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Research Paper

Suitability of Foliage Plants for Indoor Decoration Based on CO_2 Emission and Absorption Rate and Stomata Density

D. P. Karunananda* and W. K. Abeysinghe

Horticulture Research and Development Institute, Gannoruwa, Peradeniya, Sri Lanka
* Corresponding Author: dayani.karunananda@gmail.com https://orcid.org/0000-0002-6353-7230

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Abstract: Use of foliage plants for indoor decoration is pursuing tradition in several cultures. With contemporary living patterns, frequent replacement of indoor plants has become impractical. Therefore, this experiment was conducted to identify indoor plants with low carbon dioxide (CO_2) emission or CO_2 absorption ability in nights to be kept continuously indoors. Five common indoor plants (*Cryptanthus* sp., *Dieffenbachia seguine, Dracaena sanderiana, Sansevieria trifasciata* and *Zamioculcas zamiifolia*) were placed separately in 1000 L airtight chambers for 12 h in the dark. The CO_2 level in each chamber was measured before and after the experiment and the difference was calculated. The stomatal count of both adaxial and abaxial surfaces was taken in each plant type to determine the relationship between CO_2 emission/absorption efficiency and stomatal density of tested ornamental species. From the test plant species, *D. seguine, D. sanderiana and Z. zamiifolia,* showed positive CO_2 equilibrium in the chambers and the CO_2 increments were 0.16 ppm cm^{-2}, 0.39 ppm cm^{-2} and 0.18 ppm cm^{-2} of leaf area, respectively. Both *Cryptanthus* sp. and *S. trifasciata* showed negative CO_2 equilibrium at around -0.20 ppm cm^{-2} of leaf area. *Sansevieria trifasciata* and *D. sanderiana* possessed stomata in both adaxial and abaxial surfaces, while stomatal number in adaxial surface of other three test plant species was negligible. The average number of stomata *Cryptanthus* sp. was 5.56×10^4 cm^{-2}, *D. seguine* 5.03×10^4 cm^{-2}, *D. sanderiana* 9.05×10^4 cm^{-2}, *S. trifasciata* 5.25×10^4 cm^{-2} and *Z. zamiifolia* 3.51×10^4 cm^{-2}. Stomata in *Cryptanthus* sp. and *S. trifasciata* close during day time and open at night. Present study concludes that potted *Cryptanthus* sp. and S. *trifasciata* (plants with CAM photosynthesis pathway) used for indoor decoration absorb CO_2 during the night, and hence, are safe to keep indoors during day and night.

Keywords: Foliage plants, CO_2 movement, Stomatal count, Closed / open stomata in day time

Introduction

Use of foliage plants in indoor decorations has shown a positive trend in the recent past. Beautification of living environment, and the natural effect of plants contributing positively to mental health, physical health and safe indoor environment (Lohr, 2007) are their other beneficial effects. Further, plants can substantially improve indoor environmental quality by reducing the major types of urban air pollutants (Burchett *et al.,* 2011). The volatile organic compounds (VOC) and CO_2 are the two major classes of air pollutants in indoors and plants can significantly reduce these two pollutants (Soreanu *et al.,* 2013). Generally, the indoor CO_2 levels are about 10 times higher than that of the outdoor levels. Living under high CO_2 concentration could lead to several health problems such as sick building syndrome (Milton *et al.,* 2000). The city dwellers spend more than 80% of their time inside the buildings, and face higher risk due to indoor air pollution (Torpy *et al.,* 2014). Growing plants indoors is one of the potential remedies in converting concrete buildings into living-friendly environments.

There is a wide array of plants used in indoor decorations, however, past records on effects of those plants on human health are not commonly available. Burchett *et al.* (2011) reported that several test plants actively removed VOC from air while the CO_2 reduction was accomplished by green part of the plants at adequate light levels. Photosynthesis was actively performed by *Juniperus conferta* (a hanging indoor plant) in spring and summer in Japan absorbing large amounts of CO_2 than in winter (Fujii *et al.,* 2005). These results revealed that, though plants can fix CO_2, their contribution to indoor CO_2 reduction has to be studied thoroughly as CO_2 emission and absorption depend on several plant-based factors.

Aerobic respiration continues in plant cells, using O_2 and releasing CO_2. In contrast, photosynthesis uses CO_2 and produces O_2, but the process occurs only in light and stops in dark. This is a prominent mechanism in plants with C3 or C4 photosynthesis pathways. All these plants release CO_2 during nights due to dark respiration (Bader and Abdel-Basset, 2002), thus increasing the surrounding CO_2 concentration. Hence, keeping such plants indoors at night is not advisable. With the contemporary busy lives, frequent replacement of indoor plants is impractical. Hence, selection of CO_2 absorbing or low CO_2 emitting plants (beneficial indoor plants) for indoor decoration would be important. Under this scenario, Xerophytes with CO_2 absorption ability at night may have a comparatively higher potential for indoor air purification at nights. Photosynthesis of these xerophytes is different to C3 and C4 plants, and uses the CAM (Crassulacean acid metabolism) pathway. They have sunken stomata on thick epidermis, close stomata during the day to decrease water loss, and open stomata at night allowing CO_2 for photosynthesis. Some C3 plants also act as facultative CAM plants by closing stomata during the day time and open them in night under hot environmental temperature (Burchett *et al.,* 2011, Holtum *et al.*, 2007).

Production of plants for indoor decoration (indoorscape) represents more than 50% of the floriculture industry in Sri Lanka. Knowledge on beneficial indoor plants will thus be important to these producers to determine their production targets. This study was conducted to identify CO_2 emitting and CO_2 absorbing plants to facilitate the decision making process of producing such plants in large scale and promoting them to be continuously kept indoors.

Materials and Methods

Plants of five common indoor plants available in the local pot plant market and are produced in large scale, namely, *Cryptanthus* sp., *Dieffenbachia seguine* (Jacq.) Schott*, Dracaena sanderiana* Mast*.*, *Sansevieria trifasciata* Prain., and *Zamioculcas zamiifolia* (Lodd.) Engl. were obtained from the Horticultural Research and Development Institute (HORDI), at Gannoruwa, Peradeniya, Sri Lanka. Of these, *Crypanthus* sp, and *S. trifasciata* are commonly known CAM plants while *D. sanderiana* (Burchett *et al.,* 2011) and *Z. zamiifolia* (Holtum *et al.*, 2007) act as facultative CAM plants.

They were individually planted in 30 cm diameter plastic pots containing a homogenized potting mixture and few pots were without plants were used as the control. The plants were allowed to grow under a uniform condition at 2000 – 2200 lux light in a shade house for 3 weeks. Visually uniform plants from each species were used as replicates.

Plastic barrels of 1000 L covered with transparent polythene from the top were modified as air tight chambers to study CO_2 emission or absorption by the test plants during night. Selected plants were carefully placed in the chambers. Soon after placing the pots, the open end of the chambers was covered with a 200 µm polythene film fixing it tightly using several layers of sticky tapes. The chambers with plants were kept for 12 h in the dark under a black cloth cover to cease photosynthesis. After 12 h (overnight), a CO_2 detector (MS-CO_2 Model 1204003) was inserted to chambers without allowing any gas exchange and CO_2 concentration, temperature and relative humidity of each chamber were recorded. Pots with only the growth medium (control) were used to study the CO_2 emissions or absorption by soils and to calculate emission or absorption by the five tested plants. A set of empty barrels also served as controls to provide baseline data on CO_2 concentration. The total photosynthetic area of each plant was measured using grid method to calculate the net CO_2 emission or absorption of plant per unit photosynthetic area.

The experiment was carried out in a Complete Randomized Design with four replicates. The experiment was continued for 3 weeks and data were collected 3 days per week. At the end of the experiment, the stomata number of each species was counted from a nail polish imprint of adaxial and abaxial surfaces (Jacobsen *et al.,* 2012). The same method was used to prepare slides to study the behaviour of stomata in day and night. Stomata density, length and width were measured at 100 x magnification.

Results and Discussion

The characteristics of indoor plants used in the experiment are presented in Table 1. All plants used in the experiment were shade tolerant and could acclimatize at 2000-2200 lux shade level at the floriculture shade house at HORDI. *Dieffenbachia seguine, D. sanderiana, S. trifasciata and Z. zamiifolia* showed new leaf initiation during the acclimatization period, but leaf initiation or flowering was not observed in *Crypanthus* spp.

Table 1. Characteristics of plants used in the experiment.

Plant Species	Total leaf number per plant	Photosynthesis area (cm^2)	Leaf thickness (mm)	Leaf colour
Crypanthus spp.	30	1199	1.03±0.01	Pink + Green
Dieffenbachia seguine	14	1918	0.50±0.01	White+yellow+green
Dracaena sanderiana	89	1627	0.43±0.01	White+green
Sansevieria trifasciata	91	4192	0.76±0.01	Green+white
Zamioculcas zamiifolia	126	3409	0.70±0.01	Green

CO_2 emission or absorption at night

The CO_2 emission or absorption during the 12 h dark period are presented in Table 2. No significant fluctuations of RH and environmental temperature were observed during the experimental period. The CO_2 absorption and emission varied with the plant species used. The control treatment (pots with only the medium) also has emitted CO_2 while the CO_2 concentration in the empty growth chamber has not changed.

Table 2. The CO_2, RH and temperature status in experimental chambers during 12 h dark period (n=11)

Plant species	RH (%)	Temperature (°C)	CO_2 concentration in the chamber (ppm)
Crypanthus spp.	88.0	27.8	0733.9± 24.6
Dieffenbachia seguine	92.0	26.6	1268.2± 20.3
Dracaena sanderiana	93.0	27.1	1577.9± 32.7
Sansevieria trifasciata	86.0	28.0	0135.9±21.5
Zamioculcas zamiifolia	93.3	27.2	1557.1±33.0
Pot and Medium	90.0	27.0	0959.1±4.56
Empty Chamber	68.5	27.2	0395±2.0

Crypanthus sp. and *S. trifasciata* have shown a negative CO_2 balance in the growth chamber after leaving for 12 h in the dark, however, *D. seguine, D. sanderiana* and *Z. zamiifolia* showed a positive CO_2 balance (Figure 1). These results manifested that *Crypanthus sp.* and *S. trifasciata* have absorbed CO_2 in the night while other three species have emitted CO_2 to the chamber.

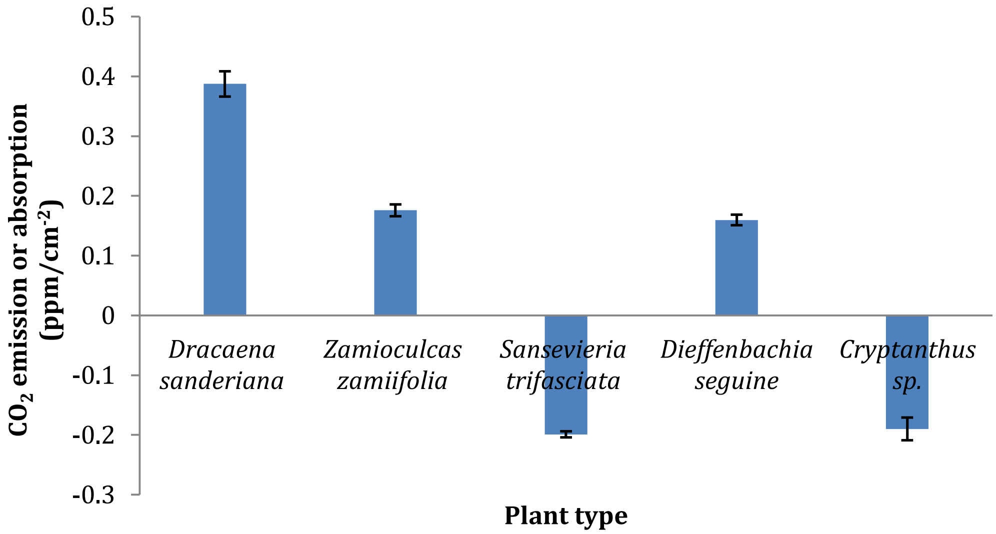

Figure 1. The CO_2 absorption or emission ability of experimented plants with respect to unit photosynthetic area. The vertical lines indicated the standard error of the means.

Table 3 shows that *D. sanderiana* and *S. trifasciata* possess stomata in both adaxial and abaxial surfaces while stomata number in adaxial surface of other species was low. The highest number of stomata was observed in *D. sanderiana* and it showed a higher CO_2 emission per unit leaf area in the night. The microscopic observation of imprints of leaf surface showed that stomata of *D. sanderiana* are open during the day time under well-watered condition. Though *Z. zamifolia* possessed the lowest number of stomata, its CO_2 emission per unit leaf area was higher than that of *D. seguine*.

Table 3. Stomata density and behaviour in selected plant species

	Stomata count/92.2 x10^3 μm^{-2}		Stomata behaviour		Average stomata density (cm^{-2})
	Abaxial	Adaxial	Day	Night	
Crypanthus spp.	56.15	00.0	Close	Open	5.56x10^4
Dieffenbachia seguine	46.10	00.0	Open	Open	5.03x10^4
Dracaena sanderiana	83.50	24.7	Open	Open	9.05x10^4
Sansevieria trifasciata	23.66	24.1	Close	Open	5.25x10^4
Zamioculcas zamiifolia	32.50	00.0	Open	Open	3.51x10^4

Both *Crypanthus* sp. and *S. trifasciata* has tightly closed stomata during the day time (Figure 2) and abaxial surface of *Crypanthus sp*. was thoroughly covered with powder-like layer, which masks the exposure of stomata to the outer environment. *Crypanthus* sp. Did not possess stomata in the adaxial surface, but the cumulative stomatal density was higher than that of *S. trifasciata*. All the experimental chambers showed higher RH values than the open environment indicating that the pots with or without plants released water to the air. This could be the evaporation + transpiration from the medium and plant.

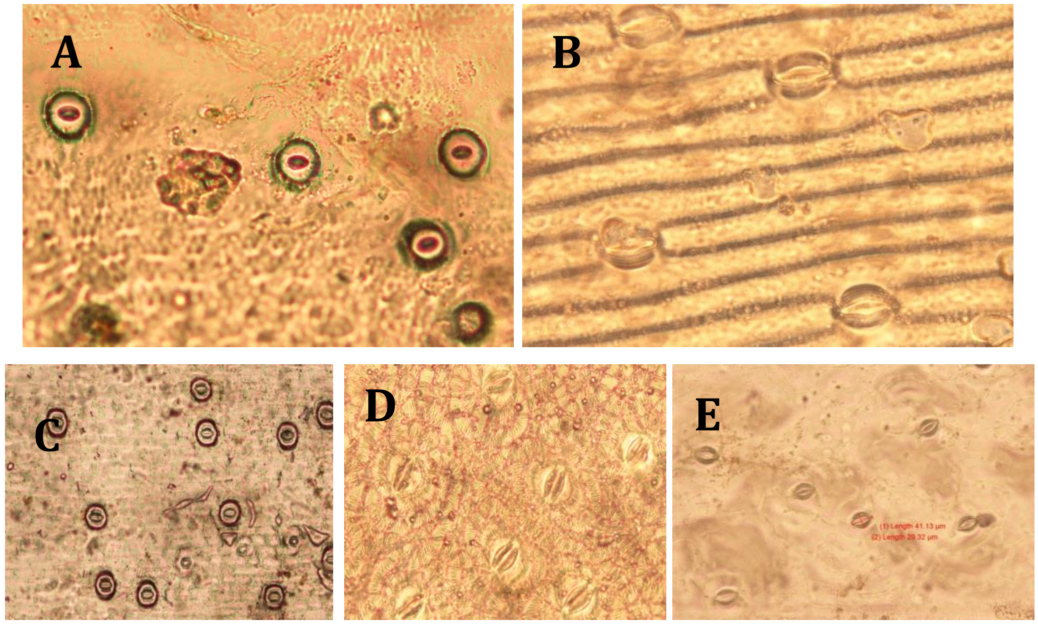

Figure 2. Microscopic photographs of (A) *Cryptanthus sp*., (B) *D. sanderiana,* (C) *S. trifasciata,* (D) *D. seguine and* (E) *Z. zamiifolia*during day time (photos are not in same scale)

The results proved that all five plant species used in the study are well adapted to indoor condition and can be easily be grown indoors. Although the main objective of this experiment was to study the air quality due to emission or absorption of CO_2 by plants kept indoors, the results showed that not only the plants, even the growing media (soil) also greatly influence on the indoor air quality. In the present study, the control pots (without plants) emitted considerable amount of CO_2 during the night and the difference of CO_2 concentrations between empty growth chamber and chamber with pot was 564 ppm. This is probably due to the soil respiration of dwelling organisms, including microorganisms, in the media. A similar observation was made by Burchett *et al.* (2011) who emphasized that organisms in potting media could significantly contribute to indoor air quality. Bond-Lambarty and Thomson (2010) showed that the increasing temperatures would result in an increase in net release of CO_2 from soil by triggering microbes to speed their consumption of plant debris and other organic matter. This shows that not only the plants, but also the potting medium should be considered in assessing the indoor air pollution. Therefore, the net CO_2 emission or absorption by tested plants in the experiment was calculated by deducting CO_2 emission by pot (growth medium) in each case.

The findings of this study clearly demonstrated the significant variations of emission or absorption of CO_2 among the selected indoor plants. It was clear that *Crypanthus* sp. and *S. trifasciata* absorb CO_2 in the dark. Both these species show absolute CAM photosynthesis, which absorbs CO_2 during the night, store in the vacuole as malic acid, and then utilize it in the Calvin cycle during the day time (Yamori *et al.,* 2014). As observed in the microscopic studies (Figure 2), the stomata in both of these species were closed during the day time and thus, allowing all gas exchanges to take place during the night when stomata are open. Therefore, it is clear that *Crypanthus* sp. and *S. trifasciata* do not contribute to enhance indoor CO_2 levels during day time. The CAM plants open their stomata during the cool nights and close them during the hot, dry-day time as an adaptation to live in dry harsh environments. Closing stomata during the day minimizes the loss of water but, because H_2O and CO_2 share the same diffusion pathway, CO_2 must then be taken up by the open stomata at night. When the stomata are closed, CO_2 generated from the metabolic activities does not escape from the leaf. Thus, stomata closure not only helps conserving water, but also assists in the building up of internal concentration of CO_2, to be utilized in photosynthesis and emitting O_2 when stomata open at night (Kluge and Ting, 1978).

Previous studies have also shown that *S. trifasciata* is one of the best indoor plants due to its highest CO_2 utilization ability at night (Wolverton *et al*., 1989). However, the present study revealed that CO_2 absorption ability per unit leaf area of *S. trifasciata* is not significantly different to that of *Crypanthus* sp. (Table 2). Furthermore, a strong relationship between the presence of stomata in leaf surfaces and CO_2 emission could not be identified in those two species in this study. Presence of stomata in adaxial and abaxial surfaces may be a species-specific character, which is related to the morphology and physiology of plant (Bader and Abdel-Basset, 2002). Though indoor CAM plants absorb CO_2 at night, the microcosm is not adequate to compensate emissions of the dwellers through breathing. Therefore, the targeted net CO_2 reduction cannot be achieved by having 1-2 plants. Use of these plants in large scale, *i.e.* as live walls, vertical gardens, etc.), could be effective in achieving such beneficial effects to some extent (Soreanu *et al.,* 2013).

The present study also provided clear evidence on the CO_2 emitting plants at night. Although the emission of these plants does not significantly influence on the indoor air quality, retaining a number of such plants (with absolute C3 photosynthetic pathway) at night may contribute to increase in the indoor CO_2 concentration. During the day time these plants emit O_2 and absorb CO_2 and the dark respiration process taking place in the absence of light, which is the most responsible event for CO_2 generation at night (Bader and Abdel-Basset, 2002). It is evident that CO_2 absorption or emission has a direct relationship with the light level of the surrounding environment. In Valladares and Niinemets (2008) have shown that shade-loving plants photosynthesize at low light levels and contribute to air purification indoors. Therefore, further research is needed to identify low CO_2 emitting as well as shade-loving plants for healthy indoor decoration. Among the used C3 plants in the present study, *D. sanderiana* showed a higher CO_2 emission at night, followed by *Z. zamiifolia* and *D. seguine* (Figure 1) suggesting that *D. seguine* is better for indoor decoration than the other two species. However, the photosynthesis capacity of these plants should be measured under different light levels prior to drawing any conclusions.

Though there are evidence that *Z. zamiifolia* (Holtum *et al.,* 2007) and *D. sanderiana* (Burchett *et al.*, 2011) act as facultative CAM plants under certain environmental conditions, the present study showed that both these species emitted a significant amount of CO_2 as normal C3 plants (Table 2). High temperature and drought condition could make *Z. zamiifolia* to be a facultative CAM plant (Holtum *et al.*, 2007). Hence, water management could be an essential practice to induce CO_2 emission of *Z. zamiifolia* and *D. sanderiana.* Further studies are required on these aspects that would help using of these plants as beneficial plants indoors.

The results of this experiment have shown that the indoor plants have not only affected the air quality, but also the indoor RH levels. Pots with or without plants, which were in chambers, have increased RH by about 20-25% (Table 2). Increasing RH indoors is the main issues in bio-purification using plants. Prolong high humidity level would lead to mould development and wall deterioration indoors (Torpy *et al.,* 2014). Hence, use of shade-loving xerophytes (CAM plants) would have high scope in indoor decoration than C3 and C4 plants.

Conclusion

The present study concludes that *D. seguine*, *Z. zamiifolia* and *D. sanderiana* plants neither close stomata at day time nor absorb CO_2 at night under normal environmental condition. Potted *Cryptanthus sp.* and S. *trifasciata* (plants with CAM photosynthesis pathway) keep stomata closed during day time but absorb CO_2 at night, hence can effectively be used in indoor air purification at night. However, the soil-based growth medium releases CO_2 at night. *Dracaena sanderiana* possess higher number of stomata in leaves and shows higher emission of CO_2 at night. However, the relationship between stomata number and CO_2 will need to be studied further. Different indoor plants and their growth medium influence the indoor air quality with respect to CO_2 concentration.

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