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Review Article

Green symbiosis: Exploring the nexus of indoor plants for comprehensive wellbeing

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Abstract
Plants enhance a space's aesthetics and benefit numerous human health and well-being. Indoor plants improve air quality around residential areas by reducing pollutants, increasing humidity levels, and regulating temperature. These plants also reduce stress and anxiety, improve mood, and boost work productivity. Hydroponics, a soilless technique for indoor gardening, can further enhance the transpiration and photosynthesis rates, improving air temperature and humidity. These plants serve as organic air filters that efficiently remove contaminants, including those that can spread viruses like SARS-CoV-2. The presence of indoor plants in indoor environments is linked to improved mental and physical health, making it cost-effective for improving indoor environmental quality. The present review discusses the benefits of incorporating indoor and gardening plants in available indoor or residential spaces, which have been discussed for human well-being and environmental sustainability using previous supporting studies.

Keywords: Covid 19 pandemic, Environment, Indoor plants, Pollution, Psychological health,

INTRODUCTION

Plants that can adapt to growing inside a closed environment or space are called indoor plants or house plants. They can be ferns, begonias, succulents, palms, climbers, etc. Some studies have shown that indoor plants have many benefits. It has a great contribution in improving human health and comfort. Being around plants benefits humans' mental health and capacity to concentrate at work and at home. Studies have shown that when people are surrounded by nature, they do tasks more effectively and accurately, resulting in higher-quality work. Natural surroundings have a soothing influence that promotes effective work environments by increasing one's ability to sustain concentration. School indoor plants excite the senses and mind, improving mental function. The presence of indoor plants in the classroom increases memory and concentration (Li *et al*., 2021).

Indoor plants, a part of nature, are proven to be the finest answer for relieving stress in our lives. The more we interact with nature, the better our health and pre-

sent level of comfort will be. Increasing our engagement with the environment can improve our quality of life and mental health. In recent studies, there has been a greater emphasis on the plant-human link, particularly on outdoor plants and their advantages. Since humans spend 80-90% of our time indoors, our interior environment should be our major priority because it directly impacts our health (Deng *et al*., 2018; Kelly & Fussell, 2019). People who spend more time outside and in nature are much happier than those who spend most of their time inside (White *et al*., 2019). People's mental health and outlook on life improve when they spend time outside among trees and gardening; they feel more alive and energized and are likely to experience stress or depression.

Plants create a pleasant atmosphere; if planted indoors, they develop a positive aura and create a sense of relaxation inside the human body and mind. Most studies show that plants create a path that connects us to nature and develops a feeling of spirituality within a human conscience. The presence of natural elements can create a sense of being cared for. Moreover, a pleasant and soothing view can help control different mood swings and create a place for a happy mind, which can help maintain good health (Parseh *et al*., 2018).

Another advantage of growing plants indoors is that they produce oxygen. According to certain research, transpiration can maintain ambient temperature and humidity (Meng *et al*., 2022), reducing the energy required for air conditioning. Green plant transpiration is thought to be naturally chilly. Maintaining the transpiration rate, in turn, may maintain the air temperature and lower the investment cost for air conditioners, which will not only purify the inner but also maintain the outer temperature (Deng *et al*., 2018).

Maintenance of the indoor environment is crucial since our inner environment is a big and direct contributor to many pollutants, which can seriously harm our health and alter our way of life because we are directly exposed to it (Abbass *et al*., 2017). Photosynthesis is when green plants use carbon dioxide and water to create food and release oxygen in the presence of sunlight (Liu *et al*., 2022). As a result, increasing the rate of photosynthesis can improve the oxygen level in the internal environment while also providing more food (Kafle *et al*., 2022).

Most people now spend 80% of their time indoors. The gases produced by the use of paints and coatings in indoor decorations and furniture, such as formaldehyde (HCHO), benzene, toluene, and xylene, contribute to an increase in Volatile organic compounds (VOCs) levels in the room, which in turn contributes to the cause of many acute diseases, such as Sick Building Syndrome (SBS) and Sick House Syndrome (SHS), which are manifested by nasal, ocular, and cutaneous irritations, respiratory dysfunction, allergies, headache, fatigue and metabolic disorders (Nag and Nag, 2019).

Indoor plants can be considered an inexpensive remedy that lowers the concentration of toxic elements in the surroundings and limits people's exposure to several dangerous substances (Abbass *et al*., 2017; Bandehali *et al*., 2021; Wei *et al*., 2021). It can also reduce some illnesses like dry skin, cough, and sore throat by humidifying the surrounding atmosphere.

Another incredible benefit of growing plants indoors is that they help with noise reduction, which can greatly reduce noise pollution. They can be used as screen plants and are an excellent solution for partitions in busy workplaces or offices. Rather than employing larger indoor plants, a good multiple arrangement of small indoor plants can absorb more noise since the right design properly utilises the surface area. Plants should be placed around the room's perimeters rather than in the center, so that the reflected sound from the wall is absorbed directly by the plants (Moya *et al*., 2019). Commonly used indoor plants, shown in Fig. 1, primarily serve aesthetic and health-related purposes within indoor environments, contributing to better air quality, mental health, and indoor ambience with relatively low maintenance requirements.

INDOOR PLANTS

Role of indoor plants on human health

Human beings have a close relationship with nature, so creating an environment like nature in their indoor space will positively impact health (Deng and Deng, 2018). Most of the time we spend inside house, the indoor environment is important for our health. Indoor plants are also known as houseplant. It includes ornamental, climbers, palms, succulents etc. Several studies have proved that planting indoor plants increases the life expectancy of human beings. Indoor plants have aesthetical, spiritual, and medicinal values. Indoor plant cultivation appears to have created a tranquil and encouraging environment that is assisting people in bettering their psychological and mental health (Fig. 2). Recent studies have shown that indoor plants can reduce psychophysiological stress, improve task performance (Han *et al*., 2022), reduce symptoms of discomfort, reduction in neuropsychological symptoms and mucous membrane symptoms (Liu *et al*., 2022) .

Houseplants add to the amount of oxygen in our home. More oxygen in the air at night is much better for a restful night's sleep (Han *et al*. 2022). Therefore, sleep apnea people should grow indoor plants for better sleep rather than using sleeping drugs. Lavender and jasmine give a lovely scent to the room. Our likelihood of developing a cold and congested nose can be reduced by up to 30% just by adding plants to our living space. Plants achieve this by eliminating dust particles from the air and raising the humidity in the immediate area, such as our room (Meng *et al*., 2022). Plants filter tox-

Fig. 1. *Some of the important indoor plant species*

ins in tobacco smoke. *Spathiphyllum*, better known as the peace lily plant, is a good choice. These plants are an effective and natural way to get rid of cigarette smoke odours and pollutants (Table 1).

Role of indoor plant providing oxygen and purifying oxygen

Keeping indoor plants improves the quality of health and lifestyle. Indoor gardening encompasses landscaping, bonsai, topiary, vertical gardening, training, and trimming, among other things. Indoor vegetation purifies the air. Indoor plants purify the air (El-Tanbouly *et al*., 2021). Phytoremediation requires indoor plants, including Phyto-stabilization, Phytoextraction, Phyto-degradations, Rhizo-filtration, and Phytovolatilization (Kafle *et al*., 2022). Photosynthesis is the process through which fresh oxygen is released into the atmosphere. Indoor plants release microscopic water droplets into the air through stomata, which increases humidity (Liu *et al*., 2022). However, at high humidity, the transpiration rate of plants slows down, keeping the interior humidity at safe levels for people (Meng *et al*., 2022). The most economical way to remove air pollutants such carbon dioxide, volatile organic compounds (VOC), carbonyl, particulate matter, organic compounds, nitrates, sulphates, ammonia, calcium, ozone, and carbonate from the air inside a building is by using indoor plants. Benzene is a chemical compound used in paints (Sarigiannis *et al*., 2019). This chemical compound is health hazardous. Most of the time, we stay at home inhaling this chemical compound indirectly leads to asthma, bronchitis, reduced pollutants levels, particularly the elimination of formaldehyde, benzene and toluene, were the main effects of the potential of indoor plants on air quality, followed by an increase in humidity and a drop in temperature (Irga *et al*., 2018). Studies reveal that the four indoor ornamental plants are effective in benzene removal efficiency that is *Epipremnum aureum*, *Chlorophytum comosum, Hedera helix* and *Echinopsis tubiflora* (Gong *et al*., 2019). Using indoor plants is a contemporary method of removing biological and chemical air pollutants. Plants are employed as an efficient environmental cleaner in a process called "Phytoremediation," which can be conducted in several ways (Kafle *et al*., 2022).

Indoor plants are regarded as natural air filters since they may clean the air by a number of procedures, such as assimilation, neutralization, precipitation, and purification (Kim *et al*., 2018; Lee *et al*., 2020). By taking in carbon dioxide and expelling oxygen, plants are known to purify the air through a process called photosynthesis. Respiration is a further method through which plants absorb oxygen and release carbon dioxide. Air penetrates and escapes the stomata during respiration and photosynthesis because they are the major instrument that plants use in absorbing and filtering procedures. Plants can absorb airborne pollutants and contribute to the ecological balance of the atmos-

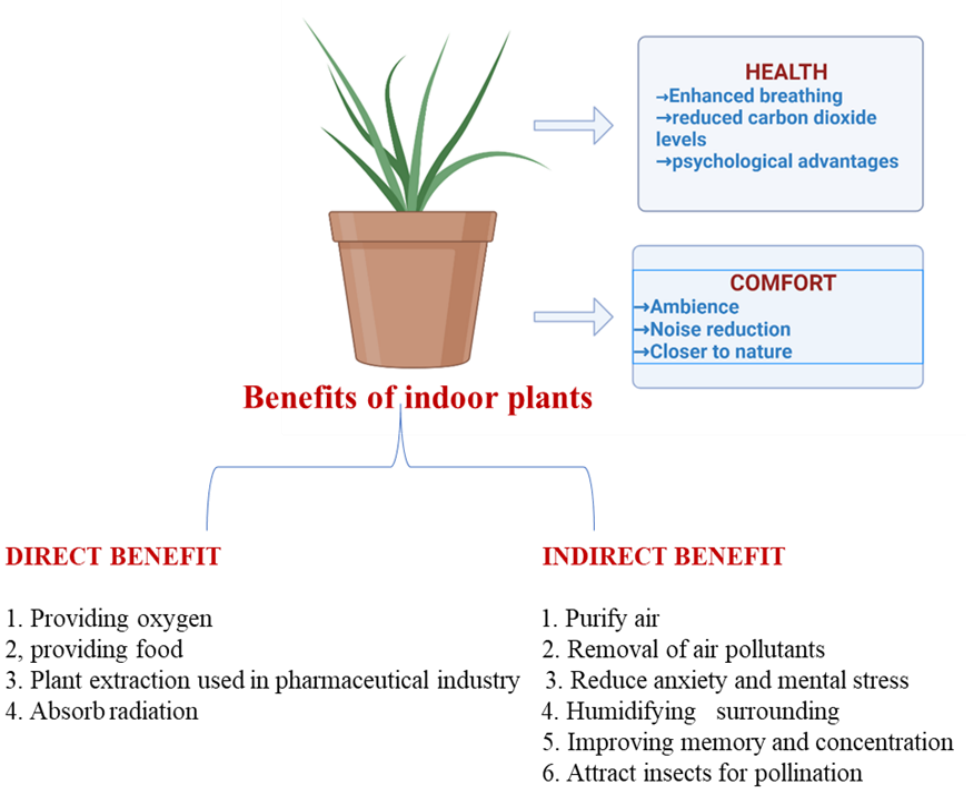

Fig. 2. *Unveiling benefits and impacts of indoor plants in relation to health environment and comfort.*

phere (Agarwal *et al*., 2019). Indoor vegetation can be regarded as an inexpensive solution that reduces indoor pollution levels and people's vulnerability to several hazardous compounds (Abbass *et al*., 2017; Parseh *et al*., 2018; Wei *et al*., 2021). Plants can release trace amounts of bioactive molecules and associated by-products, such as alkaloids and polyphenols, into the environment. This activity, which is one of the ways the plant interacts with neighbouring environmental practices, can be affected by allelochemicals, which are aerial microbes neighbouring to a plant (Mushtaq *et al*., 2019). These compounds were claimed to have antibacterial effects (Othman *et al*., 2019).

Most studies indicate that having plants around can increase productivity and be linked to good sentiments. Additionally, they might support overall health by decreasing blood pressure, perceived stress and sick-building syndrome and improving the patient's pain tolerance (Yeo, 2021). Rooms or offices with indoor plants oxygenate surroundings, thus reducing headaches and improving office performance and focus. Foliage plants can elicit positive health outcomes in an indoor environment with greater stabilization of prefrontal cortex activity and autonomic nervous activity (Jo *et al*., 2019).

Role of Indoor plants in air purification

Indoor plants act as natural air purifiers because they can clean the air through various processes, such as absorption, dilution, condensation, and filtration (Kim *et al*., 2018; Lee *et al*., 2020). Plants can remove pollutants from the air, including carbon dioxide, organic volatile substances, dust particles, biomolecules, calcium, carbonate, nitrates, sulphates, and ammonia.

According to studies, plants can absorb minute atmospheric water vapour particles, increasing interior space humidity (Liu *et al*., 2022). Plants may maintain the ecological equilibrium in the air by consuming atmospheric molecules (Agarwal *et al*., 2019). It is also believed that indoor relative humidity (RH) has a significant role in the relationships that develop between people, viruses, and plants. The typical range of internal relative humidity for human comfort is between 30 and 60%, and 40–60% appears to minimize viral spread (Audi *et al*., 2020). Plants can suppress the bioaerosols by raising humidity through foliar water absorption under humid conditions (Brilli *et al*., 2018; Chiam *et al*., 2019). Indoor plants can reduce the amount of airborne germs in a room by 50% when compared to a room without them (Fig 3). Research indicated that compared to a room without plants, a hydroponic planter system including 15 distinct houseplant species was able to, directly and indirectly, inhibit the development of airborne microorganisms. Volatile compounds emitted by houseplants might be the primary factor in reducing the number of airborne microbes in settings with plants (Irga *et al*., 2018).

Table 1. Indoor plants and their health benefits

Plants	Effect on health	References
Rosemary plant (Salvia Rosmarinus)	Reduce anxiety; this is due to the strong and heady scent of the plant.	El-Tanbouly et al.(2021); Gong et al. (2019); Han et al. (2022)
Aloe Vera (Aloe barbadensis)	Good for skin, exhale oxygen at night	
Lemon balm and Hyssop (Melissa officinalis)	Managing the symptoms of cold and flu	
Rubber tree, Hedera helix (Hevea brasiliensis)	Increase the performance of students in classroom	
Lavandula bipinnata , Euphorbia pulcherrima, Alocasia antiquorum, Gerbera jamesonii,	Enhanced human comfort	
Hymenocallis littoralis	Remove harmful chemicals from air, such as carbon monoxide, xylene, formaldehyde and toluene	

Role of Indoor plants in reducing stress and anxiety

Overthinking is the root cause of many diseases. Self-isolation during covid 19 lockdown resulted in stress and anxiety (Table 1). Stress reduces dopamine levels in the body, resulting in sleep deprivation. Indoor plants positively affect anxious emotions and other negative emotions caused by self-isolation at home (Yan *et al*., 2022). The inhabitants spend 80% of their indoor time indoors, especially children, who are increasingly ill at an early age due to limited fresh air, humid environment, and fragrance. Indoor planting generates additional income by growing and selling the plants from the propagating structure.

Role of indoor plants in providing food

Continued use of chemical fertilizers on crops causes serious health complications such as cancer and food allergies. Growing houseplants on your roof terrace or in your vegetable garden ensures you get a crop free of pesticides and insecticides. Save money by lowering the cost of shopping at the market. Biodegradable waste from your kitchen can be used to grow houseplants instead of throwing it in the trash. Growing short-duration or early-maturing varieties of crops will fulfil the daily requirements of vegetables and fruits. Growing crops in indoor hydroponics systems, like strawberries and lettuce, will generate additional income to the family. Rapid industrialization and urbanization have led to a shortage of arable land. Growing indoors is, therefore, a sustainable farming method to feed your family in the future (Avgoustaki and Xydis, 2020).

Role of indoor plants in pollination

Indoor ornamental fragrant plants attract insects, thus facilitating the process of pollination. Establishing a bee hive near the flower source will attract bees and provide honey, bee wax, and bee venom. Bee venom can be used for the treatment of rheumatoid arthritis. Honey can be used to treat coughs, and bee wax can be used to prepare cosmetics. Certain indoor plants absorb this radiation, like asparagus fern, fiddle leaf, and areca palm (Francini *et al*., 2022).

Role of Indoor plants in providing different pharmaceutical products

Indoor plant like sarpagandha contains serpentine used to treat hypertension as a sedative (reduce nervous excitement). Neem contains azadiractin used for diabetic treatment; periwinkle contains vinblastine used as a tranquilizer (blood pressure control) and cancer therapy; aloe contains aloin oil used as a skin tonic and herbal cosmetics, *mulathi* contains glycyrrhizin used to cure intestinal and peptic ulcer. Lemon balm plant helps in treating cold and flu. Some indoor plants are aromatic plants with medicinal values (Boukhatem and Setzer, 2020). This includes Java Citronella, which contains oil citronellal and is used as mosquito repellent, offering both fragrance and functionality to indoor spaces.

Role of Indoor plants in hospital for fast recovery

Indoor plants and natural scenery were pleasing to the eye, eliciting feelings of relaxation and positive emotions, contributing to opportunities for reflection and contemplation. They express a feeling of connectedness to nature: a feeling of wholeness and spirituality elicited by the elements of nature. They also express that the presence of natural elements contributed to a sense of being cared for. Certain indoor plants like orchids, succulents, and plumeria absorb carbon dioxide and release oxygen even during the night, making them ideal for keeping in the bedroom and other places in the house (Chaudhary, 2022). Other plants like Areca palm, Snake plant and peace lily, each with their unique charm, grace any space with verdant elegance, purify the air and soothe the soul.

Role of Indoor plants in COVID-19 epidemic

Over the past two decades, new strains of retroviruses have been identified that seriously threaten public health. At the end of 2019, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) appeared with a high infection rate and a significant impact on human health: 5% of infected people are hospitalized and 3.81 million deaths worldwide (El-Tanbouly *et al*., 2021). Aerosol particles containing virions are considered the main source of SARS-CoV-2 infection. Different techniques such as filtration and radiation can be used to clean the air of bio-pollution; however, these methods are expensive and unsuitable for home use (Yao, 2022). Another air purification method is that houseplants can clean the air by removing air pollutants and common airborne microbes (Morawska *et al*., 2020). The use of indoor plants could prove to be a cost-effective way to clean indoor air, which can be adapted to different environments without special requirements and can also add aesthetic value, indirectly affecting human health (Greenhalgh et al., 2021).

The COVID-19 epidemic has significantly altered people's capacity to once again live outdoors. Most national governments had issued stay-at-home directives (Gostin and Wiley, 2020; Petersen *et al*., 2020). Due to the positive effects of exposure to green spaces in public outdoor areas on mental health, restrictions on outdoor activities were likely to worsen the pandemic's psychological impacts. It has been shown that practices including appropriate aeration, preventing air cycling, restricting the number of individuals in indoor places, and air purification techniques can aid in controlling the transmission of these viruses (Morawska *et al*., 2020). By controlling indoor moisture levels, plants can most likely contribute to a reduction in SARSCoV-2 infection. Small rooms can have their humidity levels managed by using indoor plants, which lowers the SARS stability in fine particulates and reduces the speed of infection (Othman *et al*., 2019).

Role of Indoor plants in psychological benefits

People claim to feel better overall while plants are around, but in actuality, they are experiencing the physiological effects of the psychological benefits (Song *et al*., 2018). Via a range of psychological underlying mechanisms and routes, such as reduced stress or improved cognitive capacities, people and ecology can interplay to boost psychological state (Bratman *et al*., 2019). While affective reactions to visually pleasant stimuli may help people decompress and decrease stress, the positive benefits of indoor plants may be attributable to their aesthetic value (Zhong *et al*., 2022). Other ecological systems and advantages that partially correlate with psychological advantages include the advancement of the quality of indoor air or heat exchange (i.e., the uptake of hazardous risky compounds and elements, rapidly increasing moisture content, and declining heat in the home), that in fact also influences

Fig. 3. *Showing different types of indoor plants and their examples along with their suitable characteristics to be grown as indoor plants*

Table 2. Indoor plant species type that supports health benefits

Plant Species type	Indoor location	Kind of changes noticed	Reference
Hoya sp., Philodendron scandens, Aglaonema sp., Dracaena trifasciata	Computer labs: desk, floor, potted plants that swing.	Lower blood pressure, better ability to concentrate, increased attentiveness after work, and up to 14% improvement in computer-based performance.	Treesubsuntorn et al. (2021)
Epipremnum aureum, Philodendron hederaceum, Aglaonema commutatutm Schott	In the workplace, a potted plant was placed on a window seat.	The issues related to cold, tiredness, sore throat, cough, and dry skin have decreased.	Islam et al. (2021)
Dracaena fragrans cv. Massangeana	Location 1: A room with potted plants. Location 2: A bookcase stocked with books. Location 3: Neither a bookcase nor a plant are present.	When subjected to plants, female individuals performed better than male individuals. The male and female both felt their energy level drop when there were no items in the area.	Peck (2021)
Tradescantia spathacea, Zanzibar gem	Hospital waiting room with indoor plants and their posters.	Patients' stress levels were reduced as a result of them since the interior plants and posters improved the room's atmosphere.	Han and Ruan (2019)
Epipremnum pinnatum, Aglaonema sp.	Indoor plants in classrooms and hallways.	Regular contact with plants enhanced the therapeutic effects of stress.	Lee and Koo (2018); Panossian et al. (2021)

human emotions because of their intimate connection to people's body states (Bratman *et al*., 2019). Also, it has been demonstrated that inhabitants of indoor plant habitats have a decrease in overall mortality, notably from circulatory illnesses (Aerts *et al*., 2018).

Several studies have found that plants promote psychological healing by acting as visual elements in the environment that stimulate aesthetic experiences and keep people's attention (He *et al*., 2022). When access to green places is restricted, three types of involvement are crucial for psychological healing. First, seeing greenery outside your windows has psychological advantages. Experimental investigations have demonstrated that gazing out a green window may result in micro restorative episodes that hasten healing within hours or days (Jo *et al*., 2019; Spence, 2021).

Plants kept indoor's respond favourably to chemicals that reduce stress. Indoor plants have positive physiological effects on nervous system's autonomous function by lowering sympathetic activity, which typically increases whenever an individual is subjected to a stressful scenario (Table 2). Active interaction with indoor plants may have a favourable effect on the human stress response, which is mediated through cardiovascular training (Han *et al*., 2022). These physiological benefits may be caused by various natural stimuli that affect the senses of vision, hearing, sensation, and scent; studies on woodland therapy also indicate such impact (Park *et al*., 2017).

Role of Indoor Plants at workplaces

Those who work in modern buildings often enjoy the benefits of indoor plants. Those working in environments with indoor plants have entirely conquered their tension and anxiety symptoms (Aydogan and Cerone, 2021). According to research (Yeo, 2021), there is a connection between the human pain response and exposure to interior plants. As a direct consequence, hospital patients with window frames with views of plants feel very little pain compared to those with window frames with views of a wall without any plants. Field studies show that when leafy plants or foliage plants coupled with sunlight were brought into office worker's indoor workstations, their health concerns dropped (Hähn *et al*., 2021). The most declines were observed in the signs of tiredness, feeling heavy-headed, nausea, and difficulty in concentrating (Han, 2018; Song *et al*., 2018). Both the existence of plants and a glimpse of the outside environment result in the lowest overall anxiety levels, according to lab-setting scientific studies

evaluating biochemical reactions to diverse workplaces, such as neural activity and fingertip body temperature (Song and Miyazaki, 2019). Those who experience more indoor nature connection at work report much lower rates of job anxiety, mental illnesses, and sick days than those who encounter less . It is feasible to enhance nature contact at work by introducing plants into the workstation and opening window curtains to benefit from sights of elements of nature and natural sunlight. The spectrum of possible workplace mental wellbeing practices can be expanded to include these straightforward and inexpensive techniques (Stott et al., 2022).

Hydroponics in Indoor environment and relation to photosynthesis

Hydroponics, also called nutri-culture, aquaculture, soilless culture, or tank farming, is a technique where plants are cultivated in soilless media (Resh, 2022). Hydroponics indoors can help both increase the transpiration and photosynthesis rate, improving the air temperature and humidity inside a closed space (Frasetya et al., 2021). They can be grown in different soilless media like peat, coconut coir, mineral wool, sand, growstone, perlite, pine bark (Resh, 2022 and Kazzaz and Kazzaz, 2017).

Photosynthesis is a biochemical process where plants use carbon dioxide and water to create energy in the form of sugar and to release oxygen in the presence of sunlight. In natural photosynthesis, the energy conversion efficiency is low, so there is a need to improve the net photosynthesis rate for the release of oxygen and energy. In general, the photosynthesis rate is affected by many factors, like leaf area size, temperature, carbon dioxide, light, water, and minerals (Deng *et al*., 2018). So, to increase the photosynthesis rate in indoor plants, there should be the appropriate amount of light. The required light should be above the light compensation point (zero net photosynthesis) to maintain the proper oxygen levels in the air.

Indoor green plants absorb CO_2 and release oxygen during the photosynthesis process. Plant photosynthetic rates change depending on light conditions, and within a particular range, higher light intensity results in higher photosynthetic rate and higher CO_2 uptake, which in turn will increase the O_2 level in the inner environment (Liu *et al*., 2022) (Table 3).

In net photosynthesis, a higher amount of CO_2 can increase the release of O_2 . The Installation of indoor plants should be designed to remove some good percentage of indoor CO2 and release O_2 according to the optimal choice of living environment (Moya *et al*., 2019). It was discovered that to increase the elimination capacity of indoor CO_2, optimum environmental control is required (Taheri and Razban, 2021). The C fixed by the indoor plants with the amount of CO_2 exhaled by a single person, and it was found that it would take 400 plants to eliminate CO_2 exhaled by one person. It was estimated that it would require 57 m2 of leaf area to balance the respiration of a single occupant in an average-sized office (43 +2m3) without ventilation and would require 240 plants to absorb 13% of the CO_2 generated by one person (Deng *et al*., 2018). Studies using plants to counteract the CO_2 release by human were differed by different aspects (leaf area and number). Larger leaf area can eliminate more CO_2 (Shao *et al*., 2021).

While photosynthesis produces oxygen, the photoelectric process (photosynthesis in leaf tips) can generate many negative air ions (NAIs). Negative air ions (NAIs) produced by green plant photosynthesis are helpful to human health (Liu *et al*., 2022). NAIs are very important in absorbing dust, cleaning the air, and improving the environment and human health (Ravindra and Mor, 2022). NAIs can be efficiently used to control ultrafine aerosol pollutants in cleanrooms.

Hydroponics to transpiration and temperature regulation of surrounding

Indoor thermal comfort can be increased by altering the ambient temperature and relative humidity through transpiration by indoor plants. Introducing plants increases indoor relative humidity, and the additional benefit is greater with the installation of hydroponic plants (Meng *et al*., 2022). If the transpiration rate is higher than usual, it will show that the leaves are cooler than they are in their surroundings. The latent heat used to evaporate water transpired by trees consumes sensible heat in the surrounding environment that would otherwise raise air temperature and instead cools leaf surfaces and neighbouring air temperatures by advection (Winbourne *et al*., 2020).

The transpiration through green plants is said to be naturally cool. Water moves from the root to the plant leaves via transpiration, where it is transformed into water vapor and discharged into the atmosphere (Liu *et al*., 2022). Transpiration aids in the management of relative humidity indoors. The transpiration rate is strongly influenced by the morphological characteristics of the plant that is if the leaf area is larger that will directly affect the transpiration rate of the plant (Winbourne *et al*., 2020). The maintenance of transpiration rate can, in return, maintain the air temperature. It can reduce the investment cost for air conditioners, which will purify the inner and maintain the outer temperature (Deng *et al*., 2018).

Role of Indoor plants in a windowless environment

Most people spend their days working indoors at home or offices, bars, and restaurants without windows,

Table 3. Plant species type that help to reduce the fine particle matter, volatile organic compounds (VOC) and CO_2 levels

Plant Species type	Indoor location	Kind of changes noticed	Reference
Spathiphyllum sp., Aglaonema sp., Epipremnum aureum, Dracaena marginata	Plants placed in Computer Labs and offices.	A 20% decrease in particle matter on horizontal surfaces	He et al. (2020); Wang et al. (2022)
Spathiphyllum sp., Dracaena deremensis	Potted plants in office rooms.	Potted plants can lower volatile organic compounds by up to 75%.	Cummings and Waring (2020); Teiri et al. (2018)
Nephrolepis exaltata cv. Bostoniensis, Cymbidium Golden Elf, Crassula portulacea, Ficus microcarpa var. fuyuensis, Hydrangea macrophylla, Dendranthema morifolium, Dieffenbachia amona cv. Tropic Snow, Nephrolepis exaltata cv. Bostoniensis, Dracaena deremensis cv. Variegata, Spathiphyllum Supreme, Citrus medica var. sarcodactylis	Potted plants housed in a testing environment	These ten plant types can remove more than 20% of benzene from the environment.	Li et al. (2023); Parseh et al. (2018)
Chlorophytum comosum, Sansevieria trifasciata, Epipremnum aureum	Potted plants in a test jar within the greenhouse.	Every plant that was utilized was successful in reducing ozone, or O3.	Botondi et al. (2021); Grulke and Health (2020)
Dypsis lutescens, Chamaedorea elegans, Aglaonema commutatum, Ficus benjamina L., Howea forsteriana	Plants in a controlled environment within the test vessel.	Two species showed strong CO2 removal efficiency: D. lutescens and F. benjamina. In exceptionally low light, H. forsteriana and D. lutescens were able to remove net CO2.	Yeo (2021)

where there are fewer chances to see the outdoors. According to research, employees in such windowless environments show less job satisfaction, and their physical working practices are considered less pleasant and interesting than those in windowed environments (Vasquez *et al*., 2022). Indoor plants have been shown to enhance work productivity by 10 to 15% when kept in offices and other indoor environments. The general public frequently reported joy and excitement in the presence of indoor plants while negative emotions such as anger and fear were reported in the absence of indoor plants (Han and Ruan, 2019). The "stress recovery theory," originally used by van den Berg and Custers in 2011, includes the advantages of being in nature, such as decreased anxiety, dropped cardiac rates, cutaneous conductance recovery, reduced cortisol concentrations, and beneficial alterations in the function of nerves (Park *et al*., 2017; Yin *et al*., 2018). An inherent human desire to look for connections with nature and other aspects of existence is known as biophilia. The incorporation of biophilia into the framework of construction is known as biophilic design. An increasing corpus of research has been done to show how large-scale plant introductions can have positive psychophysiological and cognitive effects on humans (Li *et al*., 2022).

One of the major concerns of being in a windowless environment is the release of volatile organic compounds from wood-based products and other everyday items which are hazardous to humans (Jhanji and Dhatt, 2021). Interacting with the environment, especially when there is water around, has good benefits on emotions or behaviour, including raising self-esteem and mood, lowering rage, and improving general mental health (Maund *et al*., 2019). Shifting to a residence with a lush green space actually improves one's psychological well-being (Olszewska-Guizzo *et al*., 2021). According to research conducted in Perth, Australia, people who live in residential areas with top-notch public places have improved overall mental wellness than those who live in communities with inferior public areas (Palliwoda and Priess, 2021). Warriors who got outdoors adventure rehabilitation for their PTS (post-traumatic stress) show increases in their psychological and societal aspects of living, post-traumatic behavioural checklist, which consists optimism, and productivity (Hall and Knuth, 2019). Post-traumatic development is the term used to describe how survivors of terrible situations might improve their overall standard of existence. Humans can experience happiness when relating

to a plant's development (Malberg Dyg and Wistoft, 2018).

Natural lands have become built-up areas and agricultural land due to the ongoing expansion in urbanisation (Ke *et al*., 2018). It is now becoming more challenging to explore natural areas because of the increase in urbanisation (Ayele and Tarekegn, 2020). Those who reside in urban areas might not have the chance to visit such location or might have to travel a longer distance just to see such natural environment. Compared to urban areas, people seem happier when engaging with greenery and natural landscapes (Seresinhe *et al*., 2019). Thus, it is highly recommended that a greener interior be constructed so that the individuals indoors can also engage with nature, which may improve their ease, productivity, and mental health. According to research, when people stared at plants, their Oxy-Hb (oxyhaemoglobin) rates in the right cerebral brain were considerably lower, demonstrating an internal sense of calm. Additionally, when exposed to foliage plants, individuals showed more favourable emotions, including feelings of warmth and relaxation (Park *et al*., 2017)

Both the actual plants and the photographs of plants may make people feel calm and comforted. Moreover, potted plants offer superior psychological advantages than images (Yeo, 2021). The decision of selecting a plant or its photograph to be used depends on the environment of the room. For example, since some plants can cause allergic reactions and illness. The photographs or posters of the plant would be more appropriate in such a therapeutic environment. On the other hand, on sites such as homes, offices, and classrooms, if the individuals are not allergic to any plant species, one must put indoor potted plants in such surroundings (Allahyar and Kazemi, 2021). Research found that older women who participated in a total of fifteen gardening sessions outside had larger muscles, hand-eye coordination, and a smaller waist girth than those who remained indoors. The exact same quantity of time spent inside, however, resulted in a loss in muscular endurance and quickness and also a spike in depressed symptoms in the women (Erkkola *et al*., 2021).

The indoor plants also play a very important role in enhancing indoor environment quality (IEQ) and improving the individual's wellbeing in general. Some specific plant species can lower the carbon dioxide levels and significantly reduce the accumulation of volatile organic chemicals and particulate matter in the environment (Treesubsuntorn *et al*., 2021). Certain volatile organic compounds like formaldehyde, which is released from wooden equipment and old aged home fittings, can cause cancer in humans (Lee *et al*., 2018; Sarigiannis *et al*., 2019). Exposure to benzene and xylene may cause breathing problems and uneasiness. They may show neurotoxic effects when exposed longer (Davidson *et al*., 2021).

Conclusion

Indoor plants offer various health benefits and are a cost-effective solution for improving the air quality of indoor spaces. The process of phytoremediation helps in removing harmful chemicals, while the process of photosynthesis and transpiration helps maintain suitable oxygen and humidity levels in indoor environments. Indoor plants not only enhance the aesthetic appeal of a space but also provide numerous psychological and physical benefits, such as reducing stress and enhancing productivity. Moreover, indoor plants may offer an optional solution in reducing SARS-CoV-2 spread. It is highly recommended to incorporate indoor plants in indoor spaces, such as homes, offices, classrooms, bars, and restaurants, to promote general health and well-being and to provide people with a sense of connection with nature for environmental sustainability.

Conflict of interest

The authors declare that they have no conflict of interest.

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