Global J. Environ. Sci. Manage. 6(4): 497-508, Autumn 2020

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH PAPER

Remediation of ozone pollution by ornamental plants in indoor environment

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ARTICLE INFO

Article History:
Received 22 November 2019
Revised 01 April 2020
Accepted 06 May 2020

Keywords:
Indoor air quality
Mitigation
Ornamental plants
Ozone deposition velocity

ABSTRACT

The indoor air quality is much more matter of concern as relative to ambient or outdoor air quality, especially in the context of human health. However, very few studies have been reported for remediation of indoor ozone by plant species. The main objective of this study is to evaluate ozone deposition velocities and ozone removal effectiveness of three indoor ornamental plant species (*Dracaena deremensis*, *Tagetes erecta* and *Lilium candidum*) that can be used in the remediation of indoor ozone. Ozone deposition velocity was estimated through measurement of leaf surface areas of selected plant species and exposing them to 3-regular daytime cycles where ozone concentrations under controlled conditions first increased from 8 h followed by 16 h in the absence of ozone. Values of ozone deposition velocity after the completion of first exposure were found maximum (7.7 m/h) in case of *Dracaena deremensis and* minimum *(*0.5 m/h) after the completion third exposure in *Lilium candidum.* The ozone removal effectiveness found in the range of 0.7 to 13% for leaf surface area to room volume ratio of 0.06/m with reference to an air exchange system and background loss present in an indoor environment. Among the selected plant species, *Dracaena deremensis* has got the highest ozone deposition velocity as well as ozone removal effectiveness and *Lilium candidum* has got the lowest values. Hence, this study concludes with the sustainable use of ornamental plant species in the remediation of the indoor ozone pollution, which can further help in improving the health condition of the residents.

DOI: 10.22034/gjesm.2020.04.06

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
37	6	2

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Note: Discussion period for this manuscript open until January 1, 2021 on GJESM website at the "Show Article.

INTRODUCTION

Indoor air pollution is considered as more harmful for human health than outdoor air pollution (Metts and Batterman, 2006; Teiri *et al.,* 2018). As per UNEP, more than 3 million humans died each year due to poor indoor air quality (Weschler, 2000; Walker *et al.,* 2010). It has also been reported that 16 times more deaths occur globally due to poor indoor air quality as compared to outdoor air pollution (Aydogan *et al.,* 2011; Gall *et al.,* 2011; Sevik *et al.,* 2017). While, analyzing the general lifestyle of people, particularly in urban or suburban areas, approximately 80% to 90% of their time, they spent in indoors and therefore, deleterious impacts can be seen in the cases related to poor indoor air quality (Kunkel *et al.,* 2010). For instance, the cost of bad air quality in indoor environments in Australia was predicted to be $15 billion per year because of declining rates in productivity, huge health care costs and less per capita income (Wang and Morrison, 2010; Irga *et al.,* 2013). Australia's Commonwealth Science Council has also predicted that 10 out of 11 deaths have mostly occurred in developing world due to bad indoor air quality (Poppendieck *et al.,* 2007b). Ozone is a very strong oxidizing agent. It is one of the secondary pollutants and component of photochemical smog, which produces ill effects on human health and property (Klepeis *et al.,* 2001). It is produced by chemical reactions with precursors like NO_x, VOC_s, CO in the presence of sunlight. In the outdoors, ozone plays an important role in the chemistry of the atmosphere. Ozone also has a major role in heterogeneous reactions which often gave rise to the generation of volatile organic products (Matyssek *et al.,* 2012). This type of ozone indicates a combination of photochemical production and annihilation together with injection from the stratosphere (Vingarzan, 2004). Outdoor ozone levels mostly tend to be high in densely populated areas with high traffic density and frequent temperature inversions (Jerrett *et al.,* 2009). From health point of view, ozone is detrimental to human health. Several studies have been reported which have shown a connection between ozone exposure and pulmonary disorders (Felzer *et al.,* 2007; Cape, 2008; Iriti and Faoro, 2008). Others have depicted up to 4% rise in death rate from respiratory disorders that causes per 10 ppb rise in daily 1h maximum ozone (Nicolas *et al.,* 2007). The prominent source of indoor ozone is ambient air. As per national and international regulatory agencies, the outdoor ozone levels should not be exceeding than 70 ppb averaged for an 8h period. 70 ppbv are the new NAAQS ozone standard from 2015 onwards for urban environments (Weschler, 2006). Indoor ozone is generated by photocopiers, air purifiers, corona discharge and exchange of outdoor and indoor ozone by ventilation and infiltration. When indoor ozone reacts with substances or materials like flooring, paints, and metals, may result in the formation of more secondary products which probably be more dangerous than ozone (Bell *et al.,* 2006). On an average, about 5.2mg/h and 1.2mg/h of ozone was generated from photocopier shops and laser printers respectively (Blondeau *et al.,* 2005). According to Cros *et al.* (2012), indoor air contains 10 to 50% of outdoor pollutant concentrations and hence indoor air is almost 7-8 times more harmful than ambient air present in an urban environment. There are usually two ways which can reduce the indoor ozone concentrations. The very simplistic one is to stop the entry of ozone in air, which is present in the building while the second one is to trim down the levels of ozone once present in indoors. Past studies reported that, various indoor materials may consider as "passive" air purifiers (Yang *et al.,* 2009; Sriprapat *et al.,* 2014). For example, Yamamoto *et al.* (2010), evaluated the efficiency of 3 building materials which can efficiently remove indoor ozone and act as passive air purifiers. Abbass *et al.* (2017) has reported a simulation study which explained about the characteristics of passive removal materials and predicted I/O air exchange rates. However, still few are left after removing 50% of ozone. The most economically fit methods for indoor ozone removal is remediation through plant species. Studies on indoor plants confirms their role in removal of ozone (Wood *et al.,* 2006; Kim *et al.,* 2008; Kerschen *et al.,* 2016). For example, Hill (1971) concluded that 16 inches of alfalfa canopy are very much efficient for the removal of 5 ppm of ozone under controlled conditions. Calfapietra *et al.* (2016) showed that some plant species ozone removal capacity has increased from 0.5 to 7.8 nmol/m^2/s when there is a rise in ozone concentrations from 100 to 500 ppb. Very few studies have been reported on ozone removal by indoor plant species, particularly by highlighting their deposition velocities and ozone removal effectiveness (Abbass *et al.,* 2017; Papinchak *et al.,* 2009). Thus, there is

a stringent need to perform more studies on ozone removal so that health risks can be reduced. The present study focuses on analyzing and estimating the ozone deposition velocity and ozone removal effectiveness of selected ornamental plant species in an indoor environment. The main objective of this study is to evaluate ozone deposition velocities and ozone removal effectiveness of three indoor ornamental plant species (*Dracaena deremensis, Tagetes erecta and Lilium candidum*). This study has been carried out in the vicinity of University of Delhi campus area during 2017-2018.

MATERIALS AND METHODS

Materials

Three common indoor plants were selected based on their abundance, tolerance and sensitivity to air pollution (Saxena and Ghosh, 2013). These plants were procured from a field nursery of University of Delhi, Delhi and placed in 5 inch pot. The topmost area of particular leaf of selected plant was measured separately by standard graphical method. Table 1 displays the list of details of each selected plant species with their estimated leaf surface areas. Simultaneously, the loading factor is also calculated by dividing the leaf area of selected plant to the volume of the selected control chamber. The resultant is approximately $2.3 m^2/m^3$.

To test the reaction of ozone with pot or soil surface, selected plant species were transferred in 500 ml glass beaker three days earlier than ozone exposure experiment. The glass beaker was encouraged to use than a plastic pot because glass acts as an unreactive material for ozone (Coleman *et al.,* 2008). Inside a glass beaker, the soil was covered by an aluminium sheet cover. Moreover, to identify the role of soil for ozone uptake, another experiment was performed with only soil exposed in the beaker. The resultant treated soil was reported to have a zero effect on whole in the case of ozone removal.

Experimental design

The experimental design is schematically represented in Fig. 1. This design comprises of 1) an air supply, 2) activated charcoal filter, 3) humidifier, 4) temperature and relative humidity sensors, 5) flow controller, 6) ozone generator, 7) two 58L glass chambers and 8) ozone monitors (2 Nos.). Condensed air was used to remove essential dirt particles. Moisture free air was used in the experiment by using granular drying media. This air was passed through an adsorbent (activated charcoal) to absorb excess VOCs. The indoor temperature and relative humidity were monitored every 5-min duration by controller system fitted with the chambers (Khera Instruments, model KH – 23002, India) in the range of 40 to 75ºC with an accuracy of 0.3ºC and 0 to 100% is the range of relative humidity with 2ºC accuracy which is connected to controller system of data loggers (Khera Instruments, model KH – 10334). A mass flow controller of 0 to 20 LPM with an accuracy of 1.7% (Khera Instruments, model KH 12332) was fixed to balance the flow rate of air. Ozone generator (Model No. KH 2X01) was used for exposing the plant species with different doses of ozone. The ozone rich air supply has two lines of pathways. One is connected to the chamber and the other act as a baseline to depict inlet ozone concentrations. Two ozone monitors (Environment S.A. $O_3$42M) were used to measure ozone concentrations at every 5-min, interval upside and downside part in the chamber (0-70 ppb and accuracy 3%). All fittings including tubing and valves were of PTFE to reduce the reactivity with ozone.

Experimental plan

The experimental chamber consists of ozone-rich air with an exchange rate of 2.5 ± 0.022/h. The recorded temperature was 22 ± 1ºC with the relative humidity of 55 ± 3%. Photosynthetically active radiation (PAR) measured by an Apogee Quantum Meter (Model no. MQ200) in the range of 0-3000

Table 1: Selected plant species analyzed for ozone remediation

S.No.	General Name	Scientific Name	Leaf top surface area (cm^2)
1.	Janet Craig dracaena	*Dracaena deremensis*	1018
2.	Marigold	*Tagetes erecta*	652
3.	Madonna Lily	*Lilium candidum*	1045

µmol/m²/sec and accuracy of ±4% in various indoor environments. Sensors like temperature, relative humidity and PAR were connected to a data logger. The inlet ozone concentration was 65 ppb, which represents high indoor level. The concentrations were in the range of earlier reported field studies (Abbass *et al.,* 2017). Before starting, the chamber was first completely cleaned, dried at moderate temperature and exposed to high ozone-rich air (350 ppb) for 3 h. To remove the circulated ozone air, ozone was measured in an empty chamber and in another chamber, which contained a soil-filled glass beaker covered with aluminium foil. After that, ozone deposition velocity for chamber material and associated ones were examined. Moreover, no significant change has been recorded in ozone deposition values of empty as well as another chamber. As per our experimental plan, every plant species were treated with 8 h of ozone-rich air (65 ppb) followed by 16 h of ozone-free air. The 8-h treated time, was standardized as per NAAQS, CPCB and EPA ozone standards or permissible limit of city-dweller areas and also from earlier experimental exposure plans (Abbass *et al.,* 2017; EPA, 2016; Rim *et al.,* 2016; Kotzias and Pilidis, 2017). This 24 h cycle was repeated two more times to identify any change in the ozone deposition with three repeated cycles of ozone exposure. Thus, every experiment performed for total of three days. Fig. 2 shows the timeline of ozone re-exposure and light tests. For ozone re-exposure study, plants were exposed to elevated ozone concentrations for 8 hours first during daytime and then followed by 16h (evening or night-time) in the absence of ozone and so on. During the night-time, sunlight is not there, so the formation of ozone is not possible (Mills *et al.,* 2018). Therefore, the ozone exposure was performed after 16h i.e. next day (2nd or 3rd day) again exposed the plant species for 8 hours when ozone formation was favourable and in photochemical active state (Fig. 2a). As already mentioned above, 8 hours daytime ozone exposure was selected on the basis of the standard given by the EPA and Central Pollution Control Board (CPCB), India (Mills *et al.,* 2018) for ozone exposure analysis in urban areas. For light tests, two PAR lamps (Model no. MQ-200) were used to provide radiation of 300 µmol/m² to selected plant species placed inside the chamber. The lamps were fitted in the ceiling of the chamber by adjusting their proper distance from plant species to provide sufficient PAR. The power supply was supplied with lamps through a timer switch to maintain consistency in on and off process as displayed in Fig. 2b. In the context of this, different sets of experiments were planned to assess the role of chamber light in ozone removal. Plant samples

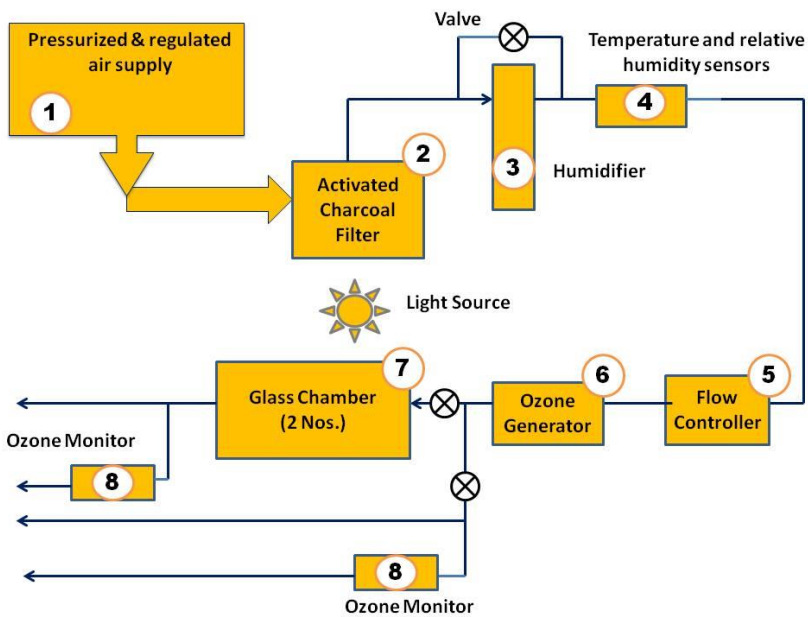

Fig. 1: The study experimental design

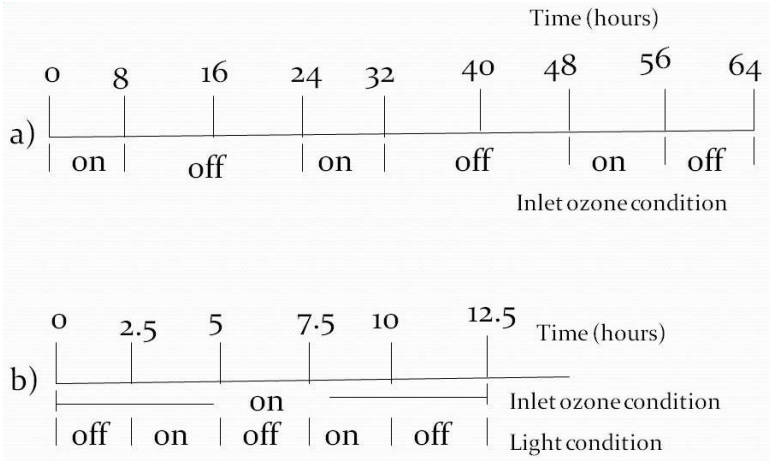

Fig. 2: Timeline of ozone re-exposure and light tests

were treated in the presence of ozone-rich air until it reached up to the endpoint (means altering by not more than 3 ppb in 20 min). After the stability was achieved, a light source was in continuous system to switch on for every 2.5 h and then switched off for 2.5 h to check the variation in ozone concentration due to plant's photosynthetic rate. A control test was also done to show that light has no role in ozone removal in an empty chamber (Fig. 2b).

Data analysis

Ozone deposition velocity

For the assessment of ozone deposition velocity, a master test was performed for empty chamber material till it reached to its endpoint (Coleman *et al.,* 2008). Abbass *et al.* (2017) method was used to test the reduced rate of master chamber surfaces. The ozone balance of test chamber is shown in Eq. 1 and short-period ozone deposition velocity shown in Eq. 2.

$$\frac{dC_{outlet}}{dt} = AER \times C_{inlet} - AER \times C_{outlet} - k_g C_{outlet} \frac{Ag}{V} - k_s C_{outlet} \frac{As}{V} \quad (1)$$

$$k_s^t = \frac{V}{As} \frac{1}{C_{outlet}^t} \left| \begin{array}{c} AER \times (C_{inlet}^t - C_{outlet}^t) \\ - k_g C_{outlet}^t \frac{Ag}{V} - \frac{C_{outlet - C_{outlet}^{t+1}}^t}{\Delta t} \end{array} \right| \quad (2)$$

Where, C_{inlet} and C_{outlet} are the concentrations of inlet and outlet ozone concentrations in the chamber (ppb) respectively. $\frac{dC_{outlet}}{dt}$ symbolizes the variation in the outlet ozone (ppb/h), AER is the air exchange rate (h^{-1}), V is the total volume of chamber subtracted total volume of soil container (m^3). Ag and As are the internal surface and corresponding sample area respectively (m^2), kg and ks are ozone deposition velocities for glass chamber and plant (m/h), respectively. The uncertainty of this experiment was analyzed by proliferation of error assessment of the instruments used: a probability analysis of 3% of observations from ozone monitors, 1.1% of observation of flow controller and 0.32% for the approximate surface area plant samples. The outcome of probability in the case of ozone deposition velocity for the empty chamber was ±0.006m/h.

Plant removal effectiveness

The effectiveness metric, H, was used in this method and is given in Eq. 3 (Abbas *et al.,* 2017):

$$H = 1 - \frac{C^*}{C^{**}} \quad (3)$$

Where C* and C** referred to predicted indoor/ outdoor concentration ratios (-) in reference to the indoor environment in the presence or absence of plant samples respectively.

H indicates the quantitative loss of indoor ozone. H is 1 if total ozone is lost, whereas 0 in case of incomplete ozone removal. The calculated effectiveness using Eq. 4 and for a time-mean conditions, with C* and C** as shown in Eqs. 4 and 5.

$$C^{*} = \frac{C_{indoor,p}}{C_{outdoor}} = \frac{1}{1 + \frac{L_b}{AER} + k_s \frac{A_s}{V \times AER}} \quad (4)$$

$$C^{**} = \frac{C_{indoor}}{C_{outdoor}} = \frac{1}{1 + \frac{L_b}{AER}} \quad (5)$$

Where $C_{indoor,p}$ is the level of ozone in assumed indoor environment in the presence of plants (ppb), $C_{outdoor}$ is the outdoor ozone concentration (ppb), L_b is the loss rate (/h) and C_{indoor} is the level of ozone in the assumed indoor environment in the absence of plants (ppb). Eqs. 4 and 5, consequently facilitate calculation of time-mean indoor/outdoor ratios of ozone, air exchange rate (AER/h), background ozone loss rate (L_b/h) and plant leaf surface area (A_s/m^2) to ozone volume (V/m^3) ratio. The values of ks are procured from calculations of steady-state ozone deposition velocity for plants.

RESULTS AND DISCUSSION

Outlet ozone concentration

The chamber outlet concentrations of various exposure experiments for selected plant species are displayed in Fig. 3 (a-c). Fig. 3a depicts that the outlet ozone level of 1st exposure rises up which is very close to linear and estimated that t=20 min till the end of the experiment. On the contrary, in case of the 2nd and 3rd exposures, the outlet ozone concentration reached up to stability after ~200 min. Moreover, it has been observed that first exposure is decreased to 10ppb as compared to later exposures (2nd and 3rd exposures) where more decrease was noted at the end of the experiment. The same pattern was followed by other tested plants by considering different but relatively lower ozone outlet concentrations (<10 ppb) Fig. 3 (b-c). This phenomenon depicts that the plants were very efficient in removing ozone during

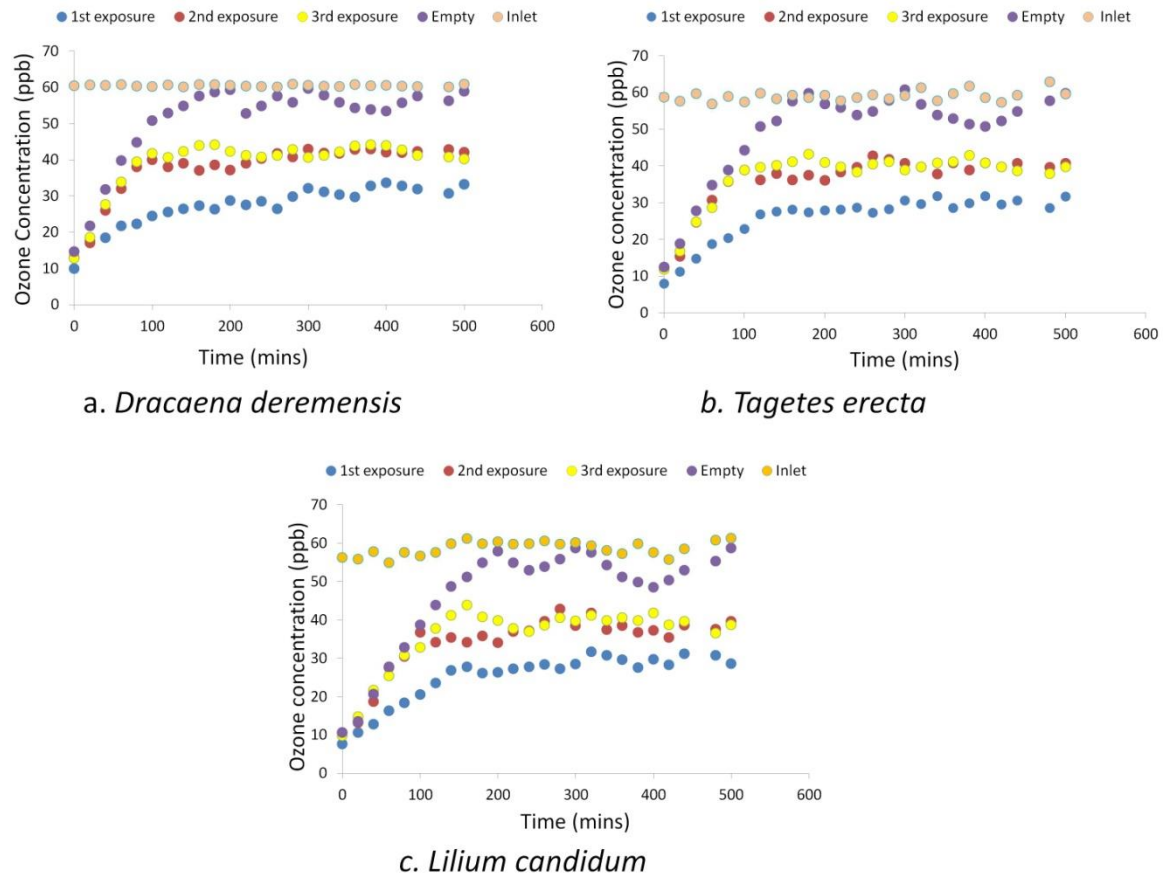

Fig. 3 (a-c): Assessment of chamber outlet concentration of numerous exposure experiments in *Dracaena deremensis*, *Tagetes erecta* and *Lilium candidum*

the first exposure experiment, in comparison to the successive exposure tests. Ozone removal is perhaps observed in a reduced state in the 2nd and 3rd exposure than 1st exposure. This is due to the fact that the leaves of these selected plant species are having high affinity for ozone during first time ozone exposure. This would bring a noticeable change in the physiology of leaf surface that will further lead to a decline in ozone removal rates. The negative change in the physiology of the leaf leads to a significant decline in the metabolism of plant system which weakens the immunity of plant cells and further the level of antioxidants also goes down. These factors are also responsible for the decline in ozone removal activity (Mills *et al.,* 2018). Such type of justification is also in accordance with the findings of Szinvei (2014); Lambers *et al.* (2008) and Kozlowski (1980), where pictures of damaged plant leaves were reported due to high ozone exposure.

Ozone deposition velocity

The background ozone deposition velocity was determined by passing an ozonated air-stream via a sterilized chamber. After stabilizing in and out ozone concentrations and AER from Eq. 1, the background ozone deposition velocity was calculated to be 0.014m/h. This concentration falls in the same range as found by Abbass *et al.* (2017) in case of the sterilized chamber. In Fig. 4(a-c) clearly shows the ozone deposition velocity of all selected three plants. It depicts that the values have been normally high in the first exposure, similar to the findings of Abbass *et al.* (2017) who also conducted experiments related to ozone uptake in case of indoor plants. With respect

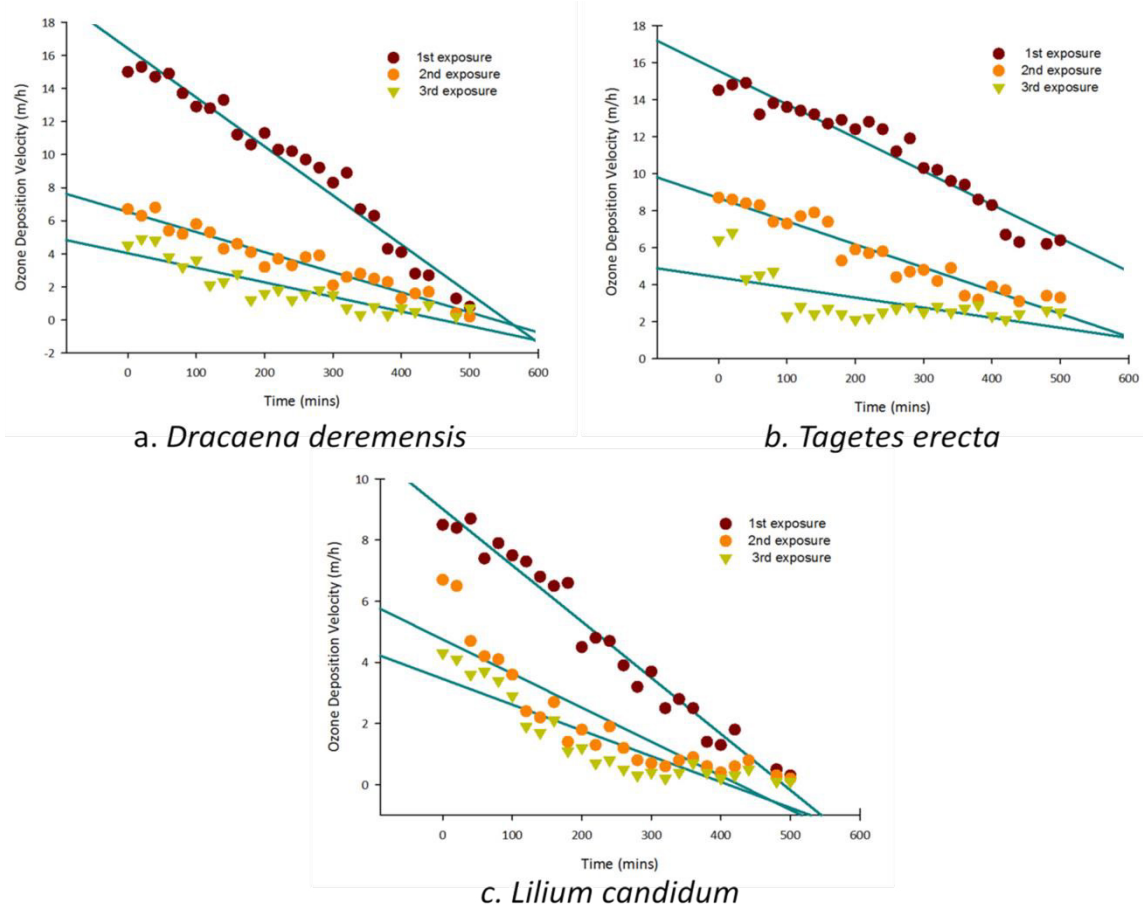

Fig. 4(a-c): Ozone deposition velocity of selected plant species

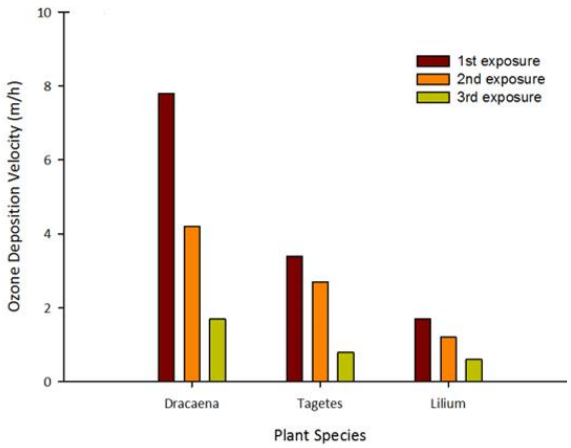

Fig. 5: Average ozone deposition velocity of selected plant species

to 2nd and 3rd exposure tests, the deposition velocity stabilizes itself in almost all cases. At the beginning of the experiment, as soon as the chamber ozone values raised from approximately 3 ppb to constant values and achieved stability. It is possibly due to the start of the experiment, substitution of reactive centres presents on the plant surfaces worked more efficiently for ozone uptake, resulting in the elevated ozone deposition velocity. After a short period of time, the ozone concentration rises up in the chamber till it reaches a steady-state value and consequently, the effectiveness of ozone uptake decreases. In addition to that, the deposition velocity graphs show to be a straight line when it approaches an arbitrary value after about 2.5 h.

These variations in ozone deposition velocity are due to leaf physiology and morphology, which involves leaf composition and structure that differs from plant to plant. Generally, those plants which are tolerant can act as a sink for the uptake of air pollutants like ozone. It has also been reported that *Dracaena deremensis* is tolerant plant species and hence act as a good sink for air pollutants (Saxena and Ghosh, 2013). Such tolerant plants have thick and waxy cuticles which accumulate lipophilic toxicants. These waxy cuticles consist of long-chain hydrocarbons like aldehydes, ketones, alcohols etc. which are having the quality to easily accumulate air pollutants like ozone and benzene (Collins *et al.*, 2000). Due to this quality of their leaf composition, the ozone deposition velocity varies from plant to plant. Thus, *Dracaena deremensis* found more efficient for ozone uptake in all the three exposures as compared to other selected plant species. The approximate constant values of the deposition velocity of selected plant species for all selected exposure tests were obtained by taking the mean of last 25 min after every 8 h test. The average ozone deposition velocity of selected plant species mentioned in Fig. 5. *Dracaena deremensis* has got the highest deposition velocity (7.7m/h) at time of first exposure test while *Lilium candidum* has got the lowest value (0.5m/h) during third exposure (Fig. 5). Previously reported study by Abbass *et al.* (2017) observed maximum (5.6 m/h) ozone deposition velocities in Golden Pothos and minimum (0.9 m/h) v_d for Peace Lily. It has also been observed that ozone deposition velocities were found to highest in a first exposure followed by second and then third exposure. To evaluate the mean concentration of *Dracaena deremensis* with other studies, the equivalent ozone deposition velocity was calculated as suggested by Papinchak *et al.* (2009). Moreover, the calculated v_d decreased by 46% and 29% at the completion of a second exposure for *Dracaena deremensis* and *Lilium candidum* respectively. Moreover, in the case of third exposure v_d decreased by and 78% and 65% for *Dracaena deremensis* and *Lilium candidum* respectively. Whereas, Abbass *et*

Table 2: Description of ozone exposure and ozone removal time

Plant Species	Stages of exposure (1, 2 & 3) (in ppb)	Ozone exposure Time (h)	Ozone removal time range (h)		
			After 1st exposure	After 2nd exposure	After 3rd exposure
Dracaena deremensis	65 in each exposure	8 h for each exposure	3.5-4	5-6	8.5-9.5
Tagetes erecta	65 in each exposure	8 h for each exposure	6-7	8.5-9	12-13.5
Lilium candidum	65 in each exposure	8 h for each exposure	9-10.5	11-12.5	14-15.5

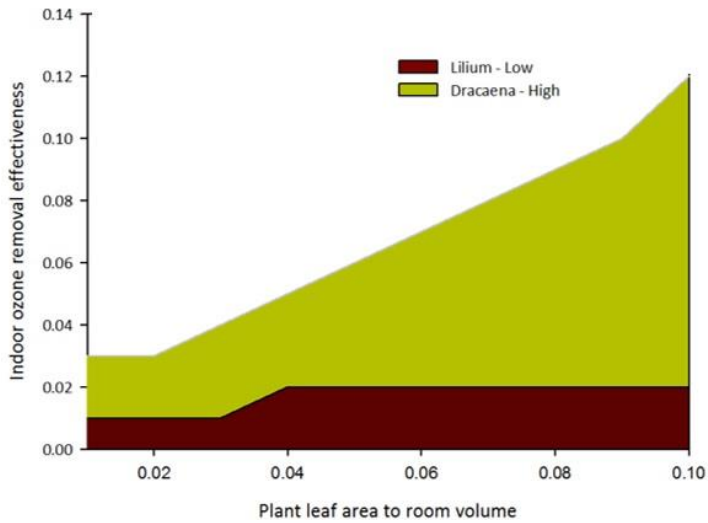

Fig. 6: Calculated values of ozone removal effectiveness of plant species

al. (2017) reported values of v_d were decreased by approximately 50% and 66% at the completion of a second exposure and third exposure, respectively. The selected plant species were also examined in terms of the total ozone removal period after each 8h exposure for three consecutive days with 16h non-exposure duration of ozone (Fig. 2). The description of all exposures, exposure time and ozone removal time range is mentioned in Table 2. In this study, the ozone generator was turned off after each (1st, 2nd and 3rd) 8h exposure. After the completion of each 8h exposure time, the ozone depletion was noted until the 50% reduction in ozone concentration was achieved with respect to each selected plant species within the chamber. The ozone removal time duration was found to be lowest (3.5-4 h) during first exposure in case of *Dracaena deremensis* and highest (14-15.5h) during the third exposure in case of *Lilium candidum*.

Ozone removal effectiveness

It is calculated as per the formula used in the methodology section. The estimated values of effectiveness are shown in Fig.6 starting from leaf area to volume ratio (0.01 to 0.1/m). It is also clearly shown that ozone removal effectiveness will be in the range of 0.1-1% for all selected plants for 0.01/m leaf area to volume ratio and 4-13% for 0.1/m leaf area to volume ratio. Whereas, in another study performed by Abbass *et al.* (2017) ozone removal effectiveness was found in the range of 0.1-2% for all selected plants with leaf area to volume ratio 0.01/m and 2-15% of leaf area to volume ratio 0.1/m. The range reported in our present study (0.01 to 0.1/m) would be achieved by placing 5 to 20 plants (each plant with different leaf area) in 60m^3 room. The data explained in Fig. 6 can also be analyzed based on floor area density, which is mandatory for the evaluation of effectiveness. For instance, attain leaf surface area to volume ratio of 0.06/m, taking the roof height of 2.5m with leaf area of selected plant species as mentioned in the methodology section. This calculated leaf area through this method resulted in ozone removal effectiveness from 0.7 to 13% from low to high values of near constant-state v_d. Whereas, ozone removal effectiveness from 0.9 to 9% from low to high values of near constant-state v_d was observed in Abbass *et al.* (2017). Such plant species can be used for ozone removal as a cost-effective measure in the indoor environment than any other control strategy or management plan or technique.

CONCLUSION

In this study, three different common indoor ornamental plants were chosen and tested to identify their efficiency to eliminate indoor ozone. It was found that mean ozone deposition velocity values are falling in the range of about 0.5 to 7.7 m/h

for selected plant species. *Dracaena deremensis* has got the highest value of 7.7m/h at the time of first exposure test while *Lilium candidum* has got the lowest value of 0.5m/h during third exposure. These values were found relatively higher than previously reported studies at the end of first exposure. Moreover, on average, ozone deposition velocities were found to highest in a first exposure followed by second and then third exposure. In addition to that v_d decreased by 46% and 29% after second exposure for *Dracaena deremensis* and *Lilium candidum* respectively, which is lower as compared to the earlier reported studies. Moreover, in case of third exposure v_d decreased by and 78% and 65% for *Dracaena deremensis* and *Lilium candidum* respectively, which is higher in case of *Dracaena deremensis* and slightly lower in the case of *Lilium candidum* than earlier reported studies. It was also found that ozone removal effectiveness will be in the range of 0.1-1% for all selected plants for 0.01/m leaf area to volume ratio and 4-13% for 0.1/m leaf area to volume ratio. The range values were found to be higher in case of both 0.01/m and 0.1/m leaf area to volume ratio in earlier reported studies. While, in the case of a hypothetical room, the calculated ozone removal effectiveness was reported to be about 0.7 to 13%, which was slightly different from their minima and maxima values in the previously reported studies. Therefore, among all selected plant species, *Dracaena deremensis* has got highest ozone deposition velocity as well as ozone removal effectiveness and *Lilium candidum* has got the lowest values. Moreover, the test was also performed to identify the impact of soil on ozone reduction and found that soil has no role in overall ozone removal from the indoor environment. This study can act as a cost-effective and most sustainable solution to reduce indoor ozone concentrations. However, very little attention has been made in this research area due to its highly challenging nature. In addition to that, more research in the future is much needed to address the cumulative impact of biogenic tree emissions, ozone removal and formation of by-products which may result from ozone exposures and further widens the scope of study in improving the indoor air quality. Such remediation studies are very much helpful for policymakers and other scientific and government organizations to implement plans for the welfare of health and society.

AUTHOR'S CONTRIBUTION

P. Saxena, has the role in conceptualization of idea of manuscript, methodology, design of experiment, data analysis, drafting of the paper and collaborative help from other institutions. S. Sonwani has role in improving quality of graphs, content of paper and improving the English language of the paper.

ACKNOWLEDGEMENT

The authors pay sincere thanks to Jawaharlal Nehru University and University of Delhi R&D Facility for control experimental chambers facility. The authors would also like to thank National Environmental Engineering Research Institute (NEERI) for providing ozone analyzers.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by authors.

ABBREVIATIONS

$	Dollar
%	Percentage
AER	Air exchange rate
A_g	Internal surface of sample area
A_s	Corresponding sample area
*C**	Predicted indoor concentration
*C***	Predicted outdoor concentration
$C_{indoor,p}$	level of ozone in assumed indoor environment in the presence of plants
C_{inlet}	Inlet ozone concentrations
CO	Carbon monoxide
$C_{outdoor}$	Outdoor ozone concentration (ppb)
C_{outlet}	Outlet ozone concentrations
CPCB	Central Pollution Control Board
D	*Dracaena deremensis*
EPA	Environmental protection agency
h	Hour

H	The effectiveness metric
I/O	Indoor/outdoor
k_g	Deposition velocity of glass chamber
k_s	Deposition velocity of plant
L	*Lilium candidum*
L_b	loss rate (/h)
LPM	litre per minute
m/h	metre/hour
m^2/m^3	metre^2/metre^3
mg/h	milligram per hour
$NAAQS$	National ambient air quality standards
$nmol/m^2/s$	nanomol/metre^2/second
NOx	Nitrogen dioxide
PAR	Photosynthetic active radiation
ppb	parts per billion
$PTFE$	polytetrafluoroethylene
T	*Tagetes erecta*
V/m^3	ozone volume ratio
v_d	Ozone deposition velocity
$VOCs$	Volatile organic compounds

REFERENCES

Abbass, O.A.; Sailor, D.J.; Gall, E.T., (2017). Effectiveness of indoor plants for passive removal of indoor ozone. Build. Environ., 119: 62-70 **(9 pages).**

Aydogan, A.; Montoya, L.D., (2011). Formaldehyde removal by common indoor plant species and various growing media. Atmos. Environ. 45:2675–2682 **(8 pages).**

Bell, M.L.; Peng, R.D.; Dominici, F., (2006). The exposure–response curve for ozone and risk of mortality and the adequacy of current ozone regulations. Environ. Health Perspect., 114(4): 532-536 **(5 pages).**

Blondeau, P.; Iordache, V.; Poupard, O.; Genin, D.; Allard F., (2005). Relationship between outdoor and indoor air quality in eight French schools, Indoor Air. 15: 2-12 **(11 pages).**

Cape, J. N., (2008). Surface ozone concentrations and ecosystem health: past trends and a guide to future projections. Sci. Total Environ., 400(1-3): 257-269 **(13 pages).**

Coleman, B.K.; Destaillats, H.; Hodgson, A.T.; Nazaroff, W.W., (2008). Ozone consumption and volatile byproduct formation from surface reactions with aircraft cabin materials and clothing fabrics. Atmos. Environ., 42(4): 642-654 **(13 pages).**

Collins, C.D.; Bell, J.N.B.; Crews, C., (2000). Benzene accumulation in horticultural crops. Chemosphere, 40(1): 109-114 **(6 pages).**

Cros, C.J.; Morrison, G.C.; Siegel, J.A.; Corsi, R.L., (2012). Long-term performance of passive materials for removal of ozone from indoor air. Indoor Air. 22(1): 43-53 **(11 pages).**

Felzer, B.S.; Cronin, T.; Reilly, J.M.; Melillo, J.M.; Wang, X., (2007). Impacts of ozone on trees and crops. CR Geosci., 339(11-12): 784-798 **(15 pages).**

Gall, E.T.; Corsi, R.L.; Siegel, J.A., (2011). Barriers and opportunities for passive removal of indoor ozone. Atmos. Environ., 45(19): 3338-3341 **(4 pages).**

Irga, P.J.; Torpy, F.R.; Burchett, M.D., (2013). Can hydroculture be used to enhance the performance of indoor plants for the removal of air pollutants? Atmos. Environ., 77:267–271 **(5 pages).**

Iriti, M.; Faoro, F., (2008). Oxidative stress, the paradigm of ozone toxicity in plants and animals. Water, Air, Soil Pollut., 187(1-4): 285-301 **(17 pages).**

Jerrett, M.; Burnett, R.T.; Pope III, C.A.; Ito, K.; Thurston, G.; Krewski, D.; Thun, M., (2009). Long-term ozone exposure and mortality. N. Engl. J. Med., 360(11): 1085-1095 **(11 pages).**

Kerschen, E.W.; Garten, C.; Williams, K.A.; Derby, M.M., (2016). Evapotranspiration from spider and jade plants can improve relative humidity in an interior environment. Horttechnology. 26(6): 803–810 **(8 pages).**

Kim, K.J.; Kil, M.J.; Song, J.S.; Yoo, E.H.; Son, K-C.; Kays, S.J., (2008). Efficiency of volatile formaldehyde removal by indoor plants: contribution of aerial plant parts versus the root-zone. J. Am. Soc. Hortic. Sci., 133(4): 521–526 **(6 pages).**

Klepeis, N.E.; Nelson, W.C.; Ott, W.R.; Robinson, J.P.; Tsang, A.M.; Switzer, P.; Engelmann, W.H., (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. J. Expo. Sci. Environ. Epid., 11(3): 231-252 **(22 pages).**

Kotzias, D.; Pilidis, G., (2017). Building design and indoor air quality -experience and prospects. Fresenius Environ. Bull., 26(1):323–326 **(4 pages).**

Kozlowski, T.T., (1980). Responses of shade trees to pollution. Arboric. J., 6(2): 29-41 **(13 pages).**

Kunkel, D.A.; Gall, E.T.; Siegel, J.A.; Novoselac, A.; Morrison, G.C.; Corsi, R.L., (2010). Passive reduction of human exposure to indoor ozone. Build. Environ., 45(2): 445-452 **(8 pages).**

Lambers, H.; Chapin, F.S.; Pons, T.L., (2008). Ecological biochemistry: allelopathy and defense against herbivores. In Plant physiological ecology, Springer, New York. 445-477 **(33 pages).**

Matyssek, R.; Wieser, G.; Calfapietra, C.; De Vries, W.; Dizengremel, P.; Ernst, D.; Tuovinen, J.P., (2012). Forests under climate change and air pollution: gaps in understanding and future directions for research. Environ. Pollut., 160: 57-65 **(9 pages).**

Metts, T.A.; Batterman, S.A., (2006). Effect of VOC loading on the ozone removal efficiency of activated carbon filters. Chemosphere. 62(1): 34-44 **(11 pages).**

Mills, G.; Pleijel, H.; Malley, C.S.; Sinha, B.; Cooper, O.R.; Schultz, M.G.; Neufeld, H.S.; Simpson, D.; Sharps, K.; Feng, Z.; Gerosa, G.; Harmens, H.; Kobayashi, K.; Saxena, P.; Paoletti, E.; Sinha, V.; Xu, X., (2018). Tropospheric Ozone Assessment Report: Present-day tropospheric ozone distribution and trends relevant to vegetation. Elementa-Sci Anthrop.,6: 40-47 **(8 pages).**

Nicolas, M.; Ramalho, O.; Maupetit, F., (2007). Reactions between ozone and building products: impact on primary and secondary emissions. Atmos. Environ., 41(15): 3129-3138 **(10 pages).**

Papinchak, H.L.; Holcomb, E.J.; Best, T.O.; Decoteau, D.R., (2009). Effectiveness of houseplants in reducing the indoor air pollutant ozone. Horttechnology, 19(2): 286-290 **(5 pages).**

Saxena, P.; Ghosh C., (2013). Ornamental plants as sinks and

bioindicators. Environ. Technol., 34(23): 3059-3067 **(9 pages).**
Sevik, H.; Cetin, M.; Guney, K.; Belkayali, N., (2017). The influence of house plants on indoor CO_2. Pol. J. Environ. Stud., 26(4):1643–1651 **(9 pages).**
Sriprapat, W.; Boraphech, P.; Thiravetyan, P., (2014). Factors affecting xylenecontaminated
air removal by the ornamental plant *Zamioculcas zamiifolia*. Environ. Sci. Pollut. Res., 21(4): 2603–2610 **(8 pages).**
Szinyei, D. (2014). Modelling and Evaluation of Ozone Dry Deposition. Doctoral dissertation, Freie Universität Berlin.
Teiri, H.; Pourzamani, H.; Hajizadeh, Y., (2018). Phytoremediation of VOCs from indoor air by ornamental potted plants: a pilot study using a palm species under the controlled environment. Chemosphere. 197:375–381 **(7 pages).**
Vingarzan, R., (2004). A review of surface ozone background levels and trends. Atmos. Environ., 38(21): 3431-3442 **(12 pages).**
Walker, I.S.; Sherman, M.H.; Nazaroff, W.W., (2009). Ozone reductions using residential building envelopes. LBNL report.
Wang, H.; Morrison, G., (2010). Ozone-surface reactions in five homes: surface reaction probabilities, aldehyde yields, and trends. Indoor Air. 20(3): 224-234 **(11 pages).**
Weschler, C.J., (2000). Ozone in indoor environments: concentration and chemistry. Indoor air. 10(4): 269-288 **(20 pages).**
Weschler, C.J., (2006). Ozone's impact on public health: contributions from indoor exposures to ozone and products of ozone-initiated chemistry. Environ. Health Perspect., 114(10): 1489-1496 **(8 pages).**
Weschler, C.J., (2006). Ozone's impact on public health: contributions from indoor exposures to ozone and products of ozone-initiated chemistry. Environ. Health Perspect., 114(10): 1489-1496 **(8 pages).**
Wood, R.A.; Burchett, M.D.; Alquezar, R.; Orwell, R.L.; Tarran, J.; Torpy, F., (2006). The potted-plant microcosm substantially reduces indoor air VOC pollution. I. Office field-study. Water Soil Air Pollut., 175: 163–180 **(18 pages).**
Yang, D.S.; Pennisi, S.V.; Son, H-C.; Kays, S.J., (2009). Screening indoor plants for volatile organic pollutant removal efficiency. HortScience 44(5): 1377–1381 **(5 pages).**

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HOW TO CITE THIS ARTICLE

Saxena, P.; Sonwani, S., (2020). Remediation of ozone pollution by ornamental plants in indoor environment. Global J. Environ. Sci. Manage., 6(4): 497-508.

DOI: 10.22034/gjesm.2020.04.06

url: https://www.gjesm.net/article_39692.html