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Original Article

Comparative Analysis of Carbon Dioxide and Oxygen Dynamics in Compartmentalized vs. Non-Compartmentalized on *Dypsis lutescens*

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Abstract

Plants play a role in influencing carbon dioxide (CO_2) and oxygen (O_2) levels in the atmosphere through photosynthesis and respiration. *Dypsis lutescens* is known as outdoor and indoor ornamental plant thus the plant is suitable as a model for studying gas exchange in different environment. Previous studies have demonstrated that plants grown in compartments and those grown without compartments represent indoor and outdoor environments, respectively. This study aims to compare carbon dioxide and oxygen dynamics and their relationship in *D. lutescens* grown in compartmentalized versus non-compartmentalized conditions to establish baseline data for gas exchange in unstressed plants. The results showed that compartmentalized conditions caused an increase in carbon dioxide concentration and a consistent decrease in oxygen levels, compared to non-compartmentalized settings. These differences seem to be influenced by abiotic factors such as relative humidity and temperature. Relationship between carbon dioxide and oxygen on non-compartmentalized and compartmentalized conditions is opposite.

Keywords: Carbon dioxide, compartment, *Dypsis lutescens*, oxygen.

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Introduction

The atmosphere contains various gases, such as oxygen and carbon dioxide. According to the National Oceanic and Atmospheric Administration (2024), oxygen ranked as the second most abundant gas in the atmosphere (209,460 ppm) after nitrogen while carbon dioxide content in the atmosphere is 420 ppm. The carbon dioxide concentration has significantly increased 40% over the last century and predicted reach around 670 ppm in 2100 (Jacobson et al., 2019). Human activity has been identified as a contributing factor to the increase in carbon dioxide emissions. These are (i) combustion of fuels from factories and vehicles, (ii) terrestrial ecosystem strength such as deforestation, and (iii) land use change for agricultural ecosystem causes soil organic carbon depletion. From these three factors, the combustion of fossil fuels has been identified as the most significant human activity contributing to carbon dioxide emissions (Salam & Noguchi, 2005).

Indoor condition also becomes an issue for carbon dioxide concentrations where indoor condition have different with outdoor condition and affected the humanity health for its air quality. Urban people spend lives indoors approximately 80% (Cetin, 2015). Air quality in indoor spaces is important for human health (Sevik et al., 2013). Indoor conditions lead to poor air quality due to air pollutants trapped inside because of closed indoor ventilation (Li et al., 2021a). Carbon dioxide concentrations are higher in indoor conditions than in ambient because of limited ventilation and high occupancy levels which causes air circulation to be limited (Bandehali et al., 2021; Jacobson et al., 2019; Satish et al., 2012). Humans become the main producer of carbon dioxide within buildings from the respiration process. The concentration of carbon dioxide in the exhaled breath of an adult human ranges from 35,000 - 50,000 ppm (Gubb et al., 2018; Kumara et al., 2018). Lowther et al. (2021) classified indoor carbon dioxide levels into three categories, (i) good or excellent indoor air quality (<1,000 ppm), (ii) moderate indoor air quality (1,000 – 1,500 ppm), and (iii) poor indoor air quality (>1,500 ppm).

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The presence of elevated levels of carbon dioxide in the air has been demonstrated to induce symptoms and diseases. Exposure to carbon dioxide > 1,000 ppm causes symptoms such as increasing in breathing rate, high pulse rate, headache, dizziness, fatigue, and rise in blood pressure (Mathur, 2018; Cetin & Sevik, 2016) while > 1,500 ppm people experience nose irritation, throat irritation, nasal discharge, cough, and eye discharge (Cetin & Sevik, 2016). High concentrations of carbon dioxide result in severe diseases such as epileptic fits, cramps, acidosis, and hypoxia (Mathur, 2018; Jacobson et al., 2019). Moreover, carbon dioxide is considered one of the main air pollutants which is of serious concern due to its effect on the climate as a greenhouse gas (Hadipoor et al., 2021).

One of the low-cost and eco-friendly methods to control the gas profile in the atmosphere is the usage of plants (Weerasinghe et al., 2023; Inbathamizh et al., 2020). Plants are important in the carbon and oxygen cycle in nature (Cetin & Sevik, 2016). They are also important as indoor decor due to their value for appearance and biological function. The appearance of ornamental plants is aesthetic which attracts people to enjoy the beauty (Ilmiyah et al., 2024). The biological function of the plant is that plants are responsible for the photosynthesis process. Photosynthesis is the synthesis process of carbon compounds and water using solar energy with the results of carbohydrates and oxygen by photosynthetic organisms (Taiz & Zeiger, 2002).

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Additionally, plants also have other roles, i.e. increasing the relative humidity by adding moisture and purifying toxins, dust fall, and total volatile organic compounds (TVOC) (Berger et al., 2022; Cummings & Waring, 2020; Susanto et al., 2021). Therefore, plants have the capacity in air-filtering to create healthy air conditions both indoor and ambient air.

Dypsis lutescens (Yellow Palm) is a plant belonging to Arecaceae or Palmae family which is commonly known as an ornamental plant both outdoors and indoors (Ijaz & Babar, 2020). The utility as indoor decor corroborated with review articles that mentioned the potential of this plant as a phytoremediation agent. *D. lutescens* is able to clean various air pollutants such as acetone, benzene, formaldehyde, xylene, trichloroethylene, carbon monoxide, and toluene (Ijaz & Babar, 2020; Ravindra & Mor, 2022; Kumar et al. 22023; Soni & Gawri, 2024).

Previous studies conducted measurements of carbon dioxide concentrations of plants both indoors and outdoors. The indoor condition was retrieved with the plant inside compartment conducted by Cetin & Sevik (2016), Shishegaran et al. (2020), and Weerasinghe et al. (2023) while the outdoors condition was measured directly under the plants without compartment conducted by Siswanto & Batoro (2019). However, there is no study about the comparison of carbon dioxide and oxygen levels between plant covered by compartment and without compartment. Indoor and outdoor condition have different conditions such as temperature, humidity, and carbon dioxide concentration (Ayanlade et al., 2023; Xu et al., 2020). Those abiotic factors influence photosynthetic performance (Kochhar & Gujral, 2020). Compartmentalized might change abiotic factors due to it restrict air circulation, simulating indoor condition with limited air circulation. On the other hand, there are various parameters related to photosynthesis such as photosynthesis rate (Ali et al., 2019), carbon dioxide assimilation (Mohamed et al., 2018), intracellular carbon dioxide concentration (Mohamed et al., 2018), carbon dioxide fixation (Selem, 2019), and carbon dioxide concentration around the plant (Cetin & Sevik, 2016; Siswanto & Batoro, 2019). Carbon dioxide concentration around the plant measurement is an indirect photosynthesis measurement process because it uses assumption reduced carbon dioxide concentration around plant caused by absorption by plant for photosynthesis process. Oxygen concentration in the air also can be measured by tool similar as carbon dioxide, by oxygen meter. In contrast to carbon dioxide, oxygen concentration assumed increases because of photosynthesis. Measurement of carbon dioxide and oxygen concentration is suitable for compartmentalized and non-compartmentalized condition on plant due to it measured the air profile around the plant. Therefore, the present study attempts to determine the carbon dioxide and oxygen concentrations profile and their relationship of *D. lutescens* covered by compartment as the indoor conditions and without compartment as the outdoor condition where this plant can be utilized indoors and outdoors.

Methods

Plant selection

Palm *D. lutescens* was bought from a local florist in Sawojajar, Malang, Indonesia. Several considerations of plant selection were similar to plant height, size, and age. There were six individuals used in this research with each treatment (without compartment and covered by compartment) conducted with three plants as replications. All plants were replanted in soil : rice husk (1:1) medium in identical polybags (18 cm in height, 20 cm in diameter) (El Rummana et al., 2024). Plants located in outdoor conditions of 25.14 ± 1 ^{o}C in temperature and exposed directly to sunlight. Sunlight intensity was recorded three times in every time observation by lux meter (model AS803, made in China). The wind speed was ignored. Acclimatization was done around five months.

Experimental setup

The transparant plastic compartment (88 x 58 cm) was covered to plants and then was closed at the bottom of the polybag to prevent air from entering the compartment. One compartment covered one individual plant only. Carbon dioxide concentrations were measured with a carbon dioxide meter (model SNDWAY SW-723, made in China) while oxygen concentrations were measured with an oxygen meter (model AR8100, made in China). Plants without compartments were measured under abaxial leaves at a distance ± 5 cm (Figure 1A) (Siswanto & Batoro, 2019 with modification) while plants with compartments were measured inside compartments (Figure 1B) (Siswanto et al., 2019). Relative humidity and temperature were measured with a carbon dioxide meter tool similar to carbon dioxide concentration. The measurements were done after covering with compartments (0, 2, 4, 6, 8, 10, 24, and 26 h). 0 h observation was done around 7.00 AM due to sunlight shining on the observation location while 10 h observation was done around 5.00 PM due to sunlight was no longer shining on the observation location.

A B

Figure 1. Measurement process of *D. lutescens* (A). without compartment (B). inside compartment.

Data analysis

Data were analyzed by descriptive statistics to determine: 1) light intensity of site, 2) abiotic factors (temperature and relative humidity) of *D. lutescens* without compartment and inside compartment. Carbon dioxide and oxygen concentrations profile of *D. lutescens* without compartment and inside compartment were analysed by unpaired t-test (α = 5%). Relationship between those gases was done by regression.

Results

Light intensity profile

Light intensity profile showed increasing in 0 to 4 h and 24 to 26 h observations. However, light intensity sharply decreases at 6 h and then reaches the lowest at 10 h (Table 1). The weather conditions affected the light intensity. In 0 to 4 h and 24 to 26 h, the weather was sunny. During observation 6 to 10 h, the weather became cloudy causing the light intensity to be slightly.

Table 1. Light intensity profile during observations

Time Observation (h)	Light Intensity (lux)
0	813.67 ± 16.56
2	1542.67 ± 928.19
4	2985.33 ± 557.01
6	639.00 ± 440.23
8	436.00 ± 176.59
10	129.33 ± 92.36
24	890.50 ± 359.92
26	2626.00 ± 509.96
AVERAGE	1091.00 ± 1042.07

Carbon dioxide and oxygen concentrations profile

Figure 2 contains carbon dioxide concentrations on *D. lutescens* measured under different conditions. All three repetitions have similar patterns in carbon dioxide concentrations. Generally, both showed a positive gradient which showed higher carbon dioxide concentrations as the observation time gets longer. However, there were times when observations showed a negative gradient. Without compartment showed decreasing on 4 and 24 h observations while covered by compartment decreasing on 26 h after 24 h always increasing. Oxygen showed a different trendline compared with carbon dioxide (Figure 3). Oxygen concentrations get lower as the observation time gets longer both without compartment and covered by compartment. However, the oxygen emission increased in 10 h observation in *D. lutescens* without compartment.

It can be inferred that light intensity influence carbon dioxide concentrations. Decreasing carbon dioxide in 4 and 26 h observations without compartment followed by very high light intensity. Lower carbon dioxide concentrations are caused by the photosynthesis process. Light intensity is a factor influencing the photosynthesis rate. Increasing light intensity increases the photosynthetic rate (Kochhar & Gujral, 2020). This statement is similar to the present study which showed higher light intensity causes decreasing carbon dioxide levels and lower light intensity induces rising carbon dioxide levels. 4 and 26 h may be the optimal light intensity for *D. lutescens*' photosynthesis rate due to in these times, carbon dioxide levels without compartment condition were the lowest while carbon dioxide on 6 to 10 h were increasing. Photosynthesis rate correlates with stomata. Stomata is a pore for gas exchange (Kochhar & Gujral, 2020). Light exposure leads to stomatal opening that causes carbon dioxide absorption and oxygen emission (Kochhar & Gujral, 2020). Weerasinghe et al. (2023) reported similar results. Light intensity treatment of 1500 and 2000 lux on *Dracaena fragrans, Chlorophytum comosum*, and *Aglaonema commutatum* inside glass chamber caused a decrease in carbon dioxide emissions. As well as 26 h observation of covered by compartment condition, there was a decrease in carbon dioxide concentrations.

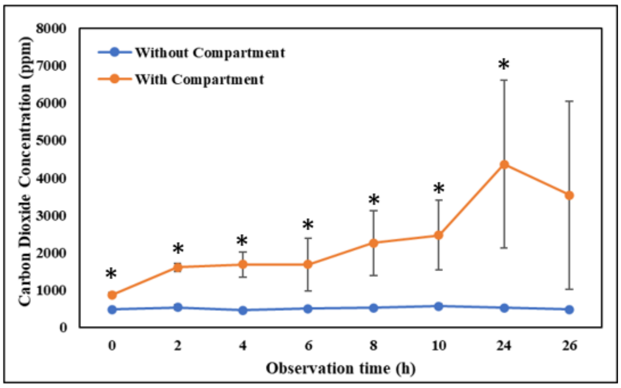


Figure 2. Carbon dioxide concentration dynamics of *D. lutescens* without compartment and covered by compartment condition. The symbol * indicates a significant difference (α = 5%) between compartmentalized and non-compartmentalized plant with unpaired t-test at the same observation time.

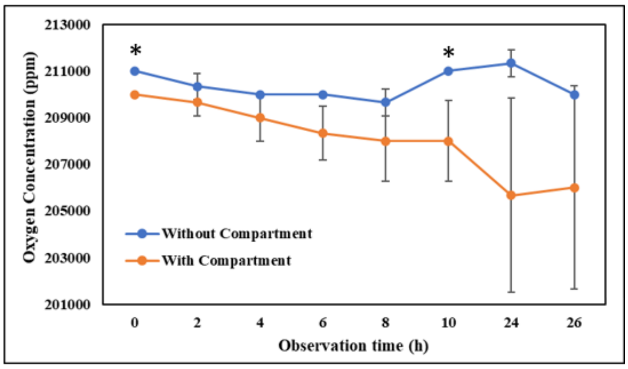


Figure 3. Oxygen concentration dynamics of *D. lutescens* without compartment and covered by compartment condition. The symbol * indicates a significant difference (α = 5%) between compartmentalized and non-compartmentalized plant with unpaired t-test at the same observation time.

24 h observation without compartment condition revealed decreasing in carbon dioxide (Figure 2) and increasing in oxygen (Figure 3) compared with 10 h. This confirms that at that time, *D. lutescens* has started the photosynthesis process. In darkness, the photosynthesis rate of plants is low, even zero in absolute darkness. However, the cellular respiration rate persists during dark conditions at a constant rate (Forbes & Watson, 1992). During the morning, the sunrise shines on the Earth with higher intensity over time. There is a point at light intensity value that induces photosynthesis and cellular respiration rate in balance, which is called the light compensation point (Forbes & Watson, 1992). From the present study, it can be inferred that the plant has passed the light compensation point in 24 h observation.

Moreover, notable thing to pay attention is the differences in carbon dioxide levels between *D. lutescens* without compartment and covered by compartment.

Carbon dioxide concentrations inside compartments were significantly higher than without compartments (Figure 2). This result is like the previous study by Weerasinghe et al. (2023) who measured carbon dioxide emissions in several plants put in a glass chamber but with low light intensity conditions. *Dracaena fragrans* and *Chlorophytum comosum* with 500 and 1,000 lux light intensity treatment and *Aglaonema commutatum* with 500 lux light intensity treatment showed increased carbon dioxide emissions. This is due to insufficient lighting with 500 and 1,000 lux light intensity. Insufficient light causes the photosynthesis rate to not be optimal (Sharma et al., 2022). This is different from the present study which showed that plants with compartments caused higher carbon dioxide despite the light intensity > 1,000 lux during 2 and 4 h observations (Table 1). It is inferred that carbon dioxide absorption is lower than carbon dioxide release. This assumption is corroborated by Shishegaran et al. (2020) reported that Spanish Moss absorbed low carbon dioxide but released high carbon dioxide emissions compared with *Aloe vera* and Thailand Native Fulia in similar microclimate condition.

Relative humidity and temperature profile

Light intensity is still in tolerance limit thus it seems not to influence the carbon dioxide and oxygen profile due to both compartmentalized and non-compartmentalized received similar light intensity. The reason for the increasing carbon dioxide and decreasing phenomenon in plants covered by compartment might be caused by other abiotic factors such as the humidity and temperature inside the compartment. Relative humidity and temperature inside the compartment were higher compared with the outside compartment (Table 2). Rising temperature to a certain limit induces increasing photosynthetic rate. However, C3 plants often decrease in carbon dioxide fixation at 25 – 30 ^{O}C because of photorespiration rate increases (Kochhar & Gujral, 2020). Corroborated by Li et al. (2021b) stated that higher air temperature induces a higher transpiration rate and inhibits photosynthetic rate in *Oryza sativa*. On the other hand, cellular respiration might also participate in this phenomenon. Cellular respiration and photorespiration have similarity to consuming oxygen and produce carbon dioxide (Kochhar & Gujral, 2020). It can be inferred that photorespiration and cellular respiration rate in covered plants with compartment conditions is higher than in uncovered plants due to lower oxygen and higher carbon dioxide inside the compartment. In plants without compartment conditions, lower photosynthetic rate than photorespiration and respiration rate can be expected as a factor that causes carbon dioxide concentration to rise in 6 to 10 h and oxygen concentration to decrease in 2 to 8 h as well as 26 h (Figure 3). According to increasing oxygen concentration in 10 h with low light intensity conditions, it is assumed that the photorespiration rate has decreased while the photosynthesis process persists. Additionally, high temperatures not only induce photorespiration but also disturb photosynthesis process by (1) damage Photosystem II (PSII) whereas PSII is a heat-sensitive photosynthetic photosystem, (2) decrease cyclic electron flow, and (3) promotes reactive oxygen species (ROS) production (Song et al., 2014). Increasing humidity also causes increasing photosynthetic rate (Chia & Lim, 2022). Like temperature, there is a certain limit of humidity which induces photosynthesis rate. Shivling & Ghanshyam (2012) reported that 65% humidity is the limit point of optimal photosynthetic rate. More than 65% induce a decreasing photosynthetic rate. Furthermore, Shishegaran et al. (2020) reported carbon dioxide concentration reduction and humidity profile between *Aloe vera*, Thailand Native Fulia, and Spanish Moss using similar device as the present study. *Aloe vera* is the best plant in carbon dioxide concentration reduction followed by decreasing in humidity. Compared with the current study, compartmentalized induced higher relative humidity followed by higher carbon dioxide concentration and lower oxygen concentration indicates current study has similar result.

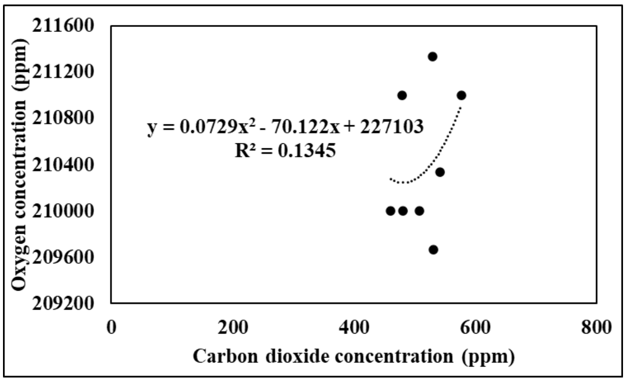
Relationship between carbon dioxide and oxygen

The relationship between carbon dioxide and oxygen gas on non-compartmentalized and compartmentalized plants is different. Non-compartmentalized condition showed positively but weakly related while compartmentalized condition showed a negative and strong relationship (Figure 4). Non-compartmentalized showed unusual conditions, higher carbon dioxide followed by higher oxygen but thing that need to be underlined is weak relationship. Since we mentioned temperature and relative humidity seem to influence compartmentalized plant for higher carbon dioxide and lower oxygen concentration, our assumption factor that affect such relationship in non-compartmentalized plant is carbon dioxide in the ambient air. Carbon dioxide measured in the tool is not only influenced by the plant but also ambient air carbon dioxide. Compartmentalized condition reflects photosynthesis process influence gas profile, higher carbon dioxide followed by lower oxygen and vice versa. Similar condition also mentioned by Moroney et al. (2013) which explains gas dynamics in the atmosphere of Earth, decreasing carbon dioxide and

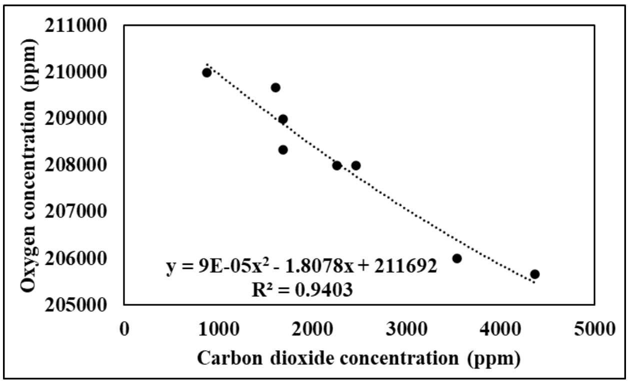
Table 2. Temperature and relative humidity profile of *D. lutescens* without compartment and with compartment condition.

Time Observation (h)	Temperature (^{O}C)		Relative Humidity (%)	
	Without Compartment	With Compartment	Without Compartment	With Compartment
0	24.37 ± 0.06	24.90 ± 0.44	95.67 ± 0.58	94.00 ± 2.65
2	25.57 ± 0.06	26.80 ± 0.20	95.33 ± 0.58	96.33 ± 0.58
4	26.90 ± 0.00	28.17 ± 0.35	89.33 ± 1.15	96.00 ± 1.00
6	24.10 ± 0.00	25.67 ± 0.25	95.00 ± 0.00	96.00 ± 0.00
8	24.07 ± 0.06	25.17 ± 0.06	95.67 ± 0.58	96.00 ± 0.00
10	24.00 ± 0.00	24.87 ± 0.15	96.00 ± 0.00	96.00 ± 0.00
24	23.83 ± 0.06	24.73 ± 0.06	97.00 ± 0.00	97.00 ± 0.00
26	25.07 ± 0.06	26.40 ± 0.17	96.00 ± 0.00	97.00 ± 0.00
AVERAGE	24.74 ± 1.06	25.84 ± 1.21	95.00 ± 2.36	96.04 ± 0.93

increasing oxygen induced by photosynthetic organisms resulted from PSII evolution. Present phenomenon related to the photosynthesis process whereas leaves absorb carbon dioxide and release oxygen (Taiz & Zeiger, 2002). Thus, it could be assumed that higher photosynthesis rate causes lower carbon dioxide and induce higher oxygen concentration around plant and vice versa.



A



B

Figure 4. Relationship between carbon dioxide and oxygen concentration (A). without compartment (B). inside compartment.

Future Prospect

From the present study, it is recommended to test the photosynthesis process of indoor plants without compartment with observation in indoor spaces by measuring the photosynthetic rate. Despite there are other variables which correlate with photosynthesis that could be measured like carbon dioxide emission, carbon dioxide removal, carbon dioxide and oxygen amounts inside chamber or compartment which carried out from several studies, it is suggested to directly measure the photosynthetic rate of plant. This is due to numerous abiotic factors influence the photosynthesis process and physiological processes, such as respiration, affect these parameters result. It is important to note that these parameters serve to measure photosynthetic ability indirectly.

Conclusion

This study concludes that carbon dioxide and oxygen concentrations of *D. lutescens* are affected by compartmentalized conditions. Covering plant by compartment resulted in higher carbon dioxide and oxygen levels which indicates not optimal photosynthetic rate. Light intensity range is still in tolerance limit thus both non-compartmentalized plant and compartmentalized plant do not show different respond since the plants were placed in transparent plastic compartments. Relative humidity and temperature are regarded as factors affecting the photosynthesis process due to relative humidity and temperature differences between inside compartment and outside compartment. Compartmentalized and non-compartmentalized resulted in different relationship between carbon dioxide and oxygen. Future investigation is needed especially for the photosynthetic rate between plants covered by compartment and without compartment which might be able to explain the phenomenon of higher carbon dioxide and oxygen levels by covered plants.

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