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Original Research

The Influence of House Plants on Indoor CO_2

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Abstract

This study aimed at determining the effect of carbon dioxide (CO_2) in the internal environment of different indoor plants. *Spathiphyllum* (*Spathiphyllum floribundum* Schott), *Yucca* (*Yucca elephantipes* Regel), *Dieffenbachia* (*Dieffenbachia amoena* Gentil), and *Ficus* (*Ficus benjamina* L.) are frequently used in studies of indoor plants that examine light temperature depending on leaf surface and the effects of CO_2 in the studied environment. As a result, decreases in CO_2 were at the highest level in *Ficus*, and *Dieffenbachia at* 25ºC, followed by *Spathiphyllum* at 25ºC and *Yucca at* 20ºC. The amount of photosynthesis increased the leaf surface. For this reason, they reduced the amount of CO_2 by increasing the amount of photosynthesis. The plant leaf surface was standardized, and calculations were made to meet the objective and the amount of CO_2 in the local environment. Based on these calculations, it was determined that the greatest reduction of CO_2 comes from the *Ficus* plant. In conclusion, the same layer as the surface are 1 m^2 leaf surface from *Ficus benjamina* on 1 m^3 without air vent in which the amount of CO_2 in one hour could be reduced to about the level from 2,000 ppm at 25ºC 480.74 ppm and 408.08 ppm at 20ºC.

Keywords: CO_2, plant, indoor, air quality, indoor plants, leaf surface

Introduction

The recent rise in urbanization has led to increased population density, particularly in urban areas. Hence the number of people per unit area has increased. Nowadays, urban people spend at least 80% of their lives in indoor environments because of increased housing and changing life conditions [1-3].

Rapid urbanization and industrialization have placed more distance between people and nature each day. This situation disrupts the harmony that is expected to exist between people and their environment. Human beings, as part of nature, carry with them a part of nature wherever they live. This has sometimes been in the form of a houseplant, a small garden, or sometimes a delicately organized park [3-5].

Plants that exist particularly in indoor environments, where people spend more than 80% of their lives, undertake many ecological and aesthetical functions. Indoor plants reduce all kinds of air pollution [6], increase productivity [7], relieve people psychologically, and minimize stress and negative feelings [3]. Previous studies have reported that the presence of plants in indoor environments reduces diseases and absenteeism [3, 8].

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One of the most important reasons plants are wanted in indoor environments is their influence on carbon dioxide (CO_2). CO_2 is one of the gases the composition of which changes in indoor environments in the fastest way as a result of human metabolic activities. The composition of air with 21% oxygen (O_2) and 0.033% CO_2 when inhaled from the normal atmosphere turns to have an O_2 level of 16-17% and a CO_2 level of 4% when exhaled from the lungs. This change leads to a rapid increase in CO_2 amount, particularly in environments such as schools, malls, and hospitals, where people are collectively active [9]. When the rate of CO_2 increases in an environment, this leads to fatigue, difficulty in perception, and sleepiness [10]. When the amount of CO_2 exceeds 1,000 ppm, headache, vertigo, fatigue, concentration disorders, and smell disorders may be experienced. When it exceeds 1,500 ppm, it results in irritation in throat and nose, nasal flow, cough, and eye drainage [11]. This is particularly evident in indoor environments where the majority of daily life is spent. The reduction in indoor air quality influences people's performance and health [10].

According to the authorities, air quality can be regarded as harmless if CO_2 levels are below 1,000 ppm, elevated if between 1,000 and 2,000 ppm, and hygienically unacceptable if above 2,000 ppm [12]. However, previous studies have shown that CO_2 amounts have reached 4,000 ppm in schools [13] and 2,500 ppm in offices [14].

The most influential way to reduce CO_2 in an environment is ventilation. Indeed, outdoor air can be 5 to 100 times as clear as indoor air [9]. However, even a short period of ventilation leads to a considerable loss of heat in the environment, particularly in winter months, leading to inadequate ventilation in indoor environments.

Another way to reduce CO_2 in indoor environments is by using plants. Plants photosynthesize in environments where light and heat are adequate as part of their natural life process. They absorb the CO_2 in the environment through their stomas for photosynthesis. Hence, they use CO_2 for photosynthesis, leading to a reduction in its amount in the environment. However, plants are also living organisms and need certain conditions to survive. They also change environmental conditions through their metabolic activities. Plants emit oxygen and absorb CO_2 when environmental conditions are suitable for their growth. When conditions change, the situation becomes reverse. This may result in negative influences on human health, particularly in indoor environments that are limited. Obviously, environmental conditions for each plant to survive change. Even when the conditions are optimal, plants may have different photosynthesis rates and thus have varying degrees of influence on indoor CO_2 amounts. Therefore, plants can be effectively used to maintain healthy conditions regarding CO_2 amounts in indoor environments where people spend most of their lives if one detects to what extent indoor conditions are suitable for plants, under which conditions the metabolic activities of plants influence indoor CO_2 amounts, and what kind of influence they have.

The purpose of this study is to reveal the influence of certain plant species that can be used as indoor plants on indoor CO_2 amounts. The study focuses on the changes made by plants on CO_2 amounts at various temperature levels. To this end, four different indoor plants were selected to determine how they change indoor CO_2 amounts at five different leaf surfaces, five different temperature levels, and under 20,000 lux light and dark conditions.

Material and Methods

This study focuses on the influence of certain frequently used indoor ornamental plants on CO_2 amounts in indoor environments. In this sense, *Spathiphyllum* (*Spathiphyllum floribundum* Schott), *Yucca* (*Yucca elephantipes* Regel), *Dieffenbachia* (*Dieffenbachia amoena* Gentil), and *Ficus* (*Ficus benjamina* L.), which are common indoor plants, constitute the study material. These plants differ from one another in terms of ecological demands and physical characteristics (e.g., leaf area and body shape).

The study was conducted in a plant growth chamber that was not in contact with outdoor air and whose internal volume was known. The light and temperature conditions of the chamber were determined independent of the outdoor environment. In addition to the plant, a measurement device that can regularly measure CO_2, temperature, and humidity and transfer measurements to the computer was placed in the plant growth chamber.

Particular attention was paid to plants' being healthy, having a proper root/body ratio, and not being exposed to any stress factor. Therefore, the pots of the procured plants were changed in the first place so that root/body ratio could be increased in favor of the roots.

The plant growth chamber in which the study conditions were provided was of the Jaiotech GC 300 brand. This plant growth chamber produces 20,000 lux light when all the lights are turned on, and its temperature can be set with a precision of 1°C (equipped with a heating and cooling system). It also has a CO_2 tank to increase environmental CO_2. It can periodically be programmed to maintain the required conditions.

Given that the study was based on absolute tightness, a glass chamber whose air tightness had been tested was placed inside the chamber. An Extech desktop indoor air quality CO_2 data logger was placed inside this glass chamber. This device is used for CO_2 measurements and is capable of measuring at 1 ppm precision. This CO_2 meter was calibrated prior to being used. It was also tested for its CO_2 tightness, and it was ensured that there would be no air intake or outlet.

The plants were placed inside the chamber for measurements. The CO_2 amount inside the chamber was set to 2,000 ppm ±10%. The initial CO_2 amount was set to be 2,000 ppm because plants generally reach maximum photosynthesis speed at levels higher than 1,200-1,300 ppm. Furthermore, previous studies on indoor air quality have demonstrated that indoor CO_2 amount reaches 2,000 ppm in environments where people are collectively active in a short period [15-16].

Raising the CO_2 amount to 2,000 ppm ±200 ppm level was performed through respiration into the device for a few minutes. The CO_2 amount in the air exhaled was around 40,000 ppm following human respiration. Therefore, respiring in the chamber where the plant was placed increased the CO_2 amount to the required level in a short period. However, the CO_2 amount became homogenized and stable in the air after a while. Therefore, at least 10 minutes passed before the chamber was closed. When the CO_2 amount reached the required level, the chamber was closed with an absolute tightness. Meanwhile, when the CO_2 amount was higher than required, the chamber was ventilated; and when it was lower than required, respiration was repeated to obtain the required CO_2 amount.

This study seeks to reveal the influences of plants on CO_2 amount in illuminated and dark environments. The selected amount of light was 20,000 lux.

The plants that were prepared for the measurements were placed inside the chamber. The measurement order of the chamber is as follows:

– 15ºC degrees, 20,000 lux light, 12 hours
– 15ºC degrees, dark environment, 12 hours
– 20ºC degrees, 20,000 lux light, 12 hours
– 20ºC degrees, dark environment, 12 hours
– 25ºC degrees, 20,000 lux light, 12 hours
– 25ºC degrees, dark environment, 12 hours
– 30ºC degrees, 20,000 lux light, 12 hours
– 30ºC degrees, dark environment, 12 hours
– 35ºC degrees, 20,000 lux light, 12 hours
– 35ºC degrees, dark environment, 12 hours

Keeping the plants in the light for 12 hours and in the dark for 12 hours is about simulating the environment that plants are used to as much as possible. Plants stay in the light and stay in the dark for a certain period every day. The measurements were planned in this manner to avoid disturbing the order the plants were used to. The device was set as explained above. The plant was then placed inside the chamber within the device. The measurement device inside the same environment as the plant was started in such a way that it would measure every five minutes and record the data, and the chamber was closed tightly.

The data were transferred to the computer after the measurement ended. The net volume of the chamber was calculated (by subtracting the volume of the pot and the body volumes of *Yucca*, *Ficus*, and *Dieffenbachia* from the volume of the chamber).

The purpose was to show the performances of the plants at the end of an hour. However, considering that the measurement device would be stable only after a while and the time it would take for the plants to get used to the values in the environment they were put in, the plants were placed inside the chamber at least one hour before starting the measurement. Hence, the measurement results that were obtained at least one hour after the plants were placed were considered for a sound measurement. Each plant remained inside the chamber for five days after being placed in it. The device was operated in that period with the settings specified above. The CO_2 measurement device performed measurements every five minutes. Afterward, the data were transferred to the computer for assessment.

As data evaluation dealt with the plant performances at the end of an hour and the values obtained at least one hour after the placement of the plants inside the chamber were considered for a sound measurement, the measurements that were performed while the chamber was making transitions between the programs were also ignored. For instance, while the climate chamber was transiting from the program of 12 hours in the dark with 20ºC to the program of 12 hours in the light with 25ºC, plant performance was ignored for one hour. The values obtained at the end of this process were considered. Hence, 10 measurements were carried out with each one lasting one hour through a device that operated for 12 hours. The data were obtained by calculating the difference between the initial CO_2 values and the values at the end of one hour.

This study aimed to reveal the influences of five different leaf surfaces on CO_2 amount. Therefore, after performing the initial measurements, approximately 1/5 of the plant leaves were cut to calculate the leaf area. In the next period, 1/4 of the leaf area was cut, followed by 1/3 and ½, so that nearly 1/5 of the initial leaf area was cut in each period. However, leaf cutting was performed based on estimations, and the leaf area was calculated after being cut.

After obtaining the data, they were standardized to determine which leaf surface had the most influence on 1 m^3 of air as well as the degree of such influence. The plant growth chamber's capacity is 70 x 70 x 110 cm. The total of volume is 0.539 m^3. For instance, assuming that in a chamber with a volume of 0.486 m^3 (after subtracting the volume of the pot), *Ficus* having 0.245 m^2 leaf area reduced CO_2 by 157 ppm in an hour. While assessing these data, a calculation was made based on the equation that the CO_2 amount in an area of 1 m^3 is reduced by 157 ppm by *Ficus* having x m^2 leaf area assuming that *Ficus* having 0.245 m^2 leaf area reduced the CO_2 amount by 157 ppm in an area of 0.486 m^3. Hence, it was recorded as follows: "*Ficus* having a leaf area of 0.504 m^2 reduces the CO_2 amount in an area of 1 m^3 by 157 ppm in one hour." This means the differences that stemmed from the pot sizes were eliminated.

While calculating the net volume of the chamber, only the volumes of *Yucca, Ficus*, and *Dieffenbachia* were considered because their body volumes could be calculated. The volumes of the leaves were ignored. The measurements indicated that leaf thickness did not even reach 2 mm in any of the studied species. When the leaf volume is calculated, for instance, assuming that *Ficus* having a leaf area of 0.245 m^2 has a leaf thickness of 2 mm (the leaf thickness of *Ficus* is lower than 1 mm), the leaf volume calculated will be 0.245 m^2* 0.002 m = 0.00049 m^3. In a chamber having a net volume of 0.486 m^3 (after subtracting the volumes of the pot and the plant body), a leaf volume of 0.00049 m^3 corresponds to nearly 1/1000 of the chamber volume. The study considered that ignoring the leaf volume would not affect the results as leaf volume, when roughly calculated, did not even reach 1/1000 of the total chamber volume. As a result, leaf volume was ignored.

Hence, measurements of the study were performed in 200 combinations involving:

– Four different species (*Spathiphyllum*, *Yucca*, *Dieffenbachia*, and *Ficus*).
– Two different light conditions (20,000 lux light and dark).
– Five different degrees of temperature (15, 20, 25, 30, and 35ºC).
– Five leaf surfaces.

Each measurement was repeated at least 10 times. Thus an attempt was made to ensure that measurement would be performed for 2,000 hours total. However, the measurements were performed for 1,990 hours because performing measurements with *Spathiphyllum* in the dark at 35ºC was not possible.

Table 1. Effect of CO_2 amount by the plants having different leaf surfaces under 20,000 lux light depending on temperature.

	20,000 lux light on species							
	Ficus		*Dieffenbachia*		*Spathiphyllum*		*Yucca*	
Temperature	Leaf Surface (m^2)	Average* (reduction of CO_2 per hour)	Leaf Surface (m^2)	Average* (reduction of CO_2 per hour)	Leaf Surface (m^2)	Average* (reduction of CO_2 per hour)	Leaf Surface (m^2)	Average* (reduction of CO_2 per hour)
15°C	0.185	-7.8	0.192	-6	0.336	-9.8	0.1395	-1.2
	0.403	-15.2	0.384	-10.5	0.426	-15.9	0.298	-1.6
	0.514	-21.1	0.469	-12.5	0.516	-13.8	0.509	-3.5
	0.726	-28.9	0.628	-16.3	0.712	-20.9	0.745	-3.8
	0.806	-40.2	0.747	-25.6	1.038	-40	0.837	-6
20°C	0.185	-75.9	0.192	-56.8	0.336	-75.9	0.1395	-22
	0.403	-163.4	0.384	-109.3	0.426	-110.3	0.298	-56.7
	0.514	-212.4	0.469	-116.3	0.516	-112.6	0.509	-71.7
	0.726	-299.9	0.628	-179.3	0.712	-129.3	0.745	-154.8
	0.806	**-321**	0.747	-187.9	1.038	**-228.7**	0.837	-120
25°C	0.185	-87.8	0.192	-61.6	0.336	-146.9	0.1395	-15.5
	0.403	-192.9	0.384	-125.6	0.426	-191.2	0.298	-33.2
	0.514	-250.1	0.469	-152.5	0.516	-193.3	0.509	-38.9
	0.726	-332.5	0.628	-197.3	0.712	-254.1	0.745	-74
	0.806	**-407.6**	0.747	-216.5	1.038	**-361.2**	0.837	-61
30°C	0.185	-43.7	0.192	-15.5	0.336	-54.6	0.1395	-7.1
	0.403	-94.6	0.384	-31.6	0.426	-54.5	0.298	-15.5
	0.514	-132.8	0.469	-40.3	0.516	-55.3	0.509	-24.2
	0.726	-183.8	0.628	-48.6	0.712	-62.5	0.745	-37.8
	0.806	-197.5	0.747	-58.3	1.038	-139.1	0.837	-46.2
35°C	0.185	-40	0.192	**0.7**	0.336	-2.9	0.1395	-3.3
	0.403	-87.4	0.384	**1.5**	0.426	-7	0.298	-6.8
	0.514	-112.8	0.469	**3.1**	0.516	-7.6	0.509	-11.1
	0.726	-157.4	0.628	**3.6**	0.712	-5.2	0.745	-17.7
	0.806	-172.4	0.747	**3.3**	1.038	-5.6	0.837	-17.1

*Mean average is reduction of CO_2 per hour

Table 2. Influences of the species on CO_2 amount under 20,000 lux light depending on temperature.

Species	Temperature				
	15ºC	20ºC	25ºC	30ºC	35ºC
Ficus	-42.08	-408.08	-480.74	-245.52	-216.68
Dieffenbachia	-29.09	-273.10	-315.41	-80.88	4.86
Spathiphyllum	-32.26	-220.92	-393.12	-123.78	-10.52
Yucca	-6.28	-167.54	-93.74	-50.96	-22.42

Results and Discussion

In the end, the extent to which the CO_2 amount was reduced by the plants having different leaf surfaces under 20,000 lux light was dependent on the temperature. The results are shown in Table 1.

The values in Table 1 show how many ppm the plants having the specified leaf surfaces reduced the CO_2 amount in one hour from nearly 2,000 ppm under 20,000 lux light condition. In the experiments conducted under 20,000 lux, all the species excluding *Dieffenbachia* reduced the CO_2 amount at all temperature levels. However, *Dieffenbachia* increased the CO_2 amount in the environment at 35ºC. In addition, deformations were observed in the leaves at this temperature. The plant that had the highest influence on CO_2 amount in the environment was *Ficus*, having a leaf surface of 0.806 m^2. It reduced the CO_2 amount in the environment by -407.6 ppm at 25ºC and by -321 ppm at 20°C. However, the values in the table indicate that the difference between the leaf surfaces could be deceptive. Hence, the data were standardized. The influence of each plant having a leaf surface of 1 m^2 on the CO_2 amount in the environment was calculated. The relevant results are shown in Table 2.

The values in Table 2 show that only *Dieffenbachia* increased the CO_2 amount at 35ºC. All the other species reduced the CO_2 amount in the illuminated environment at all temperature levels. However, the amount of reduction significantly varied from species to species. Of the species having 1 m^2 leaf surface, the one that reduced CO_2 most in 1 m^3 of air was *Ficus* (by 480.74 ppm). This reduction occurred at 25ºC. The next biggest reduction was observed again with *Ficus* at 20ºC (by 408.08 ppm). The highest reduction occurred at 25ºC for all the species, excluding *Yucca*. The highest reduction was observed at 20ºC for *Yucca*.

Calculations were made to reveal to what extent the CO_2 amount was raised in the dark by the plants having different leaf surfaces depending on temperature. The relevant results are shown in Table 3.

The results in Table 3 show that all the species increased the CO_2 amount in the environment at all temperature levels. However, *Dieffenbachia* underwent a deformation in its leaves at 35ºC. The values in Table 3 indicate that the plant that increased the CO_2 amount in the environment at the highest level was *Spathiphyllum* at 25ºC. *Spathiphyllum*, having a leaf surface of 1.038 m^2, increased the CO_2 amount by 122.5 ppm in one hour. *Ficus,* having a leaf surface of 0.806 m^2, increased the CO_2 amount in the environment by 87.8 ppm in one hour at 35ºC. To make a clearer comparison between the species, we calculated how much the plants having 1 m^2 leaf surface increased the CO_2 amount at different temperature levels in the dark. The relevant results are presented in Table 4.

The values in Table 4 show that the CO_2 amount increased at all temperature levels. This, indeed, is a quite natural result. Plants photosynthesize only in the illuminated environments and can reduce CO_2 there. In the dark, however, they perform respiration and increase the CO_2 amount in the environment. The analyses indicated that the plant that caused the highest increase in CO_2 was *Spathiphyllum* at 25ºC. *Spathiphyllum* and its 1 m^2 leaf surface increased the CO_2 amount in 1 m^3 air by 129.62 ppm in one hour. The second highest increase was caused by *Ficus* at 35ºC. Given that *Spathiphyllum* was damaged at 35ºC in the illuminated environment, its influence on the CO_2 amount at 35ºC in the dark could not be calculated.

The results show that plants change indoor CO_2 amounts differently in the illuminated environment. In general, the influence of plants on CO_2 amount increases depending on temperature. It reaches a peak at a certain level and then starts to decrease because of increasing temperature. In other words, it makes a bell-shaped curve. Kacar et al. [17] stated that the influence of temperature on photosynthesis in plant leaves generally makes a curve. Speed of photosynthesis increases with the temperature until a certain level, whereas photosynthesis rapidly decreases after a certain temperature. This is reported by many researchers [18].

However, the temperature level required for the highest speed of photosynthesis changes from (plant) species to species. According to Akman and Güney [19], usually 20-35ºC are optimum values for photosynthesis, and the positive influence of temperature on photosynthesis can continue until 30ºC. This is consistent with the results of the present study. Indeed, increasing temperature raised the influence of the plants on the CO_2 amount, and the influence of the plants on the CO_2 amount started to decrease after 25ºC for *Ficus*, *Dieffenbachia*, and *Spathiphyllum*, and after 20°C for *Yucca*. At 35°C, *Ficus* showed a considerable influence on the CO_2 amount, whereas *Spathiphyllum* and *Yucca* showed a limited influence. Meanwhile, *Dieffenbachia* started respiration at 35ºC.

In the present study, all the plants photosynthesized even at 15ºC. In general, the period of vegetation is considered to cover the days when temperature is not less than 10ºC [20]. Akman and Güney [19] reported that some conifers continue to photosynthesize even at -30ºC in temperate regions of the world.

Light is possibly the most important factor that determines the influence of plants on indoor CO_2 amount. Some studies have attempted to determine how plants

Table 3. Influences of the species on CO_2 amount in the dark depending on leaf surface and temperature.

	in the dark							
	Ficus		*Dieffenbachia*		*Spathiphyllum*		*Yucca*	
Temperature	Leaf Surface (m^2)	Average* (reduction of CO_2 per hour)	Leaf Surface (m^2)	Average* (reduction of CO_2 per hour)	Leaf Surface (m^2)	Average* (reduction of CO_2 per hour)	Leaf Surface (m^2)	*Average** (reduction of CO_2 per hour)
15ºC	0.185	7	0.192	0.7	0.336	12.4	0.1395	2.4
	0.403	15.3	0.384	3.3	0.426	28.2	0.298	5.8
	0.514	20.8	0.469	4.5	0.516	31.7	0.509	9
	0.726	27.6	0.628	4.1	0.712	44	0.745	15.9
	0.806	31.5	0.747	5.1	1.038	63.6	0.837	14
20ºC	0.185	8.4	0.192	2.7	0.336	24.3	0.1395	5.1
	0.403	18.3	0.384	6.8	0.426	26.9	0.298	10.4
	0.514	25.4	0.469	7.9	0.516	39.7	0.509	18.4
	0.726	35	0.628	10.4	0.712	45.7	0.745	26
	0.806	40.6	0.747	10.8	1.038	78.9	0.837	31
25ºC	0.185	6.2	0.192	1.8	0.336	54	0.1395	7.3
	0.403	12.7	0.384	2.9	0.426	64.3	0.298	15.4
	0.514	14.1	0.469	3.8	0.516	63.5	0.509	22.9
	0.726	21.5	0.628	5.1	0.712	67.5	0.745	40.6
	0.806	34.1	0.747	8	1.038	122.5	0.837	41.1
30ºC	0.185	11.1	0.192	2.9	0.336	22.3	0.1395	4
	0.403	23.3	0.384	4.4	0.426	30.6	0.298	9.7
	0.514	31.8	0.469	4.3	0.516	31.4	0.509	15
	0.726	43.4	0.628	6.7	0.712	41.7	0.745	27.6
	0.806	46.4	0.747	7.5	1.038	70.6	0.837	22.8
35ºC	0.185	18.7	0.192	2.1			0.1395	1.9
	0.403	40.9	0.384	2.9			0.298	4.4
	0.514	51.7	0.469	2.9			0.509	11.2
	0.726	70.8	0.628	4.7			0.745	14
	0.806	87.8	0.747	6			0.837	16.3

*Mean average is reduction of CO_2 per hour

influence the CO_2 amount in controlled environments. Cetin and Sevik [5] conducted a study regarding the reduction in CO_2 amount in an area of 0.5 m^3. During the day, *Ficus elastica* reduced CO_2 by 2,216 ppm, *Yucca massengena* by 2,578 ppm, *Ocimum basilicum* by 401 ppm, *Sinningia speciosa* by 725 ppm, and *Codia eumvariegatum* by 790 ppm. During the night, on the other hand, *Ficus elastica* increased the CO_2 amount in the environment by 351 ppm, *Yucca massengena* by 310 ppm, *Ocimum basilicum* by 11 ppm, *Sinningia speciosa* by 218 ppm, and *Codiaeum variegatum* by 84 ppm.

In another study, Sevik et al. [16] determined that during the day *Schefflera arboricola* reduced the CO_2 amount in a 0.5 m^3 area by 1,252 ppm, whereas *Fuchsia magellanica* reduced it by 252 ppm. Significant differences were observed between the plants in terms of the ratio of the CO_2 amount consumed through photosynthesis to the CO_2 amount produced through respiration (e.g., the ratio being over 3.5 in *Schefflera arboricola* and less than 2 in *Fuchsia magellanica*).

The results of the present study show that *Yucca* is one of the plants that requires direct sunlight, and *Dieffenbachia* and *Spathiphyllum* are ornamental plants that seek half-shadow conditions [16]. In the research conducted on *Raphanussativus* L. var. Saxa under high- and low-light conditions, Lichtenthaler (1979) grew plants

Table 4. Influences of the species on CO_2 amount in the dark, depending on temperature.

Species	Temperature				
	15ºC	20ºC	25ºC	30ºC	35ºC
Ficus	38.64	47.76	32.82	59.50	101.92
Dieffenbachia	7.04	15.93	8.77	11.29	8.04
Spathiphyllum	57.56	70.58	129.62	65.14	-
Yucca	18.16	35.62	50.08	30.70	17.38

under 20,000-24,000 lux as a high-light condition. Studies show that plants like *Heliamphora* and *Sarracenia* require 25,000 lux 12 to 16 hours a day [16].

Given this information, 20,000 lux was considered to provide natural growth conditions for the plants. However, light is a comprehensive issue, and quality, quantity, and duration of light, besides its intensity, are important and influential in photosynthesis [21]. Hence, future research should focus on these aspects separately in detail.

In the present study, all the plants increased their CO_2 amounts in the dark. In other words, they respired in the dark environment. This result is known and is mentioned in many studies [19, 22-23].

Another important result involves the ratio of the CO_2 amount exhaled to the environment through respiration to the CO_2 amount inhaled from the environment through photosynthesis during the day. At the optimum temperatures for the plants, the CO_2 amount obtained by the plants from the environment in the presence of light was considerably higher than the CO_2 amount they emitted to the environment through respiration in the dark. For example, at 25ºC, *Dieffenbachia* consumed 315.41 ppm CO_2 in the light environment in one hour. However, at the same temperature level it produced only 8.77 ppm CO_2 in the dark environment. That is, the CO_2 amount it consumed under 20,000 lux light conditions in one hour was 36 times as much as the CO_2 amount it produced in the dark at the same temperature. Therefore, plants can have a significant positive effect on indoor CO_2 amount in summer months when sunlight is received for a long time and temperature is high.

The plants used in the study were selected from among the most frequently used indoor plants. If research is diversified and different factors are included, considerably more effective and important results can be obtained in this matter. For example, leaf structure must be included in future research. Kacar et al. [15] reported that some plant leaves are thick and enjoy the light less. When selecting the intensity of light, the fact that optimum quantity of light is different for every plant must be considered, and plants of light and plants of shadow should not be evaluated under the same light conditions. Indeed, Kacar et al. [15] stated that the ratio of quantity of light needed for the highest amount of photosynthesis is 8:1 for plants of sun and plants of shadow. This shows how important choice of light is for maximum photosynthesis speed.

Plants are living organisms. They need certain conditions to survive. In addition, they change the conditions of the environment they are in through their metabolic activities. When the conditions in the environment are suitable for plant development, they emit oxygen to the environment and absorb CO_2 from the environment, but the opposite happens when conditions change [10]. This condition influences the CO_2 amount in the environment as well. A study on this subject concluded that the CO_2 amount in forestland averages around 391 ppm during the daytime and around 422 ppm during the nighttime in winter months, and around 148 ppm during the daytime and 229 ppm during the nighttime in summer months [24].

Many studies have shown that indoor ornamental plants can be used to reduce various indoor pollutants [25-26]. Torpy et al. [27] explored the potentials of *Aglaonemacommutatum*, *Aspidistra elatior*, *Castanospermumaustrale*, *Chamaedoreaelegans*, *Dracaena deremensis compacta*, *Dypsislutescens*, *Ficus benjamina*, and *Howeaforsteriana*to in reducing indoor CO_2 and found that the reducing effects of plants vary depending on light conditions. Plants have a great variety of reducing effects depending on light conditions. In this study, the plants were first kept in high- or low-light conditions for 93 days, thereby accustoming them to the relevant quantity of light. The CO_2 amount that was reduced under 10 µmol PAR $m^{-2}s^{-1}$ and 350 µmol PAR $m^{-2}s^{-1}$ light conditions was then determined. Then how much they reduced the CO_2 amount under 10 µmol PAR $m^{-2}s^{-1}$ and 350 µmol PAR $m^{-2}s^{-1}$ light conditions was determined. The highest values were obtained in *D. lutescens*, which had been accustomed to high-light conditions before, under 350 µmol PAR $m^{-2}s^{-1}$. *D. lutescens,* having a leaf surface of 1 m^2, reduced the CO_2 amount in the environment by approximately 657 ppm in one hour. The second highest value was obtained in *D. deremensis* (397 ppm) under the same conditions.

The results of the present study indicate that plants can considerably decrease the CO_2 amount in the air, especially in light environments. Although plants are especially used for aesthetic and visual purposes, they affect the CO_2 amount in the environment [2]. Previous research indicates that a beech tree with a leaf surface of 1,600 m^2 can satisfy the oxygen need of 10 people [3-5, 16]. Torpy et al. [27] compared eight species. In the end, they revealed that if *D. lutescens* is used, which is the species having the highest reducing effect on CO_2, 249 plants should be placed in an environment to balance the CO_2 amount produced by a human being. Torpy et al. [27] stated that if *H. forsteriana* is used for the same purpose, 206 plants will be needed since *H. forsteriana* has a wider leaf surface. According to Pennisi and Iersel [28], approximately 400 plants will be needed if *Spathiphyllum* is used for the same purpose.

Although these results indicate that indoor plants do not have an adequate effect in reducing the CO_2 amount in practice, two points should be noted. First, plants not only reduce indoor CO_2 amount but also fulfill many other functions. Before anything else, plants reduce many pollutants such as nitrogen and sulfur oxides, carbon monoxide, volatile organic compounds, particles, ozone, NO_2 (Nitrogen dioxide), formaldehydes, and heavy metals [6, 29]. Furthermore, indoor plants psychologically relieve people, reduce their stress and other negative feelings, and improve their productivity [3, 7, 30].

Conclusions

The features sought in plants to be selected should be determined based on environmental conditions to ensure a more efficient use of plants. Research on this subject is inadequate for now. More research should be carried out on different plants; plants that photosynthesize faster in indoor conditions should be investigated; and different varieties, forms, and origins of the same species should be included in analyses.

The results of this study show that plants help reduce the CO_2 amount in the light environment at different levels. Among the species used, *Ficus* is the plant that reduces the CO_2 amount in the environment the fastest. Therefore, *Ficus* is the most suitable species to be used in reducing indoor CO_2 amount, among the species included in the study. However, only four species were used in this study. If similar research is carried out on a variety of species, crucial information should be obtained with regard to which plants must be used to effectively reduce the CO_2 amount in the environment.

Environmental conditions considerably influence speeds of photosynthesis of plants and thus their influence on CO_2. Therefore, inclusion of factors such as temperature, light, plant size, and leaf structure in future research is important for determining which plants are more effective in specific environmental conditions.

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References

1. CETIN M. Determining the bioclimatic comfort in Kastamonu city. Environ. Monit. Assess. **187** (10), 640, **2015**.
2. CETIN M. Using GIS analysis to assess urban green space in terms of accessibility: case study in Kutahya. Int. J. Sust. Dev. World. **22** (5), 420, **2015.**
3. CETIN M. A Change in the Amount of CO_2 at the Center of the Examination Halls: Case Study of Turkey. Studies on Ethno-Medicine, **10** (2), 146, **2016**. Retrieved from http://krepublishers.com/02-Journals/S-EM/EM-10-0-000-16-Web/S-EM-10-2-16-Abst-PDF/S-EM-10-2-146-16-444-Cetin-M/S-EM-10-2-146-16-444-Cetin-M-Tx[7].pdf
4. CETIN M. Evaluation of the sustainable tourism potential of a protected area for landscape planning: a case study of the ancient city of Pompeipolis in Kastamonu. Int. J. Sust. Dev. World. **22** (6), 490, **2015** doi: 10.1080/13504509.2015.1081651, 2015.
5. CETIN M., SEVIK H. Measuring the Impact of Selected Plants on Indoor CO_2 Concentrations. Pol J Environ Stud. **25** (3), 973, **2016**.
6. TANI A., HEWITT C.N. Uptake of aldehydes & ketones at typical indoor concentrations by houseplants, Environ Sci Technol. **43** (21) 8338. **2009.**
7. DJUKANOVIC R., WARGOCKI P., FANGER P.O. Cost-benefit analysis of improved air quality in an office building, Proceedings: Indoor Air, 808. **2002.**
8. FJELD T. The effect of interior planting on health and discomfort among workers and school children, HortTechnology, **10** (1), 46, **2000.**
9. BULGURCU H., ILTEN N., COSGUN A. Indoor air quality problems and solutions in schools. Journal of Installation Engineering. **96**, 59, **2006** [In Turkish].
10. CETIN M., SEVIK H. Change of air quality in Kastamonu city in terms of particulate matter and CO_2 amount. Oxidation Communications. **39** (4-II), 3394, **2016**.
11. CETIN M., SEVIK H., ISINKARALAR K. Changes in the particulate matter and CO2 concentrations based on the time and weather conditions: the case of Kastamonu, Oxidation Communications, **40** (1-II), 477, **2017**.
12. TWARDELLA D., MATZEN W., LAHRZ T., BURGHARDT R., SPEGEL H., HENDROWARSITO L., FRENZEL AC., FROMME H. Effect of classroom air quality on students' concentration: results of a cluster-randomized cross-over experimental study. Indoor Air **22** (5), 378. **2012**
13. MUSCATIELLO N., MCCARTHY A., KIELB C., HSU W.H., HWANG S.A., LIN S. Classroom conditions and CO2 concentrations and teacher health symptom reporting in 10 New York State Schools. Indoor air, **25** (2), 157, **2015**.
14. APTE M.G., FISK W.J., DAISEY J.M. Indoor carbon dioxide concentrations and SBS in office workers. In Proceedings of Healthy Buildings, **1**, 133, **2000**
15. KACAR B., KATKAT V., OZTURK S. Light, plant physiology. The Nobel Broadcast Distribution, Ankara, 270, **2010** [In Turkish]
16. SEVIK H., CETIN M., ISINKARALAR K. Effects of some indoor ornamental plants on the amount of indoor Carbondioxide. Duzce University. The Journal of Science and Technology. **4** (2), 493, **2015** [In Turkish].
17. KACAR B., KATKAT V., ÖZTÜRK Ş. Plant Physiology (4. Edition). Ankara: Nobel Publication distribution **2010** [In Turkish].
18. KÖSE B. Light and temperature in viticulture and its importance, Turkish Journal of Agricultural Research, **2014** (1), 203, **2014** [In Turkish].
19. AKMAN Y., GÜNEY K. Plant biology botany. Ankara: Palme publishing **2005** [In Turkish].
20. LERMI A.G., PALTA Ş. Research on some plant characteristics of *Medicagopolymorpha* L. Bartin ecology, COMU Journal of Faculty of Agriculture., **2** (2), 141, **2014**. [In Turkish].
21. MAUSETH J.D. Introduction to botanical plant biology (4. Edition). Ankara: Nobel publication distribution. **2012**.
22. CETIN M. Determination of bioclimatic comfort areas in landscape planning: A case study of Cide Coastline. Turkish Journal of Agriculture-Food Science and Technology **4** (9), 800, **2016**.

23. CETIN M. Sustainability of urban coastal area management: A case study on Cide. Journal of Sustainable Forestry. **35** (7), 527.
24. SEVIK H., CETIN M., BELKAYALI N. Effects of Forests on Amounts of CO_2: Case Study of Kastamonu and Ilgaz Mountain National Parks, Pol J Environ Stud., **24** (1), 253, **2015**.
25. TORPY F.R., IRGA P.J., MOLDOVAN D., TARRAN J., BURCHETT M.D. Characterisation and biostimulation of benzene biodegradation in the potting-mix of indoor plants, Journal of Applied Horticulture, **15** (1), 10, **2013**.
26. IRGA P.J., TORPY F.R., BURCHETT M.D. Can hydroculture be used to enhance the performance of indoor plants for the removal of air pollutants? Atmos Environ. **77**, 267, **2013**.
27. TORPY F.R., IRGA P.J., BURCHETT M.D. Profiling indoor plants for the amelioration of high CO_2 concentrations, Urban For Urban Gree. **13** (2), 227, **2014**.
28. PENNISI S., VANDVANIERSEL M.W. Quantification of carbon assimilation of plants in simulated and in situ interiorscapes. HortScience, **47** (4), 468, **2012**
29. AYDOGAN A., MONTOYA L.D. Formaldehyde removal by common indoor plant species and various, growing media, Atmos Environ. **45**, 2675, **2011.**
30. CETIN M. Changes in the amount of chlorophyll in some plants of landscape studies. Kastamonu University Journal of Forestry Faculty. **16** (1), 239, **2016**.