Research Paper

Suitability of Foliage Plants for Indoor Decoration Based on CO₂ Emission and Absorption Rate and Stomata Density

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Abstract: Use of foliage plants for indoor decoration is pursing 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 (CO₂) emission or CO₂ 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 CO₂ 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 CO₂ emission/absorption efficiency and stomatal density of tested ornamental species. From the test plant species, D. seguine, D. sanderiana and Z. zamiifolia showed positive CO₂ equilibrium in the chambers and the CO₂ 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 CO₂ 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 5.56x10⁴ cm⁻², D. seguine 5.03x10⁴ cm⁻², D. sanderiana 9.05x10⁴ cm⁻², S. trifasciata 5.25x10⁴ cm⁻² and Z. zamiifolia 3.51x10⁴ cm⁻². Stomata in Cryptanthus sp. and S. trifasciata (plants with CAM photosynthesis pathway) used for indoor decoration absorb CO₂ during the night, and hence, are safe to keep indoors during day and night.

Keywords: Foliage plants, CO₂ 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 CO₂ 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, Cryptanthus 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 CO₂ detector (MS-CO₂ Model 1204003) was inserted to chambers without allowing any gas exchange and CO₂ concentration, temperature and relative humidity of each chamber were recorded. Pots with only the growth medium (control) were used to study the CO₂ 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 CO₂ concentration. The total photosynthetic area of each plant was measured using grid method to calculate the net CO₂ 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 (cm²) | 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                 |

CO₂ emission or absorption at night
The CO₂ 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 CO₂ absorption and emission varied with the plant species used. The control treatment (pots with only the medium) also has emitted CO₂ while the CO₂ concentration in the empty growth chamber has not changed.

Table 2. The CO₂, RH and temperature status in experimental chambers during 12 h dark period (n=11)

| Plant species          | RH (%) | Temperature (°C) | CO₂ 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 CO₂ balance in the growth chamber after leaving for 12 h in the dark, however, D. seguine, D. sanderiana and Z. zamiifolia showed a positive CO₂ balance (Figure 1). These results manifested that Crypanthus sp. and S. trifasciata have absorbed CO₂ in the night while other three species have emitted CO₂ to the chamber.

Figure 1. The CO₂ 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 CO₂ 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 CO₂ emission per unit leaf area was higher than that of D. seguine.

Table 3. Stomata density and behaviour in selected plant species

| Plant type               | Stomata count/92.2 μm²⁻² | Stomata behaviour | Average stomata density (cm⁻²) |
|--------------------------|--------------------------|-------------------|-------------------------------|
|                          | Abaxial | Adaxial | Day | Night |                                |
| Crypanthus spp.          | 56.15   | 00.0    | Close | Open | 5.56x10⁴                          |
| Dieffenbachia seguine    | 46.10   | 00.0    | Open | Open  | 5.03x10⁴                          |
| Dracaena sanderiana      | 83.50   | 24.7    | Open | Open  | 9.05x10⁴                          |
| Sansevieria trifasciata  | 23.66   | 24.1    | Close | Open  | 5.25x10⁴                          |
| Zamioculcas zamiifolia   | 32.50   | 00.0    | Open | Open  | 3.51x10⁴                          |

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.
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\textsubscript{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\textsubscript{2} during the night and the difference of CO\textsubscript{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-Lambarthy and Thomson (2010) showed that the increasing temperatures would result in an increase in net release of CO\textsubscript{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\textsubscript{2} emission or absorption by tested plants in the experiment was calculated by deducting CO\textsubscript{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\textsubscript{2} among the selected indoor plants. It was clear that Cryptanthus sp. and S. trifasciata absorb CO\textsubscript{2} in the dark. Both these species show absolute CAM photosynthesis, which absorbs CO\textsubscript{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 Cryptanthus sp. and S. trifasciata do not contribute to enhance indoor CO\textsubscript{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\textsubscript{2}O and CO\textsubscript{2} share the same diffusion pathway, CO\textsubscript{2} must then be taken up by the open stomata at night. When the stomata are closed, CO\textsubscript{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 *Cryptanthus* 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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