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Review

Effects of Air Pollution on Morphological, Biochemical, DNA, and Tolerance Ability of Roadside Plant Species

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Abstract: Air pollution is a severe problem in the modern world. Urbanization, industrialization, and traffic emit air pollutants such as carbon monoxide (CO), nitrous oxides (NOx), hydrocarbons (HCs), and particulate matter into the environment. Plants can absorb air pollutants through stomata. They adversely affect the various metabolic and physiological processes of plant species. This review describes the impact of air pollution on plant health, morphologically, physiologically, and genetically, and the tolerance ability of plants located along roadside areas. Many morphological effects, like chlorosis, necrosis, leaf area, stomatal clogging, plant productivity, leaf falling, and reduction in flower yield, are observed due to the influence of air pollution. Air pollutants also damage the DNA and affect the biochemicals of the plants, as well as pH, relative water content (RWC), simple sugar, ascorbic acid (AA), total chlorophyll content (TCH), proline, and polyamines. Some plants located under pollution stress can mitigate air pollution. Plants with higher APTI values are more tolerant of air pollution, while those with the lowest APTI values can be used as an indicator of the rate of air pollution. There is much morphological, biochemical, and DNA damage noted in this review. Different strategies can be used to diagnose the effects of air pollution in the future and develop green belts to mitigate air pollution in pollution-stressed areas.

Keywords: air pollution tolerance index; antagonistic; chlorosis; DNA damages; industrialization; stomatal clogging; urbanization

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1. Introduction

Air pollution is one of the most severe issues globally. Burning fossil fuels, urbanization, vehicular emission, and industrialization increase the emissions of air pollutants like carbon monoxide (CO), nitrous oxides (NOx), hydrocarbons (HCs), and particulate matter (PM). These pollutants enter the environment from different sources, significantly impacting plants and animals [1]. As a result of this environmental pollution, the chemical composition of the environment has been changed due to the increasing amount of toxic pollutants, which pose a significant threat to biodiversity [2]. PM adversely affects humans and plants and causes 3.3 million deaths yearly, especially in Asia [3].

Highly populated urban areas are sources of air pollution due to heavy traffic loads and anthropogenic activities [4]. Large particles, including sand, grains, and water droplets, deposit quickly, but small dust particles stay in the environment longer [5]. These pollutants affect physiological (photosynthesis and respiration), morphological (stomatal function and leaf area), biochemical (chlorophyll and amino acid), and developmental processes in plants [6]. The influence of PM and its attributes (heavy metals and poly-hydroaromatic hydrocarbons) has been noticed in morphological, biochemical, and physiological respects [7]. Due to air pollution, many effects have been observed in plants, including a reduction in the yield of flowers, number of branches, leaf area, leaf pedicles, seed germination, and seedling growth [8]. Air pollutants directly disturb plants through aerial routes and indirectly through the soil. Most florae are exposed to air pollutants, which cause anatomical changes before leaf injury [9]. Dust particles are absorbed by the leaf surface, which affects plants' physiological and biological processes. Leaf petioles trap pollutants through absorption and diffusion [10] and affect plants' morphological, biochemical, and physiological processes [11].

In the literature, different researchers report that environmental pollutions affect plants in terms of anatomical, genetic, morphological, physiological, biochemical, and tolerance abilities (Figure 1). Air pollution tolerance indices evaluate different plant species for tolerance using various parameters, such as total chlorophyll content (TCH), relative water content (RWC), ascorbic acid (AA), and pH. Similarly, the ability of plants to tolerate heavy metal toxicity help plantations that survive in air-polluted areas [12]. Plants are essential for reducing air pollution in urban environments. Mishra et al. [13] found that *Ficus benghalensis* showed more tolerance at polluted sites and *Alchornea cordifolia* showed less. Therefore, *Ficus benghalensis* is the most active tree for absorbing and mitigating air pollution. Biomonitoring studies of different plants are an essential concern for restoring an ecosystem because these pollutants released into the atmosphere adversely affect flora and fauna. It is necessary to recognize that different plants mitigate the air pollution reported by other researchers [14].

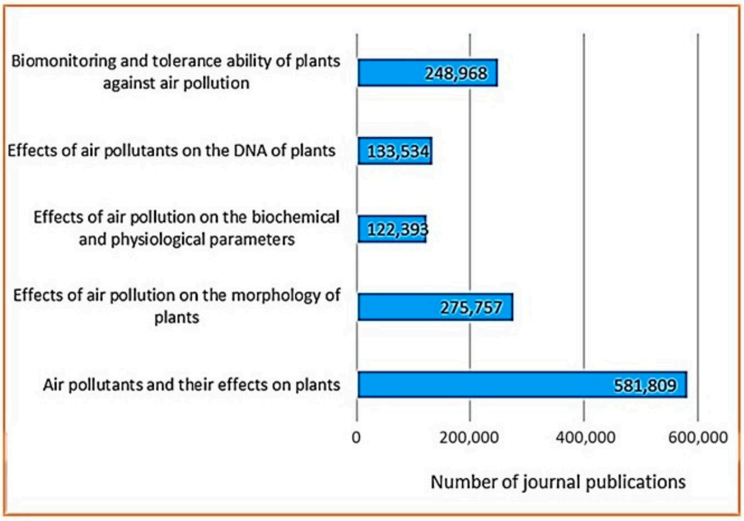

Figure 1. Statistics of journal publications on air pollution effects on plants from 2010 to 2023 (Source: Dimensions https://www.dimensions.ai/ accessed on 1 March 2024.).

The goal of this review is to understand the relationship between air pollution and plants located in pollution-stressed areas. This study also focuses on morphological, physiological, genetic, and biochemical changes in plants due to air pollution. Different strategies can be used to cure the morphological, physiological, and genetic damage in plants under air-polluted environments in the future. This will help screen plant species that can mitigate air pollution from the roadside, industries, and highly stressed pollution areas.

Air pollutants are emitted from various sources like vehicles, thermal power plants, fossil fuels, burning of garbage waste, construction, and agricultural activities [15]. Many air pollutants, such as CO, NOx, HCs, and PM, are released from vehicles. PM is an essential constituent in all emissions. PM contains heavy metals, including lead, chromium, copper, cadmium, nickel, etc., which are directly released from vehicular emissions [16]. Many natural sources of air pollutants include forest fire, dust, lightning, and volcanic and soil gases [17]. Different air pollutants released from various sources have adverse effects on plants, as shown in Table 1.

Table 1. Effects of air pollutants on plants.

Air Pollutants	Effects on Plants	References
PM	Reduction in plant growth, reduced leaf area, and several physiological changes like photosynthesis, stomatal conductance, pigment content, enzyme, and transpiration.	[7,18,19]
SO_2	Reduction in biomass growth, loss of chlorophyll, necrosis, wilting of leaves, defoliation, and production of reactive oxygen species (ROS).	[20,21]
CO_2	High concentration decreases the variety of nutrients, including protein and vitamins, which affect chlorophyll and carotenoid concentrations, micro and macro elements in plants, stomata closure, and photorespiration suppressed in plants.	[22,23]
O_3	Leaf injuries, chlorosis, and chlorophyll deficiency restrict respiration, obstruct stomata, bleaching, decrease floral yield, delay fruiting, increase the leaching, prevent photosynthesis, and stunt growth.	[3,24,25]
H_2S	Leaf lesions, defoliation, tissue death, yellowish leaves, and dark brown bands on living and dead tissues.	[26,27]
NO_2	It affects the photosynthetic pigments, damages the membrane and chloroplast, reduces the transpiration rate, reduces the growth and chlorosis, and even death of plants.	[28–30]

2. Effects of Air Pollution on the Morphology of Plants

Plants grown under air pollution respond to many changes—structural, functional, and morphological. Air pollutants reduce leaf area, yield of flowers, leaf length, and seed germination. Air pollution predominantly affects plant morphology and physiology [8].

2.1. Morphological Effects Related to Root, Seed, and Productivity

Zafar et al. [31] examined the impact of vehicle pollutants from diesel generators on *Vinca rosea* and *Rue tuberose* growth. After exposure to exhaust, pollutants significantly affected the root length, seed germination, seedling growth, and dry weight of seedlings of both species. Khalid et al. [32] studied the effect of air pollution on *Calotropis procera* characteristics. The inhibitory effect measured was related to photosynthetic pigments, stomatal conductance, and transpiration rate. Bell and Power [33] examined the impact of air pollution released from vehicle emissions on urban wild species. NO_2 is a toxic element that has a drastic effect on plant functions. NO_x and ozone O_3 adversely affect seed germination, radicle length, and stomatal conductance. Urban road dust consists of different types of heavy metals that affect many processes like transpiration, root, biomass, plant productivity, and total soluble protein of plants.

2.2. Morphological Effects on Leaf

Gaseous pollutants and PM absorbed by the plant leaf may clog the stomata. Air pollution also disturbs the seed germination rate, stomata, and pedicle length and affects plant growth [34]. Automobile pollution absorbed by the leaf surface causes necrosis and chlorosis in morphological regions and decreases the anatomical layer thickening by surviving under traffic stress [35]. Roadside plants exposed to air pollutants from vehicles can show reduced leaf area, stomatal function, and leaf numbers and increased epidermal cell numbers, branch length, and trichome length in plants [36]. Plant morphological damage is shown in the form of different diseases containing chlorosis, necrosis, and leaf burning in the plants at highly polluted stress areas. Significant reductions were demonstrated in leaf length, leaf width, leaf area, petiole length, and leaf attributes at polluted sites [37]. Many other effects, like reduction in leaf size, thinness in the cuticle of the leaf, and decreased stomatal density of *Platanus orientalis* due to air pollution, have been observed [38]. Plants' exposure to ozone causes leaf injury and white spots on the leaves, converting into brown necrosis spots. There are many symptoms shown by ozone absorption, including wilting, bleaching, and bronzing patterns in interveinal patches and the development of exceptional patterns on leaves [39]. Gaseous pollutants and PM affect the morphology of plants. Both leaf length and breadth were reduced under air pollution compared to non-polluted areas [38]. Morphological traits like leaf length, leaf area, stem length, branch number, stomatal damage, leaf injury, and leaf width were decreased in *Malva parviflora* at polluted sites compared to healthy environments. A reduction in leaf area was observed in plants located in unclean areas [40]. Shafiq et al. [41] examined the status of air pollutants on the productivity of trees. Some internal injuries and changes in physiological processes might alter plants at anatomical and morphological levels. Dry weight of leaves of *Alstonia scholaris*, *Paullinia pinnate*, *Senna saimea*, and *Peltophorum ptrocaprum* was reduced in a polluted environment. There are many morphological changes due to air pollution, as shown in Figure 2.

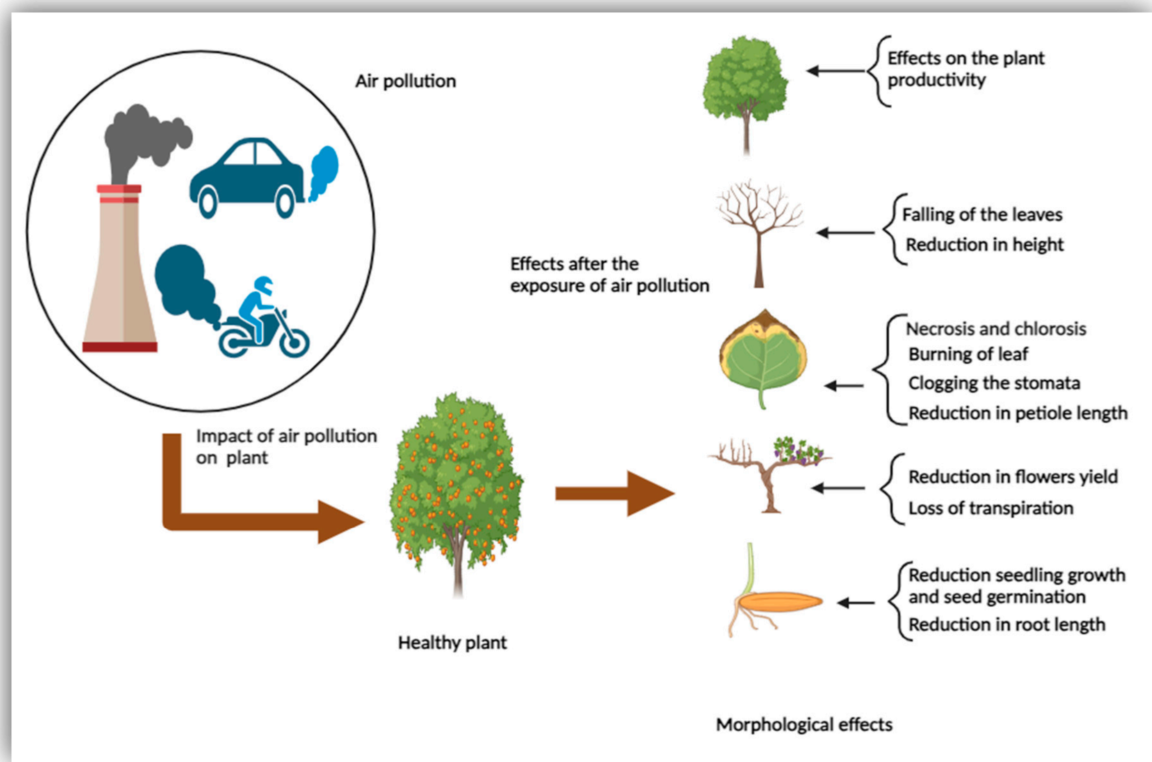

Figure 2. Effects of air pollution on plant morphology.

2.3. *Effects of Air Pollution on Stomata Structure*

Stomata are an essential factor in maintaining plants' development and growth process. Stomata comprise two guard cells that maintain stomatal function [42]. Stomatal density and width of stomata decrease due to high concentrations of CO and SO_2. Wagoner et al. [43] investigated the leaf cuticle and leaf variation in *Plantago lanceolata* at polluted and nonpolluted sites. Stomatal frequency is higher on the leaf's upper surface at contaminated sites than at nonpolluted sites. Modifying the size and frequency of stomata is essential for absorbing pollutants in a pollution-stress condition. Decreased stomatal size was observed in *Lotus corniculatus*, *Trifolium montanum*, *Trifolium pratense*, and *Trifolium repens* at the contaminated sites. Changes in the inner wall of the stomata have been observed due to air pollution [44]. Different concentrations of heavy metals released by vehicles and industries drastically affect plants. These heavy metals reduced the stomatal conductance, pore size, stomatal density, and stomatal closure of plants including *Bacopa monniera*, *Nicotiana tabacum*, *Arachis hypogaea*, and *Eichhornia crassipes* [45]. There are many process effects on stomata structure due to air pollutants, as shown in Figure 3.

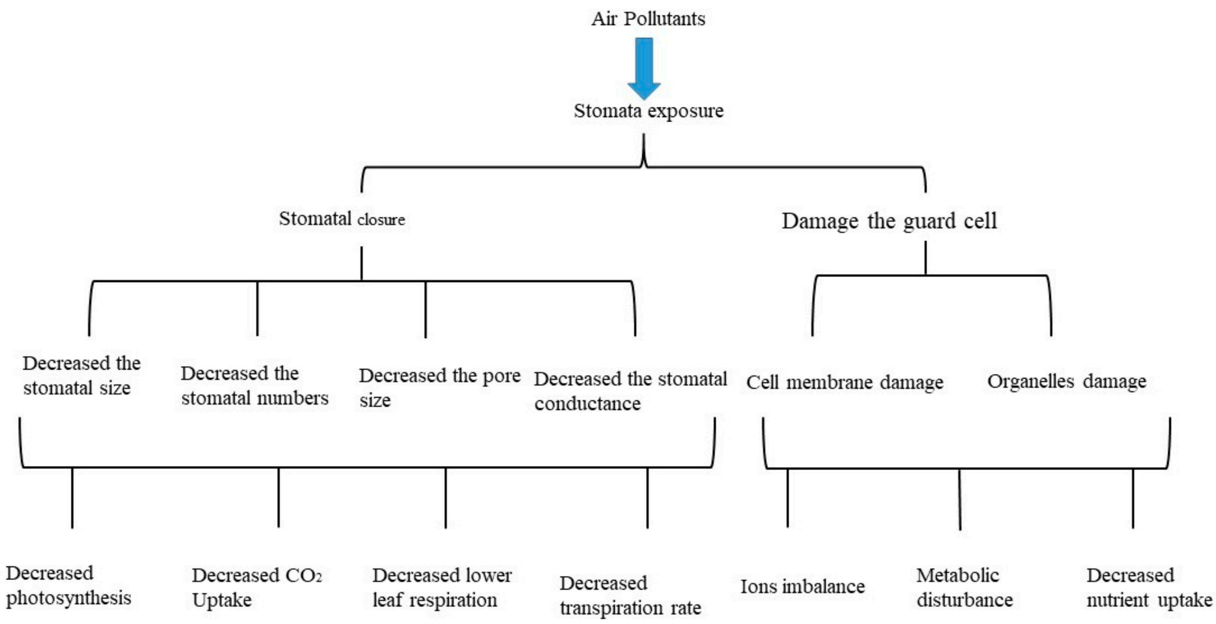

Figure 3. Schematic diagram of air pollution effects on stomata.

3. Effects of Air Pollution on Biochemical and Physiological Parameters

3.1. pH

The biochemical parameter pH helps indicate the stress of air pollution in plants due to acidity. Plant extracts from roadsides showed acidic pH due to air pollution [46]. The pH value is strongly associated with stomatal functions like photosynthesis, enzymatic activity, and cell development [47]. Degradation of chlorophyll has been observed due to pH reduction by displacing the Mg^{2+}-producing nonfunctional phaeophytin. Alterations in the pH might affect the stomatal conductance, so the acidic pH of leaf extract is due to the occurrence of oxide of sulfur and nitrogen in the air. The lower pH in guard cells causes stomatal conductance, destroys stomata's shape, decreases photosynthesis, and affects chlorophyll content [48]. The leaf extract of plants was observed to be more acidic due to the presence of various molecules. Plants located near industry or roadside areas experienced a low level of pH [46]. Higher pH in plant extract indicates increased synthesis of AA by hexose sugar for tolerance against air pollution. Alkaline pH helps plants attain tolerance against air pollution by adopting a detoxification mechanism [49]. Plants that have lowered pH are more susceptible, while those plants that have a pH of around 7 are tolerant [50].

3.2. Ascorbic Acid (AA)

AA acts as an antioxidant and free radical scavenger, plays a vital role in tolerance, is important in light reactions, and activates the defense mechanism under stress conditions. Most plant species produce AA during stressful environmental conditions [51]. AA is a non-enzymatic free radical scavenger system that reduces the byproduct mechanism of free radicals and removes air pollution, helping plants tolerate air pollution [52]. AA is high in all plant species located at polluted sites. More AA was observed at higher PM concentrations less at lower concentrations [53]. Higher concentrations of AA provide constancy to a plant with free radicals under stress conditions [54]. AA scavenges for free radicals in any adverse condition, especially air pollution. AA content decreases in plants after reducing free radicals. Plants that have lower concentrations of AA content pose a great threat to air pollution [55].

3.3. Total Chlorophyll Content

Air pollutants decrease the chlorophyll concentration and increased the proline and malondialdehyde concentration of plants [56]. Plants exposed to low-level air pollution suffer destructive effects without visible injury. Leaves absorb different pollutants from the air caused by the reduction in photosynthetic green pigments, which affects the pedicle length, seed germination, and flower numbers [57]. Chlorophyll a and b and carotenoid ratios are lower at polluted sites than at healthy sites. PM also affects the absorption of leaf light capacity and photosynthetic active radiation. As a result, secondary stress affects plant physiology processes like photosynthesis, and reduced chlorophyll content disturbs plant growth [58]. Exhaust pollution adversely affects the chlorophyll content in trees planted in polluted sites [12]. Previous research has indicated that air pollution affects leaf pH, TCH, and RWC. The concentration of TCH change may affect plants' biochemical, morphological, and physiological properties [51].

3.4. Relative Water Content

Air pollution affects plants' RWC and disturbs the transpiration rate. RWC is reduced under stressful air pollution, indicating that the lower RWC in plants located in polluted sites is dangerous for them [59]. Plants have less water, causing expansion of the leaf area, increased cell permeability, and reduction in transpiration rate due to the breaking of the water column for the uptake of water from root to aerial parts due to air pollution. High RWC helps maintain physiological processes when the transpiration is high [60]. RWC in plants was more dominant at polluted sites than at healthy sites due to maintaining physiological balance [61]. High RWC aids in tolerance to air pollution, but RWC was higher at higher PM concentrations and lower at lower PM concentrations [62]. RWC loss from leaves is due to the accumulation of PM on the surface of the leaves and dissolved nutrients [63]. Zhang et al. [4] analyzed the impact of automobile exhaust-induced pollution along roadside plantations. Air pollutants affect the respiratory activities, enzymatic activities, and uptake of water.

3.5. Simple Sugar

Simple sugar is essential for plants because it acts as an osmoprotectant and cryoprotectant and protects the integrity of the plasma membrane. It is vital for all organisms because it is the energy source [64]. Accumulating simple sugar in different plant parts increases the ability to tolerate air pollution. Sugar content reduction in crops near a cement factory caused an increase in the transpiration rate and decreased CO_2 fixation due to chlorophyll imbalance [65]. Soluble sugar is reduced in plant leaves at polluted sites [66]. Air pollutants released under stressful environmental conditions depleted the soluble sugar in the leaves of plants [67]. Sulfite reaction with sugar aldehydes and ketones also reduced the sugar content in leaves [65]. Soluble sugar decreased in those plants, which was not tolerant of pollution. In damaged *Quercus cerris* leaves, soluble sugar is reduced, probably due to photosynthetic inhibition and stimulation of the transpiration rate [68].

3.6. Proline and Polyamines

Proline is an amino acid reported during environmental stress conditions [69]. Proline is found in those species planted at polluted environmental sites [70]. Proline is an integral part of enzymes and is a source of energy during stress conditions. Reduction in proline production during stress conditions degrades other proteins [71]. Accumulation of proline under stress conditions activates the synthesis of enzymes and suppresses proline degradation. Proline content increased in *Albizia lebbeck* growing near an industrial area. Proline concentrations were increased in *Callistemon citrinus* at a petrochemical site [72]. Polyamines are essential in plant physiology, growth, and expansion processes. The exogenous activities of polyamines protect the plants against ozone damage under stressful air pollution conditions [73].

4. Effects of Air Pollutants on the DNA of Plants

The concentrations of pollutants released from vehicle emissions along the roadside can cause DNA damage to plants [74]. Plants need heavy metals for development and growth, but extreme concentrations are dangerous for their health. Heavy metals and air pollutants released from vehicle emissions are absorbed by plants from stomata. Heavy metals and air pollutants cause genotoxicity, directly affecting plant morphology and development.

4.1. Effects of Different Pollutants on DNA

The genotoxic effects of air pollution on flora are used for the quantitative and qualitative evaluation of air pollution [75]. PM interrelates with a plant's internal system and generates ROS, which causes oxidative stress. Oxidative stress causes an imbalance between free radical creation and antioxidant mechanisms, resulting in DNA damage [76]. Researchers investigated the genotoxicity induced by PM, heavy metals, and halogenated aliphatic hydrocarbons, and heavy metals resulted in plant cytotoxicity. Diesel exhaust PM contains organic compounds, sulfate, nitrogen derivatives, and metals absorbed by plants, causing genotoxicity. Numerous studies have been conducted on plants of the *Tradescantia* genus to assess the genotoxic effects of air pollutants in an urban atmosphere [77]. Air pollution due to higher traffic flow in urban areas damages the DNA and alters the leaf structure of *Tradescantia pallida*. DNA damage in plants is associated being exposed to air pollutants on busy roads. Air pollutants interact with ultraviolet radiation, causing DNA damage, such as base oxidation and DNA–DNA reactions [78]. The results of Sriussadaporn et al. [79] showed that increased concentrations of air pollutants during rainy and dry seasons induced genotoxicity in *Taraxacum officinale* and *Robinsonecio gerberifolius.*

4.2. Effects of Heavy Metals on DNA

Heavy metal toxicity also produces ROS, which cause protein oxidation, inactivation of enzymes, and DNA damage [80]. DNA damage in *Pisum sativum* root and leaves was observed by applying cadmium chloride and copper chloride. Roots showed greater sensitivity to cadmium than copper, while genotoxicity was higher in leaf cells exposed to higher cadmium concentrations [81]. DNA damage in a roadside sample of *Euonymus japonicus* leaves was higher than in a non-roadside sample [82]. Genotoxicity in tobacco plants at higher lead concentrations reduced the mitotic stage and extended the interphase in *Vicia faba* roots [83]. A previous study investigated the mitotic index increasing at low concentrations of lead while decreasing at high concentrations of lead. Many factors were investigated, such as weakening the DNA and RNA contents, weakening the protection of DNA from damage to the histone protein, and increased DNase and RNase activities under heavy metal stress [84].

5. Biomonitoring and Tolerance Ability of Plants against Air Pollution

Trees are essential constituents of the environment, and improve air quality by absorbing air pollutants in direct and indirect ways. Firstly, they directly absorb the contaminants from the air and are considered the lungs of the ecosystem. Secondly, they behave as the liver of the ecosystem because they filter pollutants through leaves [85]. Some plants adapt to environmental conditions by changing their biochemical concentrations to compete with the stress caused by air pollution. TCH, pH, AA, and RWC are used to calculate the APTI, which helps to categorize plant species' sensitivity and tolerance levels (Figure 4). Various plants that absorbed the air pollutants through the leaf and showed signs of response to air pollution stress were used as bioindicators for screening [13]. Standard values for the tolerance abilities of different plant species are shown in Table 2. The influence of air pollution on plants and their tolerance ability was calculated using four biochemical parameters—TCH, pH, RWC, and AA content—with the help of Equation (1) [86]:

$$\text{APTI} = \frac{[\text{A}(\text{T} + \text{P}) + \text{R}]}{10} \tag{1}$$

where A is ascorbic acid content (mg/g), P is pH of leaf extract, R is relative water content (%), and T is total chlorophyll content (mg/g).

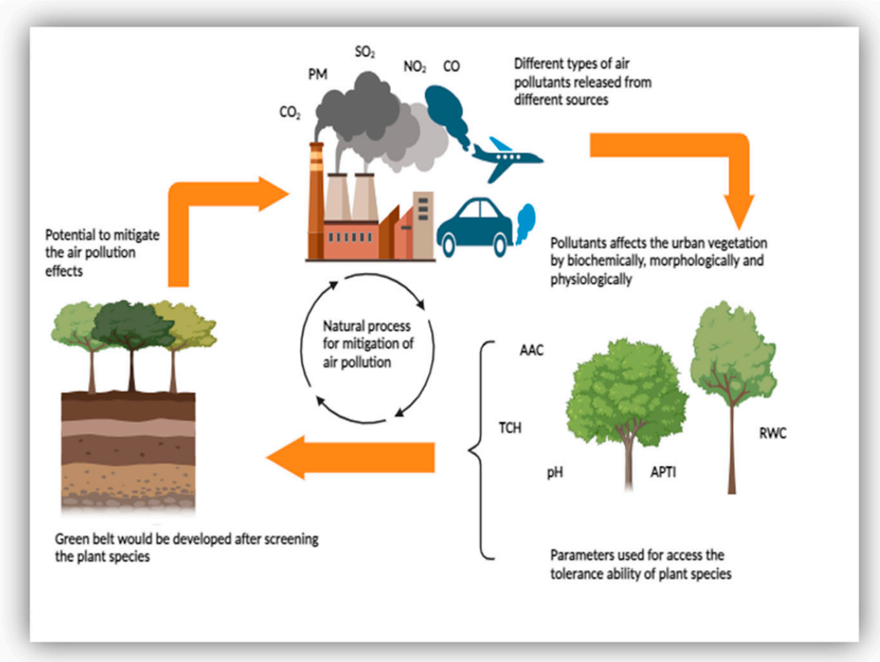

Figure 4. Procedure for the assessment of the tolerance ability of plants.

Table 2. Response of plant species using APTI.

Serial No.	APTI	Response of Plant Species
1	30–100	Tolerant
2	17–29	Intermediate
3	1–16	Sensitive
4	<1	Very sensitive

APTI Values for Different Plant Species

Plant species like *Pinus strobus* showed the maximum APTI value, while *Callosobruchus chinensis* showed the lowest value [87]. Ghafari et al. [88] evaluated the status of 18 decorative woody plant species grown in moderately moist areas of Iran. Among all species, *Yucca flamentosa* and *Berberis thunbergii* showed the highest APTI values recommended by these species planted in the park. Fatima et al. [89] evaluated APTI values for plants located at the Anwarul campus of Hyderabad, which helped in screening the plant species. APTI and API of *Azadirachta indica*, *Cassia siamea*, and *Ficus benghalensis* showed tolerance against polluted environments. This study aimed to determine the plants that have overcome air pollution stress [90]. Muhammad et al. [91] determined the effects of air pollution on some tree species. The results showed that *Ficus religiosa* was the most tolerant because of higher APTI values, while *Callistemon citrinus was* susceptible to air pollution due to the lowest APTI values. Swami and Chauhan [92] found that the highest APTI value was observed in Sal (11.27), while the lowermost (7.19) was observed in *Eulyptus*. Three species—*Annona squamosa*, *Ficus racemosa*, and *Santalum album*—growing in the Madri industrial area had higher APTI values, prompting an initiative to plant more of them in the area to reduce the air pollution effect and maintain a healthy environment [93]. APTI values for *Acacia auriculiformis* (10.89), *Alstonia scholaris* (10.08), *Chukrasia tabularis* (8.43), *Cassia fistula* (11.77), *Cassia siamea* (8.98), *Dalbergia sissoo* (10.12) were higher at polluted sites than controls [94]. Correa-Ochoa et al. [95] investigated 54 plant species, among which was *Mangifera indica*. This showed APTI values greater than 16, indicating intermediate tolerance of air pollution, while *Tabebuia chrysantharosea*, *Erythrina fusca*, and *Spathodea campanulata* showed APTI values lower than 11, indicating sensitivity to a polluted environment. Bui et al. [96] investigated APTI values of 12 plant species along the roadside. Among these 12 species, *Acer palmatum*, *Acer buergerianum*, and *Pinus densiflora* showed higher air pollution tolerance (7.75–9.94) ability than others. Bala et al. [97] found that *Polyalthia longifolia*, *Bauhinia variegata*, *Ficus religiosa*, and *Nerium oleander* showed the highest APTI values, indicating tolerance of air pollution. In contrast, *Acacia nilotica*, *Morus alba*, and *Ziziphus mauritiana* showed the lowest APTI values and were considered moderate species. *Cannabis sativa* is considered sensitive to stressful environmental conditions. Sawarkar et al. [98] explored APTI values for 10 species, among which *Ficus benghalensis*, *Mimusops elengi*, *Ficus religiosa*, *Azadirachta indica*, and *Ficus racemose* showed tolerance in a polluted environment. APTI values for *Dracaena deremensis* (13.03) and *Ficus benjamina* (12.19) indicated intermediate tolerance, eight species showed APTI values of 11.40–10.70, indicating sensitivity, and four showed APTI values of 8.58–6.76, indicating greater sensitivity [99]. APTI values for different plant species located in different dirty environments are shown in Table 3.

Table 3. Plant species have APTI values under different polluted environments.

Plant Species and Their Location	APTI Values	References
(Roadside) *Terminalia catappa*, *Mangifera indica*, *Ficus platyphylla*, *Polyalthia longifolia*, *Cinnamomum camphora*, *Nerium oleander*	20.52, 18.66, 19.24, 17.66, 36.0, 14.6	[100,101]
(Roadside) *Mangifera indica*, *Pinus roxburghii*, *Thuja occidentalis*, *Cinnamomum camphora*, *Buddleia asiatica*, *Celtis australis*, *Callistemon lanceolatus*, *Ficus elastic*, *Grevillea robusta*, *Salix babylonica*, *Cryptomeria japonica*, *Prunus persica*, *Sambucus canadensis*	10.62, 9.71, 8.47, 10.22, 6.92, 9.64, 10.23, 9.55, 9.32, 10.04, 7.05, 8.39, 9.29	[102]
(Roadside) *Nerium oleander*, *Tamarindus indicus*, *Azardicta indicia*, *Pungamia pinnata*, *Ficus religiosa*, *Polyalthia longifolia*, *Tectona grandis*	20.51, 16.55, 14.31, 15.55, 23.35, 22.88, 13.45	[103,104]
(Industrial Area) *Azadiracht aindica*, *Mangiferai ndica*, *Neriumindi cum*, *Polyalthial ongifolia*, *Cassia fistula*,	55.19, 66.64, 26.59, 58.01, 23.97	[105]
(Roadside) *Saraca asoca*, *Melia azedarach*, *Morus alba*, *Alstonia scholaris*, *Bougainvillea glabra*, *Syzygium cumini*, *Ficus benghalensis*, *Azadirachta indica*, *Eucalyptus sp.*, *Magnifera indicia*, *Ziziphus mauritiana*, *Pongamia pinnata*, *Nerium indicum*, *Polyalthia longifolia*	8.45, 8.47, 7.7, 8.5, 5.75, 7.27, 8.03, 7.86, 8.76, 8.95, 7.57, 7.21, 11.51, 12.93	[106,107]
(Industrial Area) *Mimusops elengi*, *Anacardium occidentale*, *Morinda coreia*, *Bambusa bambos*, *Lagerstroemia speciose*, *Millingtonia hortensis*, *Anacardium occidentale*, *Potentilla longifolia*, *Cassia fistola*, *Ficus benghalensis*	19.03, 12.24, 14.88, 10.58, 8.95, 10.77, 11.13, 10.91, 16.82, 26.90	[108,109]
(Roadside) *Jacaranda mimosifolia*, *Dovyalis abyssinica*, *Eucalyptus camaldulensis*, *Azadirachta indica*, *Cordia africana. Calistemon citrinus*, *Justicia schimperiana*, *Vernonia amygadalina*, *Gravillea robusta*, *Spathodeia nilotica*, *Schinus molle*, *Diospyros melanoxylon*, *Polyalthia longifolia*, *Ficus religiosa*	35.28, 20.04, 15.04, 28.38, 16.49, 21.4 15.06, 20.41, 20.95, 15.85, 35.21, 12.47, 17.30, 15.75	[110,111]

6. Future Direction

There is a need for more studies that will enable people to develop a sustainable environment, such as sustainable green urban development, maintainable urbanization and transport, and phytoremediation techniques used to mitigate air pollution. It is necessary to investigate the air pollution tolerance ability of different plant species to reduce air pollution. This study helps scientists categorize healthy plants to develop urban green belts. It is necessary to know the impacts of air pollution on crops along roadsides. The study of plant species that have the ability to tolerate air pollution and can also be used for urban green planning is encouraged.

7. Conclusions

This study showed that air pollution can cause morphological, physiological, biochemical, and genetic effects in plants. The tolerance ability of different plant species depends upon their biochemical processes. Air pollution absorbed by plants through leaves and soil predominantly affects these biochemical processes, and is reflected in plant morphology. Many biochemical, morphological, and genetic effects in plants have been noted in this review. Some plants can endure stress-polluted conditions. This review provides APTI values for plant species in air-polluted environments. The different plant species that have tolerance based on their APTI values are used to develop green belts in urban areas and mitigate air pollution. This study also contributes to our knowledge of the effects of pollution on plants and curing plant species using different strategies in the future (Figure 5).

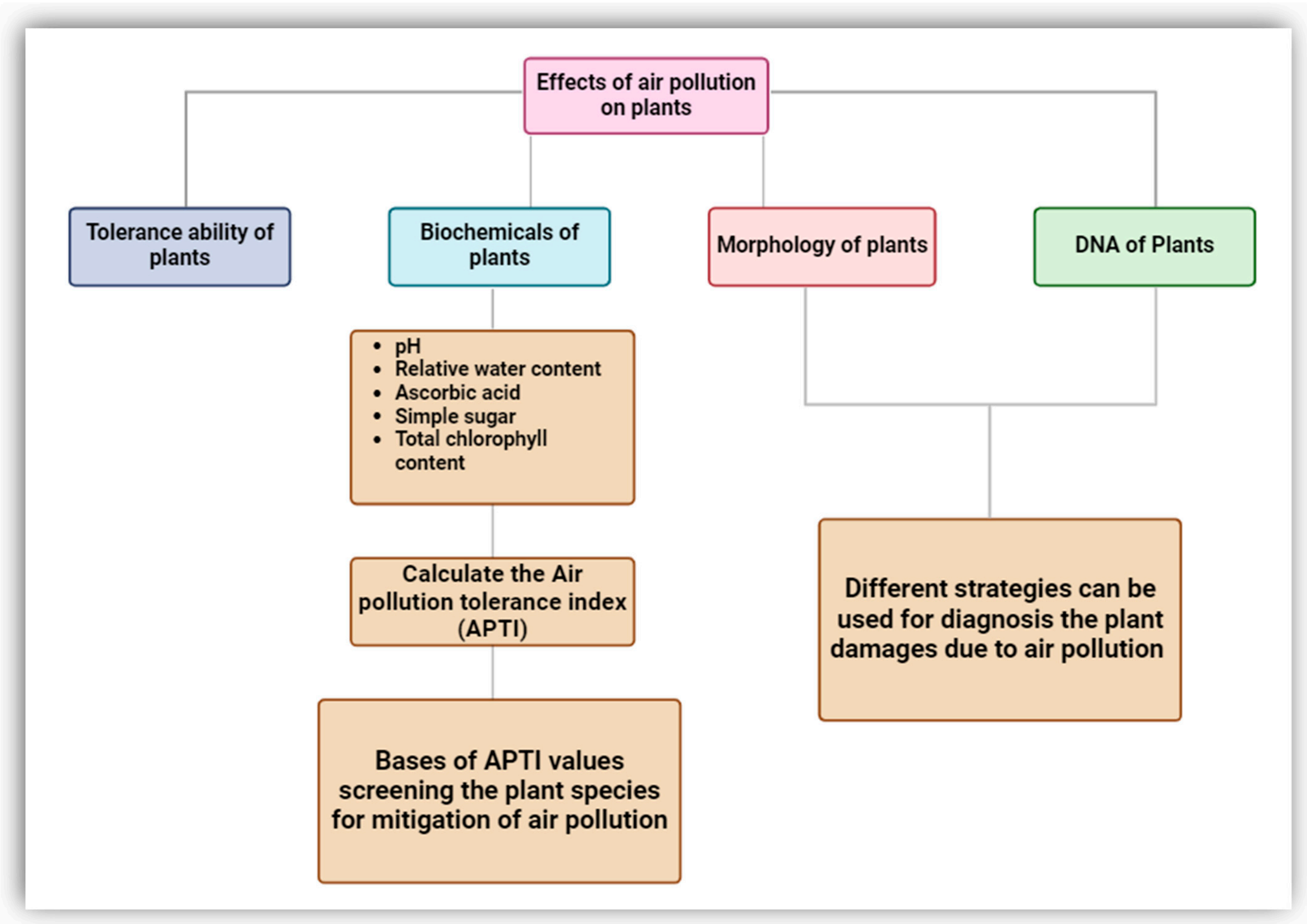

Figure 5. Schematic diagram of mitigation and diagnosis of effects on plants due to air pollution.

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