REVIEW ARTICLE

Air Pollution: Sources and its Effects on Humans and Plants

Aditya Abha Singh[1*#], Rana Eram[1], Madhoolika Agrawal[2], Shashi Bhushan Agrawal[2]

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ABSTRACT

Pollution of air is among the serious issue that the world is confronting today in developed and developing countries. An escalating number of automobiles and industries incessantly add toxic gases like SO_2, NO_x, and particulate matter into the atmosphere. Simultaneously, secondary pollutant tropospheric O_3 formed by the reactions of primary pollutant is equally hazardous. Suspension of these contaminants in air leads to damaging effects on human health and plant productivity and results in the degradation of ecosystems and biodiversity. Human health issues associated with pollutants in air include cardiovascular and respiratory diseases, nervous and reproductive system disorders, lowered life expectancy, and mutations. Moreover, air pollutants negatively affect different morphological and physiological characteristics of the plants. Air pollutants generate reactive oxygen species that negatively affect various physiological pathways in the plants inducing their anti-oxidative defense system to counteract oxidative stress. Air pollutants are also accountable for injury to vegetation and losses in crop productivity which is an increased cause of concern. Hence considering the air pollution menace, effective regulations, policies, and strategies should be developed for good human health, agricultural production, and food security.

Keywords: Air pollution; Human health; Oxides of nitrogen; Ozone; Particulate matter; Plant productivity; Sulphur dioxide.

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INTRODUCTION

Pollution of environment is a crucial difficulty the world faces today, be it air, water, noise, or soil pollution. Among these, one of the most critical environmental problems is the alarming upsurge in air pollutant concentrations. Prevalent contaminants in air include nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and particulate matter (PM) of an aerodynamic diameter of fewer than 10 μm and 2.5 μm known respectively as PM_{10} and $PM_{2.5}$, (Nowak *et al*., 2018; Wang *et al*., 2021). The presence of NO_2 and SO_2 in troposphere results in acid rain, haze, and photochemical smog in urban areas (Shon *et al*., 2011). The primary gaseous contaminant sources are industrial emissions, automobile exhausts, agriculture waste burning, oil refineries, brick kilns, etc. While the origins of indoor air pollution are wood-burning, tobacco products, household combustion products from kerosene, oil, gas, building material, carpet fibers, asbestos, pesticides, and aerosols from self-care commodities (Sharma *et al*., 2019). Ozone in troposphere is a secondary pollutant being not discharged into the atmosphere directly; but is produced in the presence of sunlight by the interaction between volatile organic compounds (VOCs), oxides of nitrogen, and carbon monoxide (Sampedro *et al*., 2020).

Air pollution has become an issue in modern metropolitan areas (Leung, 2015). Similar is the situation in megacities of developing countries, where the air quality is continually deteriorating with a steady increase in the human population (Agrawal, 2005). Approximately 80% of urban residents live in air pollution concentrations surpassing the World Health Organization (WHO) limits (Blaszczyk *et al*., 2017). Health effects due to chronic air pollution results in impacts on pulmonary, cardiac, vascular systems, stimulating inflammation, causing respiratory ailments, and speeding up atherosclerosis (Pope *et al*., 2002; Vaseashta *et al*., 2007). WHO approximations convey that annually 2.4 million individuals die due to the detrimental effects on health due to the air pollution (Sierra-vargas and Teran, 2012). Furthermore, toxic contaminants from the air ecosystems burden wildlife, and animals exposed to excessive pollutant load develop health problems. Moreover, there have also been reports of reproductive failure and congenital disabilities in them (Manisalidis *et al*., 2020).

Sometimes critical pollution levels can drastically alter the organization and functions of an ecosystem, resulting in the formation of industrial barren lands, which are the desolate open areas that develop in vicinity to the point industrial pollution sources as a result of airborne pollutants deposition, with very few regions of vegetative cover surrounded by bare land (Zvereva *et al*., 2008; Kozlov and Zvereva, 2007). Current tends of O_3 concentration have impacts on different ecological services and related processes that are interlinked in nature (Ghosh *et al*., 2021). Air pollution negatively affects the vegetative and reproductive parts of the plants. Crop production strongly relies on environmental factors, with air quality being one of them (Agrawal *et al*., 2006). Decrease in chlorophyll, nitrogen content, leaf area, and biomass have typically been detected for the crop species thriving in the polluted regions (Agrawal,

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[1]University Department of Botany, Babasaheb Bhimrao Ambedkar Bihar University, Muzaffarpur-842001, India

[2]Department of Botany, Institute of Science, Banaras Hindu University, Varanasi-221005, India

#Present Address: Department of Botany, University of Lucknow, Lucknow-226007, India

***Corresponding author:** Aditya Abha Singh, University Department of Botany, Babasaheb Bhimrao Ambedkar Bihar University, Muzaffarpur-842001, India. Email: abha2512.singh@gmail.com

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2005). Crops are most sensitive to gaseous and particulate air pollutants, and susceptible species can be utilized as air pollution indicators (Petkovsek *et al*., 2008; Joshi *et al*., 2009). In sensitive plant species pollutants can induce early senescence, leaf injury, reduced photosynthetic activity, stomatal damage, altered membrane permeability, and reduced development and productivity (Tiwari *et al*., 2006). Considering this aspect, this review attempts to highlight the sources of different air pollutants and their effects on humans and plants.

SOURCES OF AIR POLLUTION

Air pollution chiefly has two predominant origin being natural and anthropogenic sources. Natural sources include biological contaminants like fungal spores, cysts, bacteria, dust, electric storms, and solar flares, gases from volcanic eruptions, forest fires, salt spray from oceans, and dust storms. While the anthropogenic sources include emissions from industries, automobiles, agricultural activities, warfares, deforestation, etc. (Lewis, 1991; Middleton, 1995; Gheorghe and Ion, 2011). The pollution may be indoor or outdoor. The deterioration of indoor air by deleterious gases, toxic chemicals, and other substances like building materials is called indoor air pollution (Kankaria *et al*., 2014). Outdoor pollution is the pollutants emitted in the outside environment (outside of a closed building or space) predominantly from vehicles, power plants, industrial boilers, incinerators, ships or aircraft etc. (Leung, 2015). SO_2, O_3, NO_x, and PM are common indoor and outdoor air pollutants (Leung, 2015). Compared to the outdoor concentration of air pollutants, one may expect that indoor concentrations of air pollutants are lower than outdoor pollution. Owing to the closed environment of buildings that protects outdoor sources of air pollution like the traffic and the industrial emissions (Chen and Zhao, 2011); people usually spend 90% of the time in an indoor area like houses, offices, schools, work, restaurant, etc. (Klepeis, 2001; Schweizer *et al*., 2007), and thus they are exposed to indoor air pollution to a greater extent of time. In addition to the infiltration of few outdoor air pollutants, various household activities, like smoking, cooking and cleaning, contribute to the indoor pollution. The indoor air quality can be ten times more harmful than the air outside (Kankaria *et al*., 2014). The indoor air pollutant includes building materials, home products, VOCs, and naturally occurring gases (WHO, 2016). Building materials such as hardwood, plywood, brick paints and varnishes, etc., can influence indoor air quality and contribute to VOCs emission like formaldehyde. Radon can also be sometimes released from building materials such as tiles, concrete and bricks, which are obtained from the soil having the radium and is responsible for many mortalities per year due to lung cancer (Rivas *et al*., 2019). Moreover, the pollutants emitted by the incomplete combustion of solid fuels or kerosene are the most dangerous (Kankaria *et al*., 2014). In the year 2016, according to WHO, household air pollution resulted in approximately 3.8 million mortality which is 7.7% of worldwide deaths (WHO, 2016). On the contrary, outdoor air pollution is responsible for roughly 4.2 million deaths per year worldwide. Large-scale human activities like industrial set-up, power plants, automobiles, and agriculture wastes emit massive amount of environmental contaminants. Since these activities are performed on such an enormous scale, they significantly contribute to air pollution, with automobiles accounting for more than 80% of the existing pollution (Moller *et al*., 1994). While other anthropogenic activities, like fuel tank heaters, petrol stations, field cultivation techniques, and cleansing methods, as well as natural occurrences like soil emissions, volcanic eruptions, and forest fires, have a slight influence on the environment (Jacobson and Jacobson, 2002; Manisalidis *et al*., 2020). The sources of major contaminating gases and particulate matter contributing to environmental pollution are mentioned below:

Oxides of Nitrogen

Predominantly nitrogen dioxide (NO_2) and nitric oxides (NO) are the gases that are typically denoted as NO_x due to their inter convertibility in which NO is quickly oxidized to NO_2 in the atmosphere and are the chief component of photochemical smog (Carlisle *et al*., 2001). Anthropogenic emissions like car exhaust, transportation, emissions from aircraft, commercial manufacturing, industrial fossil fuel burning such as oil, coal, and natural gas, power production, biomass burning, and natural sources such as lightning and nitrate breakdown in soils generate NO_2 (Ghude *et al*., 2014; Vinken *et al*., 2014; Wang *et al*., 2021). Among these, the combustion of fossil fuels in automobiles and biomass burning are the major sources of NO_x emission into the atmosphere. It represents 75% of the total emission, with more than 50% contributed by fossil fuels combustion in automobiles, which are chiefly anthropogenic (Delmas *et al*., 1997). Thus the increase in vehicle number due to urbanization is also an important factor contributing to the increase in NO_x emission (Lyu *et al*., 2016; Van Der *et al*., 2017). Automobile pollution has a chronic impact on plants, affecting the temperature, carbon dioxide concentration, light intensity, and precipitation. Natural sources of NO_x are wildfires, lightning events and fertilized soils, the agricultural areas also contribute significant amounts of NO_x. The NO_2 is released by a high-temperature oxidation reaction in which diatomic nitrogen (N_2) breaks and undergoes subsequent oxidation resulting in the formation of NO_2 (Jyethi, 2016). Nitrogen dioxide (NO_2), a pollutant produced by high-temperature combustion processes, has been extensively investigated as an indoor air contaminant. Unflued gas/fossil fuel cooking, tobacco smoking, home heating, are the primary sources of NO_2 indoors. When domestic gas is deployed for heating and cooking, NO_2 levels in the inside environment are significantly greater than outdoor levels (Brunekreef, 2001; Pilotto *et al*., 2004; Gillespie-Bennett *et al*., 2008). Nitrogen oxides play a significant role in forming secondary pollutants like nitric acid, O_3, and peroxyacetyl nitrate (PAN). Nitrogen-fixing plants as well as the increased use of agricultural fertilizers, also contribute to the atmospheric NO_x. Moreover, the NO_2 level is likely to rise continuously, and NO_2 concentration will consistently surpass the set NO_2 pollution standard because of the progression of industrial production and the continuing enhancement in automotive exhaust discharges (Hultengren *et al*., 2004; Sheng and Zhu, 2019).

Sulphur Dioxide

Sulphur dioxide is emitted from anthropogenic as well as natural sources. Volcanic eruption and wildfires are the natural sources of SO_2 emission that adds considerable amounts of SO_x (group of compounds containing sulphur and oxygen molecules are known as oxides of sulphur and is represented by SO_x, and SO_2 is predominant among them) into the atmosphere (Vestreng *et al.*, 2007; Jyethi, 2016). The atmospheric oxidation of sulphur emitted from the anaerobic degradation of organic matters in terrestrial environments and the ocean due to microbial activities are the natural sources of SO_2 emission (Foy *et al.*, 2009; Kitayama *et al.*, 2010). Sources of anthropogenic SO_2 discharge in the environment include sulphur containing fossil fuels combustion like coal used in the thermal power plants, petroleum refineries, and smelting of sulphide-containing metallic ores (Vestreng *et al.*, 2007; Jyethi, 2016; Zhang *et al.*, 2017). Sulphur-containing pollutants are also emitted into the air by the domestic use of coal. Industrialization and large populations of cities in Europe at the turn of the twentieth century caused significant concentrations of SO_2 and NO_2, resulting in typically poor urban air quality (Stevens *et al.*, 2020). SO_2 emissions are prevalent in areas with high population density and industrial activity. After being released into the environment, SO_2 is oxidized to sulphate aerosol (Seinfeld and Pandis, 2016). This, along with other chemicals, scatters the visible light and causes haze formation and cooling of the globe (Wuebbles and Jain, 2001).

Ozone

Ozone in the troposphere is a powerful oxidant and a chief contributor to photochemical smog. It is a secondary pollutant that is created under favourable conditions involving the photochemical reactions between primary pollutants like VOCs and NO_x in the presence of sunlight. Moreover, the availability of O_3 precursors and suitable microclimatic conditions are chiefly responsible for the O_3 formation (Singh and Agrawal, 2017). Ozone is a strong oxidant and a primary component of smog (Ghosh *et al.*, 2018). The rate of O_3 formation varies depending on the presence of organic compounds, NO_2 mixing ratios, and traffic-emitted VOCs. Methane has been found to substantially contribute to tropospheric O_3 production in remote areas (Monks *et al.*, 2015; Stevens *et al.*, 2020). Microclimatic factors, for instance, higher temperatures, enhance the development of photochemical smog and O_3 (Sierra-vargas and Teran, 2012). Various studies have found that the mean concentration of O_3 in several areas has escalated, specifically the tropical countries (Singh and Agrawal, 2017; Ghosh *et al.*, 2018), and these changes are chiefly attributed to the human emitted O_3 precursors and changes in climatic pattern (Oltmans *et al.* 2006). O_3 typically displays a diurnal bell-shaped configuration in tropical regions, manifesting its peak concentration during noon and early afternoon hours and steadily declining during the late afternoon and evening (Lorenzini and Saitanis, 2003). Levels of NO_x in the environment play critical roles in tropospheric O_3 formation; like one ppb of NO_2 generates five to seven ppb of O_3 (Lippmann, 1992). Ozone in the troposphere may also be present due to intrusion of stratospheric O_3, but its proportion is far less compared to the O_3 formation due to photochemical reactions (Singh and Agrawal, 2017). The pollutant can adversely affect human health and plants as well (Agathokleous and Saitanis 2020).

Particulate Matter

Particulate matters are very small complex mixture of liquid droplets and solid particles suspended in air and are made up of several components like sulphates, nitrates, metals, organic chemicals, soils, or dust particles (Sierra-vargas and Teran, 2012; Tao *et al.*, 2013) and allergens which may be the fragments of spores or pollen (Gozzi *et al.*, 2017). Depending on the size, particulate matters are categorized into two types; one is fine particulate having a diameter of 2.5 µm or smaller, known as $PM_{2.5,}$ while the coarse particulates are having a diameter of 10µm or smaller and are known as PM_{10} (Jyethi, 2016; Gozzi *et al.*, 2017). The PM_{10} particles are mechanically generated while the $PM_{2.5}$ is emitted directly from the source or created in the atmosphere by some reaction like gas to particle conversion (Jyethi, 2016). There are primary and secondary particles depending on their origin; the primary particles are released straight away into the environment from various sources like combustion, wind-blown particles, or emissions (Giere and Vaughan, 2013; Engelbrecht and Derbyshire, 2010), while the secondary particles are produced as a result of chemical reactions (Giere and Vaughan, 2013; Engelbrecht and Derbyshire, 2010) like oxidation of VOCs to form a secondary organic aerosol, the oxidation of NO_x and SO_2 to acids. Some secondary particles are gypsum, ammonium sulphate, nitrates, chloride salts, etc. (Gozzi *et al.*, 2017). Particulate matter chiefly arises from anthropogenic actions such as gasoline, diesel, coal, and wood burning, motor vehicles, industries (Smith *et al.*, 2013), construction, and mining (Sierra-vargas and Teran, 2012; Smith *et al.*, 2013; Gautam *et al.*, 2015; Patra *et al.*, 2016; Gautam *et al.*, 2016). The cars, tractors, and coal-fired power plants are responsible for PM emissions in metropolitan cities (Sierra-vargas and Teran, 2012). They are also produced from cement kilns, lime and gypsum, sodium sulphates, magnesium oxide, calcium chlorides, potassium and sodium, soot, pesticides, insecticides, and herbicides (Gheorghe and Ion, 2011). The natural sources of particulate matter pollution are volcanic emissions, wildfires, dust storms, biogenic and sea sprays (Pope *et al.*, 2004; Volkamer *et al.*, 2006; Fountoukis *et al.*, 2014; Al-Dabbous and Kumar, 2015). In urban settlements, traffic emission contributes to about 50% of particulate matter (Li *et al.*, 2017). Fine particles can be removed by washout from the rains, while the coarse particles are removed mostly by sedimentation (Tao *et al.*, 2013).

Air Pollution Effects on Human Health

Usually, majority of the pollutants present in the air have a direct influence on human health and wellbeing (Lu *et al.*, 2002). Long-term and short-term investigations have concluded that air pollution affects respiratory health, cardiac deaths and hospital admissions, daily mortality, and other morbidity markers (Brunekreef and Holgat, 2002). Conferring to a cohort study in Sweden, diabetes appears to be induced after chronically getting exposed to air pollution (Eze *et al.*, 2014). It also affects several systems and organs (Kampa and Castanas, 2008). On gaining entry into the human body system, NO forms nitrite, which results in the oxidation of iron present in the haemoglobin, thus dissipating its effectiveness of carrying the oxygen (Sloss, 1991); nitrite may also get combined with amines to generate cancer-producing compounds (Fisher, 1998). Apart from causing pneumonia and bronchitis, NO_x can reduce the immunity towards respiratory infections like influenza (Sloss, 1991). Nitrogen dioxide contributes to the aggravation of respiratory diseases by its capability to damage the functionality of epithelial cells or the alveolar macrophages, thus enhancing the possibilities of lung infection (Frampton *et al*., 1989). Nitrogen oxide concentration greater than 2.0 ppm affects the T-lymphocytes, chiefly the NK cells and CD8+ cells, which are responsible for our immune responses (Chen *et al*., 2007). Between 2002 to 2006 MEDLINE database reported adverse impacts of NO_2 on human health. Evidences manifest that the chronic exposure to an average annual concentration lower to 40 mg NO_2/m^3 adversely effects the human health in the form of otitis media, respiratory symptoms/diseases, hospital admissions, and mortality (Latza *et al*., 2009).

Upon experiencing increased levels of SO_2, individuals, particularly the asthmatic ones, complain of irritation in nose and throat leading to dyspnoea and/or bronchoconstriction (Balmes *et al*., 1987). Sulfur dioxide contributes to respiratory illness, mucus production, and bronchospasm in healthy patients having those with some underlying pulmonary disease condition (Chen *et al*., 2007). A healthy individual experiences bronchoconstriction at a concentration of 1.6 ppm SO_2, whereas a very few minutes of exposure to 8-12 ppm SO_2 level results in throat irritation. At 20 ppm concentration, immediate cough and eye irritation are caused, and SO_2 exposure of 400-500 ppm is dangerous for life (Khan and Siddiqui, 2014).

Ozone is a very reactive and oxidative gas that causes adverse impacts on human health, like morbidity and mortality (Soni *et al*., 2021). It is reported that human health is affected above an O_3 concentration of 50 ppb (WHO, 2006). Numerous investigations have indicated that exposure to O_3 causes adverse effects on the nervous, cardiovascular, respiratory, and reproductive systems and can ultimately cause mortality (Soni *et al*., 2021). Ozone effects include problems in breathing such as inflammations of the airways, reduced lung functions, chronic respiratory problems, asthma, bronchitis, and premature mortality (Levy *et al*., 2005; Yari, 2016). Moreover, O_3 causes shortness of breath, pain in chest with deep breathing, throat irritation, and sometimes nausea (Coss, 2000), reduced lung function, and irritation in the lung's linings (Ainsworth *et al*., 2012). Patients with a history of respiratory ailments are highly vulnerable to the O_3 influences. In healthy individuals, O_3 causes reductions in lung vital capacity and resistance. Ozone is a powerful antioxidant that causes alterations in the respiratory airways of humans subjected to the exposure time and concentration (Sierra-vargas and Teran, 2012). Repeated O_3 exposure may cause permanent scarring of lung tissue. Ozone can act as a potent mutagen and cause-specific base substitutions (Jorge *et al.,* 2002). Investigations reveal significant O_3 effects on the health of the global populations, and it has been assessed that in the US it causes approximately 5,000 deaths prematurely per year (Fann *et al*., 2012; IHME, 2018). In the European Union, around 21,400 premature deaths occur yearly due to O_3 exposure (EEA, 2007).

The effects of fine particles suspended in air on well-being of humans is an utmost concern globally (Pandey and Ghosh 2022). The fine particulates are most harmful as they penetrate deep into the lungs. PM gets deposited into the respiratory compartments' extrathoracic, tracheobronchial and alveolar regions parts (Sierra-vargas and Teran, 2012). According to WHO, approximately seven million people die annually from exposure to fine particulate matter in a polluted environment. Studies performed in the US have revealed that constant encounter with delicate particles in ambient air was linked with lowered life expectancy (Pope *et al*., 1995). When $PM_{2.5}$ and $PM_{2.5}$ SO_4^{2-} concentrations increase in environment, many people in the cities can become ill. This may be due to vicissitudes in heart rhythms, respiratory problems, heart attacks, lung cancer, and acute respiratory and heart malfunctions leading to mortality (Schwartz *et al*., 1996; Pope, 2000). Inhalation of a large quantity of PM can cause reproductive and central nervous system dysfunctions (Manisalidis *et al*., 2020). Particulate matter induces cytotoxicity by mutagenicity, oxidative damage to DNA, and induction of pro-inflammatory factors (Valavanidis *et al*., 2008). The health impacts of PM rest on numerous aspects, like composition and particulate size, the duration and level of exposure, sensitivity, age, and gender of the person (Sierra-vargas and Teran, 2012). Short term exposure to $PM_{2.5}$ can elicit mortality linked to cardiovascular diseases and non-fatal events. At the same time, long duration encounter for a few years can escalate the risk for cardiovascular deaths many folds higher than exposures over a few days hence decreasing the life expectancy (Brook *et al*., 2010).

EFFECTS OF AIR POLLUTION ON PLANTS

Plants being sessile organisms, are constantly exposed to the atmosphere, and since there is a continuous exchange of gases by the leaves, any alterations in the environment is mirrored as distressed plant physiology (Saxena and Kulshrestha, 2016). Gases like SO_2, NO_2, and O_3 have direct negative effects on vegetation as they gain entry into the leaves through the stomata and follow a similar diffusion pathway to that of CO_2 (Zeiger, 2006). The degree of impairment that air pollutants can result in plants relies on the foliar influx of pollutants and their reaction products with the cellular contents (Rai *et al*., 2011). Excessive excitation energy levels in chloroplasts are induced by high exposure of the plants to air pollution, which results in an increase in ROS production and oxidative stress. Pollutants promote peroxidative damage of cellular components by producing ROS in plants. Photosynthesis is inactivated when plants are subjected to levels of pollution that exceed the physiologically acceptable limits (Mulay and Kokate, 2019). Plants exposed to SO_2, or the combination of NO_2 and SO_2, often show variances in stomatal behavior being considerably reduced responsiveness towards ABA after exposure. The Stomatal index is one of the plant's excellent anatomical adaptations to air pollution. Because fewer stomata mean fewer gaseous pollutants absorbed from the air, a low stomata number has been thought to be a marker of plant adaptation to pollution in air (Ogunkunle *et al*., 2013; Al-Obaidy *et al*., 2019; Verma *et al*., 2006). Air pollution in urban locations affects wheat plants' total chlorophyll, ascorbic acid, and carotenoid content (Joshi *et al*., 2009; Rajput and Agrawal, 2005). A decrease in carotenoid concentration due to air pollution has been reported (Tripathi and Gautam, 2007; Joshi and Swami, 2009). Seyyednejad and Koochak (2011) found that the chlorophyll content of *E. camaldulensis* leaves increased in polluted sites compared to control sites. Tripathi and Gautam (2007) revealed that *Mangifera indica* leaves exposed to air pollutants showed enhancement in chlorophyll content. At the same time, total chlorophyll and

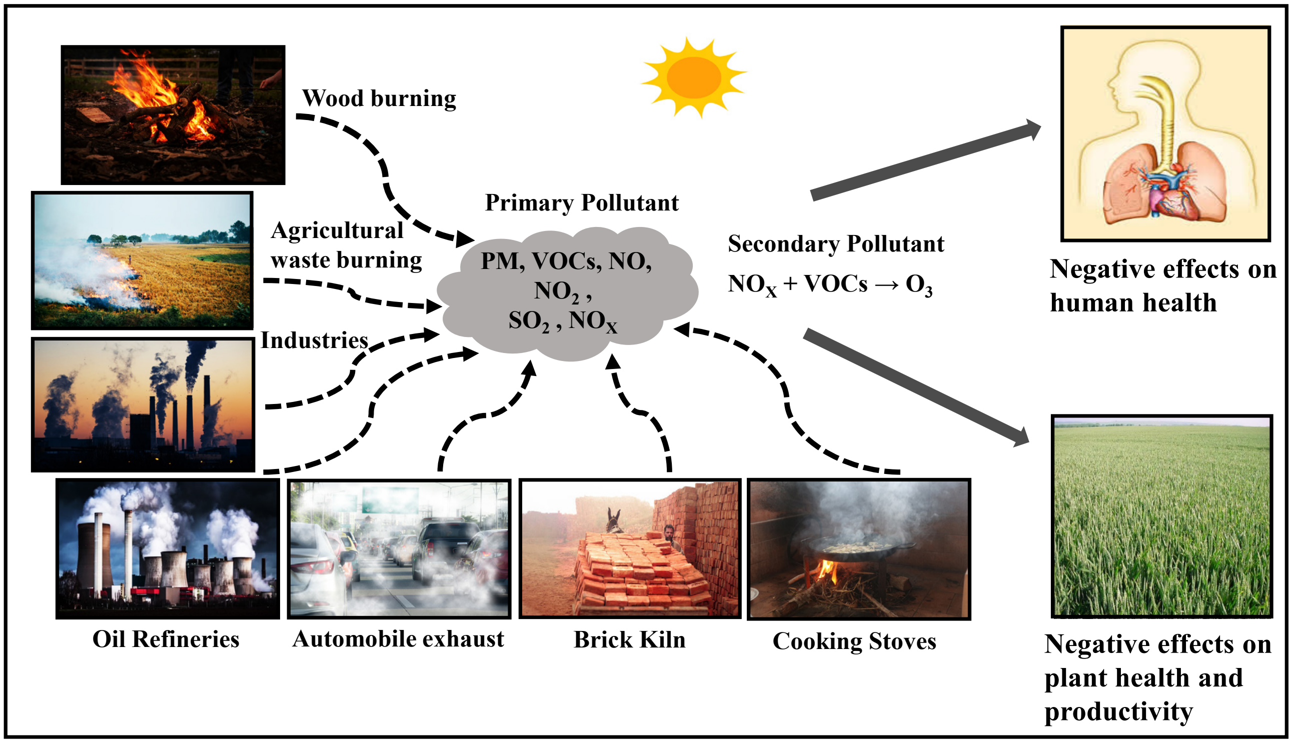

Fig. 1: The different sources of primary and secondary air pollutants and their negative effects on human health and plant productivity

the corresponding chlorophyll 'a' and 'b', concentrations of plants thriving in contaminated environments were lower (Raina and Sharma, 2003). During January, February, and March, the content of chlorophyll 'a' in wheat plants from polluted sites was 20.3, 12.2, and 15.2 percent lower, respectively, whereas the respective values of accessory pigment carotenoid were greater by 15.4, 14.8, and 16.6 percent respectively (Swami *et al.*, 2004). A significant drop in ascorbic acid, chlorophyll content, pH and carotenoid content in *Mallotus philippinensis* and *Shorea robusta* leaves was observed when stressed with roadside vehicular pollution (Swami *et al.*, 2004). With respect to the plants present at a control site, pollution-affected plants had reduced leaf area, carotenoids, chlorophylls, and soluble carbohydrate content. A decline in chlorophyll and carotenoids collectively can lead to reduced absorption capability of light-harvesting complex affecting plants' ability to dissipate surplus energy as heat under stress conditions (Ghosh *et al.*, 2020). Proline levels in leaves increased dramatically, indicating that protective mechanisms are activated in plants growing under air pollution load. These responses are considered adaptive and compensatory to the negative impacts of air pollution (Woo *et al.*, 2007; Tiwari *et al.*, 2006; Seyyednejad *et al.*, 2013). The effects of different pollutants in plants have been given below in detail.

NOx with Particular Reference to Nitrogen Dioxide

Nitrogen, a vital plant macronutrient is a crucial limiting element in plant development and growth. However, higher NO_2 exposure causes considerable variations in physiological responses and mineral ions, which have a considerable impact on plant growth (Chrysargyris *et al.*, 2016; Sheng and Zhu, 2019). Plants take up the NO_2 predominantly by foliar deposition through stomata. NO_x, when dissolved into the cells generate nitrate and nitrite ions which are toxic at high concentrations and may commence the hydrogen abstraction affecting the constituents of mesophyll cells, followed by the induction of free radical chain reactions (Sparks *et al.*, 2001). NO_2, when dissolves in cells, result in the formation of nitrite ions (NO_2^-, which are toxic at high concentrations) and nitrate ions (NO_3^-, which usually enter nitrogen metabolism) (Zeiger, 2006). Visible injury in angiosperms displays discolored grey-green or light brown spots which are inter-venial, often coalescing to form stripes, with marginal chlorosis of leaves (Rai *et al.*, 2011). High NO_2 concentrations in plants can also result in a reduction in total chlorophyll content (Xin *et al.*, 2007). In a field transect study in Haridwar, to evaluate the air pollutant stress on mustard and wheat, it was found that the site having a higher pollutant load having the concentrations of 6.5 ppb SO_2 and 9 ppb NO_2 displayed a maximum decline in growth, photosynthetic pigments, ascorbic acid content, and yield (Chauhan and Joshi, 2010). Furthermore, NO_2 promoted lipid peroxidation and protein disintegration, inducing POD activity and altering antioxidant content (Sheng and Zhu, 2019). Sugar acts as energy source that is manufactured by the process of photosynthesis (Bennett *et al.*, 1984), and due to air pollution, sugar accretion increases in various plant parts (Prado *et al.*, 2000) which plays a protective role against stress (Finkelstein and Gibson, 2002). However, soluble carbohydrates were highly declined in *Glycine max* leaves treated with various concentrations of the mixture of SO_2 and NO_2 (Hamid and Jawaid, 2009). It has been suggested that the decline in soluble sugars may be consequently due to the enhanced metabolic expenditure of energy under stress conditions (Bucker and Ballach, 1992). Exposure to oxides of nitrogen results in poor growth and loss of productivity (Rowland *et al.*, 1985). Furthermore, NO_x combined with other pollutants like SO_2 and/or O_3, can negatively affect the plant metabolism and productivity at concentrations that would not produce such effects if NO_x prevailed alone. Therefore, the effects of NO_x on plant development and productivity are significantly lower than the impact of NO_x in combination with SO_2 and O_3 (Amundson and Maclean, 1982).

Sulphur Dioxide

Lower concentrations of SO_2 stimulate the growth and physiological responses in plants, specifically those growing in sulphur-deficient soil (Darrall, 1989). However, the higher uptake of SO_2 due to higher SO_2 in the atmosphere has an adverse effect on plant metabolic processes, physiology, and morphology (Agrawal *et al.*, 2006). Furthermore, the SO_2 injury in plants has been known to be increased by high soil moisture content and relative humidity (Tankha and Gupta, 1992; Seyyednejad *et al.*, 2013). Acute injury to the leaves is due to the absorption of a high concentration of SO_2, even for a very short period. At higher concentrations, SO_2 is dissolved into cells and forms toxic bisulphite and sulphite ions. However, at a low concentration, it gets metabolized into sulphate (a non-toxic form) by the chloroplast (Kulshrestha and Saxena, 2016). The sulphite interaction with aldehydes and ketones of carbohydrates reduces carbohydrate content in an SO_2-exposed plant (Duccer and Ting, 1970; Saxena and Kulshrestha, 2016). Higher uptake of SO_2 is phytotoxic, which causes a decline in growth and productivity of the plants by distressing their different metabolic processes (Agrawal, 2003). Pollutants like SO_2 and NO_2 react with cellular water and form acid in the leaf matrix (Pierre and Queiroz, 1981). Shimazaki *et al.* (1980) demonstrated that SO_2 uptake of leaves causes the formation of O_2 molecules in chloroplasts, which damages chlorophylls. Sulphur dioxide induces visible damage to the leaves and degradation of photosynthetic pigments in natural vegetation and agricultural ecosystems plants (Agrawal and Agrawal, 1991). SO_2 damage occurs between veins in the form of bifacial lesions, which are more prominent towards the petiole. SO_2 also impacts the stomatal opening bringing about excessive water loss (Unsworth *et al.*, 1972). Moreover, plants show a reduction in photosynthesis while a rise in respiration rate due to exposure to SO_2 (Gheorghe and ion, 2011). Sulphur dioxide hinders different enzymatic activities and alters nutrient uptake, water relations, and metabolic functions (Li *et al.*, 2007). High concentration of SO_2 causes accumulation of sulfhydryl group, swelling of thylakoids, and disruption of the Electron Transport Chain. The direct interference of SO_2 with photosynthetic CO_2 fixation in photosynthesis has also been observed, including the competitive inhibition of ribulose bisphosphate carboxylase oxygenase (RuBisCO) enzyme by SO_3^{2-} ion (Agrawal and Deepak, 2003). Moreover, adverse effects with energy metabolism comprise the inhibition of mitochondrial ATP production by SO_3^{2-}. While indirect effects result from the formation of organic sulphonates and sulphites with other cell components, which causes inhibition of various metabolic enzyme systems (Malhotra and Hocking, 1976). Sulphur dioxide exposure reduced the starch content of *Phaseolus vulgaris* seedlings (Koziol and Jordan, 1978). Sulphur dioxide treatment of *Ulmus americana* seedlings resulted in a decrease in non-structural total carbohydrates (Saxena and Kulshrestha, 2016; Constantinidou and Kozlowski, 1979). ROS are produced under SO_2 exposure, which increases the activity of antioxidative enzymes like superoxide dismutase, peroxidase, etc., as well as defense molecules such as ascorbic acid (Pierre and Queiroz, 1981). In angiosperms, young seedlings and leaves are more sensitive to SO_2 pollution than the older ones (Mudd, 2012), while in conifers, needles are more sensitive to SO_2 (Gheorghe and Ion, 2011).

Thirty-days-old wheat cultivars Malviya 37, Malviya 206, Malviya 213, and Malviya 234 were examined in response to SO_2 under variable concentrations of nutrient mineral. Plants were treated with 0.15 ppm SO_2 for four hour per day and five days per week for two months resulting in a decline in biomass, pigment content, net photosynthetic rate, nitrogen, and grain yield of all the cultivars due to SO_2 at each nutrient concentration (Verma *et al.*, 2000). Black gram (*Phaseolus mungo* L.) plants treated with SO_2 dose ranging from 0 to 0.2 ppm displayed the visual symptoms as necrotic spots, chlorosis, and marginal burning of the leaves. Moreover, plant growth, photosynthetic pigments, and yield were suppressed significantly in all the treatments being directly proportional to the SO_2 exposure dose of the plants (Khan *et al.*, 2015).

Ozone

Monitoring data manifest that O_3 concentration is high enough to cause adverse effects on vegetation (Emberson *et al.*, 2001). Both cultivated crops and semi-natural vegetation display O_3 phytotoxicity. Ozone's potent oxidant actions are predominantly mediated by stomatal absorption, and the level of harm is proportionate to the dose absorbed. In plants, O_3 enters through the stomata during the photosynthetic gaseous exchange. Ozone phytotoxicity causes foliar injury and speeding up of leaf senescence (Singh *et al.*, 2014a), damaging effects on vegetative growth and reproductive processes/development of the plants (Agathokleous *et al.*, 2020; Leisner and Ainsworth, 2012). The underlying machinery displays that O_3 creates oxidative stress by the enhanced production of ROS, resulting in a chain of reactions (Foyer and Noctor, 2005). Under oxidative stress, ROS generation causes peroxidative damage of cellular lipids (Singh *et al.*, 2014b) or damage carbohydrates, proteins, and nucleic acids (Blokhina *et al.*, 2003). Therefore, to counter the oxidative stress, a group of antioxidant molecules and enzymes are induced (Ashmore, 2005; Nadgorska-Socha *et al.*, 2013). Various antioxidant enzymes (superoxide dismutase, catalase, glutathione reductase), peptides, and metabolites (ascorbic acid, proline, thiols, phenolic, and nitrogen compounds) are involved in defence reactions against ROS in plants and prevent the cellular damage caused due to oxidative stress (Gill and Tutega, 2010; Mittler, 2017). For the biochemical adjustments and the metabolic tunings to withstand the redox homeostasis, expression of genes related to enzymatic antioxidants, redox control or defense pathway, heat shock proteins, primary or secondary metabolic pathways, cell death, and senescence has been reported (Mittler, 2002; Pang and Wang, 2010).

Under long-term O_3 exposure, injury appears as tiny flecks, stipples, bronzing, or reddening on the interveinal areas of

Table 1: Effects of air pollutants on various morphological, physiological, and biochemical characteristics of the plants

S. No.	*Pollutant*	*Plant/Cultivar*	*Effect*	*References*
1.	Ambient air pollution [(CO), (SO_2), (NO_x) and (VOCs)]	*Ficus platyphylla, Mangifera indica, Polyalthia longifolia* and *Terminalia catappa*	Reductions in leaf total chlorophyll and leaf extract pH, ascorbic acid and relative water content increased	Uka *et al*., (2019)
2.	SO_2+NO_2	*Zea mays* cv. American Pioneer and Ganga	Total chlorophyll, fresh and dry weights of both the cultivars decreased	Katiyar and Dubey (2000)
3.	SO_2+NOx+ SPM+RSPM	*Triticum aestivum* (PBW-343), *Brassica campestris*	Reduction in total chlorophyll, carotenoids, ascorbic acid, plant height, shoot and root fresh weight and yield	Chauhan and Joshi (2010)
4.	SO_2+NOx+O_3	*Oryza sativa* cv. Saurabh 950 and NDR 97	Increased POD and SOD activities, total phenolics and ascorbic acid, decreased photosynthetic pigment, Ps and gs	Rai and Agrawal (2008)
5.	SO_2	*Gladiolus* (Manisha>Illusion>Aldebaran>Bright Eye> Manmohan)	Retarded growth, decreased plant height and biomass	Singh *et al*., (1990)
6.	SO_2	*Hordeum vulgare* cv. Igri	Increase in glutamate dehydrogenase and nitrite reductase enzymes during growing season	Borland and Lea (1991)
7.	SO_2	*Hordeum vulgare*: winter barley and *Triticum aestivum*: winter wheat	Decreased crop dry weight, leaf area and tiller density	McLeod *et al*., (1991)
8.	SO_2	*Solanum tuberosum* cv. Russet Burbank	Growth retardation including leaf, stem and tubers, leaf chlorophyll reduction	Qifu and Murray (1991)
9.	SO_2	*Glycine max* cv. Merrill	Reduction in Photosynthetic rate, root nodule nitrogenase activity	Sandhu *et al*., (1992)
10.	SO_2	*Triticum aestivum* cv. Malviya 206 and Malviya 234	Reductions in growth, biomass and yield	Agrawal and Verma (1997)
11.	SO_2	*Arabidopsis thaliana*	Increase in water soluble non-protein sulfhydryl content and a slight increase in the amount of glucosinolates	Van der Kooij *et al*., (1997)
12.	SO_2	*Triticum aestivum*	Reduced plant height, leaf area, biomass and yield	Deepak and Agrawal (1999)
13.	SO_2	*Quercus ilex* and *Pinus pinea*	Necrotic lesions	Hijano *et al*., (2005)
14.	SO_2	*Arabidopsis*	Increased ROS production	Li and Yi (2012)
15.	O_3	*Oryza sativa*	Reduced photosynthetic capacity and biomass	Maggs and Ashmore (1998)
16.	O_3	*Nicotiana tabacum* cultivar 'Bel-W3'	Foliar injury as necrosis on most of the oldest leaves	Esposito *et al*., (2009)
17.	O_3	*Zea mays* (cultivar HQPM1 and DHM117)	ROS and lipid peroxidation increased, secondary metabolites increased, induction of enzymatic antioxidants	Singh *et al*., (2014b)
18.	O_3	*Vigna radiata* (HUM-2 and HUM-6)	Foliar injury increased, photosynthetic rate, stomatal conductance, photosynthetic pigments, and photochemical efficiency reduced	Mishra and Agrawal (2015)
19.	O_3	*Oryza sativa* (Malviya Dhan 36 and Shivani)	Enzymatic antioxidant activity increased, ascorbic acid, thiols and phenolics increased, total soluble protein decreased	Sarkar *et al*., (2015)
20.	O_3	*Fraxinus chinensis*	Visible injury and reduced net photosynthesis	Li *et al*., (2016)
21.	O_3	*Prunus persica* (thirteen cultivars)	Increased lipid peroxidation, significantly accelerated leaf senescence, reduction in light-saturated photosynthetic rate and pigments, increased total antioxidant capacity and enzyme activity (SOD, APX and CAT)	Dai *et al*., (2017)
22.	O_3	*Viburnum lantana* L.	Foliar injury as reddish-brown to dark interveinal stippling	Gottardini *et al*., (2017)
23.	O_3	*Triticum aestivum* (fourteen cultivars)	Increase in ascorbic acid and thiol content in all the fourteen cultivars	Fatima *et al*., (2018)
24.	PM+O_3	*Triticum aestivum* (cultivar HD 2967)	Clogged stomata and enhanced leaf temperature, reduction in yield	Mina *et al*., (2021a)
25.	Ambient O_3+ PM	*Triticum aestivum* var. WR544	Ozone induced foliar injury, low yield	Mina *et al*., (2021b)
26.	PM	*Avicennia marina*	Lower photosystem II quantum yield, lower electron transport rate and reduced quantum efficiency of PSII.	Naidoo and Chirkoot, (2004)
27.	PM (Cement dust)	*Olea europaea*	Leaf total chlorophyll content decreased, reduced photosynthetic rate and quantum yield, reduced stomatal conductance to CO_2 and H_2O, decreased productivity	Nanos and Ilias, (2007)
28.	PM	*Brassica chinensis*	Reduced growth and productivity, reduced quantum efficiency of PS II	Ulrichs *et al*., (2009)
29.	Coal dust particulates	*Brassica rapa*	Significant differences in vegetative biomass, height, and vegetative node production	Elam (2017)
30.	PM	*Triticum aestivum* and *Zea mays*	Yield reduction	Zhou *et al*., (2018)
31.	PM	*Vigna radiata*	Smaller sized trifoliate leaves, decline in Chl a/b, decreased sugar content	Shabnam *et al*., (2021)

the adaxial side of the leaves (Krupa *et al*., 2001). A drop in photosynthesis rate (P_s) of O_3 treated plants is also linked to structural impairment of thylakoids, decline in the capture of excitation energy efficiency and adverse effects on the electron transport system in photosystems I and II (Calatayud and Barreno, 2001; Fiscus *et al*., 2005) and loss of the activity of the photosynthetic enzymes like RuBisCO (Wilkinson *et al*., 2012). On investigating the physiological effects on *Lonicera japonica Thunb*. as well as its autotetraploid cultivar to elevated O_3 stress, a reduction in stomatal conductance, and net photosynthesis was observed (Zhang *et al*., 2010). A decline in chlorophyll, total sulfhydryl groups reduction, loss of soluble protein content, enhanced membrane permeability, and guaiacol-peroxidase activity was found in the soybean

Table 2: Yield loss due to air pollution stress in different plant species

S. No.	*Pollutant*	*Concentration*	*Plant/Crop*	*Yield loss*	*Yield attribute*	*References*
1.	SO_2	0 to 0.2 ppm	Black gram	Yield reduction	Number of pods plant^{-1} number of seeds pod^{-1}, fresh and dry weights of pods, and weight of 20 seeds	Khan *et al*., (2015)
2.	SO_2+NO_2+PM+CO	Low polluted Site-NO_2-14 µg m^{-3}, SO_2-27 µg m^{-3}, PM_{10}-65µg m^{-3}, CO-2 µg m^{-3} High polluted site-NO_2-21 µg m^{-3}, SO_2-59 µg m^{-3}, PM-80 µg m^{-3} CO-2 µg m^{-3}	Wheat cv. (Galaxy and 8173)	35% 41%	Grain yield	Adress *et al*., (2016)
3.	SO_2+PM	(1) Ambient concentration of SO_2+PM (2) Elevated SO_2 (ambient SO_2+25µg m^{-3})	Bread and durum wheat, barley and chickpea	durum wheat < bread wheat < barley < chickpea	Highest ear/pod number plant^{-1}	Yadav *et al*., (2019)
4.	O_3	70 ppb 100 ppb 70 ppb 100 ppb	Soybean cv. PK472 Bragg	20% 33.6% 12% 30%	Weight of seeds (g plant^{-1})	Singh *et al*., (2010)
5.	O_3	Ambient O_3+10 ppb O_3	Wheat cv. HUW-37 K-9107	37-39% in the first year and 40.8% in the second year 12.8% in the first year and 14% in the second year	Weight of grains (g plant^{-1})	Mishra *et al*., (2013)
6.	O_3	Ambient O_3+15 ppb O_3 Ambient O_3+30 ppb O_3	Maize cv. DHM117 HQPM1	4.8 and 7.2% 9.5 and 13.8%	Weight of kernels plant^{-1}	Singh *et al*., (2014a)
7.	O_3	M7-32 to 83 ppb AOT 40-478 to 14,783 ppb h	Wheat Rice Maize Cotton	27 to 41% 21 to 26% 9 to 11% 47 to 58%	Annual relative yield loss	Sinha *et al*., (2015)
8.	O_3	M 12-58.2 ppb	Wheat cv. LOK-1 HUW 510	7.3% 16.2%	Weight of grains (g plant^{-1})	Singh *et al*., (2015)
9.	O_3	NFC+10 ppb O_3 NFC+20 ppb O_3	Rice cv. Malviya dhan 36 Shivani	19.8% and 28.8% 17.3% and 27.2%	Number of grains plant^{-1}	Sarkar *et al*., (2015)
10.	O_3	Elevated O_3	Pusa Basmati-1509 (PB-1509) and Pusa Sugandh-5 (PS-5)	7-45%	Grain yield	Mina *et al*., (2018)
11.	O_3	Ambient O_3+30 ppb O_3	Wheat (Fourteen cultivars)	5.3-20% 10-31.3%	Number of grains plant^{-1} Weight of grains plant^{-1}	Singh *et al*., (2018)
12.	O_3	Episodic O_3 regime having five days in each 7 day week	Wheat cv. (Korongo and Eagle)	Korongo 53% Eagle 10%	1000 grain weight	Hayes *et al*., (2020)
13.	O_3	Annual mean AOT40 4.32 to 6.87 ppm h	wheat	14%	Annual mean relative yield loss	Wang *et al*., (2021)
14.	PM	-	Rice cv. Pusa Basmati-1509 and Pusa Sugandh-5	7.5–14% reduction in grain yield under low level of PM and elevated level of PM compared to ambient level of PM	Grain yield	Mina *et al*., (2018)
15.	$PM_{2.5}$	-	Wheat and Corn	Yield reduction	Average yield	Zhou *et al*., (2018)

cultivar leaves after exposure to O_3 (Chernikova *et al.*, 2000). In the early 1970s, forest degradation in the San Bernadino Mountains, California, provided evidence that O_3 can influence photosynthetic rate, chlorophyll, and carbon allocation of the trees (Laurence *et al.*, 1994; Stevens *et al.*, 2020). Therefore, O_3 is a harmful air pollutant that causes adverse effects on several plant processes, like reduced photosynthetic activity, increased dark respiration, altered carbon allocation, stunted plant development, diminished biomass accretion, accelerated senescence, hampered reproductive fitness, which ultimately results in reduced yield (Pleijel *et al.*, 2006; Gillespie *et al.*, 2011; Singh *et al.*, 2014a; Fatima *et al.*, 2018; Ghosh *et al.*, 2018). Ozone causes significant losses in crop productivity worldwide (Ghosh *et al.* 2020). Debaji *et al.* (2014) reported relative yield loss (RYL) of the average annual total productivity to be 3-6% and 5-11% for rabi rice and winter wheat, respectively. Similarly, Feng *et al.,* (2019) found relative yield loss of 8% and 6%, respectively for rice and wheat. The yield loss in plant species due to O_3 has been provided in Table 2.

Particulate Matter

The foliar surface area of terrestrial plants serves as a natural sink for particulate pollutants. The morphological, physiological, and biochemical status of plants and their responses have been profoundly influenced by the altered ambient environment caused by particulate matter pollution in urban environment (Rai, 2016). Chaturvedi *et al.* (2013) found that a higher dust load on tree species was detected at the site with maximum pollution. Exposure of particulate matters in plants is either through vegetative surface deposition, chiefly the foliar surface, or the soil-root pathway, which alters many of the physiological processes in plants (Grantz *et al.*, 2003). Trees eliminate air pollutants by capturing PM on foliar surfaces and soaking the gaseous pollutants through leaf stomata (Nowak *et al.*, 2018). However, excess particles accumulating on leaves due to severe pollution can interfere with photosynthesis, reducing the ability of trees to remove pollution (Nowak *et al.*, 2018). Moreover, the particles can be carried away after precipitation and dissolved or transported to the soil. As a result, vegetation serves only as a temporary receptacle for many air particles, which are in due course returned to the environment or transported to the soil (Nowak *et al.*, 2018). The coarse particles' deposition chiefly affects the leaves' upper surfaces (Kim *et al.*, 2000), while finer particles affect the lower surfaces (Fowler *et al.*, 1989; Beckett *et al.*, 2000).

Particulate matter pollution can cause two types of direct injury to plants: acute and chronic. The acute injury occurs when a plant is exposed to a high concentration of particle pollution for a brief period characterized by apparent visible symptoms on the foliage, mainly as necrotic lesions. While this type of damage is quite easily detectable, chronic injury is far more subtle; it occurs due to long-term exposure to lower PM concentrations and manifests as growth and yield reductions, with little to no apparent symptoms (Rai, 2016). Dust accumulation on the surface of leaves, comprising coarse and ultrafine particles, inhibited plant growth by affecting flowering and reproduction, leaf number, area, and gas exchange. The reduced leaf area and quantity could be attributed to senescence and a lower leaf production rate (Bender *et al.*, 2002; Seyyednejad *et al.*, 2011; Rai, 2016). Foliar injury as black spots, brown and yellow areas, tissue necrosis, and in severe cases, leaf death are caused by stone dust resulting from quarrying activities (Saha and Padhy, 2011).

The automobile exhausts emit sticky PM which gets deposited on plants' leaf surface. Dust settled on leaf surface alters the amount of light available for photosynthesis. Areas near the roadsides, industries, and cement works are exposed to dust deposition on leaves which lowers the gaseous exchange of CO_2 and light penetration, as well as clogs the stomata (Gheorghe and Ion, 2011). Moreover, PM has numerous ways to adversely affect cellular machinery such as cytotoxicity through oxidative stress mechanisms, DNA damage, and harm to the photosynthetic machinery (Risom *et al.*, 2005). Particulate matter reduces the photosynthetic pigments like chlorophyll and carotenoids (Joshi and Swami, 2009; Honour *et al.*, 2009). Coal smoke pollution resulted in decline in leaf pigments concentrations, total N content, reduced sugar content, and nitrate reductase activity, whereas stimulatory effects was detected in the stomatal index in *Azadirachta indica* (Iqbal *et al.*, 2010 a, b).

Cement dust's alkaline nature triggers chloroplast damage, and dust containing hazardous soluble salts, which harms overall growth and development of the plants (Singh and Shrivastava, 2002; Prajapati and Tripathi, 2008). Moreover, the cement dust being alkaline reduces the soil mineral absorption, bringing changes in the overall morphology as well as the physiology of the plants (Raajasubramanian *et al.*, 2011). According to Prasad *et al.* (1991), cement kiln dust reduced the plants' height, biomass and net productivity. Total chlorophyll have been documented to be reduced in the leaves of numerous annual plants and conifers that have been exposed to cement dust (Nunes *et al.*, 2004; Rai, 2016). Iron ore particulate matter is emitted from the iron and steel industries and is found to be harmful to the plants. According to Pereira *et al.*, (2009), the presence of iron solid particulate matter on the *Clusia hilariana's* leaf surface significantly reduced the stomatal conductance, photosynthetic rate, transpiration, PSII potential quantum yield, organic acid accumulation, and lowered enzymatic activities of catalase and superoxide dismutase. In *Eugenia uniflora*, iron ore particle and simulated acid rain accumulation resulted in the lowest rates for transpiration, chlorophyll 'a' level, photosynthetic activity, stomatal conductance, and electron transfer rate via photosystem II. Deposition of iron ore particulate matter raised the chlorophyll amount, maximum quantum efficacy of photosystem II, and electron transport rate in *Schinustere binthifolius* (Kuki *et al.*, 2008; Neves *et al.*, 2009).

It has been found that PM pollution reduces the yield of the plants (Saunders and Godzik 1986; Rai 2016). Studies undertaken in North America and Europe have convincingly demonstrated that ambient air pollution levels in rural regions cause considerable yield losses in various crop species. Under the combination of ambient O_3 and particulate matter treatment, wheat manifested 20–30% foliar O_3 injury and displayed lowest economic yield (0.58 g/plant) (Mina *et al.*, 2021b) (Table 1). According to Zhao *et al.,* (2018), $PM_{2.5}$ adversely affects the average yield of wheat and corn, and it could potentially threaten China's national food security in the long run.

CONCLUSION

Air pollution is a growing concern for the society. NO_2 is emitted due to anthropogenic activity, like fossil fuel combustion, transportation and aviation emissions, while areas with strong industrial activity and population density frequently have SO_2 emissions. A major cause of photochemical smog is tropospheric O_3 which is a secondary air pollutant. Particulate matter is a very fine, complex mixture of liquid droplets and solid particles that remain suspended in the air. Sulphates, nitrates, metals, organic compounds, soils, and dust particles are some of the constituents of particulate matter. Respiratory illness, airway inflammations, reduced lung function, bronchospasm, cardiac hospital admissions and deaths, daily mortality, and other morbidity indicators are all impacted by air pollution. The extrathoracic, tracheobronchial, and alveolar respiratory compartments are the sites where PM is deposited and the risk of cardiovascular death can increase with prolonged exposure over the years. The gaseous pollutants SO_2, NO_2, and O_3 enter the leaves through the stomata and have a negative impact on vegetation. They cause cytotoxicity through oxidative stress mechanisms and harm the physiological processes in plants. PM gets deposited on the leaf surfaces, clogs the stomata, impair photosynthesis, and has a number of cellular-damaging activities. In response to these, there are physiological and biochemical adjustments which indicate towards the activation of defence mechanisms in plants to compensate for the air pollution stress. Hence considering the air pollution impacts there is an immediate need of air pollution check. The way to tackle the air pollution menace is through the opinion/recommendation of scientific experts coupled with public awareness. Air pollution can also be regulated in different ways, like by strict policies and implementation of emission standards and air quality standards. Moreover, international and national organizations should consider the emergence of the air pollution threat and recommend sustainable measures and solutions.

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