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Evaluation of the efficacy of selected indoor plants in reducing Total volatile organic compounds and formaldehyde

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Abstract
Indoor Air Quality (IAQ) is sturdily linked to health and wellbeing. Pure IAQ can lead to a higher quality of life, lower risk of respiratory illnesses, and a reduced risk of various chronic conditions. Total volatile organic compounds and Formaldehyde are the primary indicators of indoor air pollution (IAP). Some studies showed that the biological solution for amending IAP is the application of potential green solution offered by plants. This paper summarises the selection of some best indoor plants which can improve IAP caused by TVOCs and HCHO from fifteen indoor plants which have reported air-purifying properties.

Keywords: indoor air quality, indoor air pollution, TVOCs and HCHO

Introduction

Air is important for the survival of all living forms and its quality determines the quality of life. Indoor Air Quality (IAQ) denotes the quality of air in and around buildings. Indoor Air Pollutant (IAPs) deteriorates IAQ and is as detrimental to human health as outdoor air pollutants (OAPs) (Paleologos *et al*., 2021) [13]. IAPs can be biological or non-biological. They may be generated either by materials and conditions inside the building itself or transported from outside. IAQ of buildings may be influenced by the exchange rate of air between indoor and outdoor environments, their source emission rate and concentration (Smith, 2002) [17].

Combustions, building materials, and bio-aerosols are the key sources of indoor air pollution (Saiyed *et al*., 2001) [16]. Incomplete combustion of biomass fuels release suspended particulate matter, carbon monoxide, poly-aromatic hydrocarbons, poly-organic matter and formaldehyde which in turn adversely affect human health (Zhang and Smith, 2013). Among the IAPs, the most prevalent and consistent pollutants are Formaldehyde (HCHO) and volatile organic compounds (VOCs).

VOCs in indoor air have received appreciable attention due to their adverse health effects on humans (Cruz *et al*., 2014) [7].

The main sources of VOC are adhesives, upholstery, carpeting, copy machines, manufactured wood products, pesticides and cleaning agents (Joshi. 2008) [12]. VOCs mainly comprise propylene glycol - glycol ethers (PG), benzene and formaldehyde. Inhalation of VOCs can cause irritant reactions within the airway epithelium and badly affect the epithelial lining of the respiratory tract and mucous membrane which in turn might lead to pulmonary diseases (EPA, 2020, Alford and Kumar, 2021) [8, 1]. Formaldehyde is cited to be an omnipresent chemical found in virtually all indoor settings. Specific sources of formaldehyde include cigarette smoke, natural gas, kerosene and common household cleaning agents. Formaldehyde irritates the mucous membranes of the eyes, nose, and throat and its exposure causes serious health problems like asthma.

The influence of IAQ on life was noticed as early as 1970's and 1980's, when people were found afflicted with a particular health problem, which came to be known as the Sick Building Syndrome (SBS). Deterioration in IAQ was identified to be the cause. SBS was found to occur in people who were forced to occupy stuffed indoor spaces in offices with the introduction of personal computers and open-plan offices (Bluyssen *et al.*, 2016) [4]. The United States National Aeronautics and Space Administration (NASA) became an implausible leader in identifying biological solutions, especially the potential green solution offered by plants for improving IAQ. After a series of experiments, they went ahead to state that the plants are capable of reducing the level of VOCs in indoor environments and at the same time mend human health. Potted-plants can deliver effectual, self-regulating, low-cost, bioremediation systems against indoor air pollution, and hence progress human wellbeing and productivity (Pipal *et al*., 2016).

The present study is an attempt to screen out the most efficient IAQ enhancing plants from a sample of fifteen indoor plants (Chauhan, *et al.*, 2017; Wolverton, *et al.*, 1989; Yang, *et al*., 2009) [5, 21] well known for phytoremediation.

Materials and Methods

For this study, fifteen plants (11 monocots and 4 dicots) of similar maturity (approximately six months of growth) with reported air purifying properties were selected. All the plants were grown in a potting mixture comprising of soil, cow dung / green manure and crushed bone powder in the ratio 2:1:1 and further, were acclimatized by keeping them under controlled conditions for about four months. The experimental set-up designed for the study included a closed airtight glass chamber (90cm×40cm×60 cm) with a top lid and a small side door just enough to push in the digital air quality measuring device(SMILEDRIVE® Portable Air

Quality Pollution Meter Detector). The sensor device could check the TVOCs and HCHO (formaldehyde) levels.

The plants were placed one by one inside the chamber and trace amounts (20µl) of formaldehyde was injected each time into the chamber using a 100µl glass syringe (Hamilton-80600syringe). All the readings were considered relative to the corresponding formaldehyde reading after exposure of one, two, four and six hours in the experimental control, since the air inside was found to attain a periodic saturation (from 1-6 hrs) for which observations were recorded.

The time of injection of pollutant is begun at10.00am every day followed by periodic observations. The amount of TVOCs and HCHO in the trapped indoor air were monitored at specific intervals of time (1-hr, 2-hr, 4-hr and 6-hr) using the air quality monitor in both controls (closed chamber without plant) and experimental (closed chamber with selected plant) conditions. Triplicates of the selected fifteen plants were monitored separately for experimental accuracy.

The absorption of TVOCs as well as formaldehyde was taken at specific intervals of time and calculated by the formula,

$$\frac{\text{Reading at specific intervals of time in control} - \text{Reading at specific intervals of time in treatment}}{\text{Reading at specific intervals of time in control}} \times 100$$

Correlation between plant height and leaf area against the absorption rate of formaldehyde was also calculated using Pearson's correlation (Asuero *et al*., 2006 and Benesty *et al*., 2009) [2, 3] coefficient in MS excel. The APH (Average Plant Height) was taken by measuring the height of triplicate of selected fifteen plants. The TLA (Total Leaf Area) was found by the millimeter graph paper method (Pandey and Singh, 2011) [14]. Here, all the leaves of each plant are categorized as small, medium and large according to leaf size. The Surface area of three leaves were measured from each category and multiplied by the number of leaves in that category. By adding the values of three categories the approximate value of TLA of the plant was calculated.

Table 1: List of fifteen plants selected for the study

Sl no:	Name of plants with its code	Family	Monocot / Dicot	APH (in cm)	≈ TLA (in cm^2)
1	*Aglaonemacommutatum* (Acm)	Araceae	Monocot	31.4 ± 1.5	1348.0
2	*Aglaonemacostatum* (Acs)	Araceae	Monocot	30.4 ± 1.5	1278.0
3	*Aglaonemawiduri* (Awi)	Araceae	Monocot	26.6 ± 1.8	853.0
4	*Begoniaobliqua* (Bob)	Begoniaceae	Dicot	20.3 ± 2.0	139.0
5	*Chlorophytumcomosum* (Cco)	Asparagaceae.	Monocot	27.9 ± 1.4	459.5
6	*Dracaena marginata* (Dma)	Asparagaceae	Monocot	27.1 ± 1.5	796.5
7	*Dracaena sanderiana* (Dsa)	Asparagaceae	Monocot	22.8 ± 1.7	384.0
8	*Epipremenumaureum* (Eau)	Araceae	Monocot	17.7 ± 1.2	631.0
9	*Hemigraphis alternate* (Hal)	Acanthaceae	Dicot	26.6 ± 1.3	518.0
10	*Ocimumbasilicum* (Oba)	Lamiaceae	Dicot	11.5 ± 1.5	441.5
11	*Philodendron'cyclon gold'* (Pcy)	Araceae	Monocot	29.2 ± 2.0	1257.5
12	*Plectranthusamboinicus* (Pam)	Lamiaceae	Dicot	15.2 ± 1.4	120.0
13	*Sanseveria dwarf laurentii* (Sdl)	Asparagaceae	Monocot	26.6 ± 1.5	155.0
14	*Sanseveriatrifasciata* (Str)	Asparagaceae	Monocot	12.7 ± 0.9	125.0
15	*Spathyphyllumwallissi* (Swa)	Araceae	Monocot	27.1 ± 1.0	210.0

APH – Average Plant Height; TLA – Total Leaf Area

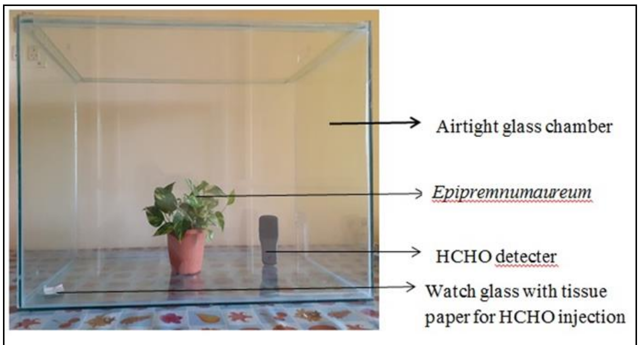


Fig 1: Experimental set up - Glass chamber placed atop a laboratory table

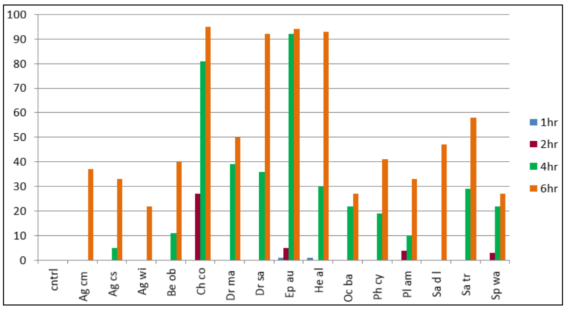
Results

The amount of residual TVOCs and HCHO that were released in the indoor air recorded using the air quality monitor is provided below (Tables 2 and 3). The exposure time was fixed at 6 hrs after preliminary experiments. Percentage of absorption of TVOCs and HCHO by selected plants at specific intervals of time as calculated (Graph 1 and 2).

As the duration of exposure was increased gradually (from 1-6 hrs) a corresponding increase could be noticed in the amount of TVOCs and formaldehyde absorbed. The absorption rate increased even above 95% in certain plants so the duration of exposure was not increased beyond the point *ie* it was fixed at 6 hrs.

Table 2: Absorption rate of TVOCs, at specific intervals of time.

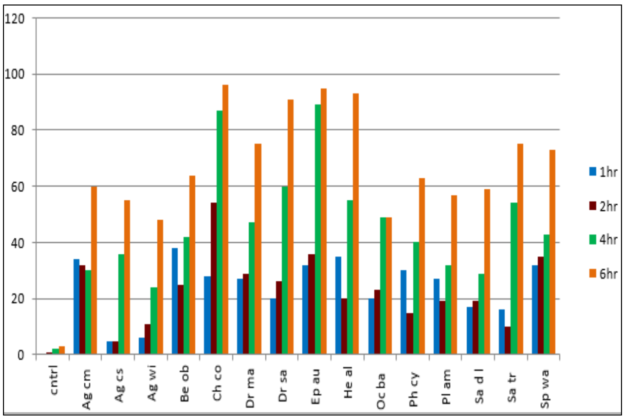
Sl no	Name of plants	Amount of TVOCs (mg/m^3)			
		1hr	2hr	4hr	6hr
1	Control (no plant)	9.999	9.999	9.999	9.999
2	*Aglaonema commutatum*	9.999	9.999	9.999	6.243
3	*Aglaonema costatum*	9.999	9.999	9.530	6.733
4	*Aglaonema widuri*	9.999	9.999	9.999	7.809
5	*Begonia oblique*	9.999	9.999	8.929	5.969
6	*Chlorophytum comosum*	9.999	7.309	1.927	0.493
7	*Dracaena marginata*	9.999	9.999	6.101	4.983
8	*Dracaena sanderiana*	9.999	9.999	6.396	0.734
9	*Epipremenum aureum*	9.935	9.460	0.798	0.594
10	*Hemigraphis alternate*	9.914	9.999	7.000	0.695
11	*Ocimum basilicum*	9.999	9.999	7.843	7.241
12	*Philodendron'cyclon gold'*	9.999	9.999	9.121	5.842
13	*Plectranthus amboinicus*	9.999	9.593	8.993	6.703
14	*Sanseveria dwarf laurentii*	9.999	9.999	8.848	5.343
15	*Sanseveria trifasciata*	9.999	9.999	7.087	4.325
16	*Spathyphyllum wallissi*	9.999	9.648	7.843	7.241



Graph 1: Percentage of absorption of TVOCs at specific intervals of time

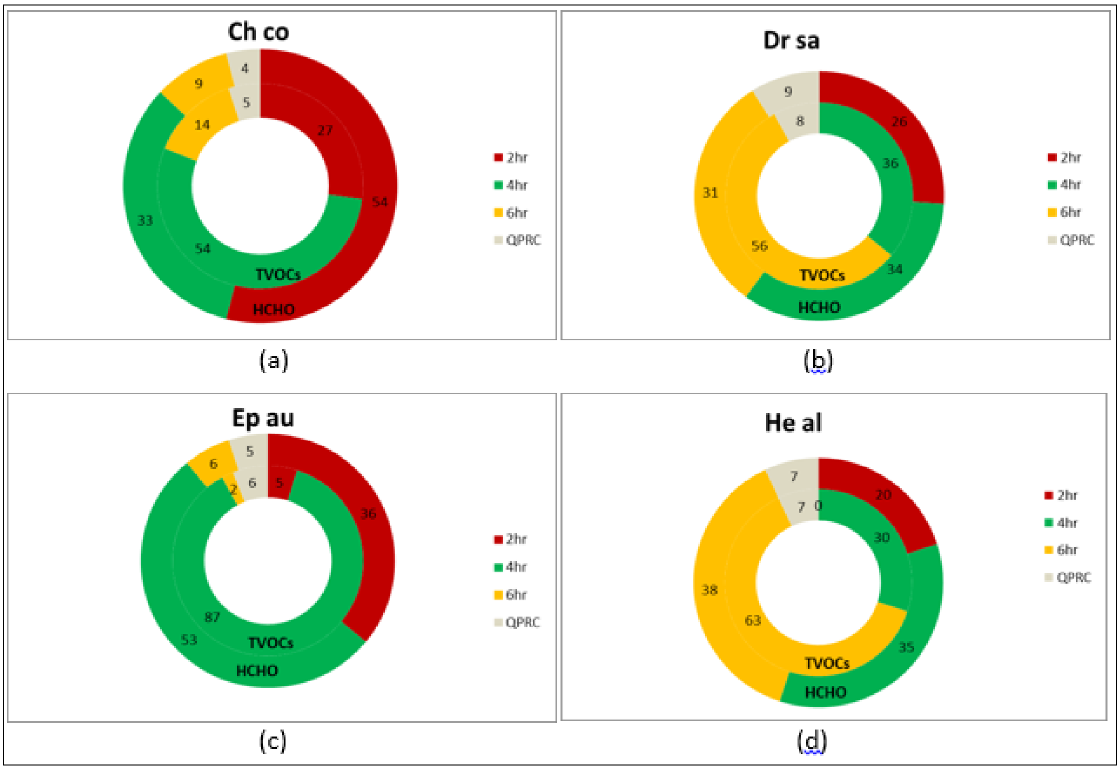
Table 3: Absorption rate of HCHO, at specific intervals of time.

Sl no	Name of plants	Amount of formaldehyde (mg/m³)			
		1hr	2hr	4hr	6hr
1	Control (no plant)	1.999	1.971	1.954	1.935
2	*Aglaonema commutatum*	1.327	1.539	1.354	0.779
3	*Aglaonema costatum*	1.904	1.874	1.253	0.871
4	*Aglaonema widuri*	1.875	1.751	1.485	1.008
5	*Begonia oblique*	1.236	1.477	1.139	0.695
6	*Chlorophytum comosum*	1.440	0.904	0.250	0.073
7	*Dracaena marginata*	1.463	1.397	1.030	0.493
8	*Dracaena sanderiana*	1.606	1.466	0.784	0.160
9	*Epipremenum aureum*	1.352	1.255	0.203	0.093
10	*Hemigraphis alternate*	1.302	1.582	0.883	0.131
11	*Ocimum basilicum*	1.600	1.525	0.993	0.983
12	*Philodendron'cyclon gold'*	1.408	1.684	1.181	0.717
13	*Plectranthus amboinicus*	1.464	1.587	1.335	0.829
14	*Sanseveria dwarf laurentii*	1.660	1.604	1.384	0.794
15	*Sanseveria trifasciata*	1.675	1.773	0.896	0.476
16	*Spathyphyllum wallissi*	1.354	1.273	1.111	0.523



Graph 2: Percentage of absorption of HCHO at specific intervals of time

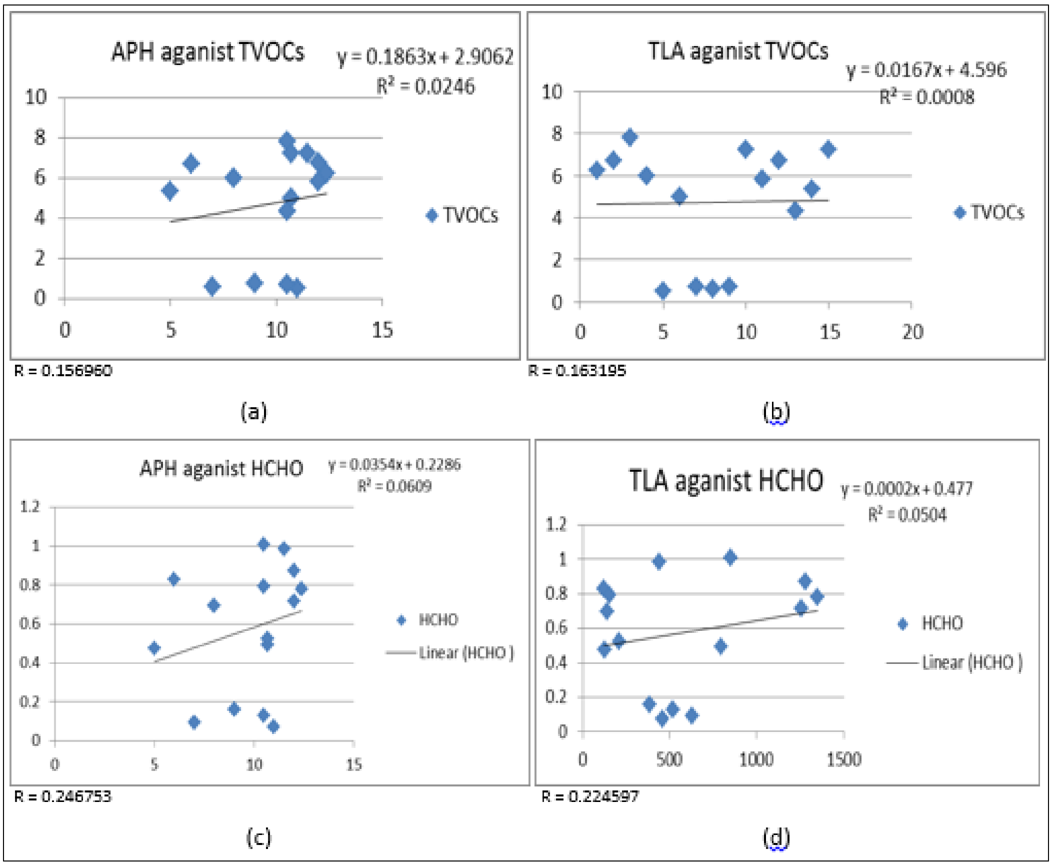
At the sixth hour, all the plants showed their maximum absorption of TVOCs and HCHO. Among them, four plants showed more than 90% of absorption rate (*Chlorophytum comosum* - 95% TVOC, 96% HCHO; *Epipremnum aureum* 94% TVOCs, 95% HCHO; *Hemigraphis alternata* 93% of both pollutants and *Dracaena sanderiana* 92% TVOCs, 91% HCHO) when compared to control. Among these, *Chlorophytum comosum* showed a steady increase of absorption from 2 to 6hrs, while *Epipremnum aureum* the difference in absorption was very evident after the 2nd to 4 hr period. *Dracaena sanderiana* and *Hemigraphis alternata* absorbed relatively less and the trend was noticed to be erratic.



(QPRC: Quantity of pollutants resides in experimental chamber)

Graph 3: Absorption rate of TVOCs and HCHO specific intervals of time by plants they have more than 90% absorption capacity of selected pollutants.

The above graphs 3 (a, b, c and d) depict the percentage of absorption of TVOCs and HCHO by the four best absorbing plants [*Chlorophytum comosum*, *Dracaena sanderiana*, *Epipremenum aureum* and *Hemigraphis alternate* (> 90% absorption rate)] at 2nd, 4th and 6thhr respectively. It is evident from the graph that in all four plants, HCHO absorption is initiated at 2hr exposure itself while absorption is evident only after 4hr for TVOCs. The absorption rates for *Chlorophytum comosum* (TVOC-54%, HCHO-33%) and *Epipremenum aureum* (TVOC-87%, HCHO-53%) are higher after 4h exposure while the rates are higher after 6hr in *Dracaena sanderiana* (TVOC-56%, HCHO-31%) and *Hemigraphis alternata* (TVOC-63%, HCHO-38%). This indicates that *Chlorophytum comosum* and *Epipremenum aureum* are capable of remediating air relatively faster. Irrespective of time, maximum rate of absorption is achieved by *Epipremenum aureum*. However, with respect to the quantity of pollutants residing in experimental chamber, *Chlorophytum comosum* was found to retain a lesser quantity and therefore performed better.



Graph 4: Pearson's Correlation coefficient between plant height and leaf area against TVOCs and HCHO at sixth hour of treatment.

Graphs 4 (a, b, c and d) shows pattern of correlation between plant height (APH) and leaf area (TLA) against TVOCs and HCHO at sixth hour of treatment. Pearson correlation coefficient (R) represents the level of correlation between two traits. Here all the R values are equal to or less than 0.2, *i e* there is no correlation between APH and approximate TLA against both TVOCs and HCHO absorption.

Thus it appears that the plant height and total leaf area have no role in regulating the amount of pollutants absorbed. However, further experiments involving replica plants of the same species with different heights and numbers of leaves would give the real picture.

Discussion and Conclusion

The efficacy of selected indoor plants in removing indoor pollutants like TVOCs and HCHO were determined under the experimental conditions. Indoor air pollutants such as TVOCs, HCHO and other particulate or biological matters cause respiratory disorders allergic in children, SBS and other discomforts to man (urban dwellers) as they the majority of their time indoors (Garrett *et al*., 1999; Guo *et al*.,2013) [9, 11]. Efforts have been taken for reducing indoor pollutants both by using technological interventions as well as biological interventions (planting indoor plants).

Although so many indoor plants are reported for their capacity to reduce indoor pollutants like TVOCs and HCHO, the use of indoor plants for indoor air purification would be a convenient way as low cost and energy (Smith and Pitt, 2009; Cornejo *et al.*, 1999) [6]. This study shows that all the selected fifteen plants could minimize the amount of TVOCs and HCHO up to a certain extent when compared to control (without plant). At the sixth hour all the plants showed their maximum absorption of TVOCs and HCHO. Plants that have the efficacy in reducing more than 90% of the two selected indoor pollutants were- *Chlorophytum comosum, Epipremnum aureum, Dracaena sanderiana* and *Hemigraphis alternate. Chlorophytum comosum* and *Dracaena sanderiana* showed a steady increase in their absorption rate during the period of observation while *Epipremnum aureum* and *Hemigraphis alternate*, some showed minor deviations. Among the better absorbers, *Chlorophytum comosum, Epipremnum aureum* were the best, indicating that they could be utilized for enhancing IAQ.

Chlorophytum comosum was found to retain a lesser quantity of pollutants in the closed chamber appears to perform better than the rest. Previous results also clearly justify the ability of *Chlorophytum comosum* in phytoremediation of formaldehyde (Giese *et al.*, 1994; Su and Liang, 2015) [10, 19]

From the Pearson's correlation results involving the plant height and total leaf area in controlling air pollution, it could be noticed that there is very little relation between the two.

In other words, APH and TLA are independent of the rate of the capacity of absorption of pollutants by plants.
Nevertheless the above results strengthen the basic idea of room decontamination with plants as published in the NASA studies (Wolverton *et al*.,1984, 1989).

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