



A Review on the Effects of Environmental Factors on Plants Tolerance to Air Pollution

Navneet Kour, Prasenjit Adak*

School of Physical and chemical sciences, Lovely Professional University, Punjab, India

Received: 25/06/2021

Accepted: 12/07/2021

Published: 20/12/2021

Abstract

Due to unsustainable, unplanned, and rapid development, air pollution has become a universal problem. Physical and chemical methods have come up with a tremendous solution but they have been proven insufficient to address this problem on a large scale. The better and natural way to overcome this problem is by plantation. Plants can adsorb, absorb and impinge pollutants on their leaf surfaces but all plants do not show the same response to a particular type of pollutants under the same geographical conditions. There are certain biochemical parameters (such as chlorophyll content, pH, ascorbic acid content, and relative water content) on which plants are selected for plantation so far in polluted areas. These parameters are not only sufficient to evaluate the tolerance of plants towards pollutants. Biochemical parameters depend upon environmental conditions and the concentration of air pollutants. The present review was an effort to investigate the various environmental factors which play a pivotal role in modifying the biochemical parameters and how it eventually affects the plants' tolerance to air pollutants.

Keywords: Environmental parameters, APTI, Air pollution, Light intensity, Humidity, Precipitation

1 Introduction

Air pollution or defilement of air of the surrounding atmosphere is a much bigger concern than any other type of pollution as it has a greater tendency of transboundary dispersion of pollutants in the entire world (1). One such threat is the rise in global temperature which can be considered as the precursor of many other associated hazards (2). Various physical and chemical methods have come up as potential solutions to these hazards. Although many of these solutions have been proven to be effective in specific cases, generally they were observed to be insufficient to address this problem on a large scale. Plantation or green vegetation was proven to be a more effective and sustainable solution to the aforementioned problems (3). The potential of different air pollutants to be absorbed by plants were presented in the order HF (Hydrogen fluoride) > SO₂ (Sulphur dioxide) > Cl (chlorine) > NO₂ (Nitrogen dioxide) > O₃ (Ozone) > PAN (Peroxy acetyl nitrate) > NO (Nitric oxide) > CO (Carbon monoxide) (4).

In developing countries like India, the rise in the concentration of ambient air pollutants is more common due to the lack of technology and resources to fight pollution and maybe a rapid expansion of population as compared to the developed countries (1). In an urban area, more than 60-70% of air pollution is caused by automobile exhaust emission and industrialization. It has been reported that automobiles account for introducing 10% of (SO₂), 30% of Suspended particulate matter, 30-40% of oxides of nitrogen (NO_x), 50% of hydrocarbons (HC), and 70% (CO

(70%) in ambient air of urban areas in India (1). 65% of CO₂ is emitted from industries and fossil fuels (5). Industries releases 9-26% of (CO₂), 36-70%, 3-7% of nitrous oxide (N₂O), and 4-9% methane (CH₄) and methane are 20 times more overpowering than CO₂ (6). Most cities in India have violated the annual average limit of suspended particulate matter for industries i.e., 360 µg/m³ (7). Plants have long been used to check the ambient air pollution level. The predominant environmental conditions of any area can be better examined by plant species grown at that site, as plants are the initial recipients of air pollutants and act as scavengers to the latter (8). Pollutants emitted from various polluted sources accumulate or impinge on the leaf surface of the plants. These pollutants enter the leaf through stomata and once they enter the plant body, they pass into the intercellular spaces of mesophyll cells and gradually diffuse into the cell sap. This intrusion of various species of air pollutants affects the plants' health detrimentally.

2 Life cycle analysis of an air pollutant

Air pollutants cause changes in the atmosphere's composition and affect the biotic environment. Concerned pollutants are particulate matter (smoke, fumes, etc), oxides of carbon, nitrogen, and sulfur, hydrocarbons, metals, oxygenated compounds (e.g., aldehydes, alcohols, acids, etc.), O₃, and other oxidants. Based on the nature of their formation two groups have been identified. Primary pollutants directly emitted from the source (e.g., SO₂, NO, CO, etc.) and secondary pollutants that are formed in the

*Corresponding author: Prasenjit Adak, School of Physical and chemical sciences, Lovely Professional University, Punjab, India, E-mail: prasenjit.23966@lpu.co.in

atmosphere as a result of chemical reactions between air constituents and primary pollutants (e.g., SO₃, O₃, PAN, etc.).

2.1 Source

Anthropogenic activities are the primary sources of air pollution including stationary sources (Factories, refineries, and power plants), mobile sources (cars, trucks, buses, etc.) as well as indoor sources (building materials and activities such as cleaning). Fossil fuel combustion, which is the backbone of global energy production, is the key driver of anthropogenic greenhouse gas emissions (GHG). Over one-fifth of global fossil fuel consumption and 26% of global GHG emissions are attributed to the transportation sector (9).

Motor vehicles account for more air pollution in the large cities of industrialized countries. More than half of the world's emissions of PM, CO₂, HC, SO₂, NO_x, and CO from fossil fuel combustion derive from vehicles and industries (10). These six critical air pollutants including particulate matter with a diameter of 2.5 µm (PM_{2.5}) and an aerodynamic diameter smaller than 10 µm (PM₁₀), SO₂, NO₂, CO₂, and O₃ cause a detrimental effect on the environment and humans as well (11).

Forest fires of rural areas generally produce an abundant amount of different kinds of particulate matter including carbon black and release it into the atmosphere. Besides this, some other natural sources of air pollution include lighting in the sky that produces NO_x in enormous quantities; hydrogen sulfide is largely produced from oceans algae, and marshy methane. Furthermore, ground-level O₃ is formed in the presence of sunlight because of the photochemical reaction of nitrogen gases and volatile or vaporizable compounds. PM mainly includes dust produced from the earth's crustal surface, coastal sea salt, pollens of plants, and animals' debris, all these are considered natural sources. Volcanic eruption disperses a huge amount of SO₂, HF, and greenhouse gases into the atmosphere together with ash and smoke particle which generally causes the ambient temperature to rise over the years (6).

Mobile sources are most leading sources of CO and NO_x. The major source of urban NO₂ and a significant source of PM is vehicle exhaust emissions. (12). The complete combustion of carbon constituted fuel (coal, fuel oil, wood, natural gas) produces CO and HC. The internal combustion engines do not allow the fuel to burn completely to produce CO₂ and water; some unburned amount of fuel gets exhausted with CO as an integral component. When the amount of excess fuel or unburned fuel is high in air/fuel mixtures, the CO concentration in the exhaust remains high. On the other hand, CO emissions are very low for weak fuel mixtures and hence they are not generally considered as important (13). It is important to monitor vehicular emissions of carbon dioxide (CO₂), from a climate perspective (12). Another leading pollutant NO_x is emitted mostly due to road transportation activities which constituted about 41% of harmful emissions of NO_x. NO, and NO₂ are usually grouped as NO_x emissions (13). Road vehicles have long been regarded as one of the most leading emission sources of particulate matter (PM) and nitrogen oxides (NO_x) (9).

NO is the main oxide of nitrogen produced inside the engine cylinder. NO_x is produced by the reactions of free nitrogen and oxygen of air during the combustion of fossil fuels contained in motor fuel at high temperatures (13). Under typical photochemical conditions in the urban atmosphere, NO₂ rapidly

interconverts between nitric oxide (NO) and this is important to measure the vehicular emissions of NO in addition to NO₂ (12). It has been reported that 92% of CO and 65% of hydrocarbons is due to transport activities which are also responsible for 4% of Sulphur oxide, 14% of particulates, and 42% of NO_x present in the atmosphere resulting in an overall proportion of about 43.4% of pollutants from only transport activities (13).

CO and Volatile organic compounds (VOCs) are emitted primarily by gasoline engines, such as passenger vehicles and motorcycles, whereas NO_x and PM₁₀ are emitted primarily by diesel engines, such as Heavy-duty Vehicles and buses (14). Some toxic compounds are present in gasoline (e.g., Benzene toluene and xylene) and are emitted into the air when gasoline evaporates or passes through the engine as unburned fuel (13). The two internal combustion engines, petrol, and diesel are the only engines in the whole world that are used in automotive transportation systems and also these two are the utmost source of air pollution. Petrol is a type of volatilized fuel and in the fuel tank the pressure builds up which empowers the evaporation of the fuel (13). Diesel engines account for a significant contribution of PM₁₀ emissions, accounting for 65 percent of the total, and heavy-duty vehicles (HDVs) account for 53 percent of the total. In gasoline-engine cars, the higher temperature of the vehicle gas tank causes faster evaporation of volatile gasoline, resulting in more fugitive VOC emissions (14). The composition depends upon many variables such as fuel ratio, speed, and engine condition. A major role is played by driving conditions because exhaust emissions are high in CO and HC at low and idling speeds, and NO_x high at high engine speeds (13). The ambient temperature has been found to have a significant impact on NO_x emissions in passenger cars. (14).

In urban areas, one of the most critical air pollutants is suspended particulate matter. The average standards set by the regulatory authorities are frequently violated in several monitored locations. Due to this, its levels are consistently high in various cities over the past several years. The annual average minimum and maximum SPM concentration calculated in residential areas of various cities ranged from about 60 µg/m³ (at Bangalore during 1991) to 521 µg/m³ (at Patna during 1995), while in industrial areas the annual average ranged between 53 µg/m³ (Chennai during, 1992) and 640 µg/m³ (Calcutta during, 1993) (15). In addition to the aforementioned mobile sources, various stationary sources are significantly responsible for the degradation of ambient air quality.

The factories, the refineries, and the power plant are directly or indirectly dependent on fossil fuel and produce CO and CO₂, (SO_x) and SPM. Industrial stacks emit SO₂ as fuels used in the industries contain a higher concentration of Sulphur which gets oxidized during the combustion and produces SO₂ that resides 10 days in the air. Besides, some of the industrial processes release a huge amount of CO and hydrocarbons into the air. World Health Organization (WHO) stated six classic air pollutants in industrialized countries as NO_x, SO₂, CO, and SPM (6). The total SPM emission from the power plant stacks is adjusted as concentrations and depends upon the boiler size. For example, the PM concentration limit is 150 mg/Nm³ for plants with a generation capacity of more than 210 MW and is 350 mg/Nm³ for generation capacity less than 210 MW. Usually, the PM which disperses from the top of the stack is in the respirable range of around 10mm or less. Some workers measured fractions of 50-60% PM_{2.5} and 90-95% PM₁₀ in the total filterable, PM in the flue

gas at a 660 MW power plant. However, the PM in the flue gas also comprises a high amount of heavy metals such as arsenic, lead, cadmium, mercury, copper, and zinc which contributes to harmful health hazards. Whereas, Flue gas from a coal-fired power plant in western India estimates around 1-7% of zinc, 2-7% of copper, 5-8% of manganese, 7-10% of cobalt, 12-18% of cadmium, 60-70% of selenium, 70-80% of mercury and some little traces of arsenic, iron, lead, and chromium which are contained in the coal was emitted in the flue gas (16).

Mainly SPM is released from the cement industries and the VOCs from petroleum and chemical industries in the environment (17). The largest share of SO₂ in the atmosphere comes from power generation from coal and oil followed by industrial combustion generation. Power plants constitute 21% of the global SO₂ emission, followed by industries and non-road vehicles which contribute about 16% and 13% emissions of air pollutants respectively. It is also observed that Sulphur content in Indian coals is much less than those found in the United States (1.0 - 1.8%) and China (0.5 - 1.0%). It is also found that Sulphur content in Indian coal has a consumption-weighted average of 0.6% (16). Agriculture activities include the use of nitrogen fertilizer which generates NO, ammonia (NH₃), and greenhouse gases such as methane (CH₄) and CO₂. During flooding, organic matter gradually reduces the water and oxygen in the soil, and methane is produced by anaerobic decomposition and aerobic produce CO₂ (17). CH₄ is 20 times more potent than CO₂ as a greenhouse gas (13).

2.2 Dispersion

A plume can be described as an air space that is inhabited by a stack emitted gaseous stream. When the plume travels, it expands and disseminates, hereby diminishing the concentrations of surroundings pollution even so the cross-sectional mass of the plume remains the same. At what speed and height, a plume will achieve are affected by the amalgamation of emission velocity, emission temperature, vertical air movement, and horizontal airflow. So, as the plume expands, its concentration goes down. As soon as the air toxics have come into symmetry with the surrounding conditions, atmospheric and meteorological factors predominantly impact the dispersion and transport of air pollutants (13). Nitrogen can be dissolved into NO and maybe in NO₂ with the help of an enormous amount of air. In the regions of intense solar transmission or radiation, these emissions are extremely important, which can stimulate reactions leading to the evolution of photochemical smog. When a vehicle is moving at high and low speeds, the exhaust flow is also fluctuating high and low respectively, while emission of partially oxidized compounds is higher. Thus, on a volumetric basis, the highest emission takes place in deceleration, this is eventually due to low exhaust flow and low air-fuel ratio (10). There are particularly three parameters upon which damage is dependent: (a) to what extent does a pollutant subsequently disperse or scatter from the source, (b) for how much time it will remain in the environment, and (c) the process of the chemical reaction which it withstands (10).

2.3 Factors affecting the pollutant dispersion

The transportation of the ambient air pollutants can be affected by many attributes like source height, gas exit temperature, etc. Various climatic and meteorological factors such as wind speed and direction influence air toxics scattering and transport. A large number of pollutants are often released at a

relatively high velocity from stacks or vents, which depending on meteorological conditions, can also help to move pollutants higher in the atmosphere (13). Depending on weather conditions, this can also assist in moving pollutants higher in the atmosphere.

Ambient temperature - A plume parcel that is much warmer than the surrounding air will generally increase the distance over which pollutants will be transported. The physical form of pollutants is also gets affected by the temperature of the plume also affects the physical form of pollutants (13).

Release height - At various heights, pollutants are emitted into the atmosphere. Greater release heights commonly result in increased pollutant dilution in the atmosphere, lower ground-level concentrations, and a longer distance to peak ground-level concentrations. Release height is one of the important essences in evaluating the local effects on air transport, such as building downwash (13).

Time of release - The dispersion and transport of pollutants are determined by the timing of their release in specific meteorological conditions.

When the pollutants are released from sources in the form of particles (or if discharged gases condense/ precipitate into particles or adsorb onto the surface of existing particles), the rate at which the pollutant is removed from the atmosphere to surfaces (e.g., plants, soils, surface water) is to be controlled or determined upon the size of the particle. The rate at which particles fall due to settling velocity increases when the proportion of particles increases. A particle of about 20 microns in diameter or of enormous size settles expeditiously and may not travel far from sources of release. However, a finer particle remains dispersed in the air perpetually. Hence, the emphasis should be on separating the finer particles at the source itself (13).

2.4 Fate of air pollutants

There are several important physical processes through which air pollutants can remove from the atmosphere. The Environment has a special ability to clean itself and remove pollutants naturally. The phenomenon through which particulates fall or settle to the surface in the absence of any precipitation event is known as dry deposition, and the removal of pollutants from the air through precipitation events is known as wet deposition.

2.4.1 Dry Deposition

The settling or sorting out of particles (aerosols, sea salts particulate matter, and adsorbed reacted gases) on vegetation due to gravity is known as Dry Deposition. Therefore, because of the lack of other removal mechanisms (e.g., condensation and/or aggregation to form larger particles), particles of smaller size gravitate to remain suspended in the air for long periods (13).

According to different meteorological conditions, fine particles may remain in the surrounding atmosphere for days or weeks and travel hundreds or thousands of miles from their origin. There are tremendous health issues produced by these particles as many of them fall in the respirable range i.e., they can reach very deep in our respiratory system and cause damage to our internal organs (10).

2.4.2 Wet Deposition

The washing out of pollutants from the atmosphere through events such as rain, snow, or hail is known as Wet deposition. It affects both particulate and vapor-phase pollutants. Precipitation

events are very much helpful in removing pollutants from the air and settling them on the earth's surface for larger particles and vapor phase pollutants which possess the property of being soluble in water. However, wet deposition may be less effective at removing fine particulates, and has a negligible impact on the levels of gaseous pollutants with high Henry's Law constants (indicating low solubility in water compared to vapor pressure). As wet deposition depends on the occurrence of precipitation events, it is better described over long periods (e.g., seasons or years). The importance of precipitation in removing pollutants from the air relies on the climatic conditions in the areas affected by pollution (13).

2.4.3 Chemical Reactions that Remove Air Pollutants

In addition to deposition, chemical reactions may take place that reduces air pollutant concentrations in the atmosphere. Air pollutants can be destroyed with the help of sunlight, through reactions with chemical pollutants. To estimate the ambient air concentration associated with pollutant releases, it is mandatory to consider chemical reactions as well as the physical removal processes. However, more harmful pollutants may get formed due to these chemical reactions (e.g., formation of secondary air pollutants like PAN (13).

3 Effect of air pollutants on plant species

For all origins of pollutants, various regulatory agencies develop strategies and enact appropriate action plans. Source complication and their effect on receptors are interlinked with source, strength, meteorology, release height, atmospheric transformations, and other factors. The gaseous and particulate pollutants (discretely or in combination) can cause severe setbacks to the overall physiology of plants (65, 66). A high concentration of pollutants causes the inactivation of plant cells. PM is more injurious to plants than other pollutants especially under humid conditions, as estimated every year worldwide, 3 million people get killed due to air pollution mainly by PM (organic and inorganic) (6). Finer and lighter particles remain suspended in the air for days; they clog the stomatal apertures and inhibit the gaseous exchange by leaves (1). Under hardening condition, pollutants like SO_2 , NO_2 , and H_2S causes more depletion of soluble sugars in the leaves of plants grown in polluted areas (68). It was observed that a load of pollutants inside the plant is directly proportional to the change in the biochemical parameters of plants (17). Depending upon the expanse of injury or damage, Plant symptoms caused by air pollutants are indicated as chronic or acute. A whole tissue is mainly killed by a chronic injury or maybe all the portion of leaf or needle is damaged by achronic injury. Acute injury happens when a plant is extremely oversensitive to a specific pollutant or by any way exposed to high levels of pollution for a shorter period. On the other hand, an acute injury is defined as an injury restricted to certain areas only which may result in dark, pigmented spots are seen on a leaf. Sometimes affected plants are dwarfed and usually found in disinfected areas. Low levels of pollution are the main cause of acute injury that can cause little injury over a brief period, or if a plant has some resistance to the pollutant. Some symptoms of acute injury are yellowing, bleaching, dwarfing, or growth loss without visible symptoms (18).

Inside the leaf SO_2 is oxidized into Sulphur trioxide (SO_3), which further combines with water to form sulfuric acid (H_2SO_4).

Thus, the acid formation in the plant's body affects metabolic activities and leads to a reduction in the productivity of the plant. Moreover, it displaces the magnesium ion from the chlorophyll molecule and degrades it into a pheophytin molecule (non-photosynthetic brown pigment). The morphological symptoms caused by the introduction of SO_2 in plants are the formation of marginal, bronzed, or necrotic areas, interveinal chlorosis, and dull coloration (19). Similarly, NO_x gets absorbed by the leaves and reacts on cell walls to form nitrous acid (HNO_2) and nitric acid (HNO_3), which lowers the cellular pH, inhibits the metabolism and free radical formation leads to toxicity, growth suppression. The morphological symptoms caused by NO_x are discolored spots or light brown color and bleached or necrotic spots in interveinal areas of leaves (7). Although fluorine is found in different environmental components such as soil, water, and air, its availability in the air is more than that in water and soil (4). It is released into the atmosphere due to various anthropogenic activities such as combustion of fossil fuels, smelting of ores like bauxite, and reduction of phosphatic rocks in fertilizers manufacturing. Then it enters the leaf via stomata and intercellular spaces of mesophyll cells and diffuses further into vascular tissue (4). Fluoride damage mostly occurs on the leaf tips and leaf margins. A characteristic effect of fluoride is in the presence of a sharply separating reddish-brown band between the necrotic and healthy tissue (18).

Injury symptoms from Ammonia are blackening and bleaching of leaves, lesions between veins, spotting, and color change of the fruits (7). When plants exposed to ozone shows a variety of symptoms such as tissue collapse, interveinal necrosis, stipple (pigmented yellow, red-brown, dark brown, red-black, or purple), flecking (silver or bleached straw line), mottling, chlorosis, bleaching. Stunted growth and flowering, bud formation suppressed (18). Vegetation grew near swimming pools, water purification plants, and sewage disposal facilities often damage due to Cl_2 . Cl_2 effects are similar to those caused by SO_2 and fluorides. Two different types of injuries can occur; plants with broad leave, necrotic, bleached, or brown areas that tend to be near the leaf margins, tips, and between the veins. (18). The most toxic Phyto air pollutant next to O_3 causes the collapse of tissue on the lower leaf surface of plants. It also causes bronzing, or silvering which develops in bands, the thickness of the leaf blade which results in collapse, bleaching and transverse bands, senescence, chlorosis, growth is stunting and premature leaf fall. It is considered as most toxic to small and young plants (18). In urban areas, ethylene is considered one of the many products of auto, truck, and bus exhaust. The plant hormones and growth regulators' activities are modified by ethylene, affecting mature tissues and normal organ development without generating leaf-tissue collapse and necrosis. Bud abscission, epinasty which is downward curling of the leaves and shoots are the injuries to broadleaved plants thereby affecting the overall growth of plants (18). After prolonged exposure to various air pollutants, plants experience morphological and physiological damage or injuries that can be studied with the help of the Air pollution tolerance index (APTI). It is a method that evaluates the plant's response to air pollutants (20). It was reported that plants with a higher amount of air pollution tolerance index can be used as a sink in polluted areas. Therefore, APTI of the plants is an important parameter to be monitored for evaluating the tolerance and sensitivity of the plant species so that the development of green belts in polluted areas can be planned accordingly (21, 22, 23).

Insensitive plants, the tip tissues, and margins were observed to experience injury at 50-200 ppm hydrogen fluoride (HF) concentration. On the other hand, intolerance plants injury was not visible even at 500ppm concentration. Initial noticeable injury (i.e., Chlorosis) was observed on the tip and extended along margins and inwards veins as load increases. Injured or dead areas of leaves further lead to premature leaf fall (4). Cl_2 initiates chlorosis, stipple, reddening, and necrosis of leaves. If sensitive plants such as radish, alfalfa were exposed to 10ppm concentration for 2 hours, they experience a foliar injury while plants like tobacco, zinnia, corn, and sunflower exhibit injuries when exposed to a similar range of pollutant concentration for 4 hours (13). H_2S was observed to cause necrosis and death of young tissues rather than old tissues as the tip of leaves experience injury. On the other hand, insensitive plants 86 ppm concentration for 5-hour exposure is more than enough for inducing serious damage in plant tissues (1). However, the plants such as *N. odorum* and *A. arabica* were found to be tolerant to SO_2 (24).

Since the late 70s plants are being used as accumulators as well as indicators of air pollution, especially for detection, recognition, and monitoring of the presence of various air pollutants. Plants are non-motile and continuously exposed to air pollutants that may serve to raise the alarm for the possible effects on human beings due to air pollution. Hence the use of plants is often advisable for the determination of the air pollution load and its effects in different areas. (25, 26). In the earlier works, a large number of plant parameters, including visible foliar injury, leaf conductance, membrane permeability, ascorbic acid relative water content, chlorophyll content, leaf extract pH, and peroxidase activity were considered for air pollution monitoring. The susceptibility of a plant to air pollution is usually quantified and correlated with the level of plant response. But it has been observed that pollution-induced changes in individual parameters alone often cause conflicts in results for the same species. Therefore, after critical analysis, it was established that all parameters such as chlorophyll, relative water content, ascorbic acid, and leaf pH equally contribute to plants' tolerance against air pollution. These parameters were computed together in a single formula (Eq. 1) to obtain an empirical value that signifies the air pollution tolerance index of plant species (24).

$$APTI = \frac{A(T + P) + R}{10} \quad (\text{Eq. 1})$$

where A is ascorbic acid, T is total chlorophyll content, P is leaf extract pH and R is relative water content. The declinations in chlorophyll, ascorbic acid, and relative water content have often been suggested as the indicators of air pollution injury in plants. However, the climatic condition, the physicochemical properties of air pollutants, and the residence time of the air pollutants in the atmosphere also have a significant impact on plant health (66). Detailed information on the biochemical parameters is immensely important for evaluating the plant's response under stress conditions. More than one biochemical parameter needs to be assessed as a single parameter may not represent the plant tolerance reliably and may lead to uncertainties in the result (67). The responses of the plant species under the exposure to air pollutants are generally determined by two factors: internal pollutant concentration level and the biochemical threshold level of tolerance for the pollutants. Once the internal concentration

exceeds the threshold level, leaf damage or a significant reduction in chlorophyll content is observed.

Apart from that, various photochemical reactions such as oxidation, reduction, and reversible bleaching of the photosynthetic pigment occur under the stressed condition which consequently reduces the chlorophyll content. Moreover, dissolution of chemicals presents in dust particles in cell sap due to alkaline condition favors chlorophyll degradation (27).

4 Effects of environmental condition

The effects and risk of air pollution on vegetation are largely determined by the environmental parameters; therefore these parameters should be included in the research works that involve the monitoring of plant tolerance (25). Three main parameters such as plant adaptability, pollutants exposure, and environmental parameters cannot be ignored as these are the factors that ultimately regulate the air pollution tolerant behavior of the plants.

It was analyzed that, under the same environmental conditions, different plant species possess different APTI values. On the other hand, it was also observed that some plant species possess different APTI values under the same meteorological conditions. Dwivedi and Tripathi analyzed plant species from the Varanasi region and Singh et al., also took plants species from adjoining areas of the same meteorological conditions, and the APTI values for the same plants or different plants species are non-identical or dissimilar (24, 28).

Several other researchers observed that *Psidium guajava*, *Syzygium cumini*, *Albizia lebbbeck*, *Dalbergia sissoo*, *Artocarpus heterophyllus*, *Polyalthia longifolia*, *Ficus religiosa*, etc. respond differently under different environmental conditions (29, 30,31,32, 34, 33.). It has also been observed that the combined effect of air pollutants and the environmental condition of the plant's habitat may alter the plant-environment relationship on a regional scale (35). Similarly, many more researchers including Paulsamy and Senthilkumar (2009), Govindaraju et al. (2012), Thambavani and Prathipa (2012), Singare and Talpade (2013) observed the same trend in their study (39, 38, 37, 36).

4.1 Seasonal variations

Seasonal variation causes change in environmental conditions which in turn, alters the biochemical parameters of the plants. During the monsoon season, pollutants may get washed away from the leaf surface and may increase the chlorophyll and ascorbic acid content in plants' bodies. Chlorophyll amounts are considerably changed by environmental effects on plant metabolism. Summer and winter seasons may exhibit a wide range of variations in plant tolerance towards air pollutants. The high content of chlorophyll was noticed in plant species like *Quercus leucotrichophora* (3.01 mg/g), while low total chlorophyll content was observed in the case of *Hypericum oblongifolium* (1.76 mg/g) during the summer season (when the temperature is at peak). A similar trend was observed by various other researchers i.e., higher chlorophyll content has been recorded in species during the rainy season than winter and summer season (3,32,42, 41, 43). In an arid climate, dust deposition interferes with photosynthesis and decreases relative water content in plant leaves, each plays a major role in determining their sensitivity towards air pollution. They increase the sensitivity of plant species towards air pollution and make them more sensitive (44). Low chlorophyll content in the winter

season may be because of the high pollution level, temperature stress, low sunlight intensity, and short photoperiod. Irrespective of the study area, higher levels of total chlorophyll were seen in *Polyalthia longifolia* (Sonner), among the evergreen trees contemplated and *Clerodendrum* (2009 Kerala). In the summer, monsoon, and winter seasons, an increasing trend was observed in the case of ascorbic acid concentration. Ascorbic acid values were found higher during summer (2.63 mg g⁻¹) followed by a winter season (2.20 mg g⁻¹) and monsoon (1.62 mg g⁻¹). The chlorophyll value was highest during the monsoon season (2.48 mg g⁻¹ FW) and the chlorophyll content found decreased to about (1.94 mg g⁻¹) during winter and (1.65 mg g⁻¹) during summer.

4.2 Effect of light intensity

Environmental parameters such as light, temperature, and humidity also play an important role in controlling the sensitivity of plants towards pollution. Light acts as the only energy source for photosynthesis but it can simultaneously function as a stress factor. Plant responses to light differ based on the lighting environment, season, genotype, cultivation practices, etc. when plants are exposed to high light (HL) intensity conditions and other abiotic stresses (e.g., drought), the energy supply (ATP), and reducing power (NADPH) through photosystems (and by the involvement of electron transport chain) exceeds the demand for metabolic processes in carbon-fixing reactions. It further, results in the accumulation of Reacting oxygen species (ROS) which can have a dual effect on plant response. Firstly, it initiates oxidative damage to the cellular components, and secondly, it induces lipid peroxidation which is toxic to the plants at high concentrations (45). On contrary, Hull and Went (1952) observed that, when plants were placed in a dark environment, they were less sensitive to ozonated hexene than the plants exposed to light (46). Koritz and went (1953) reported that, when tomato plants were placed in the dark and exposed to low levels of ozonated hexane, they exhibited no depletion in growth whereas when the plants were exposed to the light for 1.5 hours period with the same level of ozonated hexene after the dark period, they exhibited definite growth depletion (47). Heck (1964) examined that during a 4-hour dark exposure, there was no significant injury to endive plants, cotton, or tomato from an irradiated nitrogen dioxide propylene mixture but during 4 hours of light exposure in the presence of the same pollutant, severe damage was noticed.

Dugger, et al. reported that plants can be completely protected from PAN pollutants when placed in 30- minute dark exposure but show no effect on O₃ injury. Ascorbic acid concentration increases in tobacco plants due to light preconditioning (51). The increased amount of ascorbic acid represents the developmental stages of rapid leaf expansion. The increased amount of ascorbic acid concentrations in leaves due to light was 2.5 to 3.3 times higher as compared to the pollutant damage. Light initiates the resistance while pollutant decreases the resistance inside the plant. Both the amount of light inside the plant and the amount of pollutant that enters inside are inversely correlated with each other. Therefore, it was elucidated that, depending upon the plant's adaptability, some plants show tolerance under light conditions and some in shade regions (48). During light exposures plants were as much as five times more sensitive to SO₂ than during dark exposures and that light intensity had no additional sensitizing effect above a minimum of 3000 ft-c.

4.3 Effect of Temperature

Plants are most sensitive to Phyto-toxic air pollutants (Smog) during warm moderate conditions (79°F during day and 68°F) and they are less sensitive in a moderate cool environment (68°F during the day and 57°F during night time). Juhren et al. (1957) observed that, if plants are relocated from a warm (79°F) to hot (86°F) environment, then they lose their sensitivity within three days (49). Menser et.al (50) examined four Tobacco varieties and recorded their tolerance while the plants were kept at 77°F and 41°F separately. It was observed that the plants kept at 77°F were more sensitive than those kept at 41°F. Light intensity was also observed to modify the response of plants towards pollutants. Taylor et al. studied the tolerance of the pinto bean plant to O₃ under two different light intensities and it was found O₃ injuries were reduced under high light intensities, Menser et al., (1963) reported that O₃ injury to the tobacco plants was reduced when they were exposed for an extended 22-hour photoperiod before fumigation (51).

In aqueous solutions, the rate of S (IV) oxidation is very sensitive to temperature. At low temperatures in cellular solutions, whenever sulfite oxidation is slowed, more toxic S (IV) compounds will assemble as photosynthetic depression is related to the S (IV) concentration and at lower temperatures much stronger reductions of photosynthesis can be expected. However, photosynthetic depression at the end of the fumigation period at a given rate of SO₂ uptake was much stronger at 8°C when compared to leaves exposed to SO₂ at 18°C. This effect can be further explained and understood, an amount of SO₂ influences biochemical processes which are responsible for photosynthetic depression by SO₂. Anyhow, this effect is either due to an increased sensitivity of photosynthesis to S (IV) metabolites or a reduced rate of S (IV) oxidation (52). Hull and Went reported greater sensitivity at elevated temperatures when using an O₃ hexene mixture and found that plants, when exposed to an irradiated mixture of propylene-nitrogen dioxide under uniform artificial lighting, were critically injured at 80°F than at 65° or 95°F (53).

Before exposure to phytotoxic air pollutants, the temperature variations during some phases of growth have an obvious effect on the sensitivity of plants to the pollutants. Plant reducing sensitivity at low temperatures during growth for one or more days before exposure is effective. However, further research is required to be done to understand the effects of intermediate and higher temperatures over different stages of growth. During exposure to phytotoxic air pollutants, the temperature has a noticeable effect on plants.

4.4 Effect of Humidity

Humidity is the next important factor of the environment that influences the response of plants under stress. Two major physiological activities of plants that are directly controlled by humidity are transpiration water loss and stomatal opening. Temperature and humidity are directly proportional to each other (54). As temperature increases, transpiration increases because the vapor pressure difference between the moist leaf surface and air increases with increasing temperature. An increase in the temperature causes variation in biochemical parameters which further controls the tolerance ability of plants towards pollutants. (55). High ambient humidity results in the closure of stomata, which leads to less availability of CO₂ inside plants. It affects the photosynthesis process and plants become more sensitive to air

pollutants. In *H. Annuus* the net photosynthetic rate decreases due to the increase in vapor pressure difference. A similar trend was reported in the case of *C. album*. On contrary, the other species (e.g., Glycine max) do not show a reduction in net photosynthetic rates at a given intercellular carbon dioxide partial pressure in response to large vapor differences (56). A significant reduction in chlorophyll content was observed when there was a large vapor pressure difference (56). It was also reported that, if a specific range of vapor pressure difference (0 to 10 MB) is maintained, no significant change in photosynthetic rates can be observed (57). Rawson and Begg (1977) reported that, when the vapor pressure deficit increases, the transpiration rate increases. However, over the range of 8 to 27MB of vapor pressure deficit (VPD), deficit, photosynthesis of single leaves was unaffected by humidity. Linear regression ($r=0.96-0.99$) accurately defined the relationship between the rate of transpiration and humidity in all species. Thus, the rate of transpiration for a single leaf of any genus was largely determined by the vapor pressure deficit (VPD) between the leaf's intercellular spaces and the atmosphere. Water loss rates were higher in C3 crop plants (sunflower, wheat, and soybean) than in C4 crop plants (barnyard grass and sorghum). The water use efficiency of C4 species was more than double that of C3 plant species (under high irradiance conditions). Low humidity also inhibits expansive growth. (58).

Plants tend to react to atmospheric humidity in several ways. Rapid responses like stomatal movements and explosive dehiscence, seed pod, developmental changes like an epicuticular wax deposition, and evolutionary adaptations like cuticle thickness and stomatal sensitivity to humidity are just a few examples. Plants grow best when evaporative demand is poor, according to common observation. The characterization of the response mechanism will be greatly aided by a detailed understanding of the humidity parameter that induces a particular physiological response in plants. Plant-humidity interactions are likely to include one or both of two distinct processes. Humidity changes, both natural and experimental, are often linked to changes in other environmental parameters. Humidity changes affect perspiration, energy balance, and tissue temperatures. These, in turn, can influence ion uptake, carbon assimilation, water transport, and other processes all of which have additional physiological consequences that obscure direct responses to humidity.

Humidity was inversely linked to epicuticular wax development and morphological complexity in controlled-environment growth chambers at lower humidity levels. Additional changes are caused by both light and temperature. Plants grown in humid environments (such as maize) have significantly higher cuticular conductance than plants grown in less humid environments, and they lose more water under similar conditions (59). It has been reported depressing SO_2 effects on plant growth were found to be greatest during the winter when temperature and irradiance are low and humidity is high. The absorption, metabolism, and impact of SO_2 metabolites on photosynthesis can be directly affected by winter environmental conditions (low temperature, low irradiation, high humidity) when air humidity is high, pollutant uptake is significantly higher (52).

4.5 Effect of precipitation

Precipitation is another environment parameter that usually harms the net productivity and photosynthesis of plants. This

trend may vary from species to species. Excess rainfall results in the washout of the pollutants from the leaf surfaces into the soil. As a result, the plants exhibit a high chlorophyll and ascorbic acid content which results in less damage inside plants. It implies that precipitation influences plant tolerance under stress conditions (60). During extreme precipitation, the patterns suggest that xeric biomes may respond positively and on the other hand, mesic biomes may be more likely to be negatively affected. Moreover, it can be seen that seasonal changes in precipitation in the course of warm or dry seasons may have larger effects than changes during cool or wet seasons. Consequently, responses to redistributed precipitation will include a complex interplay between plant-available water, plant functional type, and resultant influences on plant phenology, growth, and water relations above ground net primary productivity (ANPP). Likewise, the effect of seasonal changes in precipitation on ANPP, phenology, leaf, and fruit development vary with the effect on soil water content. So, increased winter precipitation had a little impact on plants whereas increased summer precipitation had a more considerable impact on plants. On the contrary, changing seasonal precipitation may influence phenology, including fruit, leaf, and early/latewood development as well as tiller development of grass; extreme precipitation may impact plant water relations, hydraulic architecture, and ANPP. The severe water stress will damage the entire photosynthesis system which may even become the reason for the reduction of plants' productivity and resistivity towards pollutants. However, when the extent of precipitation exceeded the threshold volume, the reduction of net photosynthetic rate slowly decreases which means that when rainfall reached the threshold, the net photosynthetic rate will begin to stabilize (61).

4.5 Effect of geographical locations

Due to different environmental conditions plants respond differently to different air pollutants. It was noted that the same plant species act as sensitive to air pollutants at one geographic location but intermediately or highly tolerant at other locations due to the changes in environmental conditions (62). It was analyzed that, some plants such as *Delonix regia* possess a tolerance index value as low as 7 during winter at one site but on other sites, the same plant species may exhibit a higher tolerance index (13.99, 10.25, and 21.9) during summer, monsoon respectively. This variation of plants' sensitivity to air pollution could be the result of different environmental conditions or exposure to different concentrations of the ambient air pollutants (30, 39, 63, 24). Environmental factors vary widely with the geographic locations of the plant's habitats. Therefore, the responses of the plants to air pollution change with varying geographic locations. As a result, different plant species exhibit different tolerance values in different places (64).

5 Conclusions

The criteria for the evaluation of air pollution tolerance of any plant species are unable to produce reliable outcomes yet. According to the studies conducted so far, the tolerance and sensitivity of the plants depend upon their biochemical parameters which in turn, depend on the environmental conditions and concentration of ambient air pollutants. Therefore, the tolerance calculation of plants against air pollutants should recognize the environmental parameters as they act as major

controlling factors which directly or indirectly affect the tolerance of the plants. It implies that using the biochemical parameters only for evaluating plants' response to air pollutants may not properly suggest the ideal candidate plant species for projects like green belt development. The tolerant plant species should be used to develop the green belts around the industrial area but as the plant's tolerance to the pollutants is the product of several environmental factors it is of utmost necessity to consider the environmental conditions under which plants are grown and exposed. Plants that constitute green belts have certain limits of tolerance towards air pollutants. Some additional information such as source strength, seasonal variation of the pollutant emission, distance of the plants from the emission sources, width and height of the belts may be immensely helpful for evaluating the effectiveness of the green belts. Excessive emission crossing the threshold limits in terms of pollution load could lead to injury to plants causing the death of tissues and reducing their absorbing potential. The absorption efficiency of unhealthy, dead tissues and leaves is extremely low which may not serve the purpose of green patch development. In short, the purpose of the plantation projects will be met only if the pollution load is not lethal for the plant species to be deployed. Therefore, planning is needed to design green belts that are capable of absorbing pollutants and improving the quality of ambient air.

Acknowledgment

The authors would like to thank Lovely professional university Punjab, for allowing this study.

Ethical issue

Authors are aware of and comply with, best practices in publication ethics specifically about authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution to data collection, data analyses, and manuscript writing.

References

- 1 Kaur M, Sharma A, Katnoria J, Nagpal A. Air Pollution Tolerance Index (APTI): An Important Determinant for the Development of Green Space in and Around Industrial/Urban Area. 2017.
- 2 Sahu C, Sahu SK. Air pollution tolerance index (APTI), anticipated performance index (API), carbon sequestration and dust collection potential of Indian tree species—A review. *Int J Emerg Res Manag Technol.* 2015;4(11):37-40.
- 3 Sharma B, Bhardwaj SK, Kaur L, Sharma A. Evaluation of air pollution tolerance index (APTI) as a tool to monitor pollution and green belt development: A review. *J. App. Nat. Sci.* 2017 Sep 1;9(3):1637-43.
- 4 Bhawan P, Nagar EA. Central Pollution Control Board.
- 5 Change IP. IPCC. Climate change. 2014.
- 6 Munsif R, Zubair M, Aziz A, Zafar MN. Industrial Air Emission Pollution: Potential Sources and Sustainable Mitigation. In *Environmental Emissions 2021* Jan 7. Intech Open.
- 7 Das M, Das M, Mukherjee A. Air pollution tolerance index (APTI) used for assessing air quality to alleviate climate change: A Review. *Res. J. Pharma. Biol. Chem. Sci.* 1;9(1):45-54 (2018)
- 8 Kaler NS, Kashyap P, Prasad H, Singh TJ. Air pollution tolerance index (APTI) of tree species: a review. *ICJ'S.* 2017;5(4):716-20.
- 9 Louisa, K. O., O. Ghaffarpasand and F. D. Pope: Real-World Contribution of Electrification and Replacement Scenarios to the Fleet Emissions in West Midland Boroughs, UK. *Atmosphere*, 12(3), 332 (2021).
- 10 Bolaji BO, Adejuyigbe SB. Vehicle emissions and their effects on the natural environment. *J. Ghana Inst. Eng.* 4(1):35-41 (2006).
- 11 Ghaffarpasand, O., S. Nadi, and Z. D. Shalamzari: Short-term effects of anthropogenic/natural activities on the Tehran criteria air pollutants: Source apportionment and spatiotemporal variation. *Build. Env.*, 186 (2021).
- 12 Ghaffarpasand, O., C. S. D. C.S Beddows, K. Ropkins, F. D. Pope: Real-world assessment of vehicle air pollutant emissions subset by vehicle type, fuel and EURO class: new findings from the recent UK EDAR field campaigns, and implications for emissions restricted zones. *Science of the Total Environment*, 734 (2020).
- 13 Bhawan P, Nagar EA. Central Pollution Control Board
- 14 Ghaffarpasand, O., M. R. Talaie, H. Ahmadiakia, A. T. Khozani, and M. D. Shalamzari: A high-resolution spatial and temporal on-road vehicle emission inventory in 1 an Iranian metropolitan area, Isfahan, based on detailed hourly traffic data. *Atmospheric Pollution Research.* (2020).
- 15 Nithya R, Poonguzhali S, Kanagarasu S. Use of Tree Species in Controlling Environmental Pollution-A Review. *Int. J. Curr. Microbiol. App. Sci.* 2017;6(4):893-9.
- 16 Guttikunda SK, Jawahar P. Atmospheric emissions and pollution from the coal-fired thermal power plants in India. *Atmospheric Environment.* 2014 Aug 1; 92:449-60.
- 17 Sivaramanan S. Air Pollution sources, pollutants and mitigation measures. *Research Gate, DOI.* 2015;10(2.1):5106-8485.
- 18 Nouchi I. Responses of whole plants to air pollutants. In *Air pollution and plant biotechnology 2002* (pp. 3-39). Springer, Tokyo.
- 19 Sharma B, Sharma S, Bhardwaj SK, Alam NM, Parmar YS. Effect of pollution on total chlorophyll content in temperate species growing along national highway 5 in Himachal Pradesh. *International Journal of Advances in Science Engineering and Technology.* 2017;5(3):72-5.
- 20 Panda LL, Aggarwal RK, Bhardwaj DR. A review on air pollution tolerance index (APTI) and anticipated performance index (API). *Current World Environment.* 2018;13(1):55.
- 21 Bakiyaraj R, Ayyappan D. Air pollution tolerance index of some terrestrial plants around an industrial area. *International Journal of Modern Research and Reviews.* 2014;2(1):1-7.
- 22 Tsaga YC, Prasad AD. Variation in air pollution tolerance index and anticipated performance index of roadside plants in Mysore, India. *Journal of Environmental Biology.* 2014 Jan 1;35(1):185-90.
- 23 Acharya S, Jena RC, Das SJ, Pradhan C, Chand PK. Assessment of air pollution tolerance index of some selected roadside plants of Bhubaneswar city of Odisha State in India. *Journal of Environmental Biology.* 2017 Nov 1;38(6):1397-403.
- 24 Singh SK, Rao DN, Agrawal M, Pandey J, Naryan D. Air pollution tolerance index of plants. *Journal of Environmental Management.* 1991 Jan 1;32(1):45-55.
- 25 Posthumus AC. Higher plants as indicators and accumulators of gaseous air pollution. *ecological indicators for the assessment of the quality of air, water, soil, and ecosystems 1983* (pp. 263-272). Springer, Dordrecht.
- 26 Rawal DS, Sijapati JS, Rana N, Pradhananga TM. Air pollution tolerance index of some tree species of Kathmandu Valley. *Nepal Journal of Science and Technology.* 2001;3(1).

- 27 Geeta C, Namrata C. Effect of air pollution on the photosynthetic pigments of selected plant species along roadsides in Jamshedpur, Jharkhand. *Research in Plant Biology*. 2014.
- 28 Bayat L, Arab M, Aliniaieifard S, Seif M, Lastochkina O, Li T. Effects of growth under different light spectra on the subsequent high light tolerance in rose plants. *AoB Plants*. 2018 Oct;10(5):ply052.
- 29 Lakshmi PS, Sravanti KL, Srinivas N. Air pollution tolerance index of various plant species growing in industrial areas. *The Eco scan*. 2009 Oct;2(2):203-6.
- 30 Lalitha J, Dhanam S, Ganesh KS. Air pollution tolerance index of certain plants around SIPCOT industrial area Cuddalore, Tamilnadu, India. *Int. J. Environ. Bioenergy*. 2013;5(3):149-55.
- 31 Madan S, Verma P. Assessment of air pollution tolerance index of some trees in Haridwar City, Uttarakhand. *Journal of Environmental Biology*. 2015 May 1;36(3):645.
- 32 Rai PK, Panda LL. Leaf dust deposition and its impact on a biochemical aspect of some roadside plants of Aizawl, Mizoram, North East India. *International Research Journal of Environment Sciences*. 2014 Nov;3(11):14-9.
- 33 Sharma M, Panwar N, Arora P, Luhach J, Chaudhry S. Analysis of biological factors for determination of air pollution tolerance index of selected plants in Yamuna Nagar, India. *Journal of environmental biology*. 2013 May 1;34(3):509.
- 34 Priyanka C, Dibyendu B. Biomonitoring of air quality in the industrial town of Ansol using the air pollution tolerance index approach. *Res J Chem Environ*. 2009 Mar 1;13(1):46-51.
- 35 Kuddus M, Kumari R, Ramteke PW. Studies on air pollution tolerance of selected plants in Allahabad city, India. *Journal of Environmental Research and Management*. 2011;2(3):042-6.
- 36 Singare PU, Talpade MS. Physiological responses of some plant species as a bio-indicator of roadside automobile pollution stress using the air pollution tolerance index approach. *International Journal of Plant Research*. 2013;3(2):9-16.
- 37 Thambavani S, Prathipa DV. Assessment of Air Quality through Biomonitoring of selected sites of Dindigul town by air pollution tolerance index approach. *J Res Biol*. 2012; 2:193-9.
- 38 Paulsamy S, Senthilkumar P. Identification of air pollution tolerant tree species for the industrial city, Tirupur, Tamil Nadu. *Nat Environ Pollut Technol*. 2009;8(3):585-8.
- 39 Govindaraju M, Ganeshkumar RS, Muthukumaran VR, Visvanathan P. Identification and evaluation of air-pollution-tolerant plants around lignite-based thermal power station for greenbelt development. *Environmental Science and Pollution Research*. 2012 May;19(4):1210-23.
- 40 Bhardwaj A, Aggarwal RK, Bhardwaj SK. A Review on Impacts of Road Activities and Vehicular Emissions on Native Ecosystems in Mountainous Region. *Current World Environment*. 2018;14(2):194.
- 41 Bhattacharya T, Kriplani L, Chakraborty S. Seasonal Variation in Air Pollution Tolerance Index of Various Plant Species of Baroda City. *Universal Journal of Environmental Research & Technology*. 2013 Apr 1;3(2).
- 42 Jyothi SJ, Jaya DS. Evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala. *Journal of Environmental Biology*. 2010 Jan;31(3):379-86.
- 43 Gandhi UD, Reddy MA. Air Pollution Tolerance Levels of selected urban plant species in industrial areas of Hyderabad (AP), India. *Environment*. 2013 Jun;2(6):294-5.
- 44 Sanghi SB, Sharma C, Sanghi SK. Comparison of APTI Values of Some Medicinal Plants of Industrial Areas and Ratapani Wild Life Sanctuary in Raisen District of Madhya Pradesh. *International Journal of Pharmacy & Life Sciences*. 2015 Jan 1;6(1).
- 45 Dwivedi AK, Tripathi BD. Pollution tolerance and distribution pattern of plants in the surrounding area of coal-fired industries. *Journal of Environmental Biology*. 2007 Apr 1;28(2):257-63.
- 46 Hull HM, Went FW. Life processes of plants as affected by air pollution. In *Proc. Second Natl. Air Pollution Symp* 1952 (pp. 122-128).
- 47 Koritz HG, Went FW. The physiological action of smog on plants. I. Initial growth and transpiration studies. *Plant physiology*. 1953 Jan;28(1):50.
- 48 Heck WW. Plant injury induced by photochemical reaction products of propylene-nitrogen dioxide mixtures. *Journal of the Air Pollution Control Association*. 1964 Jul 1;14(7):255-61.
- 49 Juhren M, Noble W, Went FW. The Standardization of *Poa Annua* as an Indicator of Smog Concentrations. I. Effects of Temperature, Photoperiod, and Light Intensity during Growth of the Test-Plants. *Plant physiology*. 1957 Nov;32(6):576.
- 50 Menser HA, Heggstad HE, Street Oe. Response of Plants to Air Pollutants. 2. Effects of Ozone Concentration and Leaf Maturity on Injury to *Nicotiana Tabacum*. *Phytopathology*. 1963 Jan 1;53(11):1304.
- 51 Menser HA. Response of Plants to Air Pollutants. III. A Relation Between Ascorbic Acid Levels and Ozone Susceptibility of Light-Preconditioned Tobacco Plants. *Plant physiology*. 1963.
- 52 Kropff MJ, Smeets WL, Meijer EM, Van der Zalm AJ, Bakx EJ. Effects of Sulphur dioxide on leaf photosynthesis: the role of temperature and humidity. *Physiologia Plantarum*. 1990 Dec;80(4):655-61.
- 53 Heck WW, Dunning JA, Hindawi IJ. Interactions of environmental factors on the sensitivity of plants to air pollution. *Journal of the Air Pollution Control Association*. 1965 Nov 1;15(11):511-5.
- 54 Tibbitts TW. Humidity and plants. *BioScience*. 1979 Jun 1;29(6):358-63.
- 55 Forde BJ, Mitchell KJ, Edge EA. Effect of temperature, vapor-pressure deficit, and irradiance on transpiration rates of maize, *paspalum*, western wolds, and perennial ryegrasses, peas, white clover, and lucerne. *Functional Plant Biology*. 1977;4(6):889-99.
- 56 Bunce JA. Effects of humidity on photosynthesis. *Journal of Experimental Botany*. 1984 Sep 1;35(9):1245-51.
- 57 Hoffman GJ, Rawlins SL. Design and performance of sunlit climate chambers. *Transactions of the ASAE*. 1970;13(5):656-0660.
- 58 Rawson HM, Begg JE, Woodward RG. The effect of atmospheric humidity on photosynthesis, transpiration, and water uses the efficiency of leaves of several plant species. *Planta*. 1977 Jan;134(1):5-10.
- 59 Grantz DA. Plant response to atmospheric humidity. *Plant, Cell & Environment*. 1990 Sep;13(7):667-79.
- 60 Yu WQ, Wang YQ, Wang YJ, Zhang HL, Wang B, Liu Y. Effect of precipitation condition on photosynthesis and biomass accumulation and referring to splash erosion status in five typical evergreen tree species in humid monsoon climatic region of subtropical hill-land. *Journal of Central South University*. 2015 Oct;22(10):3795-805.
- 61 Banerjee S, Banerjee A, Palit D, Roy P. Assessment of vegetation under air pollution stress in urban industrial area for greenbelt development. *International Journal of Environmental Science and Technology*. 2019 Oct;16(10):5857-70.
- 62 Darley EF, Middleton JT. Problems of air pollution in plant pathology. *Annual Review of Phytopathology*. 1966 Sep;4(1):103-18.
- 63 Begum A, Harikrishna S. Evaluation of some tree species to absorb air pollutants in three industrial locations of South Bengaluru, India. *E-journal of chemistry*. 2010 Jan 2;7(S1): S151-6.
- 64 Zeppel MJ, Wilks J, Lewis JD. Impacts of extreme precipitation and seasonal changes in precipitation on plants. *Bio geosciences Discussions*. 2013 Oct 15;10(10).
- 65 Bharti SK, Trivedi A, Kumar N. Air pollution tolerance index of plants growing near an industrial site. *Urban climate*. 2018 Jun 1; 24:820-9.
- 66 Pradhan AA, Pattanayak SK, Bhadra AK, Ekka K. Air pollution tolerance index of three tree species along national high way-6 between Ainthapalli to Remed, Sambalpur District, Western Odisha, India.
- 67 Das S, Mallick SN, Padhi SK, Dehury SS, Acharya BC, Prasad P. Air Pollution Tolerance Indices (APTI) of Various Plant Species Growing in Industrial Areas of Rourkela. *Ind J Environ Prot*. 2010; 30:563-7.

- 68 Dhanam S, Rajapandian P, Elayaraj B. Air Pollution Tolerance Index and biochemical constituents of some plants growing in Neyveli Lignite Corporation (NLC), Tamil Nadu, India. *Journal of Environmental Treatment Techniques*. 2014;2(4):171-5.