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Chapter- 13

Phytoremediation of indoor air pollution using indoor plants

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Keywords: Air pollution, Indoor pollution, Phytoremediation, medicinal plants.

Abstract:

Pollution is everywhere, within our homes. This has been a major concern as indoor air pollution is present globally, especially in developed countries and cities. There are different indoor air pollutants like CO, volatile organic compounds (VOCs) like formaldehyde, benzene, nitrous oxide, trichloro-ethylene, fluorine, ammonia, radon, aldehyde, hydrocarbons etc. These pollutants have serious hazardous effects on human health. Indoor plants have been used worldwide for decoration since ancient times. But this beautification may add some beneficial aspects to control of indoor pollution through a process called as Phytoremediation. Experiments are going on to evaluate the actual contribution of these ornamental plants in indoor air pollution control. This could be a sustainable approach towards the maintenance of indoor air quality.

Introduction:

Indoor Air Pollutants

Air pollutants are substances in the atmosphere that can potentially cause damage to the environment, the climate, and human health. These pollutants are typically divided into two main categories: Bare in mind to underscore the main and the secondary pollutants. The primary pollutants are the ones that are directly discharged by sources such as factories, vehicles and even natural events such as volcanic eruptions. Regular instances of carbon monoxide, sulphur dioxide, and nitrogen oxides are examples of pollutants. On the contrary, secondary pollutants are not emitted directly but form in the atmosphere as a result of chemical reactions involving the primary pollutants. Ozone, which is a prominent component of smog, is a prominent secondary pollutant (Das et al., 2016; Prasad et al., 2023).

Pollution of the air has now turned out to be a serious world problem due to its broad impact. The fact that it is responsible for respiratory and cardiovascular diseases, premature death and it aggravates conditions like asthma and bronchitis is the reason why it is dangerous. Besides, air pollutants are responsible for the destruction of ecosystems, that is, the decrease of biodiversity

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and the alteration of water and soil conditions. Besides that, some air pollutants, such asgreenhouse gases, are responsible for the majority of climate change as they trap the heat in the atmosphere and consequently cause global warming.

There are several air pollutants. Here, some of the major pollutants are discussed.

Organic Pollutants

Volatile organic compounds (VOCs) like Formaldehyde, Toluene and ethylbenzene, Acetaldehyde, Acrolein, Naphthalene, Trichloroethylene, Tetrachloroethylene, Carbon dioxide and carbon monoxide- are organic pollutants. These chemicals are mostly vaporized easily at room temperature, and their concentration is higher than that of other pollutants in the indoor air. Aerosols, cleaning agents, varnishes, polishes, paints, pressed-wood products and pesticides are some of the VOC sources indoors (Aller, 1999; Mentese et al., 2015; De Gennaro et al., 2014).

Biomass fuels and coal are a source of energy for cooking and heating. Almost 3 billion people use biomass (wood, charcoal, crop residues, and animal dung) and coal worldwide as their primary and other household needs (Ezzati, 2008). From biomass and coal combustion CO_2 and NO_2, arsenic, fluorine and organic matter such as polycyclic aromatic hydrocarbons are emitted. Chronic obstructive pulmonary disease, respiratory infections, asthma, lung cancer and eye diseases are the hazardous effects of biomass and coal (Smith et al., 2004; Smith, 1987).

Tobacco smoke is the largest source of air pollutants in indoor environments. It has more than 4000 chemical compositions, which could lead to pneumonia and bronchitis, especially in childhood (Schwela, 2005; Jenkinset al., 1992; Bruce et al., 2000).

Carbon dioxide and carbon monoxide result from poorly ventilated kitchens, rooms over garages, and unvented combustion appliances (stoves, ovens, heaters, and the presence of tobacco smoke) (Schwela, 2014). Symptoms of exposure are sneezing, coughing, and minor eye irritation (Kaur and Misra, 2014).

Formaldehyde is a class of aldehydes that is a colorless gas. The sources of formaldehyde are different building materials, household products, or combustion processes. Indoor sources include pressed-wood products, including particleboard, panelling, fiberboard, resins, carpet backings, drapes, and upholstery fabrics, linens, and clothing; urea–formaldehyde foam insulation; adhesives; paints; coatings; and carpet shampoos plus tobacco smoke. Decreasing ventilation rate will increase the level of formaldehyde (De Gennaro et al., 2014; Nielsen et al., 2012; Nielsen et al., 2016). Formaldehyde exposure could cause respiratory symptoms, reductions in lung function, headaches, and asthma, and it can affect the nervous system (De Gennaro et al., 2014).

Toluene exists in many materials, such as gasoline, paints, and fingernail polish. Ethylbenzene is also present in paints, lacquers, and insecticides. These compounds are hazardous to human health and have adverse effects on the nerves, liver, kidneys, and respiratory system (Schwela, 2005; Sriprapat et al., 2014).

Acetaldehyde is toxic to the cilia of respiratory epithelia and may interfere with respiratory clearance mechanisms. Acetaldehyde is also a central nervous system depressant and, a proven carcinogen in animals and a potential carcinogen in humans. The acetaldehyde source of indoors is construction materials, furnishing materials such as vinyl, polyvinyl chloride (PVC) and rubber floorings, nylon carpets, particleboard furniture, plywood, fiberboard, flooring adhesives, wood panelling, and other consumer products and emitted by printers and photocopiers (Schwela, 2005; Destaillats et al., 2007).

Acrolein is a very potent eye irritant, causing lacrimation at concentrations of approximately 2 mg/m3. At high concentrations, acrolein can cause significant lung injury, including dyspnea, asthma, congestion, edema, and persistent respiratory insufficiency with decreased lung function (Schwela, 2005).

Naphthalene is a volatile white solid. It is an aromatic hydrocarbon, including a fused pair of benzene rings (Schwela, 2005). Naphthalene is mostly used as a toilet deodorant and as a moth repellent. Extended exposure to a large amount of naphthalene may damage or destroy some of the red blood cells.

Trichloroethylene (TCE) is a clear, non-flammable liquid used mainly for vapour degreasing and cold cleaning of manufactured metal parts and, to a lesser degree as a solvent for a variety of organic materials. The primary sources of TCE in the indoor air include varnishes, finishes, lubricants, adhesives, wood stains, paint removers, cleaning liquids containing TCE, and contaminated food and water (Schwela, 2005). TCE is carcinogenic to humans (ATSDR, 2011) and can affect the central nervous system (CNS), eyes, kidneys, liver, lungs, mucous membranes, and skin (Bahr et al., 2011).

Tetrachloroethylene (PCE) is a colorless liquid mostly used for dry cleaning fabrics, as a solvent for organic materials, and to degrease metal parts in the automotive and other metalworking industries. Another source of PCE is dry-cleaned clothes. Exposure to PCE vapor could cause damage to the following organs: kidneys, the liver, the peripheral nervous system (Schwela, 2005), the upper respiratory tract, the skin, and the central nervous system (CNS) (ATSDR, 2008).

Inorganic Pollutants

Nitrogen oxides are combustion by-products produced by the burning of natural gas or oil in oxygen-rich environments such as kitchen stoves and ovens, furnaces, and unventilated gas and kerosene heaters from a fireplace or wood stoves are used. Adverse effects of NO_2 exposure are breathing symptoms, bronchoconstriction, growth of bronchial reactivity, painfulness, and increased respiratory infection.

Trace elements are generally related to Particulate Matters (PM) and are Fe, Al, Mg, Zn, Co, As, Cr, Cd, Mn, Cu, Ni, and Pb. Trace elements such as Mg, Fe, and Al are greatly released from crustal sources such as parent rocks, metallic minerals, seas, and oceans. Fossil fuel combustion, forest and biomass burning, and metal processing are also sources that release many trace elements (Ugranli et al., 2016). These toxic pollutants either ingress from outside of the buildings or are generated inside because of fossil fuel combustion.

Mercury (Hg) is a persistent, poisonous, and bio-accumulative heavy metal. It can discharge into the atmosphere from a diversity of anthropogenic and natural sources like burning process of fuels (36%) and biomass (33%) (Shen et al., 2017; Loupa et al., 2017).

Ozone can cause the muscles in the airways to constrict, trapping air in the alveoli leading to wheezing and shortness of breath. The source of ozone in a building is electrostatic copying devices, mercury-raised light bulbs, and electrostatic air cleaners (Aller, 1999; Darling et al., 2016; Fadeyi, 2015).

Particulate Matters

Inhalable particulate matter is classified into three groups according to their sizes: coarse particles (2.5 $<dp<$ 10 µm), fine particles (≤2.5 µm) and ultrafine particles (UFP,<0.1 µm) (Heal et al., 2012; Irga et al., 2017). Fine particles are more potent when inhaled than coarse fractions since they can penetrate the lungs more. UFP can penetrate alveoli and enter the blood, which can be very harmful. Sources that can increase the PM concentration are Earth's crust elements from oil burning and human activities, and motor vehicles (Othman et al., 2009). An increase in exposure to PM leads to increased hospital admissions of the old and individuals with cardiopulmonary and respiratory illnesses. PM concentration inside a building is basically governed by indoor sources of fine particles, outside PM concentration, the rate of air circulation, and the particles' depositional speed (Buczy´nska et al., 2014). Studies show that indoor concentration of PM2.5 is usually higher than outdoor concentration (Buczy´nska et al., 2014).

Asbestos exposure for an extended period of time could lead to lung cancer, known as mesothelioma and asbestosis. Insulation and other building materials, such as floor tiles, drywall compounds, and reinforced plasters, are sources of asbestos (Kaur and Misra, 2014).

Phytoremediation of indoor air

Indoor plants means the plants that can grow indoors i.e., their light, temperature and water requirements are low. They may be either flowering plants (Peace lily, Kalanchoe, Amaryllis, Hydrangeas, Poinsettia) or foliage plants (cactus, palm plants, fern and succulents). National Aeronautics and Space Administration (NASA) has found that common household plants work as natural air purifiers. Interestingly indoor plants can remove a notable amount of at least 87% of VOC's in 24 hours. Succulents and many indoor house plants are further advantageous as they are small in size and add a continuous flush of fresh oxygen day and night. Studies have shown that people in buildings with plants like Money plant, Mother- In- Law's Tongue and Areca palm have 34% fewer respiratory problems, 54% less eye irritation and 24% fewer headaches (Maiti et al., 2010, 2013; Anon., 2016; Banerjee et al., 2014; Ghosh et al., 2022).

Phytoremediation means using plants and their associated microorganisms to isolate or degrade toxic substances from the environment (Chaney et al., 1997; Ensley, 2000; Prasad and Freitas, 2003). Phytoremediation can utilize six different strategies. The plant itself can use several pathways. The phytoremediation methods are cheaper than other techniques available, although it may be lengthy (Schnoor et al., 1995; Mendez and Maier, 2007; Teiri et al., 2018; Gawro´nska and Bakera, 2014). Phytoremediation is the collection of the above mechanisms in which green plants capture and degrade indoor air pollutants (Wang et al., 2014). Phytoremediation of contaminated soils acts as pollutants that accumulate and are degraded by plants. However, in botanical air filters, applying microbial activity has an important role in removing indoor pollutants. Also, VOC biodegradation can occur due to the growth of bacteria and plants. Generally, plants and bacteria have the complexity and important interactions (Wang et al., 2014).

Experiments on light and dark spaces for formaldehyde elimination were also carried out using *Ficus benjamina* L. and *Ficus japonica* plants. The aerial parts of both species reduced formaldehyde concentrations during the day but only slightly removed at night. Meanwhile, the root is capable of removing large amounts of formaldehyde during the day and night. The effectiveness of roots in eliminating formaldehyde was mainly due to microorganisms and roots. The results of this study indicate that enhanced photodegradation was the main process of removing formaldehyde (Kwang et al., 2008; Aydogan& Montoya, 2011). Formaldehyde elimination was also studied in experiments using plants from the Liliaceae, Agavaceae and Araceae families that are effective in removing formaldehyde. However, *Philodendron selloum* is the least resistant to formaldehyde exposure (Zhou et al., 2011). The plant species tested have a high potential to improve the interior environment from exposure to formaldehyde (Teiri et al., 2018b).

Recent data shows the efficiency of toluene phytoremediation increased by an average of 156 $mg/m^3/hour/m^2$ leaves of *Pinus densilora* and *Salvia elegans* (Kwang Jin Kim et al., 2011). Efficient removal of toluene and xylene was achieved using indoor plants (*Schefflera actinophylla* and *Ficus benghalensis*). Experiments show that toluene and xylene was translocated from the air to the root zone through the stem, which indicates that the root zone plays an important role in this elimination process (Kim et al., 2016).

There is intensive research to filter out dozens of plant species that are capable of eliminating many VOCs gases. For exposure to each gas as much as 10 ppm within 6 hours, it was found that *Hemigraphisalternata*, *Hedera helix*, *Hoya carnosa*, and *Asparagus densivechlorus* had the highest removal efficiency for all pollutants (Yang et al., 2009). Other types of plants have different and lower removal efficiencies. The difference in efficiency between plant species indicates the need, importance and necessity of biodiversity in the processing of pollutants by plants (Samudro & Mangkoedihardjo, 2020; Samudro & Mangkoedihardjo, 2020; Ren et al., 2017).

The average benzene removal efficiency of 70% was achieved by four common ornamental plants, namely *Epipremnumaureum*, *Chlorophytum comosum*, *Hedera helix* and *Echinopsistubiflora*. *Echinopsistubiflora* is interesting for the high ability of removal efficiency due to its high ability to transpiration and high chlorophyll content (Gong et al., 2019). The high transpiration of plants indicates that they need a lot of watering while they are used for room remediation. Likewise, the high chlorophyll content of plants indicates the need for sufficient sunlight to utilize it. Therefore, planting conditioning and maintenance need to be considered (Mangkoedihardjo & Samudro, 2014; Ni et al., 2019) in order to support the maximum capacity of plants to eliminate polluting gases. Thus, the application of biodiversity, including the diversity of plant conditions and ways of maintaining them, is able to eliminate many pollutants maximally.

Thus, the potential of plants to improve Indoor Air Quality (IAQ) depends upon the capacity of leaves to exchange gases and pollutants from indoor air through stomata. The capacity is limited by physical constraints pertaining to stomatal and mesophyll resistance. The size of the stomatal pore varies with variations in environmental conditions viz., light, temperature, humidity -and cascades of signalling through plant hormones, especially abscisic acid. Besides stomatal absorption, pollutants can get adsorbed on the external surfaces of plants or soil-root interface. The process of absorbing lipophilic semi-volatile compounds is achieved through leaf surface adsorption, where atmospheric resistance serves as a major limiting factor (Wei et al., 2017). This type of removal depends upon the total surface area and anatomical, morphological and chemical features of the plant surface, along with the characteristics of the soil substrate (Irga et al., 2013). The adsorption of pollutants, especially lipophilic VOCs, such as benzene, on plant surfaces is dependent upon the type and density of trichomes (Li et al., 2018), cuticular wax deposition and lipid composition of the epidermal membrane (Gawronska and Bakera, 2015). Research revealed that the amount of pollutants absorbed through stomata is 30- 100 times more than adsorbed on the plant surface or non-stomatal deposition (Tani et al., 2009). After entering into plant leaf either through absorption or adsorption, pollutants are translocated to shoots and roots for metabolic degradation through oxidases or hydrolases and then conjugation with different metabolic compounds (sugars, amino acids, organic acids, and peptides) to form bioproducts. These products are either re-expelled (into the air or as root exudates into the soil) or used as carbon and energy sources (Oikawa and Lerdau, 2013).

In addition to air phytoremediation, another least explored aspect is phytoremediation i.e., remediation through habituated microbes either on leaf surface or endophytes by biodegrading or transforming pollutants into less or nontoxic molecules (Sandhu et al., 2007). Leaves are the primary photosynthetic organs with dorsiventral symmetry and play pivotal roles in supporting phyllosphere microbes (Bringel and Couee, 2015). Several reports documented that both plant leaves and leaf-associated microbes mitigated air pollutants, such as Azalea leaves and the leaf-associated *Pseudomonas putida*, in reducing VOCs (De Kempeneer et al., 2004) and Poplar leaves and the leaf-associated *Methylobacterium* sp. decreased xenobiotic compounds (Van Aken et al., 2004). Thus, different mechanisms underlie the phytoremediation potential of plants for indoor pollutants.

Table 1: Research results showing some pollutants and their regulation with indoor plants

Pollutant	Potted Plant species	Results
O_3	Peace Lily (*Spathiphyllum*), Ficus species (*Ficus Decora Burgundy*), Calathia (*Calathia Species*), Dieffenbachia (*Dieffenbachia* Species), Golden Pothos (*Epipremnumaureum*)	The Golden Pothos had the highest ozone deposition velocity values among plants, and the lowest value was for Peace Lily [Abbass et al., 2017]
Toluene and Xylene	*Schefflera actinophylla* and *Ficus benghalensis*	Removal of toluene and xylene was 13.3 and 7.0 µg·m−3 ·m−2 leaf area over a 24-h period in *S. actinophylla* and was 13.0 and 7.3 µg·m−3 ·m−2 leaf area in *F. benghalensis*. It also showed that the root zone has a vital role in toluene and xylene removal. [Kim et al., 2016]
Benzene	*Syngonium podophyllum, Sansevieria trifasciata, Euphorbia milii, Chlorophytum comosum, Epipremnumaureum, Dracaena sanderiana, Hedera helix, Clitoriaternatea*	*Chlorophytum comosum* was the most efficient plant for removing benzene during the 96 h. [Sriprapat and Thiravetyan, 2016]
PM	Spider plants (*Chlorophytum comosum* L.)	The result shows the accumulation of PM at a high level on the surface of leaf [Gawro ´nska and Bakera, 2014]
Formaldehyde	Golden Pothos	Dynamic airflow through the root bed and microbes was essential for removing high efficiency; moisture of the bed root has a vital role in removing VOCs [Wang et al., 2014]
Toluene ethylbenzene	*Aloe vera, Sansevieria masoniana, Sansevieria trifasciata, Sansevieria hyacinthoides, Sansevieria ehrenbergii, Kalanchoe blossfeldiana,*	*S. trifasciata* had the highest value for removing toluene, *C. comosum* for removal of ethylbenzene, *S. trifasciata* and *S. hyacinthoides* had a high value in the absorption of toluene and ethylbenzene. [Sriprapat et al., 2014]

	Dracaenaderemensis, Codiaeum variegatum, Chlorophytum comosum, Dracaena sanderiana, Cordyline fruticosa, Aglaonema commutatum	
Benzenen-hexane	Janet Craig S. Sweet Chico	The highest value for removing TVOCs (75%) by potted-plants is when indoor average TVOC concentrations are higher than 100 ppb [Wood et al., 2006]
Benzene Trichloroethylne Formaldehyde	*Chamaedoreaseifritzii, Aglaonema modestum, Hedera helix, Ficus benjamina, Gerbera jamesonii, Dracaena deremensis, Dracaena marginata, Dracaena massangeana, Sansevieria laurentii, Spathiphyllum, Chrysanthemum morifolium, Dracaena deremensis*	These plants require low light and low metabolic rates. These plants are a suitable selection to decrease sick building syndrome, containing many new, energy-efficient buildings. The plant root-soil zone showed high efficiency for the removal of VOCs [Wolverton et al., 1989]
Benzene CO_2, CO	*Zamioculcas, Aglaonema, Dracaena*	CO2 concentration increases 10% in offices in the air-conditioned building. The CO level reduces with or without air-conditioning. Higher value removing of benzene appearance by these plants. [Tarran et al., 2007]
CO_2	Peace lily, weeping fig, areca palm Sweet Chico, Hahnii, *Chamaedoreaelegans, Dracaena marginata*, Florida Beauty, Lemon Lime, Janet Craig, *Ctenanthe oppenheimiana, Ficus repens, Hedera helix, Epipremnum, aureus, Philodendron, scandens, Dizygotheca, elegantissima*	The rate of photosynthesis change with the variation of CO_2 concentration in light indoor. The leaf area is effective to decrease CO_2 [Oh et al., 2011]. Woody plants species accumulate dry mass (and carbon) better than smaller, herbaceous species [Pennisi and van Iersel, 2012]

Conclusion

The basis for phytoremediation is the potent efficiency of some plants to assimilate, degrade, or modify toxic pollutants into non-toxic ones. Breathing walls, portable air filters for rooms or whole house filtration through heating, ventilation and air conditioning systems are some of the technologies to reduce indoor air pollution and improve indoor air quality, but all these are costly, resource consuming and, still there is a question on their efficiency. Phytoremediation seems to be the key solution to improve indoor air quality as it has many potential advantages (simple, potentially cheap and easily implemented) in comparison to other traditional or latest methods available.

One of the best tools for selecting indoor plants is the Air Pollution Tolerance Index (APTI). APTI considers biochemical properties of leaves such as ascorbic acid: relative water content, total chlorophyll and leaf extract pH. These properties affect the value of the plant's tolerance to air pollutants. For example, the high value of ascorbic acid is one of the strategies to prevent oxidative damage to the thylakoid membranes under water stress conditions (Bandehali et al., 2021). Therefore, the selection of plants for our indoor environment is also important. Costly and large resource-consuming technologies can be used for IAQ maintenance, but indoor plants are beautiful with boon and they are very easy to install and maintain.

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