore, the study also examined the effect of air pollutants on different physiological aspects of plant health including CO₂ assimilation, water loss through transpiration rate and stomatal conductance. The results of the study highlighted the following findings:

- Deposition of particulate matters on the leaves of plants growing in polluted areas led to decline in CO₂ assimilation efficiency of plants.
- Deposition of particulate matters on the leaves of plants growing in polluted areas led to decline in transpiration rate of plants.
- Deposition of particulate matters on the leaves of plants growing in polluted areas led to decline in stomatal conductance efficiency of plants.

The authors further stated that stomatal conductance in plants is controlled by a number of factors such as, age and position of leaves on the tree. Even a slight perturbation

with the leaf surface alters the stomatal behavior, as a consequence of which, several changes occur in the plant leaves such as altered photosynthetic efficiency and reduced transpiration efficiency.

The biophysical changes in plants in response to exposure to air pollution can be summarized as follows:

- Trees growing in polluted site were found to exhibit increased leaf thickness in comparison to control.
- The leaf thickness in *M. indica* was higher as compared to *G.robusta*.
- Increased thickness of leaves in plants growing in polluted areas maybe attributed to deposition of waxy cuticle wing to which the leaves become sticky in nature, as a result of which greater magnitude of dust particles get adhered to the leaf surface.
- Deposition of thicker waxy cuticle on leaf surface further retards the transpiration rate of the leaf, which has a direct effect on the stomatal conductance of plants.
- Furthermore, increased leaf thickness in polluted areas is considered to be an adaptive tolerance mechanism of plants to resist adverse effects of pollutants on plant health. The leaves of *G. robusta* have been found to exhibit thicker deposition in comparison to *M. indica*, which may be attributed to rough surface and geo-parallel position of the leaves of *G. robusta* in comparison to *M. indica*, whose leaves have relatively smoother surface. In addition to this, *G. robusta* leaves have a higher surface area and therefore are more prone to accumulation of dust particles. A number of parameters such as total chlorophyll, pH of leaves, relative water content and ascorbic acid were used to calculate the air pollution tolerance index of the plants.

A recent study by Akomolafe *et al.*, (2019) ^[2] analysed the effect of vehicular gases on two plants, namely, *Urena lobata* and *Hyptis suaveolens*, growing on roadside in Nigeria. For the study, plants samples were collected from three different geographical locations at variable distance from the main road, i.e. at a distance of 0 m, 10 m and 20 m. Plants nearest to the main road and in close proximity to the polluted area were found to contain more number of stomata in comparison to plants distant from the main road.

A recent study by Mitu *et al.*, (2019) ^[13] investigated the effect of air pollution from vehicular exhaust gases on anatomical features of different roadside plants including Mango (*Mangifera indica*), SilKoroi (*Albizia procera*) and Mahagony (*Sweatenia mahogany*). The microscopy results showed reduction in cell size of roadside plants along with deposition of black dots in several leaf parts including epidermis, palisade and spongy parenchyma in the polluted sites in comparison to the plants growing in control site.

A study by Singh *et al.*, (2023) ^[18] showed the effect of automobile emissions on anatomy and morphology of roadside grasses *Triticum aestivum* L. and *Phalaris minor* Retz. The leaf surfaces of grasses growing in polluted areas showed reduction in stomatal size in case of grass *Triticum aestivum* L. However, no such morphological changes were observed in case of *Phalaris minor* Retz. Infact, *Phalaris minor* Retz growing in polluted sites showed increase in number of stomata.

A study by Al-Obaidy *et al.*, (2019) ^[3] analysed the effect of air pollutants on seven different plant species leaves, *Olea europea* L., *Zizphus spina-christi* L. Desf., *Conocarpus*

lancifolius Engl., *Albizia lebbek* L. Benth., *Eucalyptus camaldulensis* Dehnh., *Clerodendron inermis* L. Graeth and *Dodonaea viscosa* Jacq., distribute within Baghdad city. The study was conducted in five different geographical regions over a period of 1 year. The researcher assessed the air quality in terms of various physicochemical attributes such as The Sulfur dioxide (SO₂), Nitrogen dioxide (NO₂), Carbone monoxide (CO), Volatile organic compounds (VOCs) and Suspended particulate matter (PM). The air in Baghdad city contained (SO₂) average was (0.56) ppm, while (NO₂) average was (0.80) ppm, (CO) average was (27.69) ppm, (VOCs) average was (5.99) ppm, while (PM) average was (480.80) µg /m³.

Conclusion

Vehicular air pollution has become a serious environmental problem that adversely affects the photosynthetic efficiency, physiological activities, and overall health of roadside plants. Continuous exposure to pollutants such as particulate matter, nitrogen oxides, sulfur dioxide, carbon monoxide, hydrocarbons, and heavy metals causes significant reduction in chlorophyll content, stomatal conductance, transpiration

rate, and carbon dioxide assimilation, thereby decreasing plant productivity and growth. To survive under polluted conditions, roadside plants develop several adaptive mechanisms including increased accumulation of proline, ascorbic acid, soluble sugars, antioxidant enzymes, wax deposition, and enhanced water use efficiency along with anatomical modifications such as increased leaf thickness and stomatal changes. Different plant species exhibit varying levels of tolerance towards air pollution, and species such as *Mangifera indica*, *Azadirachta indica*, *Ficus religiosa*, *Polyalthia longifolia*, and *Alstonia scholaris* have been identified as comparatively more tolerant and suitable for roadside plantation and green belt development. Overall, roadside vegetation acts both as a sufferer and a natural mitigator of air pollution by trapping dust particles, absorbing toxic gases, accumulating heavy metals, and helping maintain urban ecological balance; therefore, plantation and conservation of pollution-tolerant species should be promoted as an effective and eco-friendly strategy for improving urban air quality and environmental sustainability.

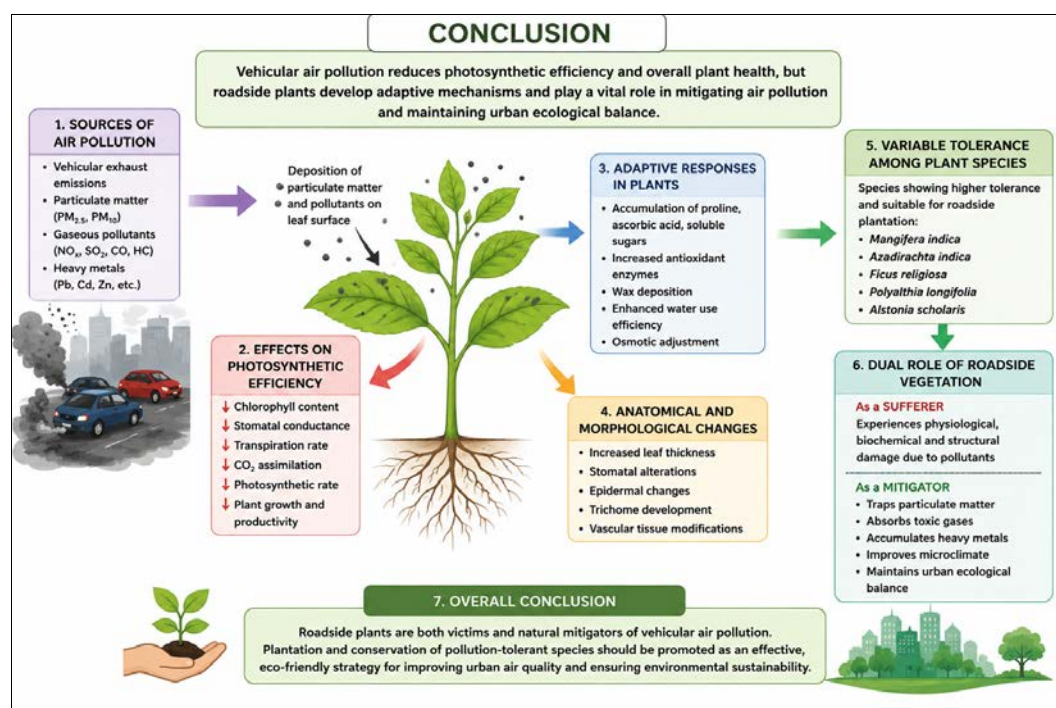


Fig 1: Effect of air pollution on plants.

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