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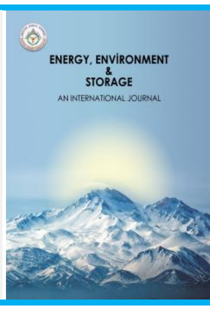

Air Cleaning Plants

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ABSTRACT. Air quality, both outdoor and indoor, is the most critical element that we must protect for the entire environment. While the deterioration of air quality primarily causes respiratory diseases in living things, it also causes corrosive effects on non-living things, such as corrosion caused by acid rain, which results from air pollution. Therefore, it is necessary to monitor and prevent air pollution by various methods. WHO plays an active role in protecting air quality through its mission. Plants are indispensable beings for the environment and life. They balance the CO_2 concentration, temperature, and humidity in the air. Plants use CO_2, light, and water during photosynthesis, which is necessary for their growth and development. They reduce the CO_2 concentration in the environment. In addition, plants, depending on their leaf characteristics, can trap particulate matter in the atmosphere. Many studies have proven that plants positively affect indoor and outdoor air quality. In this review, we aim to summarize the results of some selected studies, provide information about the air purification capacities of the researched plants, and emphasize the topic's importance.

Keywords: diesel, 1,4-dioxane, UV irradiation, chemical stability

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1. INTRODUCTION

According to WHO, "Air pollution is the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere." [1]

In the 1970s, when it was determined that atmospheric pollution was at severe levels. In contrast, the World Health Organization (WHO) determined that pollution was at urban and industrial levels, and the World Meteorological Organization (WMO) started keeping weather records on continental and global scales.[2] WHO's primary goal is to protect people's health in cities. To determine the causes of air pollution, WMO measures air pollution concentrations, investigates their effects on climate, covering continents and the world, and tries to estimate their temporal characteristics. [2] United Nations Environment Program (UNEP) and World Environment Monitoring System (GEMS) further support WHO and WMO enforcement guidelines. [2] GEMS; disseminating early warning systems, determining atmospheric pollution worldwide, and assessing its impact on climate, revealing critical problems related to land use and agriculture.

WHO projects make micro-level (urban) measurements. On the other hand, the WMO network makes measurements at the macro level (continental and world scale) and compares them. GEMS is tightly dependent on WHO projects and WMO records. [2]

Two leading causes of air pollution are the increasing population and, depending on it, industry development.

WHO has classified substances that impair air quality as outdoor and indoor air pollutants. Outdoor air pollutants determined by WHO are PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2 and CO. In addition, the WHO scanned the scientific studies on indoor air pollution and identified eight substances with definitive evidence that they are polluting and harmful as indoor air pollutants. These pollutants are benzene, CO, formaldehyde, naphthalene, NO_2, polycyclic aromatic hydrocarbons, radon, trichloroethylene, and tetrachlorethylene.

Clean air is the most necessary condition for human life. Both indoor and outdoor air pollution causes respiratory and other illnesses in living beings.

The effects of outdoor pollutants on humans, plants, and materials are summarized in Table 1.

Table 1. The effects of outdoor pollutants

Outdoor Pollutant	Effects on Human	Plant	Material
PM_{10}, $PM_{2.5}$	Cerebrovascular, ischemic hearth disease, acute lower respiratory infections, chronic obstructive pulmunary disease(COPD), **Lung cancer mortality** [3]	PMs accumulating on the leaves of green plants resulting in failure of assimilation and photosynthesis and weakening of plant development. [2,4]	They corrode materials, especially if the relative humidity is above 75%, erode building surfaces, and damage and destroy the paint of painted surfaces. [2,4]
O_3	**Respiratory Mortality.** Children, older people, and people with asthma especially are susceptible. [3]	Reduces the agricultural harvest rate and prevents the growth of forests. It disrupts plants' photosynthesis mechanism, causing less carbon dioxide absorption. [5]	causes premature deterioration of buildings [5]
NO_2	**Respiratory Mortality.** Children, older people, and people with asthma especially are susceptible. [3]	causes the brown and dark brown colored burns and spots the leaf edges, the leaves fade, chlorophyll and starch were destroyed. Physiologically, assimilation decreases. [2,4]	shows slight corrosive effect [6]
CO	**Cardiovascular Mortality:** Ischemic hearth disease (IHD) [3]	Plants are more resistant to the effect of CO than animal organisms. That's why they show damage in very high concentrations. [2,4]	Carbon monoxide is a relatively unreactive gas under ambient air conditions and is not absorbed by building materials or ventilation system filters. [7]
SO_2	**Respiratory Mortality.** Children, older people, and people with asthma especially are susceptible. [3]	High concentrations of SO_2 cause acute damage :chlorophyll is rapidly lost, cells disintegrate, and necrosis occurs. In chronic damage: gradual chlorophyll breakdown and chlorosis formation occur without any cellular collapse. This causes a reduction in metabolic activity and a decrease in photosynthesis, and development is generally suppressed. [2,4]	Historical buildings, national buildings, cathedrals, and statues are all destroyed by contact with byproducts of sulfur oxides. Sulfuric acid haze likewise destroys cotton, linen, and nylon. SO_2 increases the corrosion rate of metals such as iron, steel, zinc, copper, and nickel if the relative humidity is above 70%. [2,4]

The effects of indoor pollutants on humans and animals are summarized in Table 2.

Table 2. The effects of indoor pollutants

Indoor Pollutant	Effects on Human & animal
Benzene	Acute myeloid leukaemia, Genotoxicity [7-9]
Formaldehyde	Sensory irritation [7,10]
CO	When acute exposure-occured, exercise intolerance and increase in symptoms of ischaemic heart disease [7,11]
Naphthalene	Respiratory tract lesions causing to inflammation and malignancy in animal studies [7,12]
NO_2	Bronchoconstriction, airway inflammation, and reduced immune defense cause a raised ability for respiratory infection. [7,13]
Polycyclic aromatic hydrocarbons	Lung cancer [7,14]
Radon	Lung cancer Implicative evidence of an related with other cancers, in particular leukaemia and cancers of the extrathoracic airways [7,15]
Trichloroethylene	Carcinogenicity (liver, kidney, bile duct and non-Hodgkin's lymphoma), with the presumption of genotoxicity [7,16]
Tetrachloroethylene	Effects in the kidney suggestive of early renal disease and impaired performance [7,17]

As people spend more time indoors, there is growing unease about indoor air quality. Constructing highly sealed buildings boosts thermal capability but decreases fresh air ventilation. Aggregating and continued exposure to indoor air pollution may result in harmful health outcomes. [18]

Continuous exposure to air pollutants, the concentration of indoors can even be higher than outdoors, may bring about respiratory and cardiovascular diseases, eventually contributing to the so-called ‘sick building syndrome’ (SBS) and ‘building-related illnesses’ (BRI). [19]

Sick building syndrome (SBS) is defined by symptoms such as headaches, nausea, lightheadedness, eye irritation, mucous membranes, and respiratory systems [20]. The SBS affects people’s well-being, health, and, most importantly, productivity in indoor environments. High CO_2 levels and low humidity contribute to sicknesses, such as eye dryness, migraines, and reduced academic performance. [21] SBS has proven to be challenging to understand. At the same time, symptom frequencies tend to be higher in women due to historical reasons, social position, lack of knowledge of female physiology, and chemical hypersensitivity [22]. Furthermore, poor indoor air quality (IAQ) increases absenteeism and negative emotions [23]. This underlines the significant impact of SBS on productivity, a key concern for all stakeholders.

Plants balance CO_2 concentration, temperature, and humidity [21, 24]. They use CO_2, water, and light via photosynthesis, which is fundamental for their growth and survival [25]. During photosynthesis, plants can minimize the CO_2 levels in the environment [26]. In addition, photosynthesis in plants produces negative air ions that benefit human health [27]. However, the current research on the correlation between CO_2 levels and plants’ capacity to remove CO_2 is limited, highlighting the need for further exploration in this area. Plants’ ability to alleviate PM and CO_2 alters among plant species and environmental conditions [28].

Air phytoremediation (AP) is an ecological remediation technology that utilizes green plants to eliminate pollutants from polluted air [29, 30]. Some plants can assimilate, degrade, or modify toxic contaminants in the air into less toxic ones, making it possible to remove airborne pollutants via AP technology [29,31].

For an extensive review of published articles on air-cleaning plants, we collected the articles using databases such as Google Scholar, Science Direct, Web of Science, Scopus, and Science finder since 1980. We initially collected the references using the keyword “Air-cleaning plants,” and then keywords such as “Phytoremediation” and “Bioremediation” were utilized to conduct a more comprehensive survey of references. After thoroughly reviewing the initially selected references, we finally chose 75 papers.

2. THE PLANTS REMOVING THE INDOOR AIR POLLUTANTS

Our literature survey revealed four reviews that overlapped the topic of "plants removing indoor pollutants." Since we read seven plants mentioned in all four reviews, this section mentioned the articles on their seven plants clearing indoor pollutants.

2.1 Chlorophytum comosum (Spider Plant)

The removal of benzene, toluene, cigarette smoke, xylene, formaldehyde, ethylbenzene, and the mixture of benzene, toluene, octane, and trichloroethylene, α-Pinene, i.e volatile organic compounds-VOCs, Particulate matter (PM), and CO_2 were investigated on *Chlorophytum comosum*.

Figure 1. The photo of *Chlorophytum comosum* [32]

Sriprapat et al. [33] tested the removal capacity of toluene and ethylbenzene on the plants *Aloe vera, Sansevieria masoniana, Sansevieria trifasciata, Sansevieria hyacinthoides, Sansevieria ehrenbergii, Kalanchoe blossfeldiana, Dracaenaderemensis, Codiaeum variegatum, Chlorophytum comosum, Dracaena sanderiana, Cordyline fruticosa, Aglaonema commutatum*. The highest removal values are for toluene, *S. trifasciata,* ethylbenzene, *C. comosum*. Also *S. trifasciata* and *S. hyacinthoides* had a high value in the absorption of toluene and ethylbenzene.

Another Sriprapat et al. study [34] showed the experimental data for eight species of plant, involving *Sansevieria trifasciata*, *Euphorbia milii*, *Epipremnum aureum*, *Syngonium podophyllum*, *Hedera helix*, *Chlorophytum comosum*, *Dracaena sanderiana*, and *Clitoria ternatea*, for eliminating benzene in air and water pollutants. These indoor plants are eminent for their high tolerance to toxic pollutants. During 96 hours, it presented that *C. comosum* had the most potential among other plants for eliminating benzene from air and water pollutants.

Torpy et al. [35] researched CO_2 removal of *Chlorophytum comosum* and *Epipremnum aureum* using green wall technology.

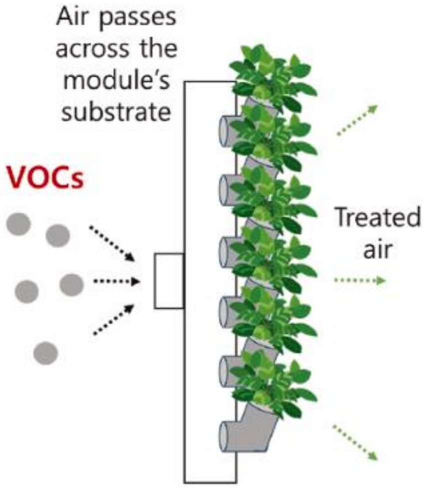

Figure 2. Active green wall system [36]

Both of the plants were active in CO_2 elimination at densities higher than 50 μmol/m^{2}s. When the intensity of the light elevated, the green wall achieved meaningful reductions in high CO_2 concentrations within a sealed room environment.

Xu et al. [37] studied the formaldehyde removal performance of *Chlorophytum comosum*. They found its volatile organic compound (VOC) removal performance to be 90%, 92%, and 95% at the light intensities of 80, 160, and 240 μmol/m^{2}s, respectively.

In the third research study by Sriprapat et al. [38], they screen fifteen plant species to determine their capability to remove xylene volatile aromatic compounds. The results exhibited that the most active plants for xylene removal after 24 hours were *C. comosum, A. commutatum, P. martianum, A. rotundum, and F. albivenis*. These plants could take up xylene at a rate of around 0.66±0.00, 0.65±0.03, 0.68±0.00, 0.66±0.00, and 0.64 ±0.54 mmol/m^2-leaf area, respectively. But, after 24 hours of xylene exposure, their activity was not the best. At 48 hours, the results exhibited that *Z. zamiifolia* reduced xylene levels significantly better than other plants ($P \leq 0.05$). This plant showed the highest xylene removal efficiency, with uptake of 0.81 ±0.01 mmol/m^2 leaf area, around four times higher than that of *G. lingulata*, the least effective of the 15 species tested. At 72 hours, *Z. zamiifolia* showed consistently high xylene removal ability. This plant could take up approximately 88 % of xylene within 72 hours of fumigation.

In 2020, Siswanto et al. [39] investigated the *comosum*, *Sansevieria trifasciata*, with a 120 m^3 /h airflow rate in a 24 m^3 testing room. This chamber experiment used the simulated cigarette smoke containing 120–150 ppm of formaldehyde, 127–145 ppm of acetone, 13–35 ppb of benzene, and 30–70 ppb of xylene. After 24 hours, VOC (Volatile Organic Compound) removal performance was 80–90%.

The removal capacity of the mixture of benzene, toluene, octane, trichloroethylene, and α-Pinene of *Chlorophytum comosum* together with 27 plant species were tested. [40] *Hemigraphis alternata, Hedera helix, Hoya carnosa*, and

Asparagus densiflorus had the best elimination efficiencies for all contaminants; *Hemigraphis alternata* showed superior removal activity for all five VOCs (i.e., benzene; 5.54 ± 0.29, toluene; 9.63 ± 0.94, Octane; 5.58 ± 0.68, TCE; 11.08 ± 0.99, and a-pinene; 12.21 ± 1.61). VOCs removal performance of *Chlorophytum comosum for* benzene; 0.75 ± 0.11, Toluene; 3.18 ± 0.14, Octane; 1.70 ± 0.08, Trichloroethylene; 2.86 ± 0.13, α-Pinene; 4.17 ± 0.21 μg/ m^3 h cm^2-leaf area.

Gawronska et al. [41] displayed that the accumulation percentage of large PM (PM_{10}) of *Chlorophytum comosum* was 68, and of fine PM ($PM_{2.5}$) was 7 in indoor environments. Irga et al. [42] used spider plant green wall to test PM removal. They found it has excellent potential for PM removal. They also displayed that the rate of air affects PM removal. The 11 L/s of airflow rate has the highest filtration among the tested rates of 4 to 15 L/s, and the removal efficiency reached up to 53 ± 10%.

2.2 Chrysanthemum morifolium (Garden Mum, Autum Mum)

Figure 3. The photo of *Chrysanthemum morifolium* [43]

Chrysanthemum morifolium, a decorative perennial shrub, could remove formaldehyde in liquid nutrient solution and soil conditions [44-45].

2.3 *Dracaena deremensis* (Corn plant)

Figure 4. The photo of Dracaena deremensis [46] & Dracaena fragrans Lemon Lime [47]

In 2004**,** Orwell et al. [48] searched the 25 ppm benzene removal capacity of *Dracaena deremensis.* They found its' removal performance of 188±48 ppm/d m^2-leaf area. In their other study, Orwell and his colleagues [49] investigated 100 ppm toluene and its xylene removal capacity. They obtained these removal data: Toluene in single: 549 ± 31.8, Xylene in single: 336 ± 21.8, Toluene in mixture: 284 ± 27.3, Xylene in mixture: 229 ± 11.4 mg/m^3 d.

Mosaddegh and co-workers [50] researched the application of a mixture of benzene, toluene, ethylbenzene, and xylene (each two ppm) to the plant. The results were 0.52 for benzene, 0.24 for toluene, and 0.76 mg/ d m^2-leaf area for ethylbenzene and xylene.

Sriprapat et al. [33] studied the *Dracaena fragrans* Lemon Lime. They measured its removal performance against toluene and ethylbenzene (each 20 ppm). After 72 hours, the plant eliminated 2.12 ± 0.17 μmol toluene and 2.36 ± 0.11 μmol ethylbenzene.

2.4 *Epipremnum aureum* (Golden pothos)

Figure 5. The photo of *Epipremnum aureum* [51]

Epipremnum aureum is one of the most typical plants for phytoremediation of indoor VOCs, including benzene and formaldehyde [34,43, 45,52-55]. This plant has different names, such as golden pothos, Ceylon creeper, hunter's robe, ivy arum, and silver vine [36]. It can remove formaldehyde (61.7% removal in 12 hours) and total volatile organic compounds (TVOCs) (30.0% removal in 12 hours) from tobacco smoke [56].

Epipremnum aureum has also been tested using some biofilter systems.

One is developed by Ibrahim et al. [57] as a botanical indoor air biofilter prototype utilizing *Epipremnum aureum* horizontally cultivated into Kenaf fiber. The act of the biofilter in eliminating VOCs after entering aromatic compounds was evaluated in a lab-scale chamber (0.24 m^3), displaying a single-pass removal efficiency of TVOCs of 46 ± 4.02%. Another tested system, an activated carbon-based phytofiltration system planted with *Epipremnum aureum*, was set up to control indoor VOCs in an office area (265 m^3) in New York, USA, over four days [58]. The system demonstrated tremendous single-pass removal efficiencies of formaldehyde (100–91.3%) and TVOCs (51.5–38.4%).

Wang and Zhang [58] checked the short and long-term strength of an activated carbon-based phytofiltration system in a full-scale chamber. This system used a mixture of granular activated carbon and shale pebbles (1:1, v/v) as the plant growth medium, with *Epipremnum aureum* horizontally planted (Fig. 6). The single-pass removal activity of toluene (2.16 ppm) by the system were 91.7%

and 77.2% at airflow rates of 250 and 930 m^3/h, respectively. Similarly, the single-pass removal activity of formaldehyde (1.64 ppm) was 98.7% and 69.0% at 250 and 930 m^3/h, respectively. The phytofiltration system reduced outdoor ventilation rates, resulting in 10–15% energy savings.

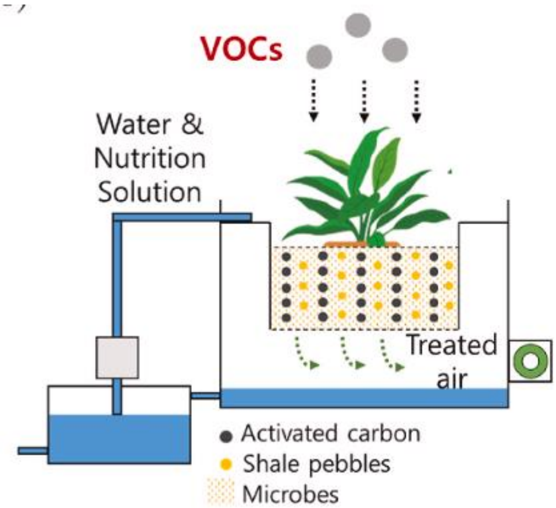

Figure 6. Phytofiltration System [36]

2.5 *Hedera helix* (English Ivy)

Figure 7. The photo of Hedera helix [59]

English ivy, *Hedera helix*, has green leaves for the year and is a climbing plant growing on surfaces like cliffs, walls, and trees. It also grows as horizontal surfaces. This plant is accepted to remove indoor VOCs, containing benzene, formaldehyde, and a mixture of benzene, toluene, octane, TCE, and α-pinene [44, 60, 34, 40, 61]. The removal rates of *Hedera helix* were 3.63, 8.25, 5.10, 8.07, and 13.28 µg/m^3 h m^2-leaf area for benzene, toluene, octane, TCE, and α-pinene, respectively, under mixed gases (each ten ppm) [40].

2.6 *Sansevieria trifasciata* (Snake plant, Mother-in-law's tongue)

Sansevieria trifasciata (sin. *Dracaena trifasciata* [63]) is a perennial plant that forms dense strands and spreads through its creeping rhizomes [64].

Figure 8. The photo of *Sansevieria trifasciata* [62]

This plant's removal performance of benzene [34] and toluene-ethylbenzene [33], a mixture of benzene, toluene, octane, trichloroethylene, and α-Pinene (each 10 ppm) [40] has been studied. The removal of benzene is 25.40 ± 0.14 µmol/h m^2-leaf area [34], 2.68 ± 0.19 µmol for toluene, and 2.74 ± 0.13 µmol for ethylbenzene in 72 hours [42]. For the mixture of VOCs study, the removal of benzene is 1.76 ± 0.48; toluene is 4.97 ± 0.70; octane is 2.73 ± 0.50; trichloroethylene is 4.61 ± 0.81; α-Pinene is 5.49 ± 1.31 µg/ m^3h cm^2-leaf area. Additionally, Permana et al. [65] did experiments utilizing a 24 m^3 chamber to measure VOCs removal by a botanical biofilter from cigarette smoke at various distances (100–315 cm). The biofilter consisted of Sansevieria trifasciata planted in soil and coconut fiber. Within 24 h, the biofilter achieved removal rates of TVOCs, formaldehyde, and acetone ranging from 40 to 65%, 46 to 69%, and 31 to 61%, respectively. Interestingly, VOCs removal was exceptionally high at a distance of 100 cm, suggesting that the biofilter likely created airflow vortices at that height.

2.7 *Syngonium podophyllum* (Arrowhead plant)

Figure 9. The photo of Syngonium podophyllum [66]

Syngonium podophyllum is a favorite houseplant known for eliminating benzene (103.4 ng/m^3 h cm^2-leaf area), toluene

(161.6 ng/m^3 h cm^2-leaf area), and formaldehyde (0.5 µg/cm^2-leaf area in 6 h) [67, 34, 68, 61].

3. THE PLANTS REMOVING THE OUTDOOR AIR POLLUTANTS

Following the similar logic in the previous section, this section includes articles about the four most mentioned and studied plants that clean pollutants in the outdoor environment.

3.1 *Sophora japonica*

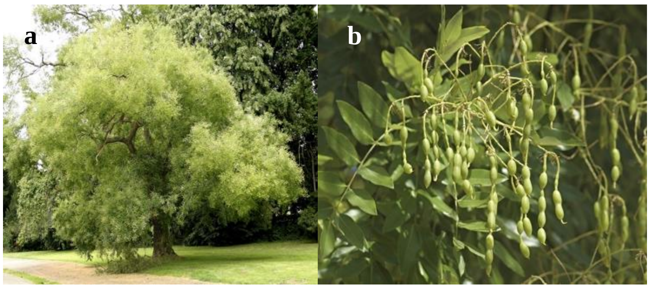

Figure 10. The photos of *Sophora japonica*[a69-b70]

Sophora japonica, the **Japanese pagoda tree [71]** (also called the **Chinese scholar tree** and **pagoda tree;** syn. *Styphnolobium japonicum)* is a species of lovely tree.

Zhang et al. [72] selected nine plant species for their research from among the dominant roadside plant species: two shrubs (*Euonymus japonicus, Rosa chinensis*), one climber species (*Parthenocissus quinquefolia*), and six tree species, including two conifers (*Pinus tabuliformis, Sabina chinensis*) and four broadleaved trees (*Sophora japonica*, *Ulmus pumila*, *Populus sp., and Ginkgo biloba*).

Sophora japonica, with its unique morphological characteristics, including significant trichomes, a dense network of grooves, and a complex cuticular wax layer, displayed the topmost PM capture capacity [73]. Needles of some species of conifers have thicker wax layers that contribute to PM deposition, suggesting that these species may have a high capacity for accumulating PM [74-76]. PM capture efficiency (362.98 µg/cm^2) and its wax layers could trap large amounts of $PM_{2.5}$; this high potential is essential for successful phytoremediation. *Sophora japonica* also showed the largest APTI (air pollution tolerance index) at both sites (traffic pollution and water reservoir). Combining the effect size of air pollution on membrane lipid peroxidation with APTI might better reflect plants' tolerance to air pollution. Shi et al. [77-78] reached the same result about *Sophora japonica* in their research.

Yue et al. [79] investigated the retention characteristics of five tree species' water-soluble and water-insoluble particulate matter in Beijing, China. They found that *Sophora japonica* has high PM (water-soluble PM and water-insoluble PM) capacities.

The team made a significant comparison in a unique study about the NOx absorption ability of *Sophora japonica* [80]. They explored the nitrogen contribution of traffic-related NOx at the road-adjacent sites (23.0%), which was higher than that of traffic-related NOx at sites far from the road (16.4%). This comparison highlighted the influence of traffic-related NOx emissions on the *S. japonica* in near-road green spaces, characterized by lower δ15N values.

3.2 *Salix babylonica*

Figure 11. The photos of *Salix babylonica* [a81-b82]

*Salix babylonica***,** known as **Babylon willow** or **weeping willow in public,** is a species of willow growing wildly in northern China but cultivated for millennia elsewhere in Asia, being traded along the Silk Road to southwest Asia and Europe. [83-84]

In a research of Wang et al. [85], measured the retention capacity of *Ulmus pumila, Salix babylonica, Ginkgo biloba*. The accumulation of $PM_{2.5}$ of *Salix babylonica* was detected as high after *Ulmus pumila* because it has a thin wax film and wax tubes.

Luo et al. [86] conducted a dynamic analysis of the retention ratio of six tree species, including *Salix babylonica*, in rainfall conditions. This research compared the broad-leaved trees (*Salix babylonica, Acer elegantulum*) with needle-leaved trees (*Pinus tabuliformis* and *Pinus bungeana*). The findings, which revealed the stronger ability of needle-leaved trees to retain $PM_{2.5}$ than broadleaved trees and the unique prismatic structure of their leaves, have significant practical implications for environmentalists and researchers alike.

Liu et al. [87] meticulously studied different PM types' retention capacity and efficiency. Their thorough research involved measuring the PM retention efficiencies of easily removable (ERP), difficult-to-remove (DRP), and total removable (TRP) particles on the leaf retention efficiency (AE_{leaf}). They found that *Pinus tabuliformis* absorbs particles with the largest average diameter (34.2 µm), followed by *Ginkgo biloba* (20.5 µm), *Sabina chinensis* (16.4 µm), *Salix babylonica* (16.0 µm), and *S. japonica* (13.1 µm). The high retention efficiencies of *S. babylonica* and *P. tabuliformis* for different particulate matter sizes (TRP and ERP of $PM_{2.5–5}$ and $PM_{5–10}$, and $PM_{>10}$ and TSP with the highest AE_{leaf}) further validate the meticulousness of their research.

In the research of Yue et al. [79], *Salix babylonica* has a high retention capacity of water-soluble PM (WSPM) after *Sophora japonica*. The water-insoluble PM (WIPM) comes after *Sophora japonica* and *P. tabuliformis*.

3.3 *Ginkgo biloba*

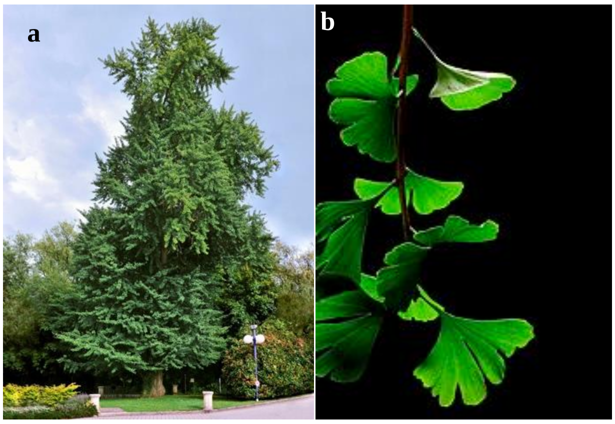

Figure 12. The photos of *Ginkgo biloba* [ab 88]

Ginkgos are enormous trees, typically coming to a height of 20–35 m [89], with some China specimens reaching over 50 m (165 ft). Their branches have an angular crown shape and are long and somewhat erratic. The tree is usually deep-rooted and invulnerable to wind and snow damage.

According to Zhang et al. [72], *Ginkgo biloba* trapped the lowest amount of PM, and the grooves on its leaf surfaces were the sparsest. In the study of Yue et al. [79], *Ginkgo biloba* has the third highest retention capacity of water-soluble PM (WSPM) after *Sophora japonica* and *Salix babylonica*. *Ginkgo biloba* has the second lowest retention capacity of water-insoluble PM (WIPM) after *S. chinensis*. Liu et al. [87] have found moderate retention efficiency in *Ginkgo biloba*. Wang et al. [85] also studied on this plant. After their experiments, they determined that the thick wax tubes of *Ginkgo biloba* reduced the interface area for locating particles and had the least capacity for PM capture.

3.4 *Sabina chinensis*

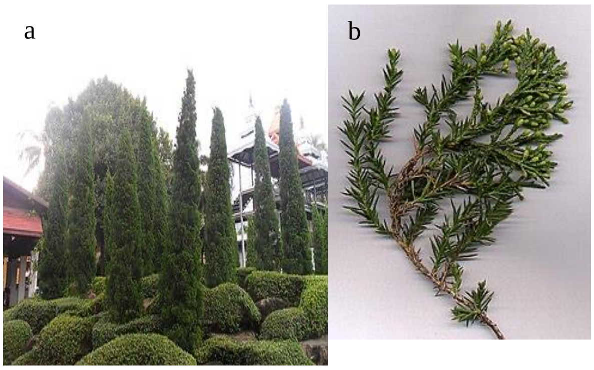

Figure 13. The photos of *Sabina chinensis* [ab 90]

Sabina chinensis (syn. Juniperus chinensis [91]) is a famous ornamental tree or shrub suitable for gardens and parks. It lives in harsh coastal conditions of hot sun and sandy, fast-draining soils.

Xie et al. [92] studied the PM retention of different trees (*Cedrus deodara, Acer palmatum, Sabina chinensis, Metasequoia glyptostroboides, Buxus sinica, Magnolia grandiflora*) under various wind conditions. The ranking of PM retention is *Cedrus deodara* > *Acer palmatum* > *Sabina chinensis* > *Metasequoia glyptostroboides* > *Buxus sinica* > *Magnolia grandiflora*, i.e., *Sabina chinensis* has the third-most PM retention capacity. In Liu et al.'s [87] investigation, *Sabina chinensis* was third in the particular absorption ranking after *Pinus tabuliformis* and *Ginkgo biloba*. However, Yue et al.'s research revealed that *Sabina chinensis*'s water-soluble and water-insoluble retention efficiency had the lowest values compared with the other studied plants. In another different concept of PM retention research [72], *Sabina chinensis* and *P. tabuliformis* had high PM as the in-wax PM (PMWT) at both sites (traffic pollution and water reservoir), showing that conifers can potentially catch a significant amount of PM in their thicker wax layers.

4. CONCLUSIONS

Air-phytoremediation is a research field with a vast literature collection. The studies accelerate after the 2000s. As a result of our literature survey, we encountered the removal capacity of indoor pollutants on 140 plants. Some plants' removal efficiency has been studied against all indoor pollutants. Only one or two indoor pollutants for some. Different techniques and, depending on that, various units have been used to measure removal capacity, like µmol in 72 hours, mmol/ d cm^2-leaf area, and µg/m^3h cm^2-leaf area. Since then, we have made a column graphic using only the removal data [36], which have the same units to summarize the removal efficiency of plants for some indoor pollutants (Figure 14-16).

According to the review by Bandehali et al. [97], recommended Peace Lily (*Spathiphyllum*), Ficus species (*Ficus Decora* Burgundy), Calathia (Calathia Species), Dieffenbachia (Dieffenbachia Species), Golden Pothos (*Epipremnum aureum*) against **ozone** indoor pollutant; *Schefflera actinophylla* and *Ficus benghalensis* against **toluene and xylene**; *Hedera helix* against **only toluene**; *Syngonium podophyllum, Sansevieria trifasciata, Euphorbia milii, Chlorophytum comosum, Epipremnum aureum, Dracaena sanderiana, Hedera helix, Clitoria ternatea* against **benzene**; ficus; golden pothos; spider fern; Christmas cactus (*Schlumbergera x buckleyi*) against **trichloroethylene, tetrachloroethylene 1,2-dichloroethane benzene, toluene m, p-xylene**, Spider plants (*Chlorophytum comosum L.*) against **PM**; *Aloe vera, Sansevieria masoniana, Sansevieria trifasciata, Sansevieria hyacinthoides, Sansevieria ehrenbergii, Kalanchoe blossfeldiana, Dracaena deremensis, Codiaeum variegatum, Chlorophytum comosum, Dracaena sanderiana, Cordyline fruticosa, Aglaonema commutatum* against **toluene, ethylbenzene**; *Chamaedorea seifritzii, Aglaonema modestum, Hedera helix, Ficus benjamina, Gerbera jamesonii, Dracaena deremensis, Dracaena marginata, Dracaena massangeana, Sansevieria laurentii, Spathiphyllum, Chrysanthemum morifolium, Dracaena deremensis* against **benzene, trichloroethylene, formaldehyde;** Golden Pothos against **formaldehyde**.

Although it has been inferred that plants give us clean indoor air from the considerable research collection, the research is still limited. The experiments were conducted in sealed and controlled chambers [98]. The conditions within sealed chambers do not scale up to those of natural indoor environments, which have high AER (air exchange rate), large volumes, and persistent VOC emissions. The conclusion of Cummings & Waring [38] that plants have an unimportant effect on indoor VOC loads is coherent with the results of field works that did not notice actual VOC decreasing when plants were planted in buildings. Regardless of potted plants not considerably changing indoor VOC concentrations, conducting chamber experiments on plants can remain a significant effort. There is still much to be acquired information about the mechanisms of botanical uptake of VOCs. Extended laboratory and field investigations must evolve a more outright and nuanced understanding of the coaction between plants and indoor environmental outcomes.

Considering the removal capacity of outdoor pollutants by plants, the research is concentrated on PM removal. Outdoor plants, trees, shrubs, meadows, and other plants have been studied. According to our literature survey, the PM retention capacity of 136 plants has been researched. Leaf roughness, cuticle characteristics, and ability to absorb moisture are essential for PM retention and caught by plants. However, not only the morphological conditions but also the physiological and developmental properties of leaves, in addition to the plant flowering form, the meteorological conditions, the traffic flows, the distance to the source, and the PM characteristics, make the processes of accumulation, wash-off, and resuspension of PM more difficult than expected, and its effect on air quality, demanding and complex [78]. It is found that, like Beckett et al. [99] and the other outdoor research, all trees examined captured large quantities of airborne particulates from the health-damaging size fractions (particle diameters of 10-2.5 µm, 2.5-1 µm, and <1 µm). For example, coniferous species were found to trap more particles than broad leaves, with pines (Pinus spp.) capturing significantly more material than cypresses (Cupresses spp.). Trees near a busy road caught substantially more material from the huge particle size fraction than those at a rural background site.

Beckett et al. [99] drew the main conclusions from their study as follows:

- Trees can trap an important amount of health-damaging particles from the atmosphere, potentially improving local air quality.

- Their study reveals significant species differences in trees' ability to capture pollutant particles, suggesting that conifers may be the most effective choice for pollution-control plantings.

- Among the broad-leaved species they studied, those with rough leaf surfaces demonstrate the highest effectiveness in capturing particles, a crucial finding for future planting decisions.

While significant research has been done on the air-cleaning ability of various plants, there is an urgent need for more experimental studies using diverse methods. As researchers, we aim to identify the most effective air-cleaning plants, such as Chlorophytum comosum, Chrysanthemum morifolium, Dieffenbachia compacta, and Epipremnum aureum, enhance their cultivation conditions, and potentially create fast-growing plants that can thrive in extreme conditions and have a high capacity for removing air pollutants.

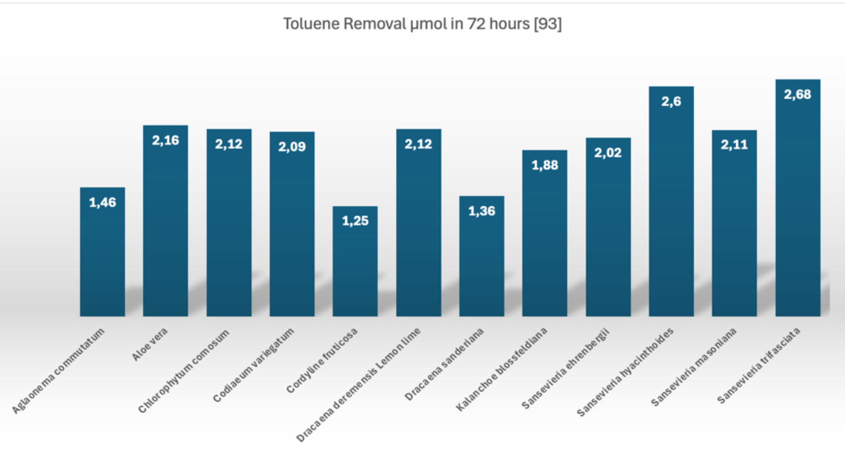

Figure 14 Toluene Removal of some plants (µmol in 72 hours)

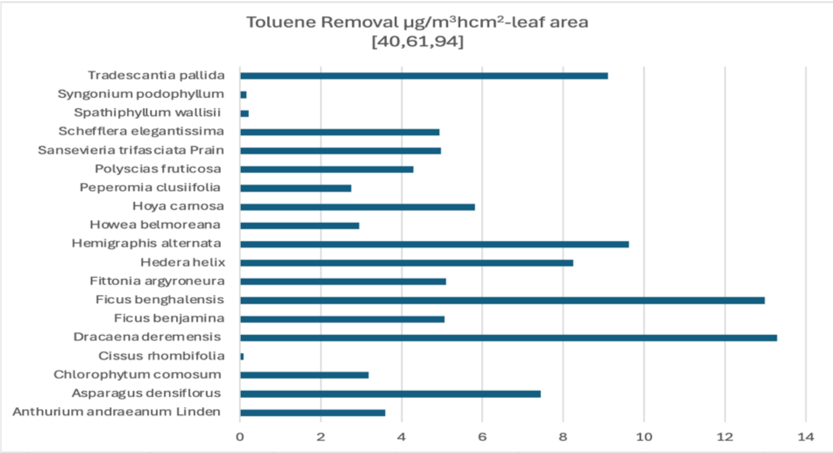

Figure 15 Toluene Removal of some plants (µg/m^{3}hcm^2-leaf area)

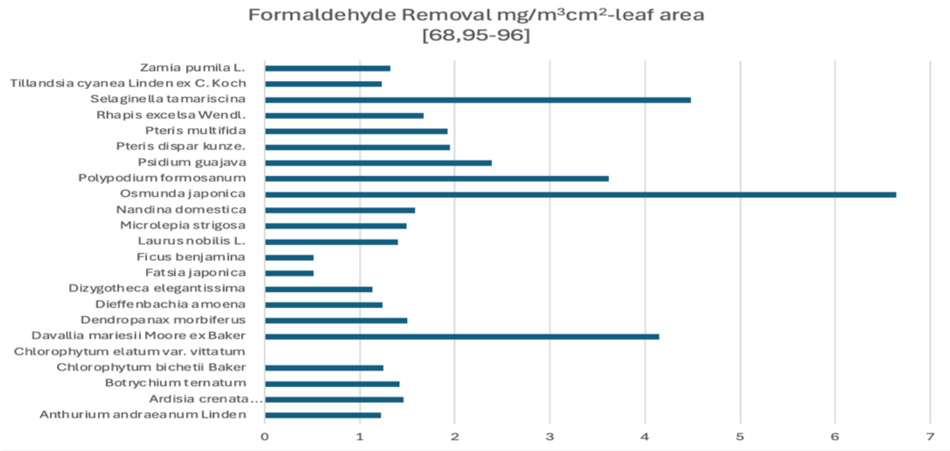

Figure 16 Formaldehyde Removal of some plants (mg/m^{3}cm^2-leaf area)

REFERENCES

[1]https://www.who.int/health-topics/air-pollution#tab=tab_1

[2] B. Cuma Air pollution and Controlling Lecture Notes Istanbul University, Faculty of Engineering, Department of Environment Engineering

[3] WHO global air quality guidelines. Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization. Licence: CCBY-NC-SA3.0IGO, 2021.

[4] T. Oğuz Can, Chap. 3: "Air Pollution and Atmosphere" Ankara University Environmental Pollution Lecture Notes.

[5]The fact sheet on ground-level ozone pollution, Ministry of Environment and Urbanization, General Directorate of Environmental Management, 2014.

[6]S. Oesch, M. Faller, Environmental effects on materials: The effect of the air pollutants SO_2, NO_2, NO and O_3 on the corrosion of copper, zinc and aluminium. A short literature survey and results of laboratory exposures, Corrosion Science, 39(9), 1505-1530, 1997.

[7] WHO guidelines for indoor air quality: Selected Pollutants. Geneva: The World Health Organization European Center for Environment and Health, Bonn Office, 2010.

[8] Kirkeleit J Riise T, Bråtveit M E Moen B Increased risk of acute myelogenous leukemia and multiple myeloma in a historical cohort of upstream petroleum workers exposed to crude oil. Cancer Cause Control, 2008, 19:13–23.

[9] Pandey AK Bajpayee M , Parmar D , Kumar R, Rastogi S K , Mathur N , Thorning, P, de Matas M, Shao Q, Anderson D, Dhawan A, Multipronged evaluation of genotoxicity in Indian petrol- pump workers. Environmental and Molecular Mutagenesis, 2008, 49:696–707.

[10] Noisel N, Bouchard M, Carrier G. Evaluation of the health impact of lowering the formaldehyde occupational exposure limit for Quebec workers. Regulatory Toxicology and Pharmacology, 2007, 48:118–127.

[11] Bell ML Peng R D, Dominici F, and Samet J M Emergency hospital admissions for cardiovascular diseases and ambient levels of carbon monoxide: results for 126 United States urban counties, 1999–2005. Circulation, 2009, 120:949–955.

[12] North DW, Abdo K M, Benson J M , Dahl A R , Morris J B , Renne R , Witschi H, A review of whole animal bioassays of the carcinogenic potential of naphthalene. Regulatory Toxicology and Pharmacology, 2008, 51:S6–14.

[13] Barck C, Lundahl J , Halldén G , Bylin G , Brief exposures to NO2 augment the allergic inflammation in asthmatics. Environmental Research, 2005, 97:58–66.
[14] Peluso M, Munnia A, Hoek G, Krzyzanowski M, Veglia F, Airoldi L, Autrup H, Dunning A, Garte S, Hainaut P, Malaveille C, Gormally E, Matullo G, Overvad K, Raaschou-Nielsen O, Clavel-Chapelon F, Linseisen J, Boeing H, Trichopoulou A, Trichopoulos D, Kaladidi A, Palli D, Krogh V, Tumino R, Panico S, Bueno-De-Mesquita H B, Peeters P H, Kumle M, Gonzalez C A, Martinez C, Dorronsoro M, Barricarte A, Navarro C, Quiros J R, Berglund G, Janzon L, Jarvholm B, Day N E, Key T J, Saracci R, Kaaks R, Riboli E, Vineis P, DNA adducts and lung cancer risk: a prospective study. Cancer Research, 2005, 65:8042–8048.
[15] Darby S, Hill D , Auvinen A, Barros-Dios J M , Baysson H, Bochicchio F, Deo H , Falk R, Forastiere F, Hakama M, Heid I, Kreienbrock L, Kreuzer M, Lagarde F, Mäkeläinen I, Muirhead C, Oberaigner W, Pershagen G,Ruano-Ravina A , Ruosteenoja E, Rosario A S, Tirmarche M, Tomáscaron L, Whitley E, Wichmann H-E, Doll R, Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. British Medical Journal, 2005, 330:223–227.
[16] Dry cleaning, some chlorinated solvents and other industrial chemicals. Summary of data reported and evaluation. Lyon, International Agency for Research on Cancer, 1995 (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 63).
[17] Lauwerys R, Herbrand J , Buchet J P, Bernard A, Gaussin J, Health surveillance of workers exposed to tetrachloroethylene in dry-cleaning shops. International Archives of Occupational and Environmental Health, 1983, 52:69–77.
[18] P. J. Irga, T. J. Pettit, F. R. Torpy, The phytoremediation of indoor air pollution: a review on the technology development from the potted plant through to functional green wall biofilters Rev Environ Sci Biotechnol 17:395–415,2018.
[19] Federico Brilli, Silvano Fares, Andrea Ghirardo, Pieter de Visser, Vicent Calatayud,Amalia Muñoz,Isabella Annesi-Maesano, Federico Sebastiani, Alessandro Alivernini, Vincenzo Varriale, and Flavio Menghini, Plants for Sustainable Improvement of Indoor Air Quality Trends in Plant Science, 23(6), 2018.
[20]Sowa,J.Hendiger,J.Maziejuk,M.Sikora,T.Osuchowski, Ł.Kamin´ska, H. Potted plants as active and passive biofilters improving indoor air quality. IOP Conf. Ser. Earth Environ. Sci., 290, 012150,2019.
[21] Bui, H.-T. Park, J. Lee, E. Cho, W. Kwon, H. Park, B.-J. Assessment of the Air Cleaning Performance and Humidity and Temperature Control by Five Evergreen Woody Plants. Atmosphere,14,1819, 2023.
[22] Niza, I.L. de Souza, M.P. da Luz, I.M. Broday, E.E. Sick building syndrome and its impacts on health, well-being and productivity: A systematic literature review. Indoor Built Environ. 2023.
[23] Deng, L. Deng, Q. The basic roles of indoor plants in human health and comfort. Environ. Sci. Pollut. Res. Int., 25, 36087–36101, 2018.
[24] Gubb, C. Blanusa, T. Griffiths, A. Pfrang, C. Interaction between plant species and substrate type in the removal of CO_2 indoors. Air Qual. Atmos. Health, 12, 1197–1206, 2019.
[25] Wu, Y. Zhong, H. Li, J. Xing, J. Xu, N. Zou, H. Water use efficiency and photosynthesis of Calamagrostis angustifolia leaves under drought stress through CO_2 concentration increase. J. Plant Interact., 17, 60–74,2022.
[26] Dominici, L. Fleck, R. Gill, R.L. Pettit, T.J. Irga, P.J. Comino, E. Torpy, F.R. Analysis of lighting conditions of indoor living walls: Effects on CO_2 removal. J. Build. Eng., 44, 102961, 2021.
[27] Zhang, Z. Tao, S. Zhou, B. Zhang, X. Zhao, Z. Plant stomatal conductance determined transpiration and photosynthesis both contribute to the enhanced negative air ion (NAI). Ecol. Indic., 130, 108114,2021.
[28] Cummings, B.E. Waring, M.S. Potted plants do not improve indoor air quality: A review and analysis of reported VOC removal efficiencies. J. Expo. Sci. Environ. Epidemiol., 30, 253–261, 2020.
[29] B. Zhang, D. Cao, S. Zhu, Use of Plants to Clean Polluted Air: A Potentially Effective and Low-Cost Phytoremediation Technology "Editorial: Air phytoremediation," BioResources 15(3), 4650-4654, 2020.
[30] Gawronski, S. W., Gawronska, H., Lomnicki, S., Saebo, A., and Vangronsveld, J., "Plants in air phytoremediation," in: Advances in Botanical Research, Academic Press, Vol. 83, pp. 319-346, 2017.
[31] Omasa, K., Saji, H., Youssefian, S., and Kondo, N. (eds.), Air Pollution and Plant Biotechnology: Prospects for Phytomonitoring and Phytoremediation, Springer Science & Business Media, 2012.
[32]https://en.wikipedia.org/wiki/Chlorophytum_comosum
[33] Sriprapat, W. Suksabye, P. Areephak, S. Klantup, P. Waraha, A. Sawattan, A. Thiravetyan, P., Uptake of toluene and ethylbenzene by plants: Removal of volatile indoor air contaminants. Ecotoxicol. Environ. Saf., 102, 147–151, 2014.
[34] Sriprapat, W. Thiravetyan, P. Efficacy of ornamental plants for benzene removal from contaminated air and water: Effect of plant associated bacteria. Int. Biodeterior. Biodegrad., 113, 262–268, 2016.
[35] Torpy, F. Zavattaro, M., Irga,P. Green wall technology for the phytoremediation of indoor air: A system for the reduction of high CO_2 concentrations. Air Qual. Atmos. Health, 10, 575–585, 2016.
[36] M-H. Yuan, S. Kang, K-S. Cho, A review of phyto- and microbial-remediation of indoor volatile organic compounds, Chemosphere 359, 1421202024.
[37] Xu, Z.J., Wang, L., Hou, H.P., Formaldehyde removal by potted plant-soil systems. J. Hazard Mater. 192, 314–318, 2011.
[38] Sriprapat, W., Boraphech, P., Thiravetyan, P., Factors affecting xylene-contaminated air removal by the ornamental plant Zamioculcas zamiifolia, Environ. Sci. Pollut. Res. 21, 2603–2610, 2014.
[39] Siswanto, D., Permana, B.H., Treesubsuntorn, C., Thiravetyan, P., Sansevieria trifasciata and Chlorophytum comosum botanical biofilter for cigarette smoke phytoremediation in a pilot-scale experiment- evaluation of multipollutant removal efficiency and CO_2 emission. Air Qual. Atmos. Health 13, 109–117, 2020.

[40] Yang, D.S., Pennisi, S.V., Son, K.C., Kays, S.J., Screening indoor plants for volatile organic pollutant removal efficiency. Hortscience 44, 1377–1381, 2009.
[41] Gawronska, H. Bakera, B. Phytoremediation of particulate matter from indoor air by *Chlorophytum comosum* L. plants. Air Qual. Atmos. Health, 8, 265–272, 2014.
[42] Irga, P. Paull, N. Abdo, P. Torpy, F. An assessment of the atmospheric particle removal efficiency of an in-room botanical biofilter system. Build. Environ., 115, 281–290, 2017.
[43]https://tr.m.wikipedia.org/wiki/Dosya:Chrysanthemum_morifolium_08NOV.jpg
[44] Aydogan, A., Montoya, L.D.,. Formaldehyde removal by common indoor plant species and various growing media, Atmos. Environ. 45, 1352–2310, 2011.
[45] Wolverton, B., Wolverton, J., Plants and soil microorganisms: removal of formaldehyde, xylene, and ammonia from the indoor environment. J. Miss. Acad. Sci. 38, 11–15, 1993.
[46]https://commons.wikimedia.org/wiki/File:Dracaena_deremensis1.jpg
[47]https://commons.wikimedia.org/wiki/File:Dracaena_deremensis_lemon_lime.jpg
[48] Orwell, R.L., Wood, R.A., Tarran, J., Torpy, F., Burchett, M.D., Removal of benzene by the indoor plant/substrate microcosm and implications for air quality. Water Air Soil Pollut. 157, 193–207, 2004.
[49] Orwell, R.L., Wood, R.A., Burchett, M.D., Tarran, J., Torpy, F., The potted-plant microcosm substantially reduces indoor air VOC pollution: II. Laboratory study. Water Air Soil Pollut. 177, 59–80, 2006.
[50] Mosaddegh, M.H., Jafarian, A., Ghasemi, A., Mosaddegh, A., Phytoremediation of benzene, toluene, ethylbenzene and xylene contaminated air by D. deremensis and O. microdasys plants. J. Environ, Health Sci. 12, 39, 2014.
[51] https://tr.wikipedia.org/wiki/Epipremnum
[52] Cai, N., Wang, X.M., Qiao, Z.Q., Li, Y.X., Zeng, H.J., Liu, S.S., Li, W.D., Absorptive capacity of formaldehyde of three kinds of shade-tolerant plants indoors. Hunan Forestry Sci. Technol. 44, 75–78, 2017.
[53] Kim, K.J., Kil, M.J., Jeong, M.I., Kim, H.D., Yoo, E.H., Jeong, S.J., Pak, C.H., Son, K., Determination of the efficiency of formaldehyde removal according to the percentage volume of pot plants occupying a room. Korean J. Hortic. Sci. Technol. 27, 305–311, 2009. (Korean with English abstract).
[54] Liu, G., Xiao, M., Zhang, X., Gal, C., Chen, X., Liu, L., A review of air filtration technologies for sustainable and healthy building ventilation. Sustain. Cities Soc. 32, 375–396, 2017.
[55] Rodgers, K., Handy, R., Hutzel, W., Indoor air quality (IAQ) improvements using biofiltration in a highly efficient residential home. J. Green Build. 8, 22–27, 2013.
[56] Liu, C., Zhang, N., Sun, L., Gao, W., Zang, Q., Wang, X., Potted plants and ventilation effectively remove pollutants from tobacco smoke. Int. J. Low Carbon Technol. 17, 1052–1060, 2022.
[57] Ibrahim, I.Z., Chong, W.T., Yusof, S., Wang, C.T., Xiang, X., Muzammil, W.K., Evaluation of common indoor air pollutant reduction by a botanical indoor air biofilter system. Indoor Built. Environ. Times 30, 7–21, 2021.
[58] Wang, Z., Zhang, J.S., Characterization and performance evaluation of a full-scale activated carbon-based dynamic botanical air filtration system for improving indoor air quality. Build. Environ. 46, 758–768, 2011.
[59]https://tr.m.wikipedia.org/wiki/Dosya:Hedera_helix_Leaves_3008px.jpg
[60] Chen, L.Y., Lin, M.W., Chuah, Y.K., Investigation of a potted plant (Hedera helix) with photo-regulation to remove volatile formaldehyde for improving indoor air quality. Aerosol Air Qual. Res. 17, 2543–2554, 2017.
[61] Yoo, M.H., Kwon, Y.J., Son, K., Kays, S.J., Efficacy of indoor plants for the removal of single and mixed volatile organic pollutants and physiological effects of the volatiles on the plants. J. Am. Soc. Hortic. Sci. 131, 452–458, 2006.
[62]https://it.wikipedia.org/wiki/File:Starr_070906-9018_Sansevieria_trifasciata.jpg
[63] "Sansevieria trifasciata". World Checklist of Selected Plant Families. Royal Botanic Gardens, Kew. Retrieved 2020-02-18.
[64] "Snake Plant". Better Homes & Gardens. Retrieved 2021-06-15.
[65] Permana, B.H., Thiravetyan, P., Treesubsuntorn, C., Effect of airflow pattern and distance on removal of particulate matters and volatile organic compounds from cigarette smoke using Sansevieria trifasciata botanical biofilter. Chemosphere 295, 133919, 2022.
[66]https://en.wikipedia.org/wiki/Syngonium_podophyllum
[67] Irga, P.J., Torpy, F.R., Burchett, M.D., Can hydroculture be used to enhance the performance of indoor plants for the removal of air pollutants? Atmos. Environ. 77, 267–271, 2013.
[68] Wolverton, B.C., Mcdonald, R.C., Watkins, E.A., Foliage plants for removing indoor air pollutants from energy-efficient homes. Econ. Bot. 38, 224–228, 1984.
[69]https://tr.wikipedia.org/wiki/Dosya:Sophora_japonica_JPG2Aa.jpg
[70] https://tr.wikipedia.org/wiki/Japon_soforası
[71] USDA, NRCS (n.d.). "Styphnolobium japonicum". The PLANTS Database (plants.usda.gov). Greensboro, North Carolina: National Plant Data Team. Retrieved 4 December 2015.
[72] Weiyuan Zhang, Yuzhen Zhang, Jirui Gong, Bo Yang, Zihe Zhang, Biao Wang, Chenchen Zhu, Jiayu Shi, Kexin Yue, Comparison of the suitability of plant species for greenbelt construction based on particulate matter capture capacity, air pollution tolerance index, and antioxidant system, Environmental Pollution 263 114615, 2020.
[73] Leonard, R.L., McArthur, C., Hochuli, D.F., Particulate matter deposition on roadside plants and the importance of leaf trait combinations. Urban For. Urban Green. 20, 249-253, 2016.
[74] Beckett, K.P., Freer-Smith, P.H., Taylor, G., Urban woodlands: their role in reducing the effects of particulate pollution. Environ. Pollut. 99, 347-360, 1998.
[75] Sæbø, A., Popek, R., Nawrot, B., Hanslin, H.M., Gawronska, H., Gawronski, S.W., Plant species differences in particulate matter accumulation on leaf surfaces. Sci. Total Environ. 427-428, 2012.

[76] Sisodia, A., Dutta, S., Air pollution tolerance index of certain plant species: a study of National Highway no-8, India. J. Environ. Res. Devel. 10 (4), 723-728, 2016.
[77] Shi J, Zhang G, An H, Yin W, Xia, X, Quantifying the particulate matter accumulation on leaf surfaces of urban plants in Beijing, China. Atmos Pollut Res 8:836–842, 2017.
[78] E. Chávez-García, B. González-Méndez, Particulate matter and foliar retention: current knowledge and implications for urban greening, Air Quality, Atmosphere & Health 14:1433–1454, 2021.
[79] C. Yue, K. Cui, J. Duan, X. Wu, P. Yan, C. Rodriguez, H. Fu, T. Deng, S. Zhang, J. Liu, Z. Guo, B. Xi, Z. Cao, The retention characteristics for water-soluble and water-insoluble particulate matter of five tree species along an air pollution gradient in Beijing, China, Science of the Total Environment 767, 145497. 2021.
[80] C. Gong, C. Xian, Y. Su, Z. Ouyang, Estimating the nitrogen source apportionment of Sophora japonica in roadside green spaces using stable isotope, Science of the Total Environment 689, 1348–1357.2019.
[81]https://tr.wikipedia.org/wiki/Salix_babylonica
[82]https://identify.plantnet.org/tr/useful/observations/1016702979
[83] Flora of China: *Salix babylonica*
[84]*"Salix babylonica". Germplasm Resources Information Network. Agricultural Research Service, United States Department of Agriculture.* Retrieved 15 December 2017.
[85] Wang H, Shi H, Wang Y . Effects of weather, time, and pollution level on the amount of particulate matter deposited on leaves of Ligustrum lucidum. Sci World J 2015:1–8, 2015.
[86] Luo J, Niu Y, Zhang Y Y Tian, X Zhou, Dynamic analysis of retention PM2.5 by plant leaves in rainfall weather conditions of six tree species. Energy Sources, Part A Recover Util Environ Eff 42:1014–1025, 2020.
[87] J. Liu, Z. Cao, S. Zou, H. Liu, X. Hai, S. Wang, J. Duan, B. Xi, G. Yan, S. Zhang, Z.Jia, An investigation of the leaf retention capacity, efficiency and mechanism for atmospheric particulate matter of five greening tree species in Beijing, China, Science of the Total Environment 616–617417–426, 2018.
[88] https://en.wikipedia.org/wiki/Ginkgo_biloba
[89] *Ansari, Abid A. Gill, Sarvajeet Singh, Abbas, Zahid Khorshid, Naeem, M. Plant Biodiversity: Monitoring, Assessment and Conservation. 2016. CABI.* ISBN 978-1-78064-694-7.
*[90]*https://en.wikipedia.org/wiki/Juniperus_chinensis
[91]https://www.worldfloraonline.org/taxon/wfo-0000437907.
[92] Xie C, Kan L, Guo J, Jin S, Li Z, Chen D, Li X, Che S A dynamic processes study of PM retention by trees under different wind conditions. Environ Pollut 233:315–322,2018.
[93] Sriprapat, W., Boraphech, P., Thiravetyan, P., Factors affecting xylene- contaminated air removal by the ornamental plant Zamioculcas zamiifolia. Environ. Sci. Pollut. Res. 21, 2603–2610, 2014.
[94] Kim, K., Kim, H., Khalekuzzaman, M., Yoo, E., Jung, H., Jang, H., Removal ratio of gaseous toluene and xylene transported from air to root zone via the stem by indoor plants. Environ. Sci. Pollut. Res. 23, 6149–6158, 2016.
[95] Kim, K.J., Jeong, M.I., Lee, D.W., Song, J.S., Kim, H.D., Yoo, E.H., Jeong, S.J., Han, S.W., Kays, S.J., Lim, Y.W., Kim, H.H., Variation in formaldehyde removal efficiency among indoor plant species. Hortscience 45, 1489–1495, 2010.
[96] Kim, K.J., Kil, M.J., Song, J.S., Yoo, E.H., Son, K.l., Kays, S.J., Efficiency of volatile formaldehyde removal by indoor plants: contribution of Aerial plant parts versus the root zone. J. Am. Soc. Hortic. Sci. 133, 521–526, 2008.
[97] Bandehali,S.Miri,T. Onyeaka, H. Kumar, P. Current State of Indoor Air Phytoremediation Using Potted Plants and Green Walls. Atmosphere, ,12,473, 2021.
[98] A. Aydogan, R. Cerone, Review of the effects of plants on indoor environments, indoor and Built Environment, 30(4) 442–460, 2021.
[99] K. Paul Beckett, Peter Freer-Smith, and Gail Taylor, Effective tree species for local air- quality management Journal of Arboriculture 26(1) 12-19, 2000.