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Natural vs. Artificial Light: A Study on the Influence of Light Source on Chlorophyll Content and Photosynthetic Rates on Indoor Plants

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Abstract: Indoor landscaping is an environmentally friendly approach that enriches the environment and fosters productivity and comfort for occupants. The practice of incorporating plants into interior spaces requires meticulous care to ensure healthy growth and prolong the benefits of interior greening. This study explores the impact of natural and artificial light, represented by fluorescent lighting on the growth and physiological responses of *Codiaeum variegatum* and *Ardisia japonica*. A natural light chamber and an artificial light chamber of identical dimensions were constructed to compare the plants' physiological responses under consistent temperature, humidity, and illuminance conditions. The results indicate that *Codiaeum variegatum* and *Ardisia japonica* exhibited higher chlorophyll content and photosynthetic rates under natural light conditions compared to fluorescent lighting. Furthermore, the study found that natural light offers a rich spectral distribution across various wavelengths, providing an advantage for plant growth. Although direct comparisons between natural and artificial light environments are inherently challenging due to the distinct characteristics of each light source, the study emphasizes the importance of considering the rich spectral distribution of natural light when designing artificial lighting systems for optimal plant growth. In conclusion, understanding the effects of natural and artificial light on indoor plants is crucial to supporting plant growth and creating more effective indoor gardening solutions. Although direct comparisons between natural and artificial light environments are inherently challenging due to the distinct characteristics of each light source, natural light provides a more advantageous environment for growth compared to fluorescent lighting, with *Codiaeum variegatum* and *Ardisia japonica* both exhibiting a higher chlorophyll content and photosynthetic rate under natural light conditions.

Keywords: natural light; artificial light; *Codiaeum variegatum*; *Ardisia japonica*; plant growth; photosynthesis

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1. Introduction

Indoor landscaping, the practice of incorporating plants into interior spaces, has gained prominence as an environmentally friendly approach to space design [1,2]. This method not only elevates the aesthetic appeal of the indoor environment but also fosters productivity and comfort by promoting psychological stability for occupants [3–5]. Similar to the need for regulating the indoor climate and preserving the structural integrity of a building to ensure human comfort, indoor plants demand meticulous care to sustain their healthy growth and prolong the benefits of interior greening [6,7].

In general, plants incorporated into indoor spaces serve as elements of interior decoration, enriching the environment beyond conventional placement methods in greenhouses or windowsills [8,9]. However, plants are often situated in less optimal locations concerning functionality and spatial efficiency, resulting in insufficient lighting conditions for their healthy growth [10–12]. Most plants employed in indoor landscaping are shade plants or tropical houseplants that can thrive in low-light conditions, unlike those planted outdoors [13,14]. Despite the growing popularity of indoor landscaping and its recognized benefits, there remains a notable research gap regarding the effects of different lighting environments on indoor plant growth [15]. Specifically, a comprehensive comparison between natural and artificial lighting sources in supporting the health and development of indoor plants is lacking [16]. Addressing this research gap is crucial for designing optimal indoor environments that foster thriving and visually appealing green spaces.

This study aims to investigate and compare the effects of daylighting (through a duct-type natural light system) and artificial lighting (using fluorescent lamps) on the growth and development of indoor plants. By conducting rigorous analysis, we aim to shed light on the importance of light source selection and its impact on indoor plants' overall health and vitality. Ultimately, this research aims to provide insights and recommendations for creating sustainable and vibrant indoor green spaces.

This research presents a novel approach by examining the specific effects of different lighting environments on indoor plant growth. While previous studies have touched upon aspects of indoor landscaping and lighting, there is a lack of comprehensive research comparing natural and artificial lighting sources in a controlled environment for indoor plants. By conducting this comparative analysis, our research contributes to filling this research gap and offers valuable insights into the optimal lighting conditions necessary for the successful cultivation of indoor plants.

To achieve our research objectives, we employed a controlled experimental design. Two varieties of indoor plants commonly used in indoor landscaping were selected as test subjects. The plants were divided into groups and subjected to two lighting environments: daylighting provided by a duct-type natural light system and artificial lighting provided by fluorescent lamps. The growth and development of the plants, including measurements such as the height, leaf count, and overall vitality, were monitored over a specified period. Statistical analysis was conducted to compare the effects of the two lighting conditions on the plants' growth parameters. The chosen methodology ensures a systematic and scientific approach to evaluating the impact of lighting environments on indoor plant growth. By analyzing and interpreting the data collected, we aimed to draw conclusive findings that would contribute to the understanding of lighting requirements for optimal indoor plant cultivation.

2. Materials and Methods

2.1. Literature Review

Light and Growth Response of Plants

Life on Earth is fundamentally reliant on the energy generated by the sun [17]. Photosynthesis holds unique biological significance as the sole process capable of harnessing this energy [18,19]. The Earth's energy supply also stems from photosynthetic activity [20]. Photosynthesis can be described as "synthesis driven by light". Photosynthetic organisms utilize solar energy to synthesize organic substances that cannot form without the input of energy [21,22]. More specifically, light energy creates carbohydrates from carbon dioxide and water, simultaneously producing oxygen [23]. In contrast, when light is insufficient, plants exhibit increased stem elongation and develop pale, weak chlorosis [24]. The wavelengths of light necessary for plant growth encompass a broad range, including ultraviolet and infrared wavelengths [25]. Plant growth tends to be stunted under indoor artificial lighting conditions [26]. As a result, the influx of natural light indoors is a critical factor for plant growth, and securing direct light conditions is essential for enhancing the role of plants in improving the human living environment (Figure 1) [27,28].

The relationship between natural light and indoor plants has been a topic of interest in the field of indoor landscaping. Previous research in this area has provided valuable insights. Still, some studies have encountered limitations due to issues with the composition of lighting environments and experimental conditions involving natural and artificial light [29–31]. These flaws have prompted a need for more meticulous execution of experiments to accurately evaluate the effects of different lighting sources on indoor plant growth.

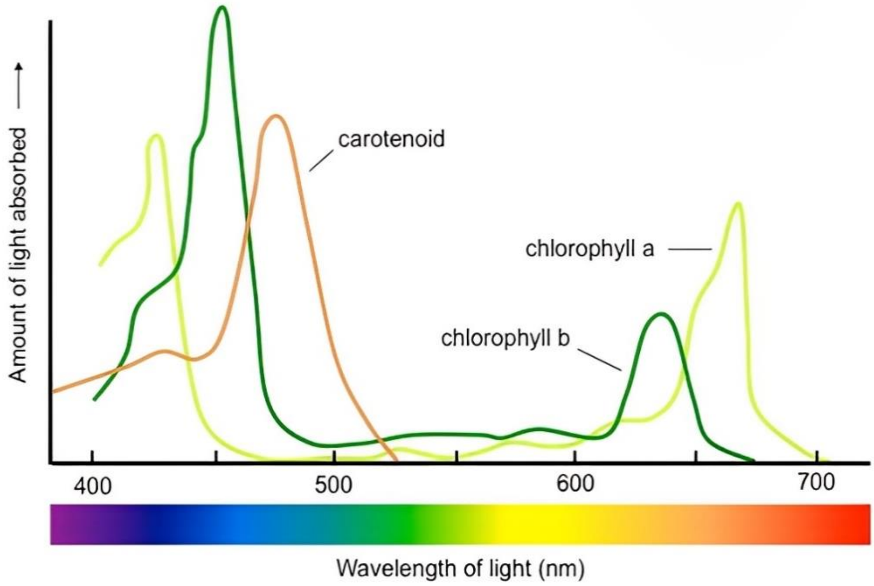

Figure 1. Absorption Spectrum of Chlorophyll a, b, and Carotenoid.

To address these limitations, recent studies have taken a more rigorous approach to investigating the relationship between natural light and indoor plants. A notable emphasis has been placed on constructing experimental chambers that simulate specific lighting conditions. These chambers have been designed to utilize either natural or artificial light sources, allowing for direct comparison and analysis of their effects on the indoor environment [32,33]. The construction of these experimental chambers plays a crucial role in controlling and manipulating the lighting conditions for accurate research outcomes. By carefully designing the chambers to replicate natural or artificial lighting environments, researchers have aimed to create controlled settings that closely mimic real-world conditions. This enables a more precise evaluation of the impacts of each lighting source on indoor plant growth.

Furthermore, advancements in experimental procedures have also contributed to the improved understanding of the relationship between natural light and indoor plants. Researchers have implemented meticulous protocols to ensure consistent and reliable measurements of plant growth parameters. By employing standardized methods and carefully monitoring variables such as temperature, humidity, and photoperiod, these studies have sought to minimize confounding factors and enhance the validity of their findings [34].

Recent literature highlights the need to carefully consider lighting environments and experimental conditions when studying the relationship between natural light and indoor plants. Researchers have recognized the limitations in previous findings and have responded by constructing specialized experimental chambers replicating natural or artificial lighting conditions. These chambers, along with improved experimental procedures, aim to provide more accurate insights into the effects of different lighting sources on the growth and development of indoor plants. By addressing these methodological concerns, researchers can advance our understanding of the optimal lighting conditions for sustainable and thriving indoor green spaces.

2.2. Experiment Methods

Natural light presents a variable influx of illumination, fluctuating based on the sun's position and weather conditions, whereas artificial lighting offers a more consistent output of luminous flux [35–37]. The lighting conditions within the chambers using natural and artificial light were controlled to create a lighting environment where the output of artificial light could be adjusted proportionally to changes in natural light [38,39]. The detailed research progression and methodology are outlined below (Figure 2).

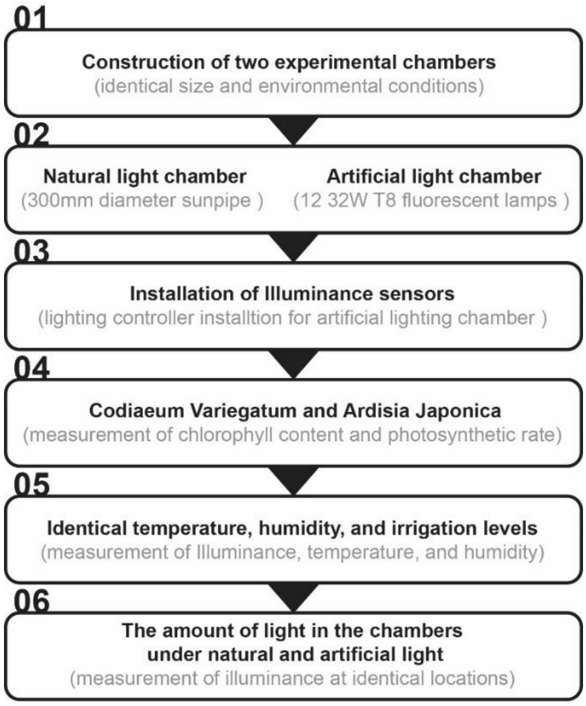

Figure 2. Experiment Flow Chart.

1. To objectively assess the impact of natural and artificial light on plants, two experimental chambers of identical size and environmental conditions were constructed; in each, two plants were inserted, one *Codiaeum variegatum* and one *Ardisia japonica* [40].
2. In the natural light chamber, a 300 mm-diameter sun-pipe (a light duct-type natural lighting system) was installed by Monodraft of England [41]. Meanwhile, twelve 32 W T8 fluorescent lamps were fitted in the artificial lighting chamber with a color temperature, or correlated color temperature (CCT), of 4500 K, and a color rendering index (CRI) of 85.
3. Illuminance sensors were installed in each chamber to maintain consistent illuminance levels between natural and artificial lighting environments [42]. Additionally, a lighting controller was employed in the artificial lighting chamber to automatically adjust the luminous output flux of the fluorescent lamps based on the measured illuminance levels [43]. A photometric sensor, which is designed to measure illuminance, or the amount of light incident on a surface, was utilized: an LI-210 sensor from LI-COR.
4. Two plant species, *Codiaeum variegatum* of 110 cm and *Ardisia japonica* of 80 cm, were chosen for the experiment [44–47]. The plants were purchased from a local market. After a one-month acclimatization process to stabilize the growth status of the plants, the chlorophyll content and photosynthetic rate were measured following a two-week experimental period under each chamber's conditions [48]. The growth response was subsequently assessed.
5. Identical temperature, humidity, and irrigation levels were maintained throughout the experiment to eliminate factors affecting plant growth [49]. The illuminance, temperature, and humidity in each chamber were continuously measured; an average illuminance of 2200–6200–1000 lux, an average temperature of 18–27–7 °C, and a humidity of 60–85–40% were maintained throughout the experiment, as detailed below in the results.
6. The amount of light in the chambers under natural and artificial lighting was monitored under the same conditions by measuring illuminance at identical locations [50]. Lastly, the differences between natural light and artificial light (fluorescent light) conditions were compared and analyzed alongside the growth state of the plants through measurements of the light spectrum in the visible light region. During midday in

a location such as Ajman, UAE, the light is direct, with less atmospheric scattering, providing uniform SPD across the visible spectrum with a peak irradiance of 1.5 mw/cm^2 per nm at around 500 nm. A T8 fluorescent lamp with a color temperature of 4000 K and a CRI of 85 may have peak irradiances of 0.1 to 0.2 mw/cm^2 per nm at 550 nm.

2.2.1. Natural and Artificial Light Experiment Chambers

To compare the effects of natural light and fluorescent light on indoor lighting environments, experimental chambers of identical size were constructed with a front cover open [51]. Considering the uniform indoor environmental conditions and ample natural light, the experimental chamber was installed on the rooftop of Ajman University's J2 building in Ajman, UAE, where the experiment was conducted, experiencing mild winter conditions, sitting at geographical coordinates of approximately 25.3995° N latitude and 55.4796° E longitude. During the experiment, temperatures averaged around 20–25 °C, and the region still enjoyed plenty of sunlight with mostly clear to partially clear skies. The minimal rainfall in winter meant that it was an ideal season for conducting this study. The comparative experiment assessing plant growth was conducted over a 10-day period, from 25 November 2022 to 4 December 2022 (Figure 3).

Figure 3. Test Chamber Installation View (Front Cover Open Condition).

As indicated in Table 1, both the natural light and artificial light chambers were constructed as cubes, each with side lengths of 1.15 m [52]. In the natural light chamber, a circular light duct with a diameter of 300 mm from Monodraft of England was installed to ensure an adequate influx of natural light [53]. A 1.15 m light duct and a diffuser plate were incorporated into the indoor light diffuser system to eliminate indoor shading caused by direct sunlight [54].

Table 1. Specification of Test Chambers.

Classification	Natural Light Chamber	Artificial Light Chamber
Specification	Both Chambers 1.15 m (Width) × 1.15 m (Length) × 1.15 m (Height)	
Ceiling Diffuser	Both Chamber 300 mm (Radius)	
Lighting Method	Light Duct	Fluorescent Lights 32 W (12 Pieces)

In the case of the artificial light chamber, similar to the natural light chamber, the light was diffused through a surface with a diameter of 300 mm to ensure uniform illumination within the chamber [55]. It was confirmed that the illuminance level at the measurement point in the natural light chamber did not exceed 10,000 lux, even under clear sky conditions [56,57]. The number of fluorescent lamps was set to 12, ensuring that the maximum output value of artificial light reached 10,000 lux based on the illuminance measurement point [58].

Furthermore, Illuminance in the chambers was measured while constantly maintaining indoor lighting for seven hours daily, from 9:00 a.m. to 4:00 p.m. After converting the illuminance levels measured in both chambers into text values, the fluorescent lamp output in the artificial lighting chamber was controlled by adjusting the output up or down according to the difference in values, ultimately equalizing the illuminance levels in both chambers [59]. A lighting controller was manufactured for this purpose [60]. By using a single sensor for both recording illuminance levels and providing input data for the lighting controller, any discrepancies in indoor illuminance levels between the two chambers were eliminated [61]. The configuration of the lighting controller, designed for lighting control, is depicted in Figure 4.

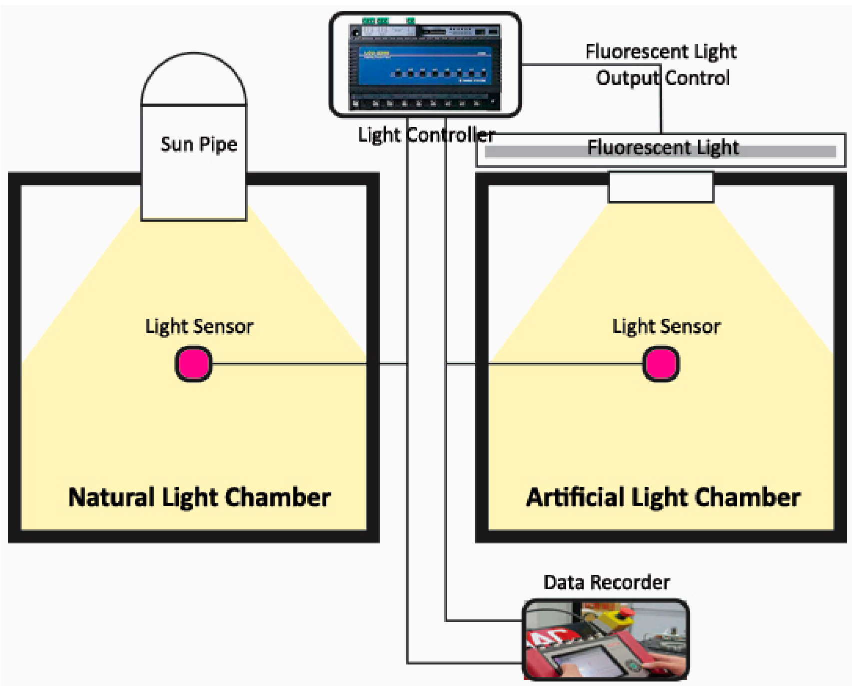

Figure 4. Lighting Control Structure for Test Chambers.

The circular light diffuser through which natural and artificial light entered each chamber was positioned at the center of the chamber's ceiling [62]. Additionally, using temperature and humidity control devices, the indoor temperature and humidity were regulated uniformly through air ventilation, and outdoor air was introduced using a ventilation fan [63].

For the ventilation of the chambers, a Panasonic FV-20NLF1E WhisperLine Remote Mount In-Line Spot ERV Ventilation Fan was used to ensure consistent airflow. This fan, which operates at 200 CFM at its highest speed setting, can achieve approximately five air changes per hour (ACH), assuming a fully sealed chamber.

The ventilation system operated continuously during daylight hours, specifically from 09:00 p.m. to 4:00 p.m. The placement of the fan and the vents was designed to promote optimal air circulation. Fresh air was introduced into the chamber via the fan, which was situated at the lower left part of the chamber. The air exited through vents strategically placed at the top right of the chamber.

These measures ensured uniform air distribution throughout the chamber, eliminating potential pockets of stagnant air and promoting a conducive environment for plant growth. A thermostat and a humidistat regulated the fan's operation, thus maintaining an indoor temperature no lower than 20 degrees Celsius and relative humidity not exceeding 60%.

This setup was identical in both the natural light and artificial light chambers to ensure the comparability of the results. The ventilation strategy was carefully devised to eliminate variations in the air quality and circulation as potential confounding factors in the study.

Chamber ventilation was set to operate only during daylight hours when natural light was present, and the artificial light output was controlled [64]. This ensured that low-temperature outdoor air did not enter the chamber at night, maintaining an indoor environment that did not create unfavorable temperature conditions for plant growth [65]. The control process for the lighting control system is as follows.

1. The illuminance in the natural light chamber is measured using an illuminance meter.
2. The measured illuminance value is converted into an electrical signal (current) and transmitted to the controller.
3. The controller calculates the dimming value necessary to maintain consistent illuminance according to the selected algorithm.
4. The calculated value is converted into voltage (0–10 V) and sent to the electronic ballast for dimming.
5. The electronic ballast for dimming adjusts the luminous flux of the fluorescent lamp based on the voltage received from the controller.

2.2.2. Indoor Environment Measurement

The fundamental premise of this experiment was to maintain consistent conditions for the plants placed in both chambers concerning the temperature, humidity, light, and irrigation required for optimal growth [66]. To compare plant growth conditions based on the characteristics of the light source, temperature, and humidity in the natural light and artificial light chambers, the illumination and light spectrum emitted from the diffuser were continuously measured and monitored during the study period [67].

The illuminance in the chambers was measured while maintaining indoor lighting for seven hours daily, from 9:00 a.m. to 4:00 p.m. Outside the designated measurement times, lighting within both chambers was blocked to preserve the lighting environment, ensuring consistent lighting conditions between the chambers even for minimal light exposure.

As depicted in Figures 5–8, it can be observed that the change in indoor illuminance levels was not constant due to external weather fluctuations (sky conditions) during the experimental period, as measured inside the two chambers. In the case of Figures 5 and 6, the external light penetration state exhibited partial penetration, resulting in fluctuations in the indoor illumination intensity. In contrast, Figures 7 and 8 demonstrate a maintained state of light penetration.

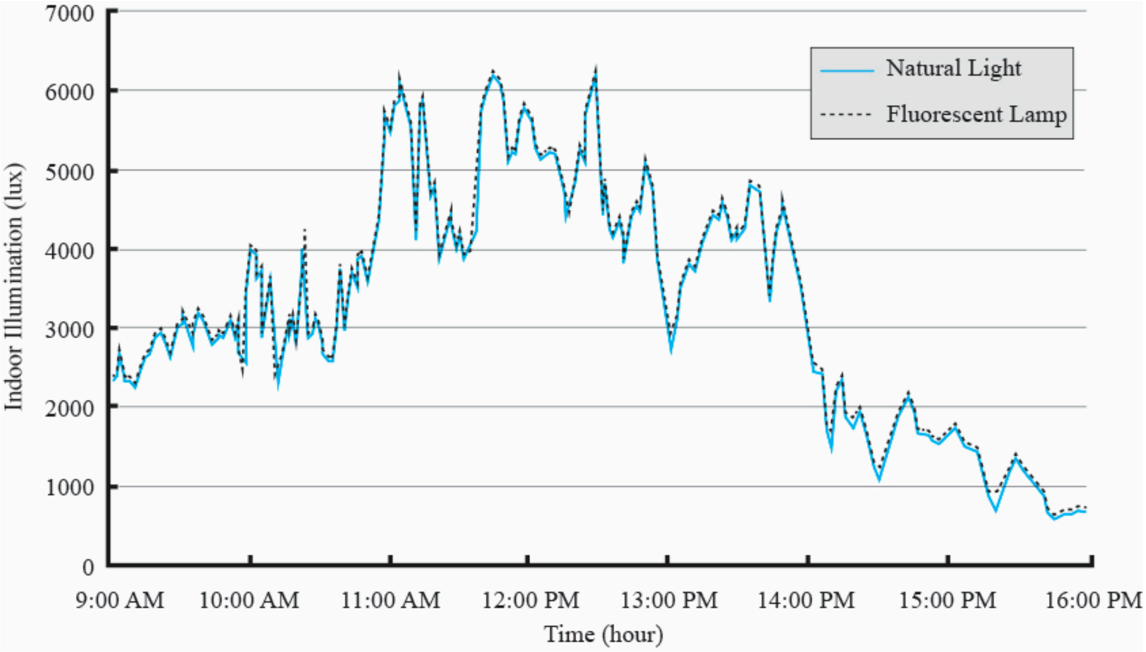

Figure 5. Illuminance Measurement Data (25 November 2022).

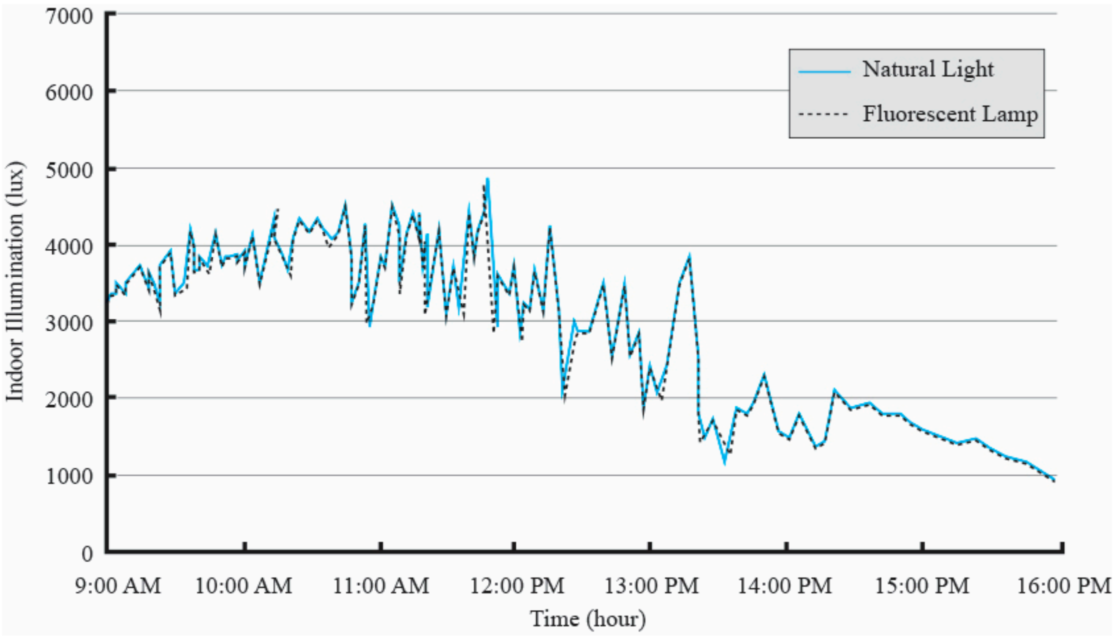

Figure 6. Illuminance Measurement Data (26 November 2022).

It can be ascertained that the variations in indoor illuminance resulting from natural light are precisely adjusted in the artificial lighting chamber through the use of lighting control [68]. The relative error of the illuminance values within the two chambers, measured over the course of the 10-day experimental period, demonstrated an average accuracy of 4.7%. By measuring the indoor illuminance, it can be verified that the lighting environment within both chambers maintains the same conditions, providing the essential light requirements for plant growth [69].

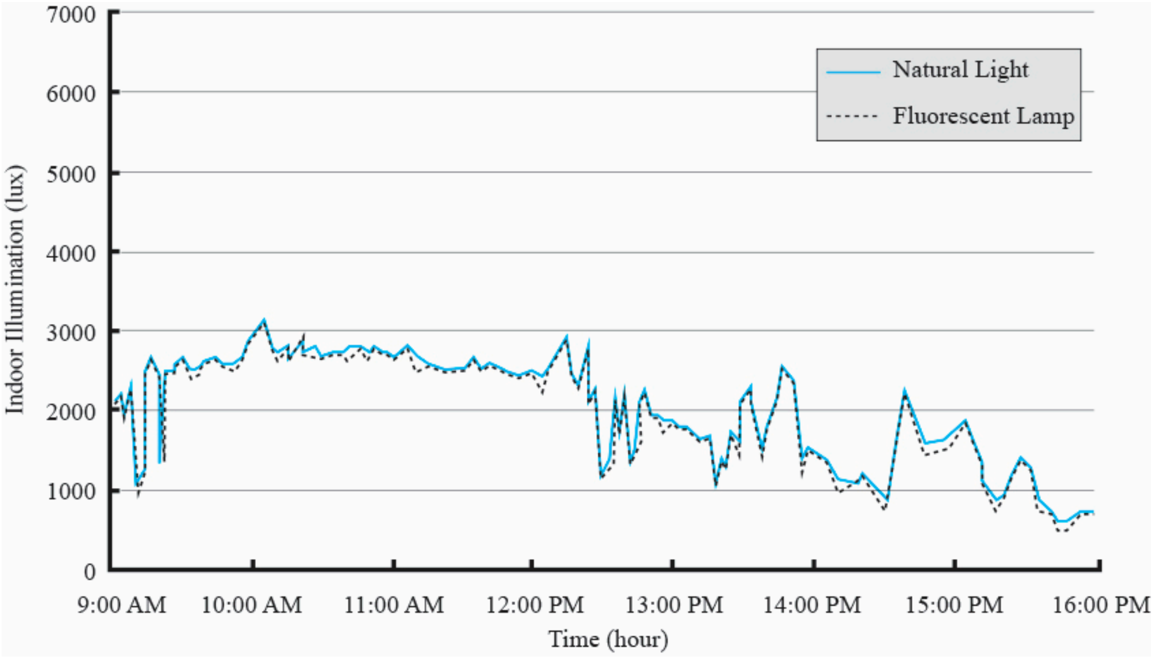

Figure 7. Illuminance Measurement Data (30 November 2022).

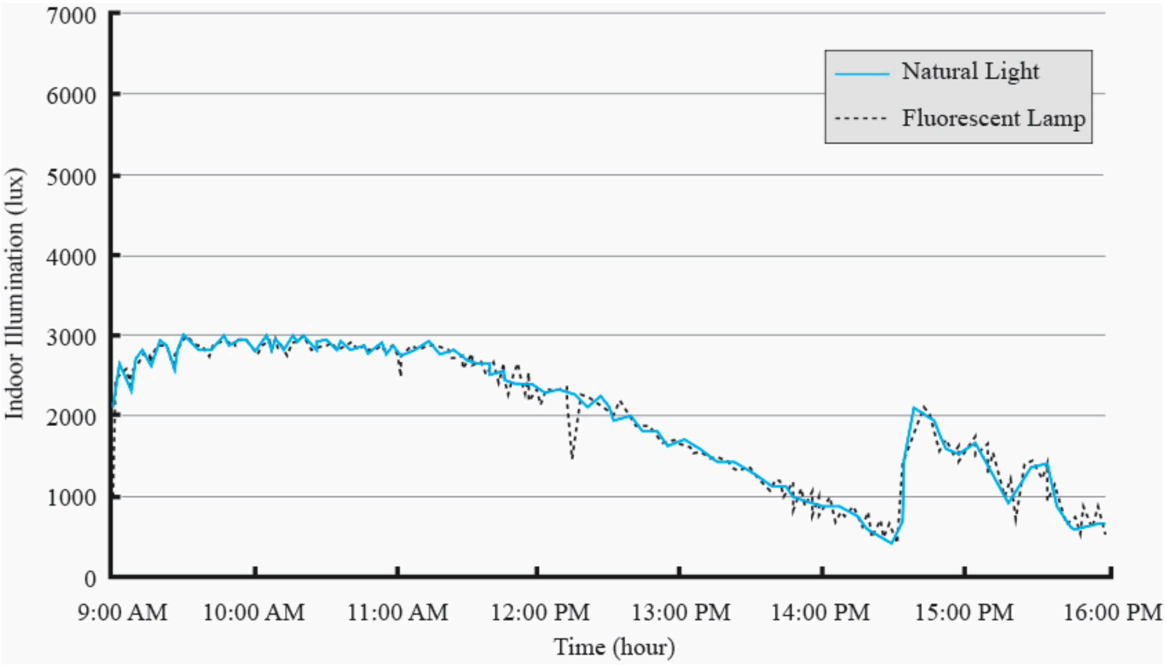

Figure 8. Illuminance Measurement Data (4 December 2022).

2.2.3. Indoor Temperature and Humidity Measurement

The temperature and humidity of each chamber were measured at hourly intervals using a temperature and humidity meter (TH-101) for two weeks, from 25 November 2022, when the experiment commenced, to 4 December 2022 (Table 2).

The temperature distribution in the natural light chamber and the fluorescent light chamber during the experimental period is illustrated in Figure 9. The temperature was quite similar in both chambers; however, between 12:00 p.m. and 5:00 p.m., when the illumination was high, the temperature in the fluorescent light room was higher by up to 2 °C. This difference can be attributed to the radiant energy of the fluorescent lamp and the heat generated by the electronic ballast affecting the room temperature.

Table 2. Indoor Environment and Plant Growth Condition Measurement Equipment.

Classification		Product Name	Manufacturer	Quantity
Temperature and Humidity		TH-101	Microtechno	2
Illuminance	**Light Sensor**	LI-210	LI-COR	2
	Data Logger	NetDAQ2640A	Fluke	1
Light Spectrum		Avaspec 2048	Avantes	2
Chlorophyll Content		SPAD-502	Minolta	1
Photosynthetic Amount		LI-6400	LI-COR	1

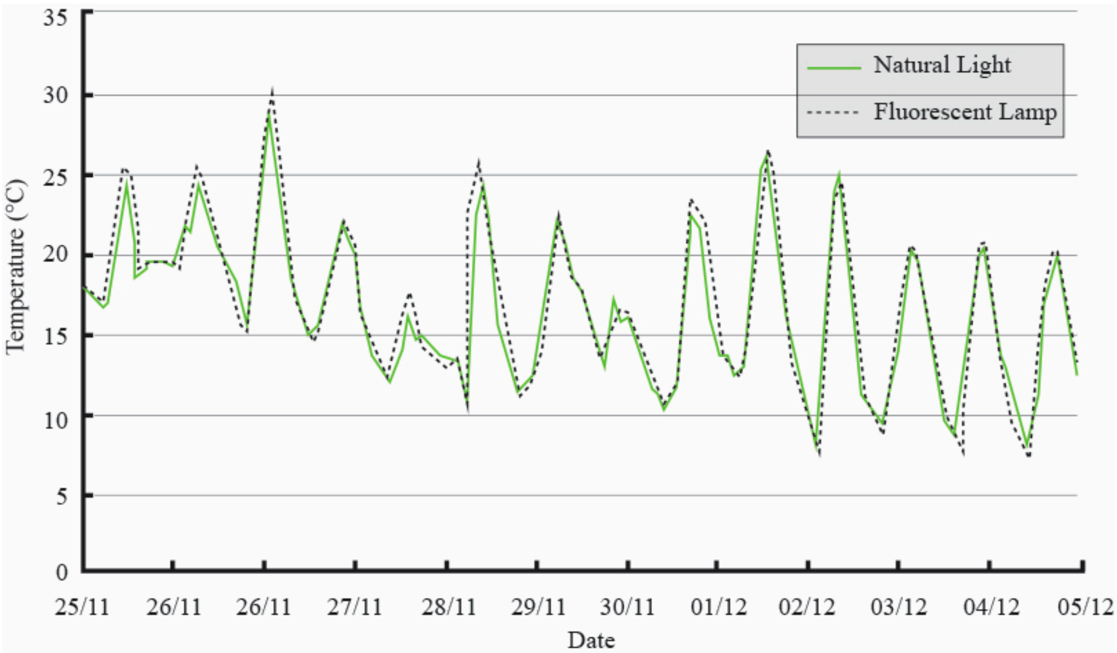

Figure 9. Temperature Measurement Data.

The humidity distribution in the natural light chamber and the fluorescent light chamber during the experimental period is depicted in Figure 10. The humidity was somewhat similar in both chambers, but the humidity in the natural light chamber was observed to be up to 15% higher in the afternoon. This difference can be explained by the relative humidity decreasing during the time when the temperature in the fluorescent lamp chamber is elevated. Although the indoor illuminance level was consistent, there were differences between the two chambers regarding the temperature and humidity. However, considering the distribution of the temperature and humidity and their variation over time, the differences in temperature and humidity between the two chambers during the measurement period did not significantly impact the growth and development of the plants placed in both chambers. It was determined that the artificial light chamber provided a more advantageous environment. Despite observable differences in temperature and humidity between the natural light and fluorescent light chambers, these variations did not significantly affect the plants' growth and development. The temperature in the fluorescent light chamber was higher by up to 2 °C during peak illumination, and the humidity in the natural light chamber was up to 15% higher in the afternoon. These fluctuations, while noteworthy, remained within the optimal growth conditions of the plants used in our study. The ability of the artificial light chamber to maintain consistent illumination, irrespective of external weather conditions or time of day, coupled with manageable temperature and humidity variances, ensured a more stable and predictable growth environment.

Consequently, the artificial light chamber was determined to provide a more advantageous environment for plant growth and development.

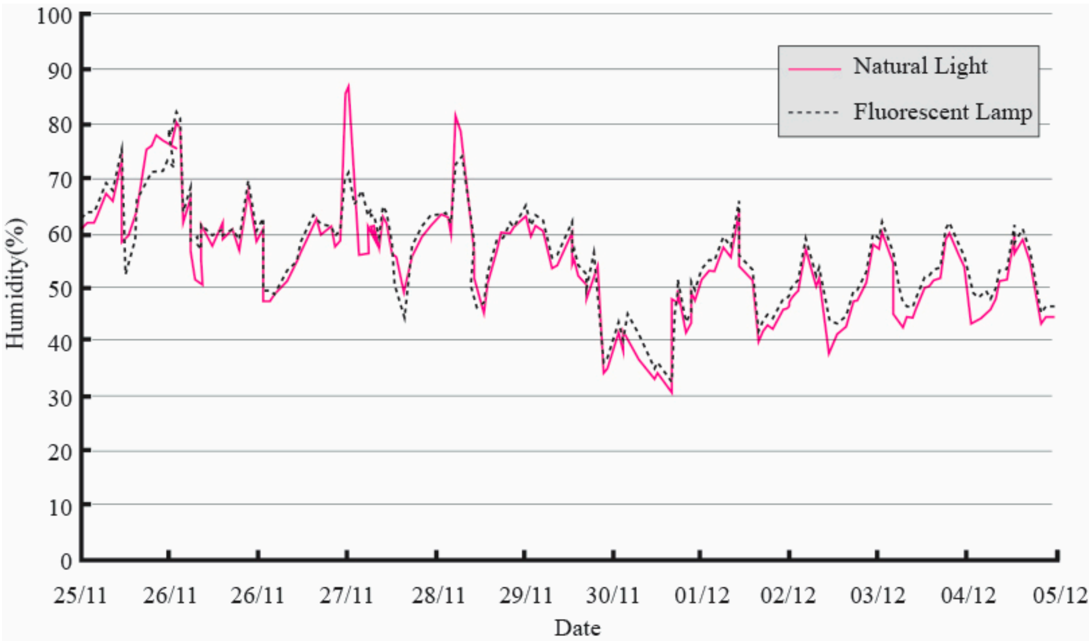

Figure 10. Humidity Measurement Data.

2.2.4. Optical Spectrum Analysis

Natural and fluorescent light spectra were measured using a spectrum analyzer (Avaspec-2048-2-SPU) at an illuminance of 2500 lx. It measures the spectrum distribution of light radiated from the light diffuser at the illuminance measurement point of the natural light chamber and the artificial light chamber [70].

Fluorescent lamps show a relatively high amount of light in specific wavelength bands (435 nm, 545 nm, and 610 nm). In contrast, natural light shows an even spectrum distribution in all wavelength bands in the visible ray region [71]. Although both chambers showed the same amount of light based on the illuminance value, it was confirmed that the light conditions of the two chambers were different in terms of the amount of light required for plant growth because the absorption spectrum of photosynthetic pigments was evenly distributed by wavelength [72]. In addition, this light spectrum distribution will significantly affect plant growth.

3. Results

Codiaeum variegatum and *Ardisia japonica*, both widely used for indoor gardening, were selected as test plants for this experiment. These plants underwent a one-month acclimatization process in a greenhouse with ample light. *Codiaeum variegatum* is a variegated species of indoor houseplant that responds sensitively to light, while *Ardisia japonica* is a domestic species well-suited for indoor conditions and is particularly resistant to low light. Figure 11 depicts the *Codiaeum variegatum* and *Ardisia japonica* used in this study.

Both *Codiaeum variegatum* and *Ardisia japonica* were grown in a natural light chamber and an artificial light chamber for 10 days each. Photosynthetic amounts were measured at light intensities of 100, 300, 500, and 700 μmol$\cdot$m$^{-2}\cdot$s^{-1}. In the case of *Codiaeum variegatum*, as the illuminance increased, the photosynthetic amount rose from 0.21 $\pm$ 0.17 μmol$\cdot$m$^{-2}\cdot$s^{-1} to 0.85 $\pm$ 0.31 μmol$\cdot$m$^{-2}\cdot$s^{-1}. Conversely, under fluorescent light, the amount of photosynthesis decreased from 0.19 $\pm$ 0.13 μmol$\cdot$m$^{-2}\cdot$s^{-1} to 0.08 $\pm$ 0.64 μmol$\cdot$m$^{-2}\cdot$s^{-1} (Table 3). This decrease is thought to be due to the oxidation of cell components, including chloroplasts, as the light changes, suppressing chlorophyll production and reducing photosynthesis.

Figure 11. *Codiaeum variegatum* (**Left**) and *Ardisia japonica* (**Right**).

Table 3. Changes in Photosynthesis Amount in *Codiaeum variegatum*.

Luminosity	Photosynthetic Amount (µmol·m^{-2}·s^{-1})		
	Before Experiment	After Experiment	
		Natural Light	Fluorescent Lamp
100	1.21 ± 0.65	0.21 ± 0.17	0.19 ± 0.13
300		0.47 ± 0.05	0.44 ± 0.11
500		0.72 ± 0.11	0.51 ± 0.29
700		0.85 ± 0.31	0.08 ± 0.64

In the case of *Ardisia japonica*, the highest photosynthetic efficiency occurred at 700 µmol·m^{-2}·s^{-1} with 1.31 ± 0.12 µmol·m^{-2}·s^{-1} under natural light (Table 4). Consequently, both *Codiaeum variegatum* and *Ardisia japonica* appear to exhibit better growth under natural light conditions compared to fluorescent lighting.

Table 4. Changes in Photosynthesis Amount in *Ardisia japonica*.

Luminosity	Photosynthetic Amount (µmol·m^{-2}·s^{-1})		
	Before Experiment	After Experiment	
		Natural Light	Fluorescent Lamp
100	1.38 ± 0.23	0.26 ± 0.06	0.26 ± 0.13
300		0.64 ± 0.05	0.64 ± 0.11
500		1.01 ± 0.14	0.97 ± 0.15
700		1.31 ± 0.12	1.05 ± 0.37

Upon measuring the chlorophyll content before and after the experiment, the chlorophyll content of croton in the natural light chamber increased by 16.3 Soil Plant Analysis Development (SPAD) units compared to its pre-experimental levels, demonstrating a more significant change than the 4.1 SPAD increase observed in the artificial light chamber (Table 5).

Table 5. Comparison of Chlorophyll Amount between *Codiaeum variegatum* and *Ardisia japonica*.

Plants	Light Source	Chlorophyll Content (SPAD)		Chlorophyll Content Increase Rate (%)
		Before Experiment	After Experiment	
Codiaeum variegatum	Natural light	29.2	45.5	55.6
	Fluorescent lamp	30.2	34.2	13.2
Ardisia japonica	Natural light	39.1	41.7	6.9
	Fluorescent lamp	39.5	40.4	2.3

The change in chlorophyll content for the golden cow increased by 2.7 SPAD in the natural light chamber compared to before the experiment, which was greater than the 0.9 SPAD increase observed in the artificial light chamber (Figure 12).

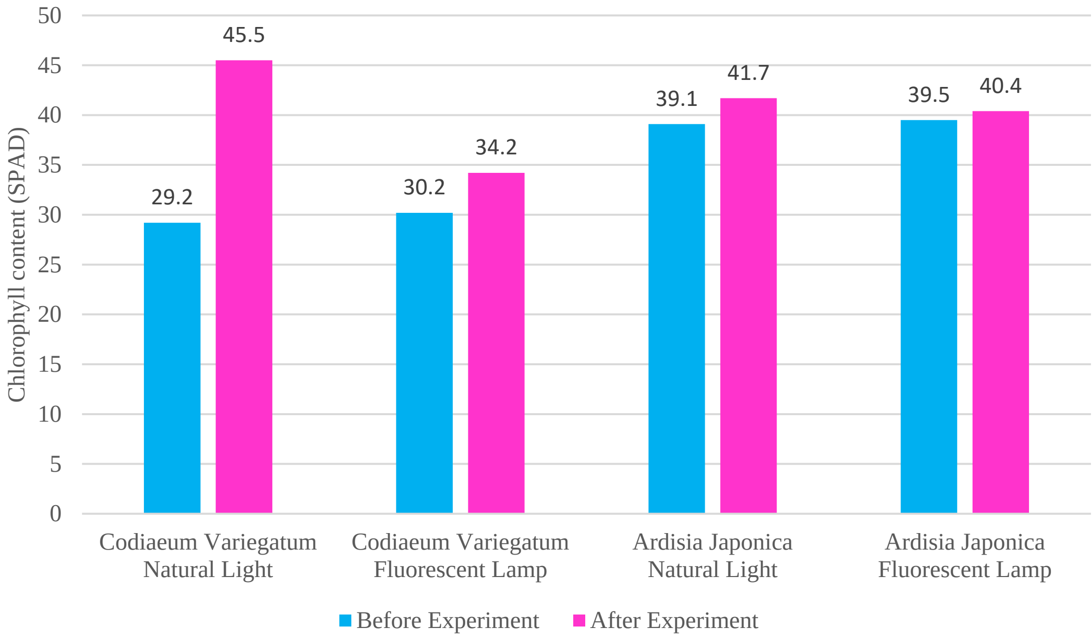

Figure 12. Chlorophyll Content Comparison between *Codiaeum variegatum* and *Ardisia japonica*.

4. Discussion

The experiment selected *Codiaeum variegatum* and *Ardisia japonica*, both widely used for indoor gardening, as test plants. These plants underwent a one-month acclimatization process in a greenhouse with ample light. *Codiaeum variegatum* is a variegated indoor houseplant that is sensitive to light; *Ardisia japonica* is a domestic species that thrives indoors and is particularly resistant to low light.

Both plants were grown in a natural light chamber and an artificial light chamber for ten days each, with photosynthetic amounts measured at light intensities of 100, 300, 500, and 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$. For *Codiaeum variegatum*, as the illuminance increased, the photosynthetic amount rose from 0.21 ± 0.17 $\mu mol \cdot m^{-2} \cdot s^{-1}$ to 0.85 ± 0.31 $\mu mol \cdot m^{-2} \cdot s^{-1}$. In contrast, under fluorescent light, the amount of photosynthesis decreased from 0.19 ± 0.13 $\mu mol \cdot m^{-2} \cdot s^{-1}$ to 0.08 ± 0.64 $\mu mol \cdot m^{-2} \cdot s^{-1}$. This decrease is believed to be due to the oxidation of cell components, including chloroplasts, as the light changes, suppressing chlorophyll production and reducing photosynthesis.

In the case of *Ardisia japonica*, the highest photosynthetic efficiency occurred at 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$ with 1.31 ± 0.12 $\mu mol \cdot m^{-2} \cdot s^{-1}$ under natural light. As a result, both

Codiaeum variegatum and *Ardisia japonica* appear to exhibit better growth under natural light conditions compared to fluorescent lighting.

Upon measuring the chlorophyll content before and after the experiment, the chlorophyll content of *Codiaeum variegatum* (croton) in the natural light chamber increased by 16.3 Soil Plant Analysis Development (SPAD) units compared to its pre-experimental levels, demonstrating a more significant change than the 4.1 SPAD increase observed in the artificial light chamber. For *Ardisia japonica*, the change in chlorophyll content increased by 2.7 SPAD units in the natural light chamber compared to before the experiment, which was greater than the 0.9 SPAD increase observed in the artificial light chamber. The experiment results indicate that both *Codiaeum variegatum* and *Ardisia japonica* show better growth and higher chlorophyll content increases under natural light conditions as opposed to fluorescent lighting.

The experiment tested the impact of natural and artificial light on *Codiaeum variegatum* and *Ardisia japonica*, both popular choices for indoor gardening [44]. The selection of these plants was purposeful, considering their varying light sensitivities: *Codiaeum variegatum* is sensitive to light, and *Ardisia japonica* is known for its resistance to low light conditions.

The photosynthetic activity and chlorophyll content, both essential indicators of plant health, were measured for these plants under varying light intensities. Notably, as the illuminance increased, *Codiaeum variegatum*'s photosynthetic activity increased under natural light but decreased under fluorescent light [45]. This observation aligns with previous studies, which suggests that excess artificial light can cause oxidative stress, impairing chloroplast function, and thus reducing photosynthesis.

In contrast, *Ardisia japonica*, more resilient to low-light conditions, reached peak photosynthetic efficiency at 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$ under natural light. These observations imply that even for low-light-tolerant plants, natural light conditions foster better growth and higher photosynthetic rates than artificial lighting [46].

Moreover, our study found a more considerable increase in the chlorophyll content of both plant species in the natural light chamber, reaffirming the beneficial effects of natural light. Prior studies have shown that increased chlorophyll content is often linked to improved plant health and growth.

These findings extend beyond academic interest and hold practical implications for indoor gardening and architecture. Enhanced growth under natural light could result in more robust, healthier plants in indoor environments, benefiting the overall indoor air quality by improving air purification and humidity regulation, qualities inherent to plants. This potential improvement in indoor environmental quality directly ties into the psychological benefits of indoor plants, contributing to improved mood, reduced stress levels, and increased workplace productivity.

Furthermore, our research supports a growing body of work advocating for incorporating more natural elements, particularly sunlight, into built environments, a concept known as biophilic design. Architects and interior designers might consider these findings when designing spaces, emphasizing natural lighting to facilitate healthier indoor plant growth and enhancing both the aesthetic appeal and environmental quality of indoor spaces.

5. Conclusions

To examine the impact of natural and artificial light on indoor plants, the physiological responses of two indoor plant species, *Codiaeum variegatum* and *Ardisia japonica*, were assessed under each lighting condition. A natural light chamber and an artificial light chamber of identical dimensions were constructed. Upon comparing the physiological responses of the plants under consistent temperature, humidity, and illuminance conditions, the findings of this study can be summarized as follows.

While the study's chambers attempted to replicate indoor conditions, the plants clearly preferred natural light. This suggests the value of reconsidering the extensive use of artificial lighting in indoor spaces, instead promoting more natural light incorporation for the benefit of both the plant life and the people sharing those spaces.

First, a comparison of the chlorophyll content and photosynthetic rates of *Codiaeum variegatum* and *Ardisia japonica* under natural light and fluorescent light conditions revealed that, for *Codiaeum variegatum*, the chlorophyll content was 32.9% higher and the average photosynthetic rate was 48.5% higher under natural light. In the case of *Ardisia japonica*, the natural light environment exhibited a 3.5% higher chlorophyll content and a 9.6% higher photosynthetic rate compared to fluorescent lighting. The study confirmed that the growth performance varies depending on the type of plant and light source, with natural light providing a more advantageous environment for growth than fluorescent lighting conditions.

Second, given the inherent differences between light sources, it is challenging to make an absolute comparison between the growth environments provided by natural light, which exhibits fluctuating illuminance, and artificial light, which maintains a constant level of illumination. Nonetheless, under the same illuminance conditions, natural light offers a rich spectral distribution across various wavelengths, providing an advantage for plant growth. These light source characteristics should be considered when designing artificial lighting systems for optimal plant growth.

In conclusion, this study highlights the significance of understanding the effects of natural and artificial light on indoor plants' growth and physiological responses. The findings indicate that natural light provides a more advantageous environment for growth than fluorescent lighting, with *Codiaeum variegatum* and *Ardisia japonica* exhibiting higher chlorophyll contents and photosynthetic rates under natural light conditions. Although direct comparisons between natural and artificial light environments are inherently challenging due to the distinct characteristics of each light source, the study emphasizes the importance of considering the rich spectral distribution of natural light when designing artificial lighting systems for optimal plant growth. By doing so, we can better support plant growth and create more effective indoor gardening solutions.

This study underscores the beneficial influence of natural light on indoor plants, such as *Codiaeum variegatum* and *Ardisia japonica*. However, our understanding of how indoor plants interact with their environment extends beyond their light preferences.

The environmental benefits of indoor plants are manifold. They improve indoor air quality by absorbing pollutants, increasing humidity, and can reduce ambient noise levels. These factors can lead to a more pleasant and healthy indoor environment. Moreover, plants can have a role in energy conservation. Strategically placed, they can reduce the need for artificial air conditioning, cooling the air through the process of transpiration.

Psychologically, the presence of plants in indoor spaces has been shown to improve mood, reduce stress, and increase productivity and creativity. They offer a visual connection to nature, which can enhance psychological well-being, a concept known as biophilia. As our study suggests, this psychological effect may even be enhanced when plants are grown under conditions that best mimic their natural environment.

Furthermore, indoor gardening can serve as a fulfilling hobby, providing individuals with a sense of achievement when their plants thrive, improving mental health in the process. It could also be an educational tool, teaching both children and adults about plant biology and ecology.

However, this study has limitations. Our experiment maintained consistent temperature, humidity, and illuminance, but there might be other environmental factors affecting plant growth that were not controlled for. Moreover, the inherent characteristics of natural and artificial light make direct comparisons challenging. A limitation of this research is the absence of replication in the experimental design. Replication refers to the process of conducting independent, repeated trials or experiments to validate and confirm the findings. In the context of biological experiments, replication becomes especially crucial due to the inherent variability observed among living organisms. By not including independent replicates in the study, there is a risk that the observed results might be influenced by specific factors or idiosyncrasies within the experimental conditions. Biological systems are highly complex and can exhibit substantial variations in response to different stimuli or environmental factors. Therefore, conducting replicates helps to capture this inherent variability and provides a more comprehensive understanding of the phenomenon under investigation. While the primary audience for this research may be architects and field professionals, it is important to recognize that the use of living organisms (plants) introduces a level of biological complexity that cannot be ignored. Furthermore, as science communication aims to bridge the gap between scientific knowledge and the general public, it becomes even more critical to transparently address the limitations of a study. Future research could explore the effects of various types of artificial light sources on a broader range of indoor plant species, perhaps focusing on those known to provide the greatest environmental and psychological benefits. Further investigation into the potential benefits of hybrid lighting systems combining natural and artificial light may also be warranted.

By acknowledging the various benefits that indoor plants offer and by understanding their specific needs—in this case, the demonstrated preference for natural light—we can optimize indoor horticulture practices. In turn, this optimization will enhance the environmental, psychological, and other benefits that indoor plants bring to our living and working spaces.

Future research could expand upon these findings by exploring the effects of various artificial light sources and light spectra on a broader range of indoor plant species. Additionally, investigating the potential benefits of combining natural light with artificial lighting systems to create hybrid solutions could lead to more efficient and sustainable approaches to indoor horticulture.

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