RESEARCH ARTICLE

Phytoremediation of Indoor Air using *Spathiphyllum wallisii* Regel, for Formaldehyde as an Indoor Pollutant

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Abstract

Formaldehyde removal capacity of *Spathiphyllum wallisii* Regel was assessed to know the indoor air quality. The gaseous formaldehyde of about 5 ppm was released into the static chamber of volume 1 m^3. Test plant used was *Spathiphyllum wallisii*, a house plant surviving in low light. The indoor plant was chosen based on its growth in the medium. Medium was inoculated with *Sphingomonas* consortium, which helps the process of phytoremediation. Activated charcoal was also added in the medium, to increase the absorptive surface. The exposure given was for 24 hours. Experiment was replicated for five times. Air quality in the chamber was monitored on advanced formaldehyde detector, at the start of the experiment and after 24 hours. Leaves of the plants were analysed by DNPH using LCMS method for quantification of formaldehyde. Quantification of formaldehyde from leaves ranged between 0.09-1.006 ppm. Formaldehyde detector showed reduction in formaldehyde quantity from 4.998 to 0 ppm in 24 hours. This clearly indicates that *Spathiphyllum wallisii* can be used as a phytoremediator for indoor air quality, especially for formaldehyde absorption.

Keywords: Indoor pollution, Formaldehyde, *Spathiphyllum wallisii*, LCMS analysis.

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Introduction

People spend a considerable long time inside closed spaces. Their health is affected due to Volatile Organic Compounds (VOCs) present in indoor environments. Many VOCs in indoor air have high concentrations than outside air (Russel *et al*., 2014). There are many air cleaning products available in the market which remove chemical and biological indoor pollutants. These products have limitations in use (Mansour *et al*., 2015).

Formaldehyde (HCHO) is a common indoor air pollutant which is released through many household sources. It is a gas in its natural state. Formaldehyde levels ranges from 0.10 to 3.68 parts per million (ppm) in homes. Higher levels have been found in new manufactured or mobile homes than in older conventional homes. The permissible exposure limit (PEL) for formaldehyde in the workplace is 0.75 parts formaldehyde per million parts of air (0.75 ppm) measured as an 8-hour time-weighted average (https://www.ncbi.nim.nih.gov).

Formaldehyde is of great concern in today's world due to its carcinogenic effects on human being. It is released through many building products, many wood-based structures (Teiri, 2018), perfumes, room spray, smoke from mosquito coils and incense sticks (Ghate, 2016). Formaldehyde is an important base chemical in the process industry with a world production rate of approximately 10 million metric tons annually (Winkelman, 2003). Formaldehyde can cause sensory irritation and nasopharyngeal cancer. It has a 30-min average concentration guideline value of 0.1 mg/m^3 (WHO, 2010).

Indoor volatile organic compounds (VOCs) such as formaldehyde can result in "multiple chemical sensitivity" and "sick building syndrome" (Shinohara *et al*., 2004) and several other physical symptoms for those exposed (*e.g*., allergies, asthma, headaches) (Kostiaineh, 1995; Jones, 1999). The World Health Organization estimates that undesirable indoor volatiles represent a serious health problem that is responsible for more than 1.6 million deaths per year and 2.7% of the global burden of disease (WHO, 2002). 18 out of 59 VOCs the indoor concentrations were higher than at least one guideline value (Logue *et al*., 2011). The level and composition of VOCs that a person is exposed to daily varies according to personal activities and indoor sources (Edwards *et al*., 2001).

The level of VOCs in indoor air can be reduced by using low-emission products and dispersing and diluting the emitted VOCs by means of ventilation (WHO, 2010). If further reduction of the pollution is needed, techniques such as filtration and adsorption to e.g. activated charcoal or silica gel exist (Yu *et al*., 2009). An alternative way to reduce the level of VOCs in indoor air is the use of plants. Several ornamental potted plant species have the ability to absorb VOCs from indoor air (Yang *et al*., 2009). The plants act as 'sinks' and consequently reduce the VOC concentration in the air. Plants also prove to be useful in providing psychological and social benefits for humans (Bringslimark *et al*., 2009; Thomsen *et al*., 2011).

Plants are known to absorb gaseous formaldehyde and can metabolize it. The pollutant enters plant leaves through stomata and cuticles. It is also absorbed by the abaxial surface of leaves and even younger leaves. Once absorbed by the leaves, it generally enters the Calvin cycle after a two-step

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enzymatic oxidation to CO_2 (Kwang *et al*., 2010). Approximately 60% to 90% of 14C-Formaldehyde was recovered from the plants (Giese *et al*., 1994). Microorganisms found in the potting mixture of indoor plants are also involved in the removal of VOCs. Plants excrete significant amounts of carbon into the root zone that stimulates the development of microorganisms in the rhizosphere. Consequently, phytoremediation of indoor air is seen as a potentially viable means of removing volatile pollutants in homes and offices (Wolverton *et al*., 1989).

It is established that formaldehyde is an important air pollutant and therefore, *Spathiphyllum wallisii*, a known absorbent indoor plant, surviving in low light conditions, was chosen and its formaldehyde removal capacity from indoor spaces was determined.

Materials and Methods

Spathiphyllum wallisii is a commonly cultivated, flowering house plant species chosen for experiments (Fig. 1).

These plants are native to humid, shady tropical habitat and they were chosen due to their easy growth in all types of media tested in the laboratory. Also, these plants require less maintenance and are fast growing. They were chosen to test their ability to absorb formaldehyde, a common indoor pollutant.

Experimental plants were purchased from local vendors. They were repotted in 10 cm diameter pot with 2 kg of potting mixture. Composition of the potting mixture was kept standard for growing all test plants. The standard composition used was vermicompost (1.5 kg) + enricher (½ kg) + 1 gm activated charcoal + 2 ml *Sphingomonas* consortium. Activated charcoal was added for large absorption surface and consortium of *Sphingomonas* was added for fast activity to absorb and break poisonous pollutants. All horticultural practices were taken care of. The factors such as local growing conditions and growth patterns were studied. Acclimatization of experimental plants within the indoor environment was done with temp 22±2°C, 35±5% relative humidity. The light conditions were adjusted to the survival of selected plant. A glass chamber, of 1 m^3 meter was used for the exposure experiments (Fig. 2).

Dimensions of glass chamber for control were 1 m^3. All research experiments were carried out at the Research Lab, Know How Foundation, Bavdhan, Pune, MS, India.

Fig. 1: Figure showing *Spathiphyllum wallisii* plant

Exposure to Formaldehyde

The concentration in the glass chamber was noted on Advance Formaldehyde Detector (Make - Smiledrive) and accordingly adjusted to 5 ml/ lit with the help of pouring formalin on potassium permanganate. Little variation in initial concentration was observed which varied between 0.3 to 0.4 ml/lit.

A battery-operated fan was placed in the chamber for continuous air circulation. Thermo-hygrometer was kept in the chamber for monitoring temperature and humidity. Reading for light intensity was taken on photometer. Test plants with all standards were kept in the treatment chamber. Air monitoring in the chamber was done on advanced air detector (Make:Smiledrive). Plants for control were placed in the control chamber. The air filled with gaseous pollutants was monitored after insertion of formaldehyde dose and after 24 hours. Five sets of plants were exposed for testing. Data expressed in the terms of average of five replicates.

The plant was removed from the chamber after exposure and the leaves were studied for any visible injury symptom. For each exposed plant the following parameters were considered: 1) Visible injury 2) PII 3) LCMS analysis by D.N.P.H. method. A Pollution Indication Index (PII) was then calculated by the formula:

Pollution Indication Index (PII) = [Number of leaves exposed (E))/(Number of leaves affected (A)] × (100)

Fig. 2: Treatment chamber with fans and formaldehyde detector

After each treatment, leaves of treated plants were collected for analysis. All samples were analyzed by DNPH method on Xevo TQD Waters triplequad LCMS at MAARC Labs Pvt. Ltd., Nanded Phata, Sinhagad Road, Pune 411041.

The method for Formaldehyde analysis by DNPH by LCMS is as follows:

A. Reagent A preparation

Take 1000 mg of 2,4 DNPH on watchglass and add 1 mL of 4 M HCL. Keep it on waterbath and evaporate to dryness. Weigh 0.7 g of dried 2,4 DNPH in 10 mL of volumetric flask. Make up to the mark with 10 mL orthophosphoric acid. Take 3.5 g of above solution and make up to 50 mL with acetonitrile. This is reagent A.

B. Standard preparation

Take 50 mg of 40% Formaldehyde solution in 50 mL volumetric flask. Make up with acetonitrile. Take 1 mL of this solution in 100 mL volumetric flask. Add 3 mL of reagent A and make up with acetonitrile (Reagent B). Let it stand for 1.5 hours and RT.

C. Sample preparation

Take 2 g of sample in 50 mL centrifuge tube. Add 20 mL acetonitrile and 5 mL reagent A and vortex. Add 25 mL acetonitrile and vortex. Let it stand for 1.5 hours. Filter and inject to LC/MS/MS.

Mobile Phase A: Acetonitrile
Mobile Phase B: 0.1 % formic acid and 5 mM Ammonium formate in water.

Results and Discussion

After exposure, all plants were monitored for visible injury. At the end of 10 days, no visible injury was observed in all replicates of the plants as compared to control. Treated plants did not show change in leaf color even after ten days. PII calculated after the treatment was 0.

Spathiphyllum wallisii showed average formaldehyde removal capacity ranging from 0.09-1.006 ppm for m^{-3} area, by DNPH on LCMS over 24 hours. These values are taken on the basis of result of five plants tested (Table 1, Fig. 3).

Formaldehyde quantification results as chromatogram of LCMS are represented in Figs. 4-9. Values in the table are represented in ppb.

Results of Formaldehyde Detector

When formaldehyde levels were monitored before and after insertion of *Spathiphyllum wallisii*, it was observed that the initial highest level of HCHO on formaldehyde detector was 4.998 ppm reduced to 0 ppm after 24 hours, after insertion of experimental plant. Formaldehyde levels on formaldehyde detector reduced in all treatments (Table 2, Fig. 10).

Ability of *Spathiphyllum* plants to remove formaldehyde may be enhanced due to the activity of *Sphingomonas* bacteria added in the mixture. The ability of gram-negative bacteria is well demonstrated by Evans *et al.* (1965). They have shown oxidative metabolism of Phenanthrene by soil pseudomonas

Table 1: Quantification of formaldehyde by DNPH on LCMS

Treatment	*HCHO in ppm*
1	01.0066
2	0.8009
3	0.0901
4	0.2164
5	0.4578

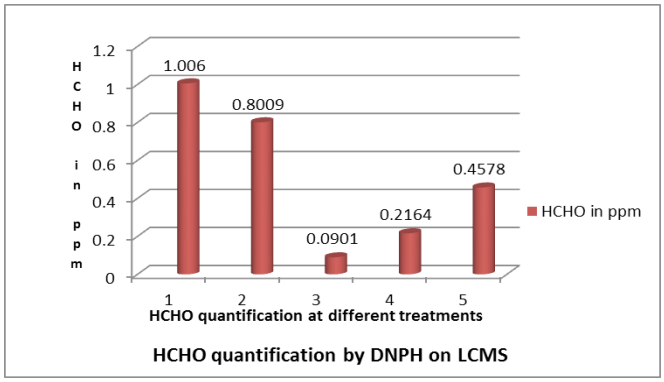

Fig. 3: Quantification of formaldehyde by DNPH on LCMS

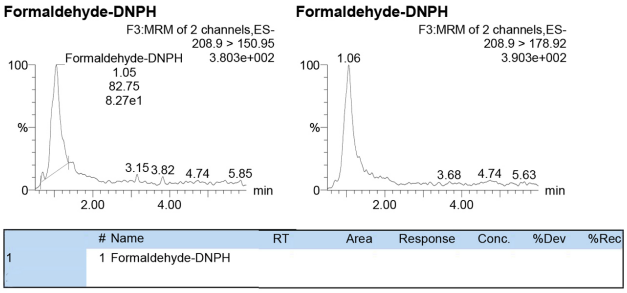

Fig. 4: Chromatogram for control

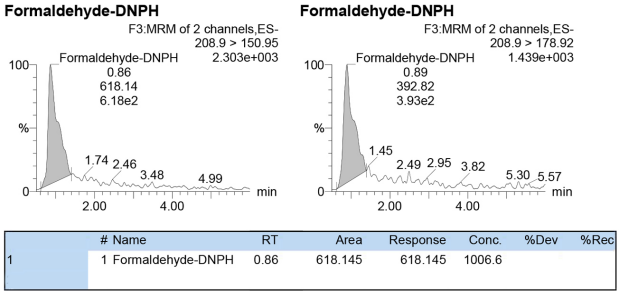

Fig. 5: Chromatogram for first treatment showing formaldehyde concentration on LCMS

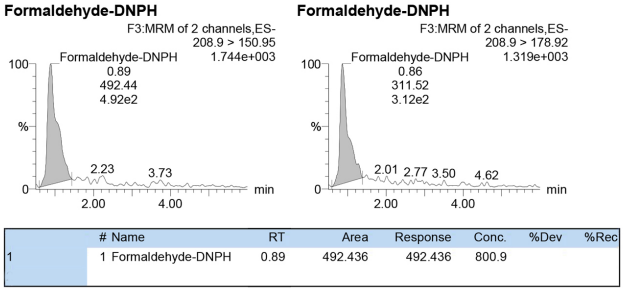

Fig. 6: Chromatogram for second treatment showing formaldehyde concentration on LCMS

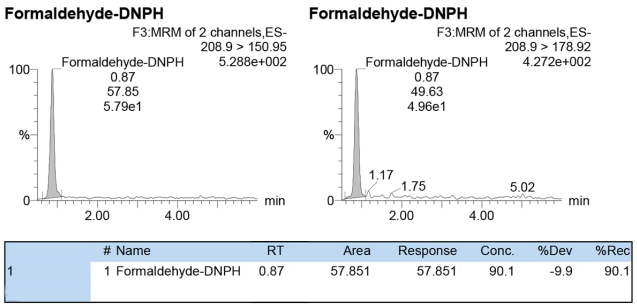

Fig. 7: Chromatogram for third treatment showing formaldehyde concentration on LCMS

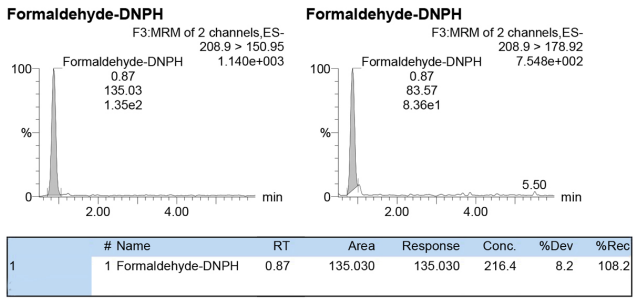

Fig. 8: Chromatogram for fourth treatment showing formaldehyde concentration on LCMS

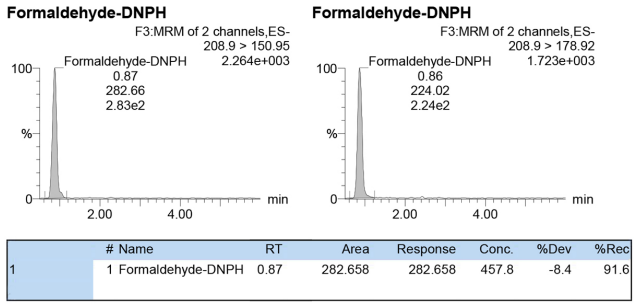

Fig. 9: Chromatogram for fifth treatment showing formaldehyde concentration on LCMS

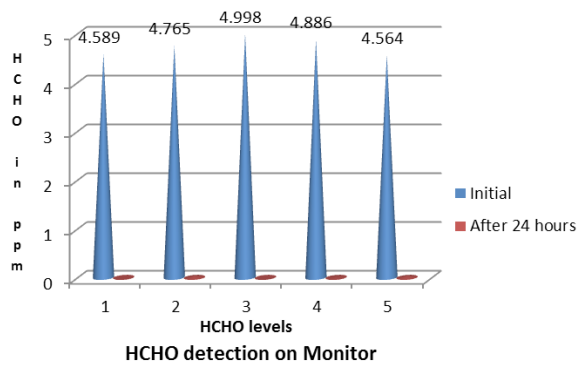

Fig. 10: Formaldehyde quantification on HCHO detector

through trans-3,4-dihydro-3,4-dihydroxyphenanthrene to 3,4-dihydroxyphenanthrene, which then undergoes cleavage. It is already demonstrated that bacteria in the growing medium have a positive effect on removing chemicals from sealed chamber (Wolverton and Wolverton, 1993). Tarran *et al*. (2007), have studied use of living pot-plants to cleanse indoor air. In

Table 2: Formaldehyde quantification on HCHO detector

Initial level of HCHO	*Level of HCHO after 24 hours*
4.589	0.002
4.765	0.034
4.998	0
4.886	0.015
4.564	0.034

laboratory studies, with nine 'indoor plant' species, and 'field' studies in 60 offices, they have shown that potted-plants can reliably reduce total volatile organic compound (TVOC) loads, a major class of indoor pollutants, by 75%, to below 100 ppb.

Eighty six species of plants were assessed for the efficiency of volatile formaldehyde removal. Specifically, the phytoremediation potential was assessed by exposing the plants to gaseous formaldehyde in airtight chambers and measuring the rate of removal of formaldehyde as per time and area of chamber. *Osmunda japonica, Selaginella tamariscina, Davallia mariesii, Polypodium formosanum, Psidium guajava, Lavandula* spp., *Pteris dispar, Pteris multifida*, and *Pelargonium* spp. were the most effective species tested. Ferns had the highest Formaldehyde removal efficiency (Kwang *et al*., 2010). *N. obliterata* plant considerably removed formaldehyde vapors from the polluted air during continues long time fumigation (Teiri *et al*., 2018). Xu *et al*. (2011) reported formaldehyde removal efficiencies of about 95% for spider plant-soil system, 53% for *Aloe vera*-soil system, and 84% for golden pothos-soil system with an inlet concentration range of 1-11 mg/m^3.

In similar chamber study experiments, we observed that *Spathiphyllum wallisii* could absorb formaldehyde in the range of 0.09-1.006 ppm. This activity was enhanced by addition of *Sphingomonas* consortium and activated charcoal in the medium. Formaldehyde detector showed reduction in formaldehyde quantity from 4.998 to 0 ppm in 24 hours. It also indicates that *Spathiphyllum wallisii* is a good absorber of formaldehyde.

Conclusions

Formaldeyde is a common indoor pollutant released through many household sources. This experiment was carried out to find the formaldehyde absorption capacity of *Spathiphyllum wallisii*, a common flowering house plant. Plant showed excellent absorption capacity on DNPH by LCMS indicated by the range of absorption from 0.09-1.006 ppm. This is much higher than the permissible limits of formaldehyde. The mechanisms of how formaldehyde (HCHO) is removed by potted plant were related to the plant species, the soil and the microorganisms in the soil, the growing media of the plant, light intensity, temperature and HCHO concentration in indoor air. Considering the Permissible Exposure level (PEL) of formaldehyde for indoor spaces and chamber volume of 1 m^3, we can easily calculate number of plants required based on their formaldehyde removal capacity.

To know the full capacity of absorption by *Spathiphyllum* in real-life settings, investigations on site experiments were initiated in this research work. Our laboratory results show that *Spathiphyllum* has a potential to alter indoor air in turn it will affect the health and well-being of the inhabitants.

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