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RESEARCH ARTICLE

Abating indoor air contaminants through foliage ornamentals

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Abstract

Plants are found to remove toxic gases in the indoor atmosphere. It is well documented that plants in indoor space not only add aesthetic value but contribute and promote the improvement of indoor air quality (IAQ). Hence, this present study was taken up with an objective to study the impact of foliage ornamentals on IAQ in digital printing unit. In this experiment, three indoor foliage ornamentals *viz*., garden croton (*Codiaeum variegatum*), dumb cane (*Dieffenbachia bowmannii*) and song of India (*Dracaena reflexa*) were tested in the digital printing unit. Six plants of each genus were separately placed in the experimental unit (15 x 15 x 12 ft printing unit) for a week. A control experiment was done on the adjacent printing unit without plants and kept as control. The IAQ was monitored on an hourly basis by uHOO smart air monitor and the mean data on humidity, carbon dioxide (CO_2), PM 2.5, carbon monoxide (CO) along with ozone (O_3) were recorded and analyzed. It is evident from the experiment that all three foliage ornamentals *viz.*, *C. variegatum*, *D. reflexa* and *D. bowmannii* improved the IAQ placed in the digital printing unit. However, among the three genus, *Dieffenbachia* recorded a more positive effect in modifying the indoor air during the experimental period.

Keywords: carbon monoxide; CO_2; humidity; indoor air quality; ozone; plants; PM 2.5

Introduction

Due to rapid urbanization and technological developments, people are spending more time indoors than outdoors. Hence, IAQ is considered an important criterion for the well-being of humans. Further, the presence of more CO_2, decreased humidity and less accumulation of PM increase ozone levels ends in harmful effects resulted in sick building syndrome. The printing industry is a fast-growing industry in the globe with multicoloured fascinating outputs. The materials used for printing are solvents such as ethanol, toluene, ethyl acetate, isopropanol, n-propanol, hexane, toluene-xylene-naphtha mixture, methyl ethyl ketone, isopropyl acetate, n-propyl acetate, glycols and other glycol ethers. At higher levels of usage this may lead to modifying the IAQ. IAQ is the most essential part of the environment which directly influences human health during recent days. People inhale 6 - 10 L/min of air (or) 15000 L/day. IAQ lowers relative humidity, raises temperature and contains more than 200 indoor volatile organic compounds. Indoor air has been found to be up to 100 times more polluted than outdoor air (1). Developments in information technology have allowed people to connect and remain connected to the computer environment. However, this diffusion of information technology causes a great deal of stress, such as technostress, which is a modern disease of adaptation caused by an inability to cope with the new computer technologies in a healthy manner. Indoor air pollutants i.e., airborne bacterial count (ABC), CO, CO_2, formaldehyde (HCHO), nitrogen dioxide (NO_2), O_3, radon (Rn), respirable suspended particulates (RSP) and volatile organic compounds (VOCs) are a serious threat to human health, causing millions of deaths each year (2). The permissible limit for CO is 50 ppm, CO_2 - below 1000 ppm, NO_2 - 40 µgm^3, O_3 - 100 µgm^3, VOC - 0.3 - 0.5 mg m^3, respirable suspended particle - 0.18 µgm^3 and the airborne bacterial count - 500 cfu m^3; above the limit many harmful effects were identified (3). According to studies on the measurement of IAQ (4, 5), this variable is critical for health and quality of life. Therefore, the urban landscape designers are in a condition to search for a sustainable ecological and environmental approach. Potted plants can improve IAQ for building occupants, but of particular interest (6), that just one plant within the workspace can significantly enhance staff morale and simultaneously promote well-being as well as improve performance. Plants remove VOCs from indoor air through stomatal uptake, absorption and adsorption to plant surfaces (7-9).

The printing industry is one of the commercial industries without which displays cannot be made. The IAQ present in the printing unit is vulnerable and causes harmful effects to humans (10). The solvents widely used in printing industry are ethanol, toluene, ethyl acetate, isopropanol, n-propanol, hexane, toluene-xylene-naphtha mixture, methyl ethyl ketone, isopropyl acetate, n-propyl acetate, glycols, ethers and water (11, 12). These volatile compounds are highly toxic in exceeding levels. Cleaner air has also been found to have a causal relationship with better cardiovascular health and mental acuity.

Human exposure to VOC has in general been related to dizziness, palpitation, the irritation of eyes, respiratory tract and skin, whereas the toxicity of a particular VOC depends on its chemical identity. For instance, the toxicologically derived guideline value published by the German Environment Agency is very low for pentachlorophenol (0.1 µg m^{-3}) and relatively high for monocyclic monoterpenes (1000 µg m^{-3}). Currently, there is no fully satisfying method for air purification (13), but plants may be capable of making a substantial contribution to IAQ (14). In general, the absorption of VOC can occur through the aerial plant parts (cuticle and stomata), the roots, microorganisms residing in the growing media and the growing media itself (15). However, in many experiments, it is not clear whether the plant and/or the substrate (with the contained microorganisms and roots) adsorbed the pollutants. Conclusions of previous studies concerning the efficiency of plants as indoor air purifiers differ and the capacity of plants to remove VOC is influenced by many factors, among those are for example plant species, light intensity and pollutant identity and concentration. Several Indoor plant species have been shown to remove gaseous indoor volatile pollutants. Plants are known to absorb and metabolize gaseous HCHO. HCHO enters plant leaves through stomata and the cuticle and is more readily absorbed by the abaxial surface as well as by younger leaves (16, 17). Once absorbed by leaves, it generally enters the Calvin cycle after a two-step enzymatic oxidation to CO_2. About 60 % to 90 % of radioactivity applied as 14C- HCHO was recovered from the plants (16). HCHO was assimilated about five times faster in the light than in the dark. Some of the HCHO is converted to S-methylmethionine and is translocated in the phloem to various organs (e.g., seeds and roots) (12). Benzene and toluene also enter the Calvin cycle after ring cleavage and are typically converted to organic and amino acids (17). With this background information, an experiment was carried out in a digital printing unit where the source of pollution seems to be more to study the influence of two foliage ornamental plants *viz*., *C. variegatum*), *D. reflexa*) and *D. bowmannii*) on minimizing indoor air pollution in digital printing unit.

Materials and Methods

This experiment was carried out to study and assess the impact of three indoor ornamental plants *C. variegatum*), *D. reflexa* and *D. bowmannii* on abating the indoor air pollutants in a digital printing unit. The size of the printing unit is 15 x 15 x 12 ft. Six plants of each genus were placed separately at different locations for observations for a week. The average height of the plants was 2.5 ft with 12 - 15 leaves in the case of *C. variegatum,* 6 leaves in the case of *D. reflexa* and 6 leaves in *D. bowmannii*. The IAQ was monitored on an hourly basis by installing an uHOO smart air monitor and the mean data on temperature, humidity, CO_2, PM 2.5, CO and O_3 were recorded and statistically analyzed. A control experiment was done without plants in another printing unit room next to the unit with plants and the data was kept as control. The experiment was conducted with completely randomized design.

Results and Discussion

From the experiment data, it was noticed that significant variations were found in relative humidity, CO_2 content, PM 2.5, O_3 and NO_2in the printing unit with the indoor plants in the experiment chamber.

Influence on humidity

The data on temperature does not show marked differences by both the indoor plants tested and resulted in non-significant. However, the data on relative humidity showed a gradual increase with the indoor plants. From the data, it was found that the humidity levels were found to be higher in the morning hours and reduced after 10.00 a.m. as the printing machines start working during day hours. The humidity levels were found to be decreased under the unit arranged with plants compared with control. Among the three indoor plants, P-3 *D. reflexa* recorded the lowest humidity levels (56.69 %) over control. This is followed by P-2 (*D. bowmannii*) with 56.85 % and P-1 (*C. variegatum*) with 57.08 %. The reduction in humidity levels may be since plants absorb water vapor through stomata in their leaves and the moisture then travels to the roots. This helps reduce the high humidity levels and when the moisture transpires from their leaves, it leaves a cooling effect on the surrounding air. Further, they can also reduce indoor temperatures (18, 19).

Influence on CO_2

CO_2 is one of the most common molecules found in the air. In this present study the concentration of CO_2 at initial levels exceeded to 1727.92 ppm at 2.30 p.m. It was evident from the data that the CO_2 levels were reduced due to the indoor plants in the experiment chamber. A significant reduction in CO_2 concentration over control was observed in all the treatments with plants. However, the CO_2level was lowered from 904.81 ppm in P-2 (*D. bowmannii*), 946.8 ppm in P-1(*C. variegatum*) and 1026.42 ppm in P-3 (*D. reflexa*) compared with control (1225.09 ppm) respectively. The results of the present study indicate that plants can considerably decrease the amount of CO_2 in the indoor air. Although plants are especially used for aesthetic and visual purposes, they affect the CO_2 amount in the environment (20). The results of the present experiment are in accordance with the findings (21).

Influence on PM 2.5

In this experiment, during the morning hours i.e. 9.30 to 10.30 a.m., the particulate was found to reach the peak (11.03 µg/m^3) in control. The results revealed that all the foliage plants reduced the PM content in the experiment chamber from 5.85 µg/m^3 to 2.99 µg/m^3 over control. Among the three plants experimented, P-2 (*D. bowmannii*) recorded a maximum reduction from 2.99 µg/m^3 which is followed by P-3 (*D. reflexa*) with 3.32 µg/m^3. However, in, a moderate reduction of 3.84 µg/

m^3 was recorded under P-1(*C. variegatum*). Particulate matter is a mixture of solid and liquid phases and differs in size, origin and chemical compositions. In this study, even though the PM is at a safe level i.e. <50, it was evident from the data that all the plants reduced the PM level. The results obtained in this experiment are in conformity of the study made by (22, 23).

The performance of the indoor plants altering the humidity, CO_2 and PM 2.5 on the IAQ of digital printing unit was given in Table 1.

Influence on O_3

From the experiment, the maximum of 9.2 ppb was recorded at 9:30 a.m., 6.30 p.m. and 7.30 p.m. respectively. The O_3 levels were found to be reduced from 7.3 ppb (control) to 4.8 ppb (P-2). The maximum O_3 reduction was observed under P-2 (*D. bowmannii*) with 4.8 ppb which is followed by P-1-(*C. variegatum*) with 5.6 ppb and P-3 (*D. reflexa*) with 5.8 ppb over control (7.3 ppb). O3 consists of three oxygen atoms. In nature, it is created when the ultravoilet (UV) light from the sun breaks down the oxygen molecule into two single oxygen atoms which quickly attaches itself to another oxygen molecule (O_2) to become O_3. Most countries adopt the OSHA standard for Industries and 50 ppb for IAQ requirements. The maximum O_3 exposure limit of 50 ppb is also adopted by ASHRAE for IAQ requirements. The results from this study clearly showed that both the foliage plants are known for absorbing and detoxifying or degrading many harmful compounds such as NO_2, CO, HCHO, benzene and others (24, 25, 27) and are also able to accumulate PM.

Influence on NO_2

NO_2 is red brown gas that is released on burning fuel. In high concentrations it can cause respiratory irritations. Long term exposure also leads to chronic illness and respiratory infections. In the present experiment, both the foliage ornamentals reduced the NO_2 concentrations in the experiment chamber. It was noticed that, under control (Without plants), a NO_2 level of 1.6 ppb was recorded. It is interesting to note that under both the plants the NO_2 was found 0 with 100 percent difference. The performance of the indoor plants altering the O_3 and NO_2 on the IAQ of digital printing unit was presented in Table 2.

It is evident from the experiment that all the three foliage ornamentals *viz.*, *C. variegatum, D. bowmannii* and *D. reflexa* improved the IAQ placed in the digital printing unit. This is possible through adsorption of gaseous contaminants and particulate (dust and bio aerosols) onto leaf surfaces; degradation of gaseous contaminants through various metabolic pathways; removal of CO_2 and production of O_2 through photosynthesis; increasing humidity levels through leaf transpiration and evaporation from rooting media and reducing airborne concentrations of dust and bio aerosols. It was stated that during the development of the leaf the plant cell walls undertake secondary cell wall formation, facilitated by expansion proteins that allow the development of the cell wall by introduction of matrix polysaccharides such as cellulose, pectin and hemi-cellulose (27). Moreover, it is also known that plants consume pollutants and transform them in "food" or other compounds. Plants clean the indoor air by absorbing pollutants into their leaves and transmitting the toxin to their roots, where they are turned into food for the plant. Results of the present experiment showed that on comparing the IAQ under control (without plants) and with plants in the experimental chamber, significant improvement on humidity levels, reduction in CO_2, reduction in particulate matter and reduction in O_3 values. It is well documented that plants in indoor space not only add aesthetic value but contribute and promote the improvement of indoor air quality. Likewise, ornamental plants can be effectively used as bio-indicators of air quality (28, 29). The most sensitive part of the plant is leaf and therefore, it is affected by air pollutants. Leaves play a major role in the absorption and accumulation of air pollutants to reduce the level of pollutants. The mechanism by which plants reduce or remove indoor air pollutants is done mainly through leaf stomata and after they have penetrated the leaf, in the intercellular spaces the gases are distributed and absorbed by water films. This may be the reason for the improvement of air quality in the digital printing unit.

Table 1. Performance of indoor plants altering the humidity (%), CO_2 (ppm) and PM 2.5 (µg/m^3) on the IAQ of digital printing unit

	Humidty (%)				CO_2 (ppm)				PM 2.5 (µg/m^3)			
Time	**Control**	**P-1**	**P-2**	**P-3**	**Control**	**P-1**	**P-2**	**P-3**	**Control**	**P-1**	**P-2**	**P-3**
6.30 a.m.	64.2	63.22	62.99	62.83	809.42	783.42	735.42	785.22	3.03	2.52	2.53	2.83
7.30 a.m.	66.1	65.12	64.89	64.73	799.92	720.42	704.92	754.72	3.03	3.02	2.53	2.83
8.30 a.m.	66.2	65.22	64.99	64.83	789.92	722.92	711.42	742.22	2.03	2.02	1.53	1.83
9.30 a.m.	59	58.02	57.79	57.63	1137.92	830.92	817.92	930.42	11.03	6.02	4.53	4.03
10.30 a.m.	47.8	46.82	46.59	46.43	1271.92	883.92	854.42	962.72	10.03	6.02	5.03	4.03
11.30 a.m.	55.5	54.52	54.29	54.13	1313.92	1020.42	929.92	1006.42	3.03	3.02	2.53	2.53
12.30 p.m.	58.2	57.22	56.99	56.83	1645.92	1184.92	1149.42	1038.22	8.03	4.02	2.53	4.53
1.30 p.m.	59.4	58.42	58.19	58.03	1150.92	1069.92	1007.92	1115.72	6.03	3.02	2.03	4.53
2.30 p.m.	45.9	44.92	44.69	44.53	1727.92	995.92	957.92	1134.42	10.03	6.02	4.53	3.33
3.30 p.m.	56.3	55.32	55.09	54.93	1714.42	993.92	944.42	1299.92	8.03	4.52	3.53	4.53
4.30 p.m.	57.6	56.62	56.39	56.23	1424.92	996.92	967.92	1372.92	5.03	3.02	2.53	3.03
5.30 p.m.	55.3	54.32	54.09	53.93	1191.42	1014.92	946.42	1173.42	4.53	2.52	1.53	3.33
6.30 p.m.	56.8	55.82	55.59	55.43	1105.92	1081.92	1016.92	1082.22	5.03	5.02	4.03	3.33
7.30 p.m.	64.6	63.62	63.39	63.23	1066.92	955.92	922.42	971.42	3.03	3.02	2.53	1.83
Mean	58.06	57.08	56.85	56.69	1225.09	946.8	904.81	1026.42	5.85	3.84	2.99	3.32
SE.d	2.32	2.49	2.68	2.09	34.21	38.6	36.24	35.22	0.90	0.88	0.87	0.88
CD (p=0.5)	4.66	5.00	5.38	4.20	68.74	77.58	72.84	70.79	1.80	1.76	1.74	1.76

(P-1: C. *variegatum*, P-2: D. *bowmannii*, P-3:D. *reflexa*)

Table 2. Performance of indoor plants altering the O3 (ppb) and NO2 (ppb) on the IAQ of digital printing unit

	O_3 (ppb)				NO_2 (ppb)			
Time	**Control**	**P-1**	**P-2**	**P-3**	**Control**	**P-1**	**P-2**	**P-3**
6.30 a.m.	5.2	5.2	5.2	5.2	0	0	0	0
7.30 a.m.	5.2	5.2	5.2	4.7	1	0	0	0
8.30 a.m.	5.2	5.2	5.2	4.7	0	0	0	0
9.30 a.m.	9.2	5.2	4.2	4.2	16	0	0	0
10.30 a.m.	6.2	5.2	4.2	4.2	0	0	0	0
11.30 a.m.	6.2	4.7	4.2	5	0	0	0	0
12.30 p.m.	7.2	5.7	4.7	5.7	0.3	0	0	0
1.30 p.m.	6.2	5.7	4.7	5.5	0.3	0	0	0
2.30 p.m.	8.2	5.2	4.2	6.5	1	0	0	0
3.30 p.m.	8.2	6.2	5.2	7.7	0.3	0	0	0
4.30 p.m.	8.2	6.2	5.2	7.6	1	0	0	0
5.30 p.m.	8.7	6.2	5.2	5.2	1	0	0	0
6.30 p.m.	9.2	7.2	5.2	7.2	1	0	0	0
7.30 p.m.	9.2	5.2	4.7	7.95	0.5	0	0	0
Mean	7.3	5.6	4.8	5.8	1.6	0	0	0
SE.d	0.042	0.043	0.037	0.036	NS	NS	NS	NS
CD (p=0.5)	0.084	0.086	0.074	0.072	NS	NS	NS	NS

(P-1: *C. variegatum*, P-2: *D. bowmannii*, P-3:*D. reflexa*)

Conclusion

From the experiment, it is concluded that, the foliage ornamentals *viz.*, *C. variegatum*, *D. bowmannii and D. reflexa* improved the IAQ placed in the digital printing unit size of 15 x 15x 12 ft. However, among the three foliage ornamentals, *D. bowmannii* recorded more positive effects in modifying the indoor air during the experiment period.

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Authors' Contributions

DD contributed to the conceptualization and analysis of the study, including writing the original draft manuscript. AV and SS carried out data analysis. SB advised on data processing and interpretation of the results. Each author examined the manuscript and participated in the data analysis. All authors have read and agreed to the published version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests related to this research.

Ethical issues: None

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