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Morpho-Anatomical and Biochemical Responses of Plants to Air Pollution

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Abstract Air pollution has been aggravated by developments that typically occur as countries become industrialized: growing cities, increasing traffic, rapid economic development and industrialization, and higher energy consumption. The development of sustainable and cost effective technologies for air pollution abatement is one of the promising areas of research. The quest of an alternative eco-friendly technology relating to restoration of urban ecosystem has resulted in the study of influence of air pollutants on plants as an integral part of pollution ecology. Although, review relating to use of plant species in controlling air pollution have been carried, but extensive review on the use of anatomical, morphological, physiological and biochemical parameters of plants of urban forest as biomarkers of air pollution has not been done. The objective of this paper is to review the responses of plants to air pollution.

Keywords Air Pollution Tolerance Index, Anticipated performance Index, Micromorphological, Physiological, Biochemical

1. Introduction

The atmosphere is one of the key components of the environment that is vital for the welfare of urban inhabitants. Climatic conditions straightforwardly impacts life and property. Air is a valuable normal asset that structures the premise of human presence on earth. Climatic air gives oxygen to plants and creatures by which they are to live. Clean air contains 78% nitrogen, 21% oxygen 0.93% argon, 0.038% carbon dioxide and other follow gases [17]. A variety in the vaporous piece of earth's air emerging from human exercises is a noteworthy worry of the world today. The consistent increment in human populace, vehicular movement and commercial enterprises had brought about high concentration of gaseous and particulate pollutants [34].

Air quality decides the wellbeing status of the general population. Lately, there has been an incredible increment in urban populace. It has been accounted for by United Nations Environment Program (2006) that more than 350 urban communities of the world are having a populace of more than One Million individuals. Quick urbanization has brought about expanding urban air contamination in significant urban communities, particularly in developing nations. Expansive measure of pollutants has been transmitted as a consequence of this urbanization and industrialization which invariably has its many environmental issues such as air, water and noise pollution as well as waste management [10]. In urban and Industrial regions and in addition it's encompassing zones around the world, air quality distortion is major ecological issue [46].

It has been accounted for that urban outside air contamination is in charge of 49,000 unexpected losses in Africa yearly. In Africa, 35% of malady rate is brought on by natural impact [25]. It is assessed that more than 1 billion individuals are presented to open air contamination yearly. Urban air contamination is connected to up to 1 million unexpected losses and 1 million pre-local passings every year. Urban air contamination is evaluated to cost around 2% of GDP in developed nations and 5% in developing nations. A late report discharged by the Harvard School of Public Health showed that air contamination from traffic congestion adds to more than 2,200 unexpected losses every year in the United States costs the health system a huge amount of money. In a large portion of the world's developing economies, many of the vehicles are older – and the damage to people's health from pollution may be much worse than in advanced economies. The adjustment of surrounding environment emerging from air pollution in urban region is applying a significant impact on the morphological, biochemical and physiological status of plants, and in this manner its reactions. The unsafe impacts of air contamination on plants are all around perceived [96, 110]. Plant reactions to air pollution are useful in early diagnosis of airborne contaminants; estimating the concentration of pollutants and getting direct distinguishing proof of various

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air pollutants on the premise of plant species. The main focus of the review highlights the effects of air pollution on the anatomical, micromorphological, physiological, biochemical and enzymatic activities of plants.

2. Impact of Air Pollution on Micro Morphology and Anatomy of Plants

The utilizing of the tree leaves as aggregate biomonitors of air pollution is of incredible environmental significance [11, 114]. The leaves go about as air pollution receptors and biological absorbers or filters of pollutants [113, 23], shockingly not as much as consideration has been given to morphological and anatomical parameters of plants as markers of reactions to changing urban environment quality [8]. It has been accounted for that morpho-anatomical adjustments are promising measures to gauge the air quality of the urban habitat [22].

Studies have recorded changes in plants because of a wide range of environmental pollutants, and the vast majority of these works allude to physiological modifications [36, 54, 74]. Stomatal and epidermal cell size, lower recurrence, thickening of cell wall, epicuticular wax deposition alterations and chlorosis are among the auxiliary alterations in leaves subjected to air pollution [87, 92, 101]. A few authors considered foliar epidemis as a bioindicator of environmental quality [60, 5, 8]. [101] observed that general plant development was influenced with serious mutilations in foliar epidermal characters. It likewise brought up the significance of the cuticle and epidermal features in the determination of resistance/ sensitivity of each species to environmental pollutants.

The histo-anatomical structure of the leaves of some Fabaceae species as influenced through air contamination demonstrated a stomatal abatement in size and increment to thickness of leaves and additionally dark phenolic deposits in palisade and light parenchyma [26]. Studies on impact of micromorphology and leaf epidermal components of plants revealed that in the polluted sites, leaves became smaller with reduced length and width and stomata index per leaves area [88].

[58] reported that *Nerium indicum* Mill., *Boerhaavia diffusa* L., *Amaranthus spinosus* L., *Cephalandra indica* Naud and *Tabernaemontana divaricata* L. can without much of a stretch maintain a strategic distance from the impacts of air pollution by modifying their physiological pathways relating to photosynthesis and respiration. Stomatal closure of *Boerhaavia, Amaranthus, Cephlandra* and stomatal clogging up in Nerium and Tabernaemontana help these plants in preventing the entry of poisonous gases.

[84] reported that acclimatization of plants to air pollution may change their morphological structure, for example, thicker epidermal cells and more trichomes. [67] examined the anatomic and morphological attributes of normal birch *Betula pendula* (Roth.) leaves influenced by industrial emissions. The most clear negative changes showed up as the decrease in the thickness of the cuticle and width of the lower epidermis cells. A factually critical increment in the thickness of the pallisade and elastic mesophyll, thickness of a lamina and thickness of the upper epidermis tissue were determined as the adaptive changes. In a study directed on the foliar epidermal characteristics of *C.siamea*, [80] discovered increment in densities of stomata, trichomes and epidermal cells, longer trichomes and decrease in size of epidermal cells at polluted sites when contrasted with at reference site.

[49] investigated the cuticular and epidermal elements of *Syzygium cuminii* L. and *Lantana camara* L. growing near a diesel generator set and at a control site. They watched extremely noteworthy contrasts in trichome recurrence, stomatal opening and callus arrangement in the two sets. In another study, [48] reported significant structural changes on leaf surface structures of *Calotropis procera* L. and, *Nerium indicum* L. under the impact of automobile exhausts pollutants

[32] reported structural and micro-morphological changes in leaves of *Salix alba* as brought on through air pollution. [40] reported that reduction in size of epidermal cell and stomata, and increment in the quantity of epidermal cells, stomata and trichomes occur on exposure to SO_2 contamination.

[57] explored the anatomical and micromorphological modifications in leaves of *Eugenia uniflora* and *Clutia robusta* subjected to simulated acid rain. There was disintegration and morphological change of epicuticular wax in both upper and lower epidermis of the plant. [78] examined *Platanus orientalis* leaves subjected to automobile air pollution in urban and rural sites. At the urban site, stomatal thickness and stomata widths were lower on leaves from the urban than those from country site. [109] observed that air pollution brought on through auto fumes demonstrated checked modification in epidermal attributes, with diminished number of stomata, stomata records and epidermal cells per unit zone, while length and expansiveness of stomata and epidermal cells were observed to be expanded in leaves samples, in this manner its use as biomarkers of auto pollution.

Decrease in leaf surface range and length of petiole causes less contact with natural toxins, particularly air pollution and enhances resistance of plants against pollution. Some physiological unsettling influence may have happened which brought on decrease in morphological and anatomical characters of plant species [93]. Leaf length is viewed as one of the qualities, which mirror the capacity of plant to ensure against stress [6].

3. Effect of Air Pollution on Ascorbic Acid Content of Plants

Ascorbic acid content is the measure of ascorbic acid present in the leaf of a plant. It likewise assumes a critical part in light response of photosynthesis, actuates guard component, and under stress condition, it can supplant water from light response. Ascorbic acid in plants has been shown to play an important role in pollution tolerance [93]. Be that as it may it's reducing activity is pH dependent. High pH may build the productivity of change from hexose sugar to Amino Acid (AA). Pollution load dependent increase in ascorbic acid content of all the plant species may be due to the increased rate of production of reactive oxygen species (ROS) during photo-oxidation of SO_2 to SO_3 where sulfites are generated from SO_2 absorbed. The plants with high sensitivity to SO_2 and NO_2 shut the stomata faster when exposed to the pollutants [101]. However the reducing activity of ascorbic acid is pH dependent being more at higher and less at lower pH hence the leaf extract pH on the higher side gives tolerance to plants against pollution. It has been reported that a definite correlation between ascorbic acid content and resistance to pollution exist in plants. Resistant plants contain high measure of ascorbic acid, while sensitive plants have a low level of ascorbic acid. In this way, plants keeping up high ascorbic acid level even under contaminated conditions are thought to be tolerant to air pollutions [46].

4. Effect of Air Pollution on Relative Water Content of Plants

Relative water content (RWC) is the measure of water a plant contains when it is unequipped for taking in more water. This state is known as full saturation. A plant does not need to be in this state so as to survive. In any case, knowing the rate of water a plant is fit for holding is one approach to figure out whether a plant is stressed. The high water content inside of a plant body will keep up its physiological equalization under stress, such as exposure to air pollution when the transpiration rates are usually high. High RWC favours drought resistance in plants. In the event that the leaf transpiration rate diminishes because of the air pollution, plant can't live well because of losing its motor that pulls water up from the roots to supply photosynthesis (1%-2% of the aggregate). At that point, the plants neither convey minerals from the roots to leaf where biosynthesis happens, nor cool the leaf [55]. Leaf water status relies on a few physiological variables, for example, leaf turgor, development, stomatal conductance, transpiration, photosynthesis and respiration. The relative water substance demonstrates change in leaf grid hydration condition and will create higher acridity condition when RWC is low. More water will weaken causticity [71]. Relative water substance is connected with protoplasmic porousness in cells causes loss of water and broke up supplements, bringing about right on time senescence of leaves [4].

5. Effect of Air Pollution on Chlorophyll Content of Plants

Chlorophyll measurement is an important tool to evaluate the effects of air pollutants on plants as it plays an important role in plant metabolism and any reduction in chlorophyll content corresponds directly to plant growth [111]. Chlorophyll is the chief photoreceptor in photosynthesis, the light-determined procedure in which carbon dioxide is "settled" to yield starches and oxygen. Leaf chlorophyll substance and carotenoids in this manner can give valuable information about physiological status of plants. Depletion in chlorophyll immediately causes a decrease in productivity of plant and subsequently plant exhibits poor vigor. Consequently, plants keeping up their chlorophyll even under polluted environment are said to be tolerant ones [100]. Chlorophyll pigments exist on highly organized state, and under stress they may undergo a few photochemical responses, for example, oxidation, reduction, pheophytinisation and reversible bleaching; consequently any modification in chlorophyll focus may change the morphological, physiological and biochemical conduct of the plant [24]. [40] observed a reduction in chlorophyll a, chlorophyll b, total chlorophyll content, carotenoid, total sugar, protein, dust-catching limit and leaf size in the specimens from contaminated sites containing containing automobile exhaust and industrial pollutants and from pollution-free. [30] study on automobile exhausts effect on diverse biochemical parameters of the ordinarily occurring roadside trees revealed a reduction in total chlorophyll content, protein and amino acids of *F. religiosa, R.co*mmunis and *C. papaya* leaves in relationship to their different controls. They were observed changes in biochemical substance in *Cassia occidentalis* as a result of auto pollution. [50] investigated changes in biochemical contents in *Cassia occidentalis* in response to automobile pollution and observed critical reduction in chlorophyll a, chlorophyll b and total chlorophyll substance.

It is already reported that pollution stress decreases the chlorophyll level in tree species ([75, 68, 9, 49]. The chlorophyll content of plant varies from species to species; age of leaf and also with the pollution level as well as with other biotic and abiotic conditions [43]. Studies [61] also suggest that high levels of automobile pollution decreases chlorophyll content in higher plants near roadsides. Air pollution emitted from automobiles adversely affected the ambient air and tree (*Ficus religiosa*) and (*Polyalthia longifolia*) pigments thus can be utilized for urban plantation and greenbelt development in industrial area to reduce the level of air pollution [115]. Chlorophyll content of plants varies from the pollution status of the area i.e. higher the pollution level in the form of vehicular exhausts lower the chlorophyll content and as well varies with the tolerance as well as sensitivity of the plant species i.e. higher the sensitive nature of the plant species lower the chlorophyll content [35]. [24] compared the effect of air pollutants generated from the exhaust of industries and automobiles on the chlorophyll content of leaves. Photosynthetic pigments chlorophyll a, chlorophyll b and carotenoids were quantified and a reduction in the photosynthetic pigments of plant leaves growing in higher polluted site as compared to none or less polluted ones was recorded.

6. Effect of Air Pollution on Plant Carotenoids

Carotenoids are a class of regular fat-dissolvable pigments located chiefly in plants, green growth and photosynthetic microscopic organisms, where they assume a basic part in the photosynthetic process; furthermore shield chlorophyll from photoxidative destruction [13]. A reduced carotenoid content under air contamination has been reported [104].

7. Effect of Air Pollution on the Leaf Extract pH

Leaf extract pH is the pH of the concentrates from the leaves of the plant. Photosynthesis is diminished in plants when the leaf pH was low [55]. Plants with low pH are more prone to air contamination, while those with pH around 7 are more tolerant [100]. In vicinity of acidic pollutants, the leaf pH is brought down and decrease extraordinarily in sensitive species [75]. Consequently, the larger amount of leaf pH offers resistance to the species against contamination. [91] have reported that in the presence of acidic pollutant, the leaf pH is brought down and the decline is more prominent in sensitive species. A movement in cell sap pH towards the acidic side in vicinity of an acidic pollutant may diminish the productivity of transformation of hexose sugar to ascorbic acid. The relationship between visible injury and hidden injury using few biochemical parameters, results showed that pH of the leaf wash and cell sap increased with increase in distance from pollution sources, pH of the leaf wash and cell sap gets reduced due to the presence of pollutants, which are acidic in nature, while total phenol content increases as a result of air pollution impact [76].

8. Effect of Air Pollution Total Phenol

Air pollution induces qualitative and quantitative changes in secondary metabolite composition [39, 56]. Phenol acts as a free radical scavenger to protect plants away from damage by oxidative stress. The role of phenol in the resistance mechanism of plants against air pollution was reported by [15]. In the study, total phenols in the leaves of plants growing in the polluted site were higher compared to the control. Increase of the phenolic compound level has also been observed after the exposure of plants to several toxic pollutants [83]. Air pollution influences the accumulation of phenolic content in the leaves [72, 76]. [61] reported that Changes in concentrations of total flavonoids and phenolics in *Catharanthus roseus* L." and "*Ocimum sanctum* L. may serve as biomarkers of urban auto pollution as both the parameters showed a positive relationship with the vehicular pollution load across the different sites. [83] have also reported significant increase in total phenol contents in wheat under air pollution stress. This is without cost, so being exposed to pollutants suffers from the damage caused by air pollution. Consequently, they develop leaf injury symptoms specific to particular air pollutant or mixture and alter their metabolism and leaf architecture to acclimatize to new environment. However, despite these changes, plants survive well at the polluted environment sites [108].

9. Air Pollution Tolerance Index

Air pollution tolerant index expresses the capacity of a plant to battle against air contamination. The Air pollution tolerance index of species is given as [A(T+P)]+ R/10, where A is the Ascorbic acid content of the leaf in mg/g^{-1}, T is the aggregate chlorophyll of leaf in mg/g-1, P is the leaf extricate pH, and R is the percent relative water content of leaf tissue. The aggregate whole is separated by 10 to acquire a reasonable figure. Plants which have higher index value are tolerant to air contamination and can be brought about as sink to alleviate contamination, while plants with with low index value show less resistance and can be utilized to demonstrate be levels of air pollution (Singh and Rao, 1983). Consequently, on the premise of their indices, diverse plants may be classified into tolerant, moderately tolerant, intermediate and sensitive plants [16, 94]. The identification and categorization of plants into sensitive and tolerant groups is is fundamental in light of the fact that sensitive plants serve as markers and tolerant ones as sinks for the decrease of air contamination in urban and industrial spaces [99]. In this APTI detailing, the physiological whole A (T+P) + R, the expansion of aggregate chlorophyll and leaf pH values (T+P) was incorporated as they are firmly connected with one another and a plant needs to keep up their level to endure contamination stress. The degradation of chlorophyll in the plants under air pollution stress is straightforwardly identified with the cell pH under two regimes below and above 3.5 [85, 116]. The multiplication of ascorbic acid with (T+P) measures the plant detoxification capacity. A relationship between's ascorbic acid with chlorophyll is known. At more than pH 3.5, Superoxide radicals are dismutated into Hydrogen peroxide (H_2O_2) by Superoxide dismutase (SOD). Ascorbic acid plays important roles in the protection of chlorophyll from H_2O_2 induced damage. In this manner large amounts of ascorbic acid are required by the plant to gain imperviousness to contamination. As chlorophyll combination is encouraged by ascorbic acid, a lessening in ascorbic acid may hamper the chlorophyll union in green parts of the plant (Agrawal et al, 1991). Since decreasing force of ascorbic acid shields the chloroplast from contaminations in pH subordinate way, the presentation of ascorbic acid (AA) as a multiplicant in the formular A(T+P) speaks to the limit of chloroplast in moderation of pollutants after their entrance inside the plant cells. The acquaintance of relative water content with A (T+P) demonstrates the capability of cell membrane in maintenance of cell integrity under polluted conditions. In the interim, T, the TCh is additionally identified with AA efficiency and AA is packed chiefly in chloroplasts. Photosynthetic proficiency was noted emphatically reliant on leaf pH. Photosynthesis decreased in plants when the leaf pH was low. Consequently, in the proposed APTI recipe, P, the leaf extract pH and T, the TCh have been added together and then multiplied with AA content.

Numerous authors like [17, 99, 1] utilized Ascorbic acid content, chlorophyll, relative water substance and leaf extract pH to assess the weakness of a few plants to air contaminations by registering these four physiological parameters together in an arrangement implying their air pollution tolerance index (APTI). Similar study of air pollution tolerance index was also conducted by [41, 105, 2] reported that the plants show alteration in the biochemical processes or accumulation of certain metabolites by the effect of certain pollutants. The air pollution tolerance indices (APTI) of ten frequently grown plant species around Industrial area showed that *Pongamia glabra* (6.49%) had the higher APTI value which reflects the higher tolerance level in air pollution. Similarly *Terminalia cattapa* (2.1%) showed lower APTI value which is a reflection of its sensitive nature against air pollution [51].

[70] exhibited different pollution tolerance capacities of plant species attributed the APTI values to differential response from plants to four physiological variables to be specific: Ascorbic acid, total chlorophyll, leaf extract pH and relative water content as influenced by air pollution. The author reported that *Delonix regia* as the most tolerant plant, *B. Spectabilis, D.erecta* and *A. occidentalis* as modestly tolerant plants in the study area. An evaluation of air pollution tolerance index [APTI] of *Polyalthia longifolia*, (Sonner) Thw , *Alstonia scholaris*, R. Br., and *Mangifera indica*, L.,during different seasons in the roadside areas studied revealed *Polyalthia longifolia*, (Sonner) Thw. to be a tolerant variety and the others as sensitive species to air pollutants [35].

[103] studied the susceptibility levels of different plants on the basis of their Air Pollution Tolerance Indices. Results revealed *Ficus glomerata* to be tolerant and *Acacia nilotica* to be sensitive species. The evaluation of the resistivity and susceptibility level of tree species to air pollution on the basis of Air Pollution Tolerance Index (APTI) value showed that *Polyalthia longifolia, Albizia saman, Azadiracta indica, Pongamia pinnata, Swietenia mahogany, Michelia champaca, Millingtonia hortensis* and *Tamarindus indica* are tolerant to air pollutants and can be used as an effectively indicators and pollution scavengers.

A study of Air Pollution Tolerance Index (APTI) on plant species growing at the cross-roads of Ahmedabad city showed order of tolerance as follows *Ficus benghalensis* ≥ *Ficus religiosa* ≥ *Ficus glomerata* ≥ *Azadiracta indica* ≥ *Polyalthia longifolia* [16]. [71] assessment of air quality usingair pollution tolerance index approach in polluted sites concluded that species like , *Mangifera indica, Tamarindus indica Litchi chinensis Artocarpus heterophylls and Delonix regia* can be potentially used for biomonitoring of air quality in polluted areas.

[2] examined the air pollution tolerance indices (APTI) of plant species around three industrial areas The result shows that the most tolerant tree species in the industrial areas with respect to APTI were *Ficus religiosa*, *Azadirachta indica* and *Pongamia pinnata* (L.*)* industrial area and minimum in Electronic city. [44] opined that changes in air pollution tolerance index are biochemically induced from ambient environmental condition and reported *Albizia amara* to be an intermediately tolerant species. [66] evaluate air pollution tolerance index (APTI) of five different plant species around City area and Navsari Agricultural University campus (Control). Among the trees in the selected area *Cassia fistula* depicted the highest APTI value as compared to other species followed by *Saraca asoca* and *Sizygium cumini* and proved to be tolerant variety in the city area as per the APTI value. However, *Tectona grandis* and *Terminalia catapa* found to be intermediate sensitivity for the polluted site (City area).

[43] initiated the identification of tolerant as well as sensitive herbal tree and plant species available in the campus of Periyar University. In the study, 30 herbal trees and 30 herbal plant species were selected for the evaluation of Air pollution tolerance index (APTI). The author concluded that since, biomonitoring of plants is an important tool to evaluate the impact of air pollution on plants, the tree species such as *Empilica offficinalis*, *Callistemon citrinus, Pithecellobium dulce*, and plant species such as *Withonia somnifera*, *Chrysanthemum coronariums*, and *Mirabilis jalaba* can be used as biomonitors of vehicular pollution stress. [7] evaluated pollution tolerance indices of plant species growing within the locality of contaminated and controlled sites. All the plants were found to be sensitive to pollution. The APTI values were within the range of 7.38 to 10.12 within the contaminated site and 6.44 to 9.6 in control site. as compared between the 2 sites; though no vital distinction between APTI values was found, all the values were slightly higher within the polluted site than the controlled for all the six plants except in *Leucaeana leucocephala* and a substantial variation was determined among the four parameters when their percentage variations were considered. *Aegle marmelos*, *Senna sp.* and *Vine spectabilis* were found to be tolerant towards pollution.

10. Enzymatic Responses of Plant Species to Air Pollution

Urban air pollution is a problem in developing and developed countries [53]. There is steady extension of toxic gasses and other substances arising from rapid growth of industries and automobile vehicles [33]. Air pollutants can enter into plant tissues via stomata and increase the level of reactive oxygen species (ROS) causing serious damage to the DNA, proteins and lipids ([94, 29]. The plant cells have several antioxidative defence mechanisms to protect plants against these oxidative stressors [38, 77, 79, 69, 89, 20]. These defence mechanisms include both enzymatic (e.g. superoxide dismutase, catalase, peroxidase and ascorbate peroxidase, glutathione reductase) and non enzymatic metabolites (e.g. tocopherol, carotenoids, glutathione and ascorbate).

An increase in SOD and POD activities gave rise to tolerance in plants exposed to SO_2, NO_2, and O_3 either as single or combined pollutants has shown that SOD and CAT/POD enzyme system serve as an interlinked primary protection in reducing the potential for cellular injury [86, 14]. The reduction in cellular damage mediated by oxyradicals in plants with SOD has been reported by [17]. It has been reported that CAT activity increased in plants exposed to polluted areas [112, 59]. A study in the changes in antioxidant enzyme activities of wild plant species in polluted areas revealed that CAT activity was found to be low in 9 of the 12 species growing in 0-100m sample area [64]. Studies on activity of Catalase enzyme in some *Ficus species* have shown that Catalase activity was less in the leaves of plant growing in polluted area compared to those growing in low polluted area [14].

The level of peroxidase enzymes is universally accepted as an indicator parameter to environmental pollution [40].

[115] studies on effect of air pollutants in biochemical parameters of selected plant species revealed an increase in POD activity at commercial and heavy traffic street location comparison to residential locations. The activity of peroxidase enzymes was investigated in Populus plants exposed to ozone air pollutant and the higher activity of peroxidase enzymes was reported due to ozone exposure [12]. The increase in peroxidas activity varies with the plant species and the concentration of pollutants. [42] reported that leaves of the resistant plants might have high peroxidase activity. Leaves of the trees characterized by considerable resistance to the action of SO_2 may have a high peroxidise activity [42]. Peroxidase activity in plants has been shown to be a sensitive indicator of pollutant exposure [53, 90] and suggested as a marker to evaluate air pollution [81, 37]. The Peroxidase activity of 6 plants growing within 0-100m in a polluted area was high, while 4 plants were low compared to the control (Mutiu *et al*., 2009).

Superoxide dismutase activity in 5 plants species within 100m in polluted area was high, while it was low in other species [64]. Increased Superoxide dismutase activity from pollutants exposure was found in Snap bean [52], Pine and Spruce [100] and Sugar beet [21]. However, some studies reported no change in SOD activity in plants [65].

[64] studied the changes in antioxidant enzyme activities of wild plant species in polluted areas. Catalase (CAT) activity was found to be low in 9 of the 12 species growing in the polluted area, compared to the control plants areas. CAT detoxifies H_2O_2 by breaking it down directly to form water and oxygen. If CAT activity is reduced, H_2O_2 which is toxic to living cells can accumulate in cell compartments. Nevertheless, it was determined that CAT is less efficient than POX in scavenging H_2O_2 because of its low substrate affinity [97].

The main response to pollutants is provided by an increase in SOD and POX activities as long as the stress level does not exceed the plant's defensive capacity [97]. POX activity in plants has been shown to be a sensitive indicator of pollutant exposure [53, 90], and suggested as a marker to evaluate air pollution [81, 107]. Peroxidase enzyme belongs to the class of oxidoreductase, which occurs in a wide variety of trees and shrubs and has been extensively studies in attempts to develop a method for early identification of chronic injury from air pollution. [112, 59] reported that catalase activity increased in plants exposed to polluted areas or substrates.

11. Anticipated Performance Index (API) of Trees

The Air Pollution Tolerance Index shows the effect of the pollutants only on the biochemical parameters. In order to combat air pollution by planning the green belt development in a particular area, many socio-economic factors are to be considered. Thus, the Anticipated Performance Index has been used to determine the same [27]. This is a grading system where a tree species is graded based on APTI along with socio-economic parameters. Based on the grading system, a tree gets a maximum of 16 points, which are scaled to percentages and based on the score obtained; the category will be determined [18]. Several studies have been carried out to estimate the anticipated performance Index of tree species. [62] estimated the anticipated performance Index of select urban trees, results indicated that in terms of API, *M. indica*, comes under good category. *F. religiosa, S. siamea, E.microtheca, A. auriculiformis, S. cumini* scored good, thus *M.indica* was highly recommended for planting in terms of mitigating air pollution as well as an urban tree. Research on Anticipated Performance Index of certain tree species in India showed that, *Mangifera indica* and *Ficus religiosa* with the highest scoring was assessed good for heavy traffic areas or planting along roadsides [102].

[63] study, revealed that evaluation of Anticipated Performance Index of plants is useful in the selection of appropriate tree species for urban green belts development. The study indicated that *Ficus benghalensis, Mangifera indica, Swetenia mahoganii* and *Saraca indica* are the most tolerant plant to grow in industrial areas.The results on

Anticipated Performance Index value of selected tree species studies carried out by [106] revealed that *Spathodea campanulata* and *Enterolobium saman* were judged to be good performers, while *Muntingia calabura* qualified for the moderate performer category *Peltophorum pterocarpum* was found to unsuitable as a pollution sink because of its lower anticipated performance.

[82] assessment of different plants based on their API values reveals that *Artocarpus heterophyllus* is most tolerant and can be expected to perform well as it falls under the category of very good performer and its plantation in urban as well as peri-urban areas are recommended. *Psidium guajava* and *Hibiscus rosa sinensis* were moderately suitable for plantation in Green Belt and their plantation in town squares and on the outskirts of villages and towns may considerably reduce air pollution. In the remaining plant species, one was identified as poor performer and one was coming under very poor category. Study on air pollution biomonitoring in an urban area of Varanasi by [73] recommended *Ficus infectoria* as the best performers while *Mangifera indica* and *Ficus religiosa* were classified into the excellent performer category. [19] study indicates tree species (*Eucalypytus oblique*) and shrub species (*Bougainvillea glabra*) are accepted to perform well for the development of “Green belt” in campus area of university, Rohtak, Haryana. The study also reveals that evaluation of anticipated performance index (API) of plant species is useful in the selection of suitable plant species for urban green belt development.

12. Conclusions

Air pollution tolerance Index and Anticipated Performance Index have demonstrated that plants in locality can be utilized to choose most appropriate plants for the advancement of woodlands. It is noteworthy that alot of studies have been done on these themes in Asian continent; such cannot be said in other climes. It therefore behooves on researchers to carry more studies in order to distinguish plants that can be utilized for air pollution alleviation in the area. The importance of urban trees cannot be over emphasized as studies have revealed their ability to cleanse the atmosphere. It therefore becomes imperative that Researchers, Urban Planners as well as aboriculturists should cross fertilize ideas as it relates pollution scavenging and urban greening, thus the fundamental information of essential learning of natural and human environment is vital. It can be deduced from this review that biomonitoring of air pollutants will complement instrumental air quality monitoring; consequently the planting of pollution remediation species at strategic location can indicate the air pollution health of the area. Research emphasizes should incorporate combination of plant responses to stresses caused by air pollutants in field conditions.

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