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Assessing the effect of specific plants on indoor carbon dioxide levels

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ABSTRACT

Indoor environments, where people spend nearly 90% of their lives, significantly influence health and well-being through air quality, specifically carbon dioxide (CO_2) concentrations. This study investigates the role of indoor plants in modulating CO_2 levels under controlled light and temperature conditions. Three indoor plants – Bonsai, Dieffenbachia, and Yucca – were positioned inside a glass-walled compartment to prevent direct sunlight while providing sufficient illumination, simulating typical indoor light conditions. CO_2 concentrations were monitored using CO_2 Datalogger, which recorded data every 5 minutes. The results demonstrate that all tested plants effectively reduced CO_2 concentrations, with Dieffenbachia showing the most substantial decrease, followed by Yucca and Bonsai. This research highlights the potential of indoor plants not only to enhance indoor air quality but also contribute to health and productivity by mitigating CO_2 accumulation, offering a sustainable strategy to improve environmental conditions in indoor spaces.

Keywords: indoor air pollution, carbon dioxide, indoor plants, air quality, human health.

INTRODUCTION

Historically, humans have recognized the health advantages of interacting with nature (Hartig et al., 1991). From an evolutionary standpoint, it is suggested that humans have adapted to respond positively to natural environments due to evolutionary processes (Ulrich and Parsons,1992), while a cultural viewpoint argues that cultural influences shape human interactions with nature (Ulrich, 1983). Supporting the evolutionary approach, the biophilia hypothesis posits that humans innately form emotional bonds with nature and other living beings (Wilson, 1984), a trait that remains ingrained in our biology even as we transition to urban living (Kellert and Wilson, 1993). Additionally, the stress reduction theory (Ulrich, 1983) defines stress as a response that encompasses psychological, physiological, and behavioral reactions to threats to well-being (Ulrich et al., 1993), with nature playing a crucial role in stress relief. The Attention Restoration Theory (Kaplan and Kaplan, 1989) further suggests that natural environments are crucial for rejuvenating directed attention necessary for effective functioning. Empirical evidence continues to grow, showing that nature contact benefits human emotions, physiological health, attention, behavior, and overall health, as demonstrated by numerous studies and systematic reviews (Hartig et al., 2014; van den Bosch and Sang, 2017; Britton et al., 2020; Coventry et al., 2021; Menardo et al., 2021; Ohly et al., 2016; Stevenson et al., 2018; Twohig-Bennett et al., 2018; Mari et al., 2022).

Poor air quality remains a significant global issue, as noted by the World Health Organization in 2014. Indoor air quality (IAQ) is crucial in buildings because it impacts the health and productivity of occupants, according to Hashim et al. (2019). Moya et al. (2018). Mari et al. (2022), highlight that both internal and external factors, such as temperature, humidity, and ventilation, influence indoor air quality due to emissions from inside and outside sources. In modern construction, spaces like homes, schools, and offices often have inadequate ventilation, designed to be more airtight and energy-efficient for air conditioning, which unfortunately increases indoor air pollutants. Major indoor pollutants include particulate matter (PM), volatile organic compounds (VOCs) such as benzene, toluene, ethylbenzene, xylene (BTEX), formaldehyde, and polyaromatic hydrocarbons (PAHs), along with inorganic pollutants like ozone (O_3), nitrogen oxides (NO_x), carbon dioxide (CO_2), and sulfur dioxide (SO_2). These pollutants can lead to Sick Building Syndrome (SBS), which causes symptoms like respiratory issues, severe headaches, eye and skin irritation, allergies, fatigue, and metabolic problems, as Nezis et al. (2022) described. However, introducing indoor plants can help reduce these pollutants while enhancing aesthetics, as Su et al. (2015) suggested.

The quality of air within indoor spaces is crucial for human health. Deterioration in indoor air quality significantly affects human health and productivity (Sevik et al., 2013).

CO_2 concentrations can fluctuate quickly due to human metabolic activities indoors. Normally, air inhaled by humans consists of 21% O_2 and 0.033% CO_2, but upon exhalation, it changes to 16–17% O_2 and 4% CO_2. This shift can rapidly increase CO_2 levels in places with high human density, such as schools, shopping malls, and hospitals (Bulgurcu et al., 2006). Elevated CO_2 levels can lead to fatigue, reduced alertness, and sleepiness. Additionally, higher concentrations of CO_2 often cause various complaints related to performance degradation, which are hard to link directly to their cause. When CO_2 levels exceed 1.000 ppm, symptoms such as headaches, dizziness, fatigue, and concentration difficulties arise, accompanied by noticeable odors that annoy, when the concentration exceeds 1.500 ppm, individuals may experience irritation of the throat and nose, nasal discharge, coughing, and irritation of the eyes (Ercan, 2012).

Nisitha et al. (2023) reviewed the effectiveness of indoor plants in reducing pollutants like CO_2 and VOCs through phytoremediation. The study highlights the roles of plant leaves and roots in pollutant removal and their ability to regulate humidity and temperature, enhancing indoor air quality. Golden Pothos, Snake Plant, and Areca Palm were identified as the top performers in improving air quality and reducing various indoor pollutants.

Susanto et al. (2023) provided a comprehensive summary of indoor air pollution and offered evidence-based perspectives on the effectiveness of indoor plants as an alternative method for indoor remediation.

Han et al. (2022) conducted a systematic review and meta-analyses to examine the impact of indoor plants on human physiological, cognitive, and behavioral functions, finding that plants generally improve relaxation and cognitive performance. Significant benefits were noted in areas like diastolic blood pressure and academic achievement. The study, which pulled data from major databases up to February 2021, highlighted the need for more greenery in buildings to enhance urban health and functionality.

Environmental variables, particularly light and temperature, influence plants' effect on indoor air quality. To ensure human comfort, indoor areas are generally maintained at temperatures between 20 °C and 25 °C, a range that also promotes optimal plant growth.

Light levels in indoor environments can differ significantly. In spaces without artificial lighting, the amount of light varies with the time of day, influencing plant metabolic processes. This variation in light affects how plants impact indoor CO_2 levels.

Plants may effectively control carbon dioxide levels in indoor settings, yet research in this area is somewhat scarce. This research aims to investigate the impact of specific indoor plants on CO_2 levels, particularly focusing on how sunlight influences these effects.

MATERIALS AND METHODS

This study utilized three popular indoor plant species: bonsai, Dieffenbachia, and Yucca. The plants were housed in a glass-enclosed chamber designed to block direct sunlight while allowing light to filter through, a condition preferred by most indoor plants. This compartment was airtight and measured approximately 0.5 m³ (0.7×0.7×1 m). CO_2 levels within this compartment were monitored using a CO_2 Datalogger, programmed to record CO_2 levels every five minutes.

For the duration of the study, the local sunrise occurred at approximately 06:00 and sunset at around 19:00. Measurements taken at about

06:30 were considered for analysis, and a 24-hour measurement period was utilized to assess daily changes in CO_2 levels more accurately. While the plants were kept in the glass compartment for nearly 45 hours, only the data collected during 28 hours were considered for the final analysis.

Before the study, the plants were regularly watered once a week, and the experiment took place the day after one such watering session. In addition to their standard care, the plants received a bi-weekly liquid manure fertilizer formulated for indoor plants, administered over two watering sessions. All plants were potted in peat soil.

RESULTS AND DISCUSSION

The effect of bonsai on CO_2 concentrations

Figure 1 illustrates the impact of Bonsai on CO_2 concentrations over 24 hours. Initially, CO_2 levels remained relatively stable, only starting to rise around sunset and continuing until sunrise. Beginning at 2588 ppm at 06:30, the CO_2 concentration slightly fell to 2586 ppm by 07:30. It then sharply decreased to 1457 ppm by 17:30 and dropped further to 1353 ppm by 20:30. Subsequently, the CO_2 levels started to rise, reaching 1678 ppm by 07:30 the following morning, before decreasing again. Throughout the day, CO_2 levels decreased from 2588 ppm to 1678 ppm, a reduction of 1235 ppm, compared with a nighttime rise of 325 ppm. Bonsai absorbs approximately 3.8 times more CO_2 during the day than it emits at night.

Figure 1 highlights Bonsai's modest but noteworthy ability to reduce CO_2 levels over a 24-hour cycle. The data shows a significant drop in CO_2 concentrations from midday to early evening, gradually increasing overnight until sunrise. This diurnal pattern suggests that while Bonsai plants are effective in CO_2 absorption, their smaller leaf area limits the magnitude of this effect compared to larger plants. However, Bonsai's aesthetic and space-efficient form makes them suitable for small spaces where larger plants might not be practical, offering a balance between functionality and design within indoor environments.

The effect of dieffenbachia on CO_2 concentrations

Figure 2 illustrates the impact of Dieffenbachia on CO_2 concentrations over 24 hours. Initially, CO_2 levels remained relatively stable, only starting to rise around sunset and continuing until sunrise. Beginning at 2168 ppm at 06:30, The CO_2 concentration marginally reduced to 2167 ppm by 07:30. It then significantly decreased to 512 ppm by 17:30 and dropped further to 210 ppm by 20:30. Subsequently, the CO_2 levels started to rise, hitting 482 ppm by 07:30 the following morning, before decreasing again. Throughout the day, CO_2 levels dropped from 2168 ppm to 210 ppm, a decline of 1958 ppm during daylight hours, in contrast with a nighttime increase of 272 ppm. Dieffenbachia absorbs approximately 7.2 times more CO_2 during the day than it emits at night.

Figure 2 presents Dieffenbachia as the most effective plant among those tested in reducing CO_2 concentrations. The sharp decline in CO_2 from morning to late afternoon reflects Dieffenbachia's robust photosynthetic activity, facilitated

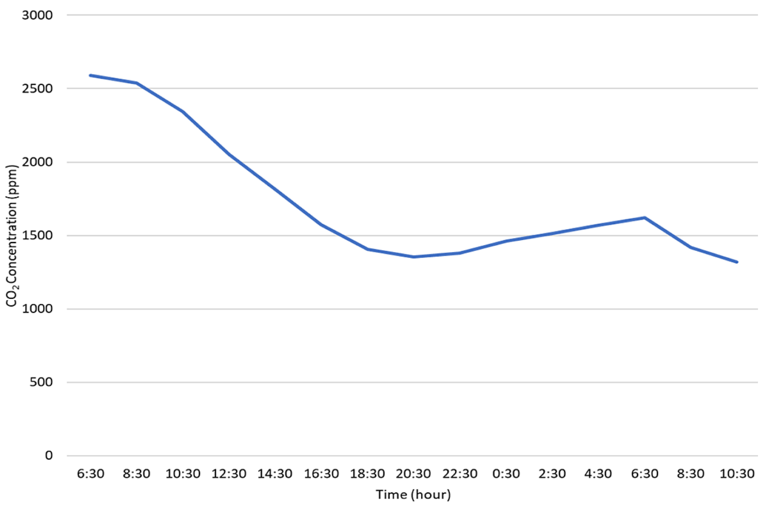

Figure 1. Change in CO_2 amount created by Bonsai with time

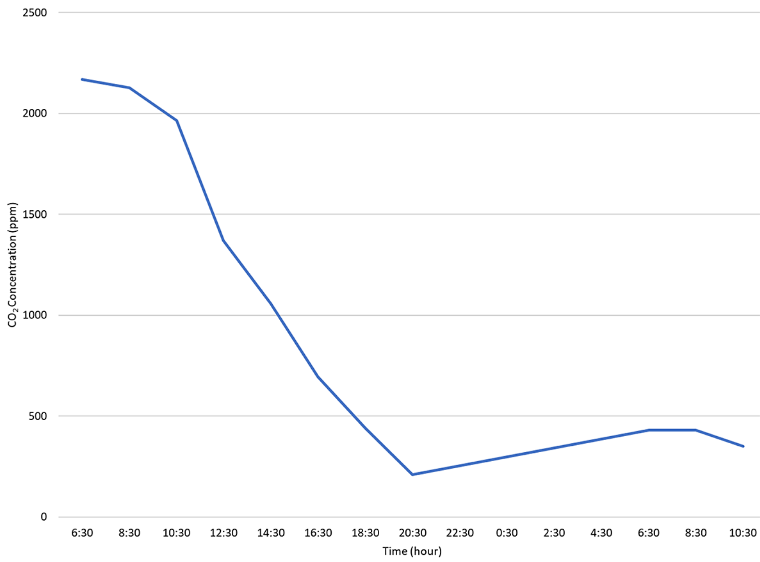

Figure 2. Change in CO_2 amount created by Dieffenbachia with time

by its large leaf surface area. This makes it particularly valuable in office settings or residential areas where air quality is a concern. The overnight rise in CO_2 also suggests that while Dieffenbachia significantly lowers CO_2 levels during the day, maintaining multiple sources of air purification might be necessary to sustain low CO_2 levels around the clock.

The effect of yucca on CO_2 concentrations

Figure 3 illustrates the impact of Yucca on CO_2 concentrations over 24 hours. Initially, CO_2 levels remained relatively stable, only starting to rise around sunset and continuing until sunrise. Beginning at 2308 ppm at 06:30, The concentration initially fell to 2167 ppm by 07:30. It then sharply declined to 516 ppm by 17:30 and decreased further to 480 ppm by 20:30. Subsequently, CO_2 levels started to rise, reaching 770 ppm by 07:30 the following morning, before falling again. Throughout the day, CO_2 levels dropped from 2308 ppm to 770 ppm, a reduction of 1828 ppm during daylight hours, compared with a nighttime increase of 290 ppm. Yucca absorbs approximately 6.3 times more CO_2 during the day than it emits at night.

Figure 3 depicts Yucca's performance, which shows a pattern similar to Dieffenbachia but slightly less efficient. Yucca's gradual reduction

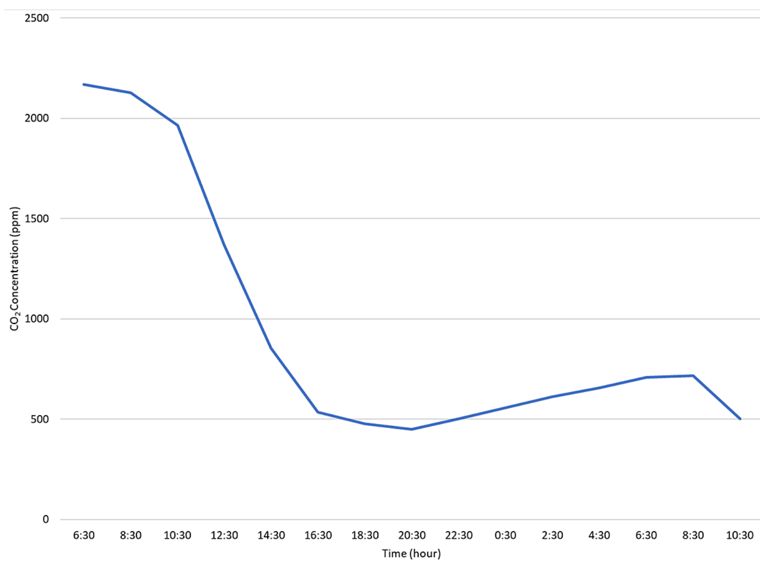

Figure 3. Change in CO_2 amount created by yucca with time

of CO_2 throughout the day can be attributed to its adaptation to various light conditions, making it an excellent candidate for less sunlit areas of homes and offices. Yucca's ability to significantly reduce CO_2 during the day and its moderate increase at night highlights its role in sustainable indoor air quality management, especially in settings that experience varying light conditions.

These findings contribute and support previous research in signifying that indoor plants play a role in improving indoor air quality in terms of CO_2 levels. Similar to the results obtained by (Nisitha et al., 2023) studying Dieffenbachia and Yucca plants. It also aligns with Wolverton et al. (1989) study using Lily and Snake plants, and the study by Ulrich (1992) on Yucca and Bonsai plants. Likewise, Dieffenbachia, Bosnia and Yucca effectiveness in reducing CO2 levels as presented in this study aligns with the results obtained by other studies i.e. (Han et al., 2022) and (Hashim et al., 2019). This implies that indoor plants serve as a natural air filters to enhance and sustain indoor spaces. The study's outcomes are consistent and expand upon existing research, asserting the pivotal role of indoor plants in improving the air quality in indoor spaces. These findings help for creating healthier and sustainable indoor environments.

CONCLUSIONS

The study offered invaluable information on how indoor plants can improve air quality in indoor spaces by directly controlling CO_2 levels. The systematic analysis and assessment results indicate that Bonsai, Dieffenbachia, and Yucca help reduce CO_2 volume throughout the day but increase the gas at night. The cyclical character of CO_2 control proves the high relevance of this group of plants to daytime interior spaces, like offices, school premises, or shopping malls, ensuring healthier conditions during active hours.

Moreover, not being exposed to the same light spectrum did not reduce Bonsai, Dieffenbachia, and Yucca's ability to minimize CO_2 levels. As a result, these plants can be used in different areas, not ideally lit ones, to boost air circulation. Therefore, based on the shared characteristics, it is possible to state that indoor air filters are effective in different spaces. Dieffenbachia is the most effective plant tested; the other two can also reduce CO_2 to a considerable extent. Thus, the identified findings suggest that a strategic approach is required to be applied to plant choice related to the types of pollutants it can address.

Integrating suitable plant species into indoor spaces promises to reduce CO_2 levels and enhance these environments' overall health, productivity, and aesthetic appeal. This is especially pertinent in urban areas and modern architectural contexts where traditional ventilation solutions may fall short.

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