Eco Cities 2025, 6(1), 3081.
https://doi.org/10.54517/ec3081

Article

Analysis of carbon fixation and humidification ability of indoor cultivation of *Ficus pandurata Hance*

Jing Li[*]**, Xitong Cao, Xinyu Lu, Guohao Li, Runzhuo Wu, Kangshuo Xu**

School of Resource and Environmental Engineering, Shandong Agriculture and Engineering University, Jinan 250010, Shandong, China
*** Corresponding author:** Jing Li, ripplelj@126.com

CITATION

Li J, Cao X, Lu X, et al. Analysis of carbon fixation and humidification ability of indoor cultivation of *Ficus pandurata Hance*. Eco Cities. 2025; 6(1): 3081.
https://doi.org/10.54517/ec3081

ARTICLE INFO

Received: 19 November 2024
Accepted: 13 December 2024
Available online: 7 January 2025

Abstract: To investigate the impact of prolonged exposure to enclosed, low-light environments on carbon fixation and oxygen release in green plants, as well as their capacity to regulate transpiration and humidification, this study utilized *Ficus pandurata Hance*, a common indoor ornamental plant, as the experimental subject to examine the net photosynthetic rate (P_n) and transpiration rate (T_r). LI-6800 portable photosynthesizer was employed to assess the P_n and T_r of *Ficus pandurata Hance* cultivated under varying temperatures (15 ℃, 20 ℃, 25 ℃, 30 ℃, 35 ℃) and different CO_2 concentrations (400 μmol·mol^{-1}, 800 μmol·mol^{-1}, 1200 μmol·mol^{-1}) at different parts of the room (indoors or near windows). The results of the light response curve and the CO_2 response curve measurements indicate that the P_n of *Ficus pandurata Hance* shows a trend of initially increasing and then decreasing as the light intensity or CO_2 concentration increases. It is noteworthy that under different photosynthetically active radiation (PAR) and CO_2 concentrations, the maximum P_n of *Ficus pandurata Hance* cultivated by a window is significantly higher than that of indoor-cultivated plants. Under appropriate temperature control (20~30 ℃), the P_n and T_r of *Ficus pandurata Hance* are highest at 800 μmol·mol^{-1} CO_2 concentration. Under appropriate ventilation conditions (CO_2 concentration < 1200 μmol·mol^{-1}), the plants have stronger carbon fixation ability under appropriate temperature conditions and stronger transpiration—induced humidification ability under non-low temperature ($T \geq 20$ ℃) conditions. To sum up, in the case of high CO_2 concentration caused by poor indoor ventilation and dense population, cultivation of *Ficus pandurata Hance* by the window and proper control of temperature above 20 ℃ can obtain good ecological benefits of carbon fixation, oxygen release, transpiration and humidification.

Keywords: *Ficus pandurata Hance*; net photosynthetic rate; transpiration rate; temperature; carbon dioxide

1. Introduction

The indoor thermal environment and air quality are pivotal factors that significantly influence working conditions, as well as the health and productivity of occupants. In contemporary society, the extension of human living and working hours in indoor environments—particularly during and following the COVID-19 pandemic—has resulted in a heightened demand for improved indoor thermal comfort and air quality among occupants [1,2]. The incorporation of vegetation not only enhances aesthetic appeal but also markedly improves indoor environmental quality through the intrinsic capabilities of plants—including carbon fixation, oxygen production, transpiration, and humidification [3,4]. Plants such as *Spathiphyllum wallisii*, *Hedera helix*, *Chlorophytum comosum*, and *Epiremnum aureum* can all improve indoor environments to varying degrees [5,6]. In addition to the above characteristics, many indoor plants can also stagnate and absorb toxic and harmful substances [7].

The building exhibits a variety of characteristics that influence indoor environmental conditions, including inadequate air circulation, inconsistent lighting levels, and temperature differentials between indoor and outdoor spaces resulting from the use of air conditioning in summer and heating in winter. Additionally, factors such as occupancy density, ventilation conditions, and the spatial arrangement of green plants also play significant roles [8]. Collectively, these elements affect variations in indoor light intensity, temperature fluctuations, and CO_2 concentration to differing extents. Consequently, the ecological benefits derived from carbon fixation, oxygen release, transpiration, humidification, and cooling provided by indoor green plants are similarly impacted [9]. And light, temperature, and other environmental factors are important factors affecting plant growth and survival [9,10]. Therefore, identifying optimal indoor environmental conditions that align with the growth requirements of green plants is essential for maximizing their ecological contributions. In response to these challenges, this study focuses on *Ficus pandurata Hance* as a research subject to investigate its gas exchange responses under varying light intensities, temperatures, and CO_2 concentrations. The objective is to determine the ideal cultivation environment that enhances its photosynthetic carbon fixation capabilities alongside oxygen release while effectively contributing to transpiration humidification and cooling processes. This research aims to provide empirical data supporting the maximization of ecological benefits offered by *Ficus pandurata Hance* within indoor settings.

2. Materials and methods

2.1. Site

The experiment was conducted from early April to mid-May. The experimental site is situated in the south-facing office of the school, with dimensions of 7.5 m × 3.5 m × 2.5 m. This office features a single floor-to-ceiling window located on its southern wall, measuring 1.2 m × 2.5 m. The photosynthetically active radiation (PAR) near the window was approximately 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$, while that within the room measured around 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The average indoor daytime temperature was approximately 25 ℃, and the average nighttime temperature was about 18 ℃.

2.2. Material

The commonly utilized green plant, *Ficus pandurata Hance*, was selected for laboratory experiments. This small shrub, classified within the genus Ficus of the Moraceae family, is frequently employed as an indoor ornamental plant due to its considerable aesthetic appeal. The selected plants were uniform in size and exhibited optimal growth conditions, being free from dead leaves, decay, or any signs of pest and disease infestation.

2.3. Method

Three pots of the plant were placed near the window for cultivation (window-cultivated), while 3 pots were positioned indoors (indoor-cultivated—placed on the north wall of the office, away from the window). Watering was conducted in accordance with the dry and wet conditions of the cultivated soil. The experiment commenced after a maintenance period of 1 to 2 weeks. LI-6800 portable photosynthesis system (Li-COR, USA) was utilized to measure relevant indicators daily from 08:00 to 12:00 [9]. During the experiment, all doors and windows remained closed, with only one person present indoors to minimize personnel movement. The changes in indoor environmental conditions under these circumstances are presented in **Table 1**.

Table 1. Diurnal variation of CO_2 concentration in a closed chamber.

	CO_2 concentration in the morning	CO_2 concentration at nightfall	The difference of CO_2 concentration between the morning and nightfall
Five-day average	($\mu mol \cdot mol^{-1}$)	($\mu mol \cdot mol^{-1}$)	($\mu mol \cdot mol^{-1}$)
	480.02 ± 37.94	828.15 ± 56.73	348.13 ± 51.68

When determining, select healthy, vigorous, and clean leaves, and set up 3–5 parallel for each treatment.

(1) Light response curve

The measurement period for the light response curve was conducted from 09:00 to 11:00, the airflow rate was maintained at 500 $\mu mol \cdot s^{-1}$ [11,12]. Measurements of the light response curve were performed at room temperature with a CO_2 concentration of 400 $\mu mol \cdot mol^{-1}$. Based on preliminary experimental results indicating significant photoinhibition under high light conditions, the initial value of PAR for the light response curve was established at 1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Following data stabilization, an automated measurement protocol was employed, specifically setting PAR values to 1500, 1300, 1100, 1000, 800, 700, 600, 550, 500, 400, 300, and down to zero $\mu mol \cdot m^{-2} \cdot s^{-1}$. A stabilization time of between 120 and 180 seconds was implemented.

(2) CO_2 response curve

Based on the results of the light response curve analysis (**Figure 1**), PAR was established at 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$, with a flow rate maintained at 500 $\mu mol \cdot s^{-1}$. The induction period under a CO_2 concentration of 400 $\mu mol \cdot mol^{-1}$ was set to 6–8 min. Following data stabilization, an automated measurement protocol was initiated. Carbon dioxide was supplied from a CO_2 cylinder, and concentrations were adjusted to 400, 300, 200, 100, 50, 25, and zero as well as subsequently to 400, 700, 900, 1000, 1500, and 2000 $\mu mol \cdot mol^{-1}$; the stabilization time for each setting ranged from 120 to 180 s.

(3) The net photosynthesis and transpiration rates of *Ficus pandurata Hance* under different temperatures and CO_2 concentrations

Based on the measurement of light response curves, the correlation measurements under different temperatures and CO_2 concentrations were carried out under 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR, and the flow rate was set to 500 $\mu mol \cdot s^{-1}$. Measure the net photosynthetic rate (P_n) and transpiration rate (T_r) of *Ficus pandurata Hance* window-cultivated under different CO_2 concentrations (400 $\mu mol \cdot mol^{-1}$, 800 μmol·mol^{-1}, 1200 μmol·mol^{-1}, respectively simulating ventilation, indoor people and ventilation or indoor people and no ventilation, and indoor people and no ventilation), and different temperatures (35 °C, 30 °C, 25 °C, 20 °C, 15 °C, respectively simulating high summer temperature, middle-high summer temperature, spring or autumn or winter with cooling in summer, spring or autumn or winter with moderate temperature ventilation and heating, and winter with low temperature ventilation and heating). The data is stabilized for 3–5 min before counting. For each treatment, 1–2 leaves of similar size, similar growth and basically the same position were selected from each pot of plants for measurement (a total of 3–5 parallel leaves were set for each treatment).

3. Results and analysis

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

3.1. Light response curve

Figure 1a shows P_n curve of *Ficus pandurata Hance* under light-compensation point at different cultivation positions within the range of 0–100 μmol·m^{-2}·s^{-1} PAR, in order to better understand the light compensation point of different cultivation positions of *Ficus pandurata Hance* under low light intensity.

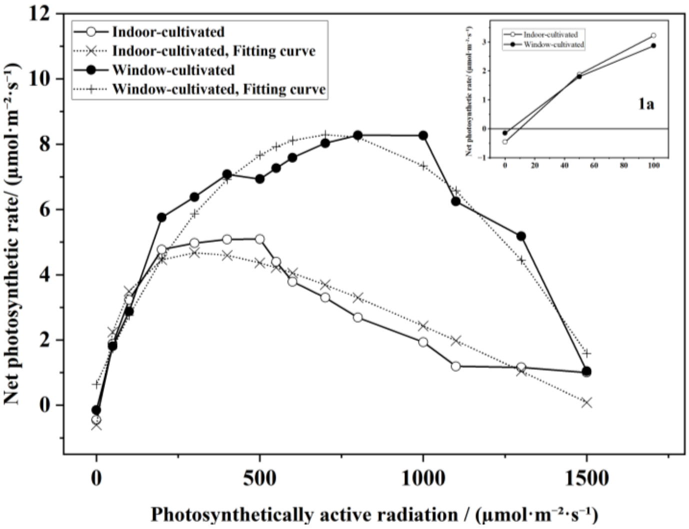

Figure 1. Light response curves of *Ficus pandurata Hance* at different culture locations: **(a)** The photosynthetic rate curve from 0 to 100 μmol·m^{-2}·s^{-1}. (The solid line represents the measured value, and the dotted line is the fitting curve [13].

As can be seen from **Figure 1**, the changes of P_n of *Ficus pandurata Hance* at each culture position in the room showed that with the increase of light intensity, the P_n increased first and then decreased. When the PAR was lower than 200μmol·m^{-2}·s^{-1}, the P_n of *Ficus pandurata Hance* cultured at different locations increased rapidly with the increase of light intensity. When PAR was higher than 200μmol·m^{-2}·s^{-1}, the plants' P_n could continue to increase, but the growth rate became slow. The plant window-cultivated exhibited a maximum P_n of 8.27 μmol·m^{-2}·s^{-1} at 800 μmol·m^{-2}·s^{-1} PAR, whereas the indoor-cultivated plant reached its peak rate of 5.09 μmol·m^{-2}·s^{-1} at a lower light intensity of 500 μmol·m^{-2}·s^{-1}. Subsequently, the P_n declined with increasing light intensity.

The P_n of *Ficus pandurata Hance* window-cultivated is significantly higher than that of those grown indoors. Prior to reaching 800 μmol·m^{-2}·s^{-1} PAR, the P_n of the window-cultivated plants exhibits continuous growth. Between 800 μmol·m^{-2}·s^{-1} and 1000 μmol·m^{-2}·s^{-1}, this rate remains relatively stable. As light intensity continues to increase, the P_n gradually declines, ultimately aligning with that of indoor-cultivated plants when PAR reaches 1500 μmol·m^{-2}·s^{-1} (the P_n value for window-cultivated plants is 1.04 μmol·m^{-2}·s^{-1}; for indoor-cultivated plants, it is 1.00 μmol·m^{-2}·s^{-1}).

By fitting the curve with the Ye model [13], it can be seen that the light saturation point (LSP) of *Ficus pandurata Hance* window-cultivated was 718μmol·m^{-2}·s^{-1}, while the LSP of *Ficus pandurata Hance* indoor-cultivated is 311 μmol·m^{-2}·s^{-1}. This indicates that the LSP of *Ficus pandurata Hance* window-cultivated is significantly higher than that of the indoor-cultivated individuals. As illustrated in **Figure 1a**, the light compensation point (LCP) of *Ficus pandurata Hance* window-cultivated (fitted result < 0; observed value: 3.736 μmol·m^{-2}·s^{-1}) is slightly lower than that of individuals indoor-cultivated (LCP, fitted result: 7.786 μmol·m^{-2}·s^{-1}; observed value: 9.668 μmol·m^{-2}·s^{-1}). Under low PAR (0–100 μmol·m^{-2}·s^{-1}), *Ficus pandurata Hance* from different lighting conditions exhibited comparable P_n, with indoor-cultivated plants showing a marginally higher rate than those window-cultivated. Additionally, from **Figure 1**, it can be observed that *Ficus pandurata Hance* exhibits a clear photoinhibition phenomenon. The plant window-cultivated can only show photoinhibition at a higher PAR level of 1000 μmol·m^{-2}·s^{-1}, while the indoor-cultivated plant shows a significant decrease in P_n at a PAR level above 500 μmol·m^{-2}·s^{-1}.

Due to its strong adaptability to light, *Ficus pandurata Hance* can thrive in both high and low light conditions, making it a popular choice for indoor ornamental cultivation [14]. Experimental results indicate that the light compensation point of *Ficus pandurata Hance* indoor-cultivated is relatively low (approximately 20 μmol·m^{-2}·s^{-1} for most shrubs and trees on average [15]). The response of *Ficus pandurata Hance* to light varies significantly depending on its indoor cultivation location. In addition, plants positioned near windows exhibit a higher light saturation point compared to those situated further inside the room, and they also demonstrate marked differences in their responses to high light intensities. This further suggests that the adaptability of *Ficus pandurata Hance* to light varies significantly based on its cultivation location. The light saturation point for *Ficus pandurata Hance* grown near windows can approximate that of many outdoor shrubs and trees (762.3 μmol·m^{-2}·s^{-1}) [12]. Consequently, when cultivating *Ficus pandurata Hance* indoors, those positioned by windows exhibit enhanced adaptability and efficiency in light utilization, thereby demonstrating superior carbon fixation and oxygen release capabilities.

3.2. CO_2 response curves

Figure 2b presents P_n across CO_2 concentrations ranging from 0 to 100 μmol·mol^{-1}, facilitating a clearer understanding of the CO_2 compensation points associated with different cultivation locations of *Ficus pandurata Hance*.

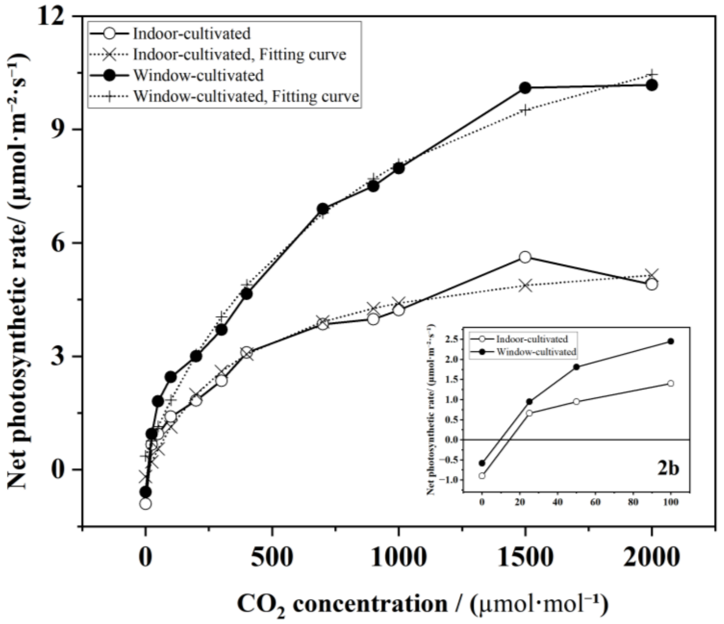

Figure 2. CO_2 response curves of *Ficus pandurata Hance* at different culture locations: **(b)** shows the photosynthetic rate when CO_2 concentration is from 0 to 100 μmol·mol^{-1} (The solid line denoted the measured values and the dashed line represented the fitted curve [16].

As illustrated in **Figure 2**, the P_n of *Ficus pandurata Hance* cultivated under various environmental conditions demonstrated a pattern where the rate initially increased with rising CO_2 concentrations before subsequently declining. Notably, the maximum P_n was achieved at a CO_2 concentration of 1500 μmol·mol^{-1}, reaching 10.10 μmol·m^{-2}·s^{-1} for plants window-cultivated, and indoor-cultivated plants was 5.63μmol·m^{-2}·s^{-1}. When CO_2 concentrations exceed 1500 μmol·mol^{-1}, the P_n of indoor-cultivated plants exhibits a significant decline, whereas the P_n of plants window-cultivated levels off gradually, with a less pronounced downward trend. Meanwhile, as illustrated in **Figure 2b**, the CO_2 compensation point (LCP; fitted result < 0, observed value 9.543 μmol·mol^{-1}) for plants window-cultivated is lower than that of those grown indoors (LCP; fitted result 10.999 μmol·mol^{-1}, observed value 14.390 μmol·mol^{-1}). Throughout the entire range of CO_2 measurement concentrations, the P_n of plants window-cultivated consistently exceeds that of their indoor counterparts.

Throughout the process of increasing CO_2 concentrations, the P_n of *Ficus pandurata Hance* exhibited a gradual increase, suggesting that under conditions of limited air circulation indoors, higher CO_2 concentrations correlate with enhanced photosynthetic oxygen release capabilities. Furthermore, the P_n of plants window-cultivated is consistently significantly higher than that of those indoor-cultivated across the entire range of CO_2 concentrations, indicating that window-side cultivation more effectively enhances the carbon fixation and oxygen-releasing capacity of *Ficus pandurata Hance*. Additionally, the compensation point for plants window-cultivated is lower than that for indoor-cultivated plants, signifying a greater ability to utilize

CO_2. Therefore, compared to *Ficus pandurata Hance* indoor-cultivated, those grown by windows demonstrate superior carbon fixation and oxygen-releasing abilities.

3.3. Leaf net photosynthetic rate

As depicted in **Figure 3**, with increasing temperatures, the P_n of *Ficus pandurata Hance* across varying CO_2 concentrations exhibit a pattern of initial increase followed by a decline; however, the magnitude of this change varies. At normal CO_2 concentration (400 μmol·mol^{-1}), these plants demonstrate similar adaptability to different temperatures, with only slight increases in P_n as temperature rises, resulting in minimal differences in P_n among various temperatures. In contrast, at elevated CO_2 concentrations (800 μmol·mol^{-1} and 1200 μmol·mol^{-1}), the maximum P_n occurs at 25°C, accompanied by substantial variability between temperatures (a change rate of 249.88% at 800 μmol·mol^{-1} and 70.47% at 1200 μmol·mol^{-1}). Under moderate temperature ranges (25–30 °C) and high CO_2 concentrations (800 μmol·mol^{-1} and 1200 μmol·mol^{-1}), the P_n of *Ficus pandurata Hance* is significantly higher than that observed under normal CO_2 conditions.

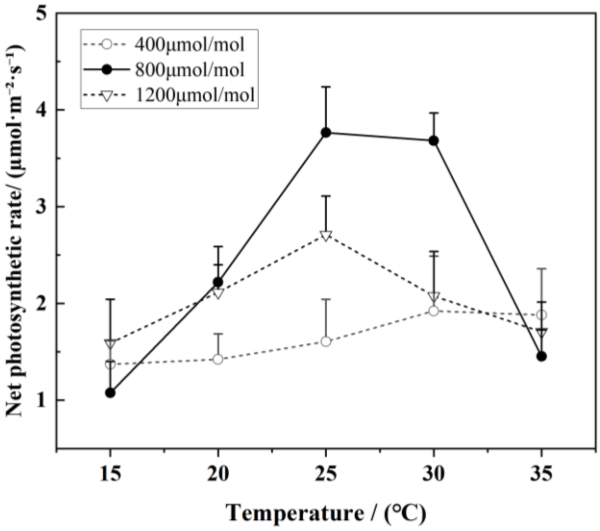

Figure 3. Net photosynthetic rate of *Ficus pandurata Hance* window-cultivated under different temperature and CO_2 conditions.

Therefore, under conditions of adequate indoor air circulation (atmospheric CO_2 concentration of 400 μmol·mol^{-1}), *Ficus pandurata Hance* exhibits minimal sensitivity to temperature fluctuations and maintains a relatively stable P_n. Conversely, when indoor air circulation is restricted and CO_2 concentrations are elevated (800 μmol·mol^{-1} and 1200 μmol·mol^{-1}), *Ficus pandurata Hance* can sustain a comparatively high P_n provided that the temperature remains within an optimal range; specifically, the P_n can reach 2.35 times and 1.69 times those observed under normal conditions at CO_2 concentrations of 800 μmol·mol^{-1} and 1200 μmol·mol^{-1}, respectively. Additionally, it can achieve near-normal P_n even at high/low temperatures. This indicates that *Ficus pandurata Hance* can effectively perform its ecological role of carbon sequestration and oxygen release regardless of the air circulation within the building. Especially under suitable temperature conditions (indoor conditions with air conditioning for temperature control in summer and heating for temperature control in winter), the air-stagnant indoor environment (high CO_2 concentration conditions) can promote *Ficus pandurata Hance* to carry out photosynthesis and release oxygen. Therefore, *Ficus pandurata Hance* is suitable for indoor cultivation in all seasons and temperatures (such as indoor conditions with air conditioning for temperature control in summer and heating for temperature control in winter) and can play a better ecological role of carbon sequestration and oxygen release.

3.4. Leaf transpiration rate

As can be seen from **Figure 4**, with the increase of temperature, the T_r at different CO_2 concentrations increases first and then decreases. At 15 °C, the T_r of the plant was lowest under different CO_2 concentrations, and it changed significantly with changes in temperature. When the CO_2 concentration was 800 $\mu mol \cdot mol^{-1}$, the T_r was the highest under all temperature conditions. At room temperature (20–25 °C), the T_r of *Ficus pandurata Hance* under high CO_2 concentration (800 $\mu mol \cdot mol^{-1}$, 1200 $\mu mol \cdot mol^{-1}$) was higher than that under normal CO_2 concentration (400 $\mu mol \cdot mol^{-1}$). At high temperature (30–35 °C), the T_r of *Ficus pandurata Hance* was the lowest when CO_2 concentration was 1200$\mu mol \cdot mol^{-1}$.

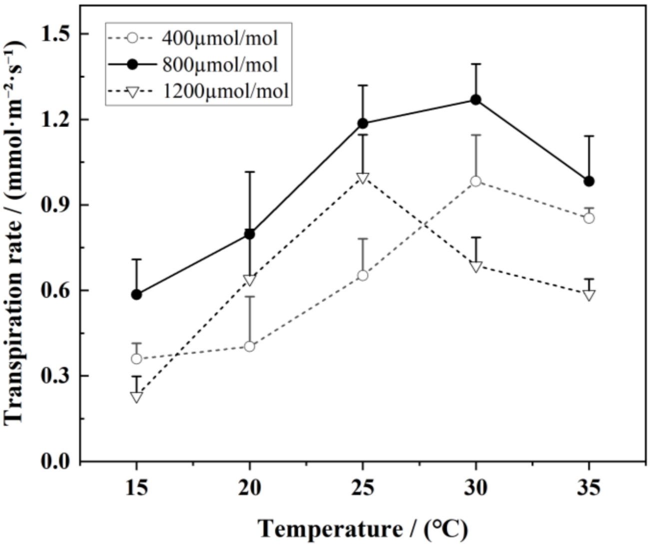

Figure 4. Transpiration rate of *Ficus pandurata Hance* window-cultivated under different temperature and CO_2 conditions.

At a CO_2 concentration of 800 $\mu mol \cdot mol^{-1}$, the T_r of *Ficus pandurata Hance* was highest at the intermediate temperature (25–30 °C), indicating that when the temperature is suitable, *Ficus pandurata Hance* has the strongest evapotranspiration and humidification ability in indoor environments with slightly poor air circulation and moderate population density (refer to **Table 1**, where one person is in a closed indoor environment with a CO_2 concentration of 800 $\mu mol \cdot mol^{-1}$). In indoor environments with poor air circulation and high population density (CO_2 concentration > 800 $\mu mol \cdot mol^{-1}$), *Ficus pandurata Hance*'s evapotranspiration and humidification ability is still better than that in well-ventilated conditions when it is at a suitable temperature (20–25 °C). This indicates that under suitable temperature conditions (indoor conditions with air conditioning for temperature control in summer and heating for temperature control in winter), *Ficus pandurata Hance* can play a better humidification ecological role in indoor environments with slightly poor air circulation. Under high temperature conditions, proper ventilation (CO_2 concentration < 1200 μmol·mol^{-1}) can enable *Ficus pandurata Hance* to play a better humidification ecological role.

4. Discussion and conclusion

The relatively closed indoor environment is often accompanied by low light level (1–50 μmol·m^{-2}·s^{-1}), high CO_2 concentration (1000–5000 μmol·mol^{-1}), easy to adjust the temperature (can be properly controlled by heating or air conditioning) and other characteristics[5,6,17]. As one of the important media to improve indoor air quality, indoor green plants (also an important low-carbon method), due to the above indoor environment characteristics are quite different from the original environment of plants, so the changes in indoor light conditions, temperature, CO_2 concentration, etc., will greatly affect the immediate changes in photosynthesis and transpiration, which will affect the plant's carbon fixation and oxygen release, as well as its transpiration and humidification ecological benefits[18,19].

There is often a problem with low light levels in the room. Studies have shown that increasing the indoor light intensity to 300 μmol·m^{-2}·s^{-1} can significantly increase the CO_2 assimilation ability of indoor plants, and the increase of assimilation ability also increases the relative humidity of air[6]. In addition, 'CO_2 fertilization effect' shows that many plants have higher carbon assimilation ability under high CO_2 concentration conditions [20]. In this study, by measuring the light response curves and CO_2 response curves of *Ficus pandurata Hance* at different culture locations, we can see that the light saturation point for *Ficus pandurata Hance* window-cultivated is 718 μmol·m^{-2}·s^{-1}, accompanied by a lower light compensation point. This suggests that plants grown near windows exhibit a broader adaptability and enhanced capacity for light energy utilization compared to those cultivated in low-light environments. Furthermore, *Ficus pandurata Hance* grown near windows displays both a lower CO_2 compensation point and a higher saturation point, further underscoring its superior ability to utilize CO_2 resources in indoor settings. Consequently, *Ficus pandurata Hance* is particularly well-suited for cultivation near windows, where adequate light is available while minimizing the risk of excessive light intensity leading to photoinhibition [21]. In conclusion, cultivating *Ficus pandurata Hance* in window areas can significantly enhance its ecological functions related to carbon fixation and oxygen release.

At the same time, by investigating the physiological responses of plants across a range of temperatures, light intensities, and CO_2 concentrations, it is possible to accurately determine the optimal growth conditions for indoor plants to maximize their ecological contributions. This study demonstrates that under optimal indoor cultivation conditions, the P_n of *Ficus pandurata Hance* can approximate that of broadleaf tree species growing outdoors (4.357 μmol·m^{-2}·s^{-1}) [22]. The closed architectural design of buildings frequently results in insufficient ventilation, combined with a high density of indoor occupants, which can contribute to elevated

CO_2 concentrations within the indoor environment (**Table 1**) [5,17]. *Ficus pandurata Hance* when cultivated indoors can demonstrate notable capabilities for carbon sequestration and oxygen release, as well as transpiration and humidification ecological functions under conditions of high CO_2 concentration (**Figures 2–4**). For example, at optimal temperatures (25–30 ℃) and a CO_2 concentration of 800 $\mu mol\cdot mol^{-1}$, the ecological benefits associated with carbon sequestration and oxygen release-alongside transpiration and humidification-are particularly pronounced; similarly, at room temperature (20–25 ℃) with a CO_2 concentration of 1200 $\mu mol\cdot mol^{-1}$, these abilities remain superior to those observed at a CO_2 concentration of 400 $\mu mol\cdot mol^{-1}$. Moreover, under high-temperature conditions with adequate ventilation (CO_2 concentration $< 1200\ \mu mol\cdot mol^{-1}$), *Ficus pandurata Hance* continues to make significant contributions to humidification ecological benefits. This result also fully reflects the ‘CO_2 fertilization effect’ [20].

In conclusion, to optimize the ecological benefits of *Ficus pandurata Hance* when cultivated indoors and enhance its positive impact on the working and living environment of indoor occupants, it is recommended that the plant be positioned near a window. Furthermore, under conditions of effective temperature regulation (indoor conditions with air conditioning for temperature control in summer and heating for temperature control in winter) [23], both stagnant air and moderate airflow can enable *Ficus pandurata Hance* to demonstrate enhanced carbon sequestration, oxygen release, transpiration, and humidification capabilities compared to scenarios involving complete ventilation.

Author contributions: Conceptualization, JL; methodology, JL; software, JL; validation, XC and KX; formal analysis, JL; investigation, KX; data curation, XC and KX; writing—original draft preparation, XC, XL and KX; writing—review and editing, JL and XL; plant management, GL and RW; funding acquisition, JL. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Key R&D Program (Soft Science Project) of Shandong Province, China (2023RKY06020); Educational research planning project - Education Advancement Shandong (JCHKT2024164); Student Innovation Project in Shandong Agriculture and Engineering University (2021XJCX045); Educational innovation subject in Shandong Agriculture and Engineering University (22XJKTY08, 23XJSZZ01).

Conflict of interest: The authors declare no conflict of interest.

References

1. Chuang KJ, Lee CY, Wang ST, et al. The Association between Indoor Carbon Dioxide Reduction by Plants and Health Effects. Indoor Air. 2023; 2023: 1-6. doi: 10.1155/2023/1558047
2. Tham KW. Indoor air quality and its effects on humans—A review of challenges and developments in the last 30 years. Energy and Buildings. 2016; 130: 637-650. doi: 10.1016/j.enbuild.2016.08.071
3. Yan LY. Experimental study on the influence of active living wall on indoor thermal environment and CO_2 concentration. Qingdao University of Technology. 2022.
4. Liu F, Yan L, Meng X, et al. A review on indoor green plants employed to improve indoor environment. Journal of Building Engineering. 2022; 53: 104542. doi: 10.1016/j.jobe.2022.104542

5. 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 Quality, Atmosphere & Health. 2016; 10(5): 575-585. doi: 10.1007/s11869-016-0452-x
6. Gubb C, Blanusa T, Griffiths A, et al. Can houseplants improve indoor air quality by removing CO_2 and increasing relative humidity? Air Quality, Atmosphere & Health. 2018; 11(10): 1191-1201. doi: 10.1007/s11869-018-0618-9
7. Sandamali GYHKI, Nishani RIV, Priyantha DM. The Entophytic and Potting Soil Bacteria of the Sansevieria trifasciata Plant Have a Purifying Impact on Indoor Toluene. International Journal of Environmental Research. 2023; 17(4). doi: 10.1007/s41742-023-00538-6
8. Yue XC, Yang QZ. Indoor air environmental pollution and environmental protection. Resources Economization & Environmental Protection. 2021.
9. Xing HS, Wu JM, Chen J, et al. Research progress on limiting factors of plant photosynthesis and vegetation productivity. Acta Ecologica Sinica. 2023.
10. Arnold PA, Shuo W, Notarnicola RF, et al. Testing the evolutionary potential of an alpine plant: phenotypic plasticity in response to growth temperature outweighs parental environmental effects and other genetic causes of variation. Journal of Experimental Botany. 2024.
11. Hu P, Ma J, Kang SJ, et al. Chlorophyllide-a Oxygenase 1 (OsCAO1) Over-Expression Affects Rice Photosynthetic Rate and Grain Yield. Rice Science. 2023; 30(2): 87-91. doi: 10.1016/j.rsci.2022.05.006
12. Wu ZJ, Zhang DD. Study on Photosynthetic Characteristics of Ficus Plants. Journal of Southwest University (Natural Science Edition). 2014.
13. Ye Z, Suggett DJ, Robakowski P, et al. A mechanistic model for the photosynthesis–light response based on the photosynthetic electron transport of photosystem II in C3 and C4 species. New Phytologist. 2013; 199(1): 110-120. doi: 10.1111/nph.12242
14. Chen SP. Cultivation and management of Ficus pandurata Hance. China Flowers & Horticulture. 2019.
15. Zhang X, Qin LH, Liu QJ. Relationship between photosynthetic characteristics and litter decomposition rate of main tree species in Changbai Mountain broadleaved Korean pine forest of northeastern China. Journal of Beijing Forestry University. 2023.
16. Ye ZP. A review on modeling of responses of photosynthesis to light and CO_2. Chinese Journal of Plant Ecology. 2023.
17. Zhang X, Wargocki P, Lian Z. Physiological responses during exposure to carbon dioxide and bioeffluents at levels typically occurring indoors. Indoor Air. 2016; 27(1): 65-77. doi: 10.1111/ina.12286
18. Wu CF, Guo J, Wang GB. Morphological and physiological responses of male and female Ginkgo biloba to temperature changes. Journal of Nanjing Forestry University (Natural Sciences Edition). 2024.
19. Mohmed G, Heynes X, Naser A, et al. Modelling daily plant growth response to environmental conditions in Chinese solar greenhouse using Bayesian neural network. Scientific Reports. 2023; 13(1). doi: 10.1038/s41598-023-30846-y
20. Mo ZK, Li MZ, Wang B. Spatiotemporal variation trend analysis of atmospheric CO_2 fertilization effect of forests in Heilongjiang Province. Journal of Northeast Forestry University. 2022.
21. Shibaeva TG, Mamaev AV, Sherudilo EG, et al. Responses of Tomato and Eggplant to Abnormal Light/Dark Cycles and Continuous Lighting. Russian Journal of Plant Physiology. 2024; 71(1). doi: 10.1134/s1021443723602951
22. Wu ZJ, Zhang Y, Liu YQ, et al. Effect of Soil Drought Stress on Growth and Physiological Characteristics of Ficus lyrata. Northern Horticulture. 2011.
23. Dong D, Tai Y, Luo Y, et al. Numerical simulation of effect of vegetation configuration on human thermal comfort. Journal of Environmental and Occupational Medicine. 2023.