Remediation of ozone pollution by ornamental plants in indoor environment

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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 of 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.

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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, VOC, 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; Sripriapat 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 confirm 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/m²/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 2.3m$^2$/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>
<thead>
<tr>
<th>S.No.</th>
<th>General Name</th>
<th>Scientific Name</th>
<th>Leaf top surface area (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Janet Craig dracaena</td>
<td><em>Dracaena deremensis</em></td>
<td>1018</td>
</tr>
<tr>
<td>2.</td>
<td>Marigold</td>
<td><em>Tagetes erecta</em></td>
<td>652</td>
</tr>
<tr>
<td>3.</td>
<td>Madonna Lily</td>
<td><em>Lilium candidum</em></td>
<td>1045</td>
</tr>
</tbody>
</table>
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 16 h (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 16 h 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
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.

\[
\frac{dC_{\text{outlet}}}{dt} = AER \times C_{\text{inlet}} - AER
\]

\[
\times C_{\text{outlet}} - k_g C_{\text{outlet}} \frac{Ag}{V} - k_s C_{\text{outlet}} \frac{As}{V}
\]

\[
k^*_s = V \frac{1}{As} \left| AER \times \left( \frac{c^t_{\text{inlet}} - c^t_{\text{outlet}}}{c^t_{\text{outlet}}} \right) - k_g c^t_{\text{outlet}} \frac{Ag}{V} - \frac{c^t_{\text{outlet}} - c^{t+1}_{\text{outlet}}}{\Delta t} \right|
\]

Where, \( C_{\text{inlet}} \) and \( C_{\text{outlet}} \) are the concentrations of inlet and outlet ozone concentrations in the chamber (ppb) respectively. \( \frac{dC_{\text{outlet}}}{dt} \) 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):

\[
H = 1 - \frac{C^*}{C^{**}}
\]

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.
\[ C^* = \frac{C_{\text{indoor,p}}}{C_{\text{outdoor}}} = \frac{1}{1 + \frac{L_b}{A_{\text{ER}}} + k_s \frac{A}{V \times A_{\text{ER}}}} \]  

(4)

\[ C^* = \frac{C_{\text{indoor}}}{C_{\text{outdoor}}} = \frac{1}{1 + \frac{L_b}{A_{\text{ER}}}} \]  

(5)

Where \( C_{\text{indoor,p}} \) is the level of ozone in assumed indoor environment in the presence of plants (ppb), \( C_{\text{outdoor}} \) is the outdoor ozone concentration (ppb), \( L_b \) is the loss rate (/h) and \( C_{\text{indoor}} \) 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 \( k_s \) 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 1\(^{st}\) 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 2\(^{nd}\) and 3\(^{rd}\) 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 (2\(^{nd}\) and 3\(^{rd}\) 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 0.014 m/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

![Ozone deposition velocity graphs](image)

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

a. *Dracaena deremensis*  
b. *Tagetes erecta*  
c. *Lilium candidum*
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 (7.7 m/h) at time of first exposure test while Lilium candidum has got the lowest value (0.5 m/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) 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>
<thead>
<tr>
<th>Plant Species</th>
<th>Stages of exposure (1, 2 &amp; 3) (in ppb)</th>
<th>Ozone exposure Time (h)</th>
<th>Ozone removal time range (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dracaena deremensis</td>
<td>65 in each exposure</td>
<td>8 h for each exposure</td>
<td>After 1st exposure: 3.5-4, After 2nd exposure: 5-6, After 3rd exposure: 8.5-9.5</td>
</tr>
<tr>
<td>Tagetes erecta</td>
<td>65 in each exposure</td>
<td>8 h for each exposure</td>
<td>After 1st exposure: 6-7, After 2nd exposure: 8.5-9, After 3rd exposure: 12-13.5</td>
</tr>
<tr>
<td>Lilium candidum</td>
<td>65 in each exposure</td>
<td>8 h for each exposure</td>
<td>After 1st exposure: 9-10.5, After 2nd exposure: 11-12.5, After 3rd exposure: 14-15.5</td>
</tr>
</tbody>
</table>
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 60m³ 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 7.7 m/h at the time of first exposure test while *Lilium candidum* has got the lowest value of 0.5 m/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 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**

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**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**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>$</td>
<td>Dollar</td>
</tr>
<tr>
<td>%</td>
<td>Percentage</td>
</tr>
<tr>
<td>AER</td>
<td>Air exchange rate</td>
</tr>
<tr>
<td>( A_g )</td>
<td>Internal surface of sample area</td>
</tr>
<tr>
<td>( A_s )</td>
<td>Corresponding sample area</td>
</tr>
<tr>
<td>( C^* )</td>
<td>Predicted indoor concentration</td>
</tr>
<tr>
<td>( C^{**} )</td>
<td>Predicted outdoor concentration</td>
</tr>
<tr>
<td>( C_{indoor,p} )</td>
<td>Level of ozone in assumed indoor environment in the presence of plants</td>
</tr>
<tr>
<td>( C_{inlet} )</td>
<td>Inlet ozone concentrations</td>
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<td>( CO )</td>
<td>Carbon monoxide</td>
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<td>( C_{outdoor} )</td>
<td>Outdoor ozone concentration (ppb)</td>
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<td>( C_{outlet} )</td>
<td>Outlet ozone concentrations</td>
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<td>CPCB</td>
<td>Central Pollution Control Board</td>
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<td>( D )</td>
<td><em>Dracaena deremensis</em></td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental protection agency</td>
</tr>
<tr>
<td>( h )</td>
<td>Hour</td>
</tr>
</tbody>
</table>
\[ H \] The effectiveness metric
\[ I/O \] Indoor/outdoor
\[ k_d \] Deposition velocity of glass chamber
\[ k_s \] Deposition velocity of plant
\[ L \] \textit{Lilium candidum}
\[ L_d \] 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
\[ T \] \textit{Tagetes erecta}\n\[ V/m^3 \] ozone volume ratio
\[ \nu_d \] Ozone deposition velocity
\[ VOCs \] Volatile organic compounds

**REFERENCES**


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