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Impact of Air Pollution on Plant Physiology and Ecosystem Health

Jongtosang Aier[1], Kusuma Kumari Panda[1*], Sanjeev Kumar[2]
[1]Amity Institute Of Biotechnology, Amity University Uttar Pradesh (AUUP),Noida,India, [2]Advik Biotech Lab , Greater Noida, U.P. 201310.

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KEYWORDS

Air pollution, Human Health, Ecosystem Stability, Particulate matter, Photosynthetic Activity, Reactive Oxygen Species (ROS), Urban Vegetation.

ABSTRACT: Air quality in major cities of developing countries has deteriorated significantly in recent decades due to rapid increases in traffic, vehicular and industrial emissions, and the reduction of urban vegetation cover. This study synthesizes findings from multiple sources to examine the impacts of air pollution on human health, vegetation, and overall ecosystem stability. Air pollutants, including particulate matter, vehicular exhausts, and industrial emissions, have been linked to severe health effects in humans, particularly those with respiratory and cardiovascular diseases. Additionally, these pollutants disrupt plant ecosystems, leading to vegetation injury and crop yield losses.

The study explores the effects of various air pollutants on plant morphology and biochemistry. Pollution-induced stress causes significant changes in leaf morphology, including reductions in leaf area, petiole length, and overall growth. Sensitive species exhibit stomatal damage, early senescence, decreased photosynthetic activity, and disturbed membrane permeability. Furthermore, air pollution impacts pigment content in plants, notably reducing chlorophyll and carotenoids, thereby decreasing photosynthetic efficiency and plant productivity.

The study also highlights the role of soluble sugars and proline in plants' stress responses. Air pollution leads to a reduction in soluble sugars due to chlorophyll degradation and increased respiration rates. Conversely, some resilient species show an increase in soluble sugars and proline, suggesting these compounds play crucial roles in plant defense mechanisms against environmental stressors. The accumulation of proline, in particular, is linked to protection against oxidative stress and lipid peroxidation induced underscores the profound impact of air pollution on plant physiology and ecosystem health, emphasizing the need for effective pollution control measures and the importance of urban vegetation in mitigating air pollution effects.

1. Introduction

The fast growth in traffic, industrial and vehicular emissions, and the loss of urban vegetation cover have all contributed to the severe decline in air quality in developing countries' main cities in recent decades(Kim et al. 2015;Santos et al. 2015).Globally, air pollution is estimated by the World Health Organisation to cause approximately one million premature newborn deaths annually(Litchfield et al.,2018).

Human health is negatively impacted by air pollutants such as particulate matter (PM), vehicle exhaust, and industrial emissions. They also disrupt plant ecosystems and have an impact on the entire planet by altering the atmosphere(Raabe et al.,1999).Recent years have seen an increase in environmental concern due to air pollution, which are to blame for crop yield losses and vegetation damage(Joshi and Swami,2007).Air pollutants such as particulates, heavy metals, CO, SOx, NOx, and polyaromatic hydrocarbons (PAHs) are thought to be mostly produced by vehicles(Kulshreshtha and Sharma 2015;Kisku et al. 2013).When these pollutants are released, not only does the quality of the surrounding air decline, but it also puts people's health at danger, especially those with respiratory and cardiovascular conditions.(Jahan et al. 2016; Adrees et al. 2016). As a result of the ongoing growth in the human population, road traffic, automobile traffic, and industry, the concentration of gaseous and particle pollutants has continued to rise(Joshi et al., 2009). Global evidence has shown that air pollution has detrimental consequences on ecosystems and biota. Analysis of the impacts of air pollutants on plants and

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crops at many levels, from biochemical to ecological, has been the subject of much experimental studies. In contrast to urban locations, suburban and rural areas have been found to have higher ozone concentrations, whereas urban sites have One of the main things limiting plan productivity and survivability is environmental stress, like as air pollution (Woo et al., 2007).The primary cause of this significant issue is industrialization.There are two categories for pollutants: main and secondary.Pollutants that are released into the atmosphere and cause direct air pollution are referred to as primary pollutants, whereas secondary pollutants are those that are created in the air as a result of interactions or reactions between primary pollutants(Agbaire,2009). According to observations, a variety of contaminants, including hydrocarbons, ozone, particulate matter, hydrogen fluoride, peroxyacyl nitrates (PAN), and oxides of sulphur and nitrogen, have a significant negative impact on plants, especially those growing in metropolitan areas (Jahan and Igbal, 1992).The greatest contributors to air pollution are industrialization and automobiles. Additionally, crop plants can be used as indicators of air pollution because they are sensitive to gaseous and particle pollution(Joshi et al., 2009).In urban environments, trees play an important role in improving air quality by taking up gases and particles (Woo and Je ,2006).Compared to the results produced from directly determining the pollutant in the air during a brief period of time, the influence seen by vegetation is a time-averaged result that is more dependable as an indicator of the overall impact of air pollution.Yet, a lot of trees and shrubs have been found and are being utilised as dust filters to monitor the increasing level of urban dust pollution (Rai et al., 2010).

Large leaf areas are provided by plants, to varying degrees depending on the species, for the impingement, absorption, and storage of air pollutants to lower the level of pollution in the air (Liu and Ding, 2008). The use of plants as bio-monitors of air pollution has long been recognised, since they are the first to absorb pollution from the air. They scavenge a variety of airborne particles from the atmosphere(Joshi and Swami,2009).

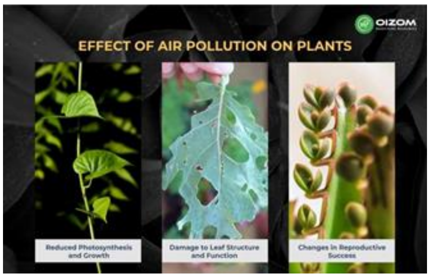

Fig 1: Effect of air-pollution on plants.

2. Effect on leaf morphology

Fig 2: Effect of Air pollution (sulfur dioxide) on blackberry (Rubus)

In sensitive plant species, pollutants can induce stomatal damage, early senescence, decreased photosynthetic activity, disturbed membrane permeability, and decreased growth and yield (Tiwari et al.,2006).Reduced leaf production rate and increased senescence may be the cause of reductions in leaf area and number. Because of the smaller leaf area, there is less radiation absorbed,which lowers the photosynthetic rate (Tiwari et al.,2006). Dineva (2004) and Tiwari et al.(2006) recorded a reduction of the leaf area and petiole length under pollution stress conditions.

There has been a report of significant reduction in different leaf variables in the polluted environment in comparison with clean atmosphere (Jahan and Iqbal, 1992).In the polluted air, their study on Platanus acerifolia showed some changes in leaf blade and petiole size in the polluted air.It was observed that the length, petiole length, and leaflet area of the contaminated plant, G. officinale, had significantly decreased.Five different tree species' leaf blade dimensions were found to be reduced in areas with high dust and SO_2 pollution (Jahan and Iqbal, 1992).Drought stress has also been noticed in

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A. Light injury B. Moderate injury C. Heavy injury

Fig 3: Effect of PAN on milkweed leaves (Source:https://extension.umd.edu/learn/air-pollution-effects-vegetables)

in leaf area (Hale et al., 1987).

Under the stress of air pollution, Albizia lebbeck leaves showed an increase in length, breadth, and loss in leaf area. Furthermore, research on Callistemon citrinus leaves planted in industrial areas reveals a decrease in leaf length, leaf breadth, and leaf area (Seyyednejad et al., 2009a, b). Cassia siamea plants growing at two different sites i.e, both the polluted and non-polluted area on two important roads of Agra city exhibited significant differences in their flowering phonology and floral morphology (Chauhan et al., 2004).Studies by researchers revealed that a reduction in total leaf area offset the boost of photosynthetic rates in elevated CO2.Naido and Chricot (2004) demonstrated how the area of an Avicenia marine leaf decreased due to the effect of air pollution exchange of gases. Reducing the leaf area in order to balance the tissue's water content is one strategy to boost tolerance in contrast to stress (Hale et al.,1987). This seems to be a defence strategy used by this species.

3. Effect on the pigments content

Reduction of CO2 availability in leaves and inhibition of carbon fixation was observed when air pollution stress leads to stomatal closure. The common used indicator of impact of increasing air pollutants on tree growth was the net photosynthetic rate (Woo et al.,2007). When plants are constantly exposed to the environment, pollutants are absorb, accumulate and integrate these pollutants into the plant systems. Depending on the sensitivity level of plants it has been shown that visible changes in plants would include alteration in the biochemical processes or accumulation of certain metabolites (Agbaire and Esiefarienrhe, 2009).

It has been observed that a gradual disappearance of chlorophyll and increase in the yellowing of leaves, which may be associated with the gradual reduction in the photosysthetic capacity(Joshi and Swami, 2007).Green plants contain chloroplasts, which contain chlorophyll, which is referred to as a photoreceptor. Chlorophyll "a", "b", "c", and "d" refer to a family of related molecules rather than a single molecule that makes up chlorophyll. Since chlorophyll "a" is a molecule that is present in every plant cell, the concentration of this molecule is what is reported during a chlorophyll analysis (Joshi et al., 2009).Since chlorophyll is essential to plant metabolism and any decrease in chlorophyll content immediately affects plant growth, measuring chlorophyll content is a useful method for assessing the impact of air pollution on plants (Joshi and Swami, 2009). Chlorophyll serves as a plant productivity indicator. Some pollutants cause the total chlorophyll concentration to rise, while others cause it to fall (Agbaire and Esiefarienrhe, 2009). The concentration of pigments changed in the leaves of six different tree species that were exposed to air pollution and died from car emissions (Joshi and Swami, 2009).

This drop in the concentration of chlorophyll in the contaminated area may be caused by the shading effects of suspended particulate matter deposition on the leaf. It could clog the stomata, preventing gaseous exchange. This raises the temperature of the leaf, delaying the synthesis of chlorophyll. Less photosynthesis results from a leaf surface that is dusty or covered in encrustation, which lowers the amount of chlorophyll (Joshi and Swami, 2009).A significant decrease in total chlorophyll at the main location where air pollutants like SO2 and NOx attack it. Through the stomata, air pollutants enter the tissues, partially denaturing the chloroplast and reducing the pigment content of the cells in contaminated leaves. Chlorophyll is destroyed by high concentrations of gaseous SO2 (Tripathi and Gautam, 2007).Numerous studies have found that exposure to air pollution reduces the amount of chlorophyll (Tiwari et al., 2006; Tripathi and Gautam,

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2007; Joshi and Swami, 2007, 2009; Joshi et al., 2009). Conversely, a number of studies have demonstrated a rise in the amount of chlorophyll under air pollution. For example, Tripathi and Gautam (2007) found that Mangifera indica leaves exposed to air pollution had a 12.8% increase in chlorophyll content. In a 2009 study, Agbaire and Esiefarienrhe showed that plants from the experimental site had higher chlorophyll contents than those from the control.

Seyyednejad et al. (2009a) have reported an increase in the concentration of carotenoid, total chlorophyll, chlorophyll a, and chlorophyll b in Albizia lebbeck and Callistemon citrinus. Research demonstrated that the earliest sign of flour's impact on plants is chlorosis (Kendrickk et al., 1956). Yun (2007) shown that in sensitive tobacco species, PSII function impairment results in a decrease in photosynthesis (Yun, 2007).Carotenoids are pigments that help plants absorb light. They can be found in the plasma of photosynthetic or non photosynthesising plant tissues. However, a more crucial function is undoubtedly playing in shielding living things from the damaging effects of free radical oxidation (Fleschin et al., 2003). RuBP carboxylase activity, net photosynthesis, and total chlorophyll content were all significantly reduced in plants fumigated with 40, 80, and 120 ppbv concentrations of O3 (Chapla and Kamalakar, 2004).

Caretenoids are a class of naturally occurring fat-soluble pigments that are mostly found in algae, plants, and microorganisms that use photosynthesis as a source of energy. Carotenoids are vital structural elements of the photosynthetic antenna and reaction centre, providing protection to photosynthetic organisms against potentially damaging photo oxidative reactions (Joshi and Swami, 2009). In higher plants, they function as auxiliary pigments. They support the valuable but much more delicate chlorophyll and shield it from photo oxidative degradation. They are tougher than chlorophyll but far less effective at absorbing light (Joshi et al., 2009). According to Joshi and Swami's 2007 study, Eucalyptus cirtiodora had the greatest drop in caretenoids out of the four plant species that were exposed to air pollution.

The amount of caretenoids in the leaves of six species exposed to vehicle emissions was also found by Joshi and Swami (2009). They found that the concentration of caretenoids in leaf samples taken from contaminated regions had decreased (Joshi and Swami, 2009).

4. Effect of sugar

For all living things, soluble sugar is a vital component and a source of energy. During photosynthesis, plants produce this organic material, which they then break down during respiration (Tripathi and Gautam, 2007). In their investigation, Tripathi and Gautam (2007) found that all tested species at all polluted areas had significantly lost soluble sugar. Plant physiology is shown by the concentration of soluble sugars, which also establishes a plant's susceptibility to air pollution. Because of the degradation of chlorophyll, there is a reduction in the amount of soluble sugar in polluted stations, which can be linked to both increased respiration and decreased CO2 fixation. It has been shown that, in hardening conditions, pollutants such as SO2, NO2, and H2S can increase the depletion of soluble sugars in the leaves of plants grown in polluted environments.The reaction of sulfite with aldehydes and ketones of carbohydrates can also cause reduction in carbohydrate content (Tripathi and Gautam, 2007).

According to some research, the sensitive trees' concentrations of soluble and total sugars dropped noticeably as a result of air pollution. September saw a greater decline in the sugar contents in the injured Q. cerris leaves. Damaged leaves' decreased total sugar content most likely correlated with either photosynthetic inhibition or respiration rate stimulation (Tzvetkova and Kolarov, 1996). Additionally, it has been demonstrated that a rise in soluble sugar serves as a leaf defence mechanism in Pinto beans exposed to varying zone concentrations (Dugger and Ting, 1970).

Pine needle soluble sugar levels dropped after exposure to ozone (Wilkinson and Barnes, 1973). They then went up, often in tandem with foliar damage (Dugger and Ting, 1970; Miller et al., 1969). Following chronic exposure, a rise in soluble soluble sugars was also noted (Miller et al., 1969). Grown on industrial soil, Albizia lebbeck and Callistemon citrinus showed an increase in soluble sugar (Seyyednejad et al., 2009a). Research found that plants that were more resilient to air pollution had higher concentrations of soluble sugar than sensitive species (Kameli and Losel, 1993; Ludlow, 1993). Research on the ability of Prosopis juliflora and Dodonea viscosa to withstand industrial air pollution revealed an increase in soluble sugar (Abedi et al., 2009a, b, Koochak and Seyyed Nejad,2010).

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5. Effect of proline

Some workers has published the increase in free proline content in response to various environmental stresses in plants (Levitt, 1972). Excess Reactive Oxygen Species (ROS), which are exceedingly reactive and cytotoxic to all organisms, can be caused in plant cells by traumatic environmental stressors such as high and low temperatures, droughts, and air and soil pollution (Pukacka & Pukacki, 2000). Excessive excitation energy of chloroplasts is caused by high exposure to air pollution; this leads to an increase in ROS production and oxidative stress (Woo et al., 2007). Reactive oxygen species (ROS) are produced by plants in response to pollutants, and these species cause peroxidative destruction of cellular components, which is what causes the harmful effects of the pollutants (Tiwari et al., 2006).According to reports, proline functions as a free scavenger to shield plants from oxidative stress-related damage. Proline is of particular importance because of its widespread accumulation in plants during environmental stress, even though the scavenging reaction of ROS with other amino acids, such as tryptophan, tyrosine, histidine, etc., is more efficient than with proline (Wang et al., 2009).

Research by Tankha and Gupta (1992) demonstrated that proline content increased as SO2 concentration increased. Given that SO2 and CO are present in the industrial area as a result of chemical activity, these results most likely show that it has been impossible to determine a safe threshold toxic SO2 concentration for a given species' level of pollution because other environmental factors have a significant impact on the extent of damage (Seyyednejad et al., 2009b). Plant defence responses may involve proline, a universal osmolytic that accumulates in response to various stresses (Khattab, 2007). Proline undoubtedly plays a major part in defence against various forms of stress. Plants respond physiologically to osmotic stress by accumulating proline (Szekely, 2004).

Pollutants cause damage to pigments, deplete cellular lipids, and cause polyunsaturated fatty acids to peroxide in plants (Tiwari et al., 2006). Lipid peroxidation and proline accumulation seem to be related in plants under various stress conditions (Wang et al., 2009). If a link of this kind is present, proline accumulation may be crucial in preventing lipid peroxidation caused by air pollution.

Proline buildup frequently happens under various conditions in a range of plants.For example, proline accumulation in leaves of plants exposed to SO2 fumigation (Tankha and Gupta, 1992),heavy metals (Wang et al., 2009) and salt (Woodward and Bennett, 2005) stress has been reported (Tankha and Gupta, 1992; Wang et al.,2009;Woodward and Bennet, 2005).

6. Conclusions

Air pollution, driven primarily by industrialization and vehicular emissions, has significantly deteriorated air quality in developing countries, adversely affecting both human health and the environment. The exposure to various pollutants like particulate matter (PM), sulfur oxides (SOx), nitrogen oxides (NOx), heavy metals, and polyaromatic hydrocarbons (PAHs) has been linked to severe health risks, especially respiratory and cardiovascular diseases. Additionally, these pollutants have profound impacts on plant ecosystems, leading to vegetation injury, crop yield losses, and ecosystem disturbances.

Plants, serving as bio-monitors, are notably sensitive to air pollution, exhibiting changes in leaf morphology, pigment content, sugar levels, and proline accumulation. Pollution-induced stress can cause stomatal damage, reduced photosynthetic activity, and early leaf senescence, leading to diminished plant growth and productivity. Decreases in chlorophyll content and disruptions in biochemical processes are common responses in plants exposed to pollutants, indicating a reduction in photosynthetic efficiency and overall plant health.

Moreover, environmental stress from pollutants triggers an increase in reactive oxygen species (ROS), causing oxidative damage. Plants often accumulate proline in response to this stress, which helps mitigate the harmful effects of ROS and other pollutants. This adaptive mechanism highlights the resilience of plants and their role in indicating and mitigating pollution levels.

In conclusion, the detrimental effects of air pollution on plants are evident across various biochemical and physiological parameters. Understanding these impacts is crucial for developing strategies to improve air quality and protect both human health and the environment. Enhanced urban vegetation and stricter pollution controls are vital measures to address these challenges and foster a healthier ecosystem.

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