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Uptake of toluene and ethylbenzene by plants: Removal of volatile indoor air contaminants

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ABSTRACT

Air borne uptake of toluene and ethylbenzene by twelve plant species was examined. Of the twelve plant species examined, the highest toluene removal was found in *Sansevieria trifasciata*, while the ethylbenzene removal from air was with *Chlorophytum comosum*. Toluene and ethylbenzene can penetrate the plant's cuticle. However, the removal rates do not appear to be correlated with numbers of stomata per plant. It was found that wax of *S. trifasciata* and *Sansevieria hyacinthoides* had greater absorption of toluene and ethylbenzene, and it contained high hexadecanoic acid. Hexadecanoic acid might be involved in toluene and ethylbenzene adsorption by cuticles wax of plants. Chlorophyll fluorescence analysis or the potential quantum yield of PSII (Fv/Fm) in toluene exposed plants showed no significant differences between the control and the treated plants, whereas plants exposed to ethylbenzene showed significant differences or those parameters, specifically in *Dracaena deremensis* (Lemon lime), *Dracaena sanderiana*, *Kalanchoe blossfeldiana*, and *Cordyline fruticosa*. The Fv/Fm ratio can give insight into the ability of plants to tolerate (indoor) air pollution by volatile organic chemicals (VOC). This index can be used for identification of suitable plants for treating/sequestering VOCs in contaminated air.

1. Introduction

Recently, volatile organic compounds (VOCs) have become a major pollutant problem of indoor air environments. Toluene and ethylbenzene are chemicals in a group of VOCs that are also found in indoor air habitations (Bernstein et al., 2008). Toluene can be found in many products such as gasoline, paints and fingernail polish (ATSDR, 1994), while ethylbenzene is also present in paints, lacquers and insecticides (International Agency for Research on Cancer (IARC), 2000). These compounds can create a hazard to human health and the environment when present in air. Furthermore, they have been linked to problems with the nervous system, liver, kidneys, and respiratory system (Kishi et al., 1993; WHO, 1996).

Control of VOCs in the atmosphere is a major environmental problem. Current methods for treating VOCs include absorption and adsorption which are effective but may produce secondary waste or have a high operation cost. Therefore, phytoremediation is an alternative method for treating VOC contaminated air. Several previous reports have proposed treating air pollutants by various plant parts (Wolverton et al., 1989; Jen et al., 1995; Conrejo et al., 1999; Liu et al., 2007; Nelson and Wolverton, 2011). Some previous works about the effectiveness of potted-plants in a field study also showed that 50–75 percent of TVOC were reduced by potted-plants (Wood et al., 2006).

More research has been directed toward identifying the most efficient plant for removing volatile indoor air pollutants, despite the fact that the physiology of these plants is not well understood. Stomata and cuticles of plants are proposed to be important pathways for VOCs uptake (Keymeulen et al., 1993; Kvesitadze et al., 2009). Furthermore, a literature review found that although under dark conditions, pollutant gas was continuously taken up by plants (Orwell et al., 2004). The physiology of plants stomata of each species, the physico-chemical properties of plants cuticles and the physico-chemical properties of the pollutants including its water solubility or lipophilicity might be important factors that affect the uptake efficiency of each species (Simonich and Hites, 1995). Therefore, the objectives of this study were to investigate the removal of toluene and ethylbenzene by plants along with the affecting factors, including stomata and cuticular, on toluene and ethylbenzene removal efficiency. The twelve plant species studied for toluene and ethylbenzene removal efficiency were *Aloe vera*, *Sansevieria masoniana*, *Sansevieria trifasciata*,

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Sansevieria hyacinthoides, *Sansevieria ehrenbergii*, *Kalanchoe blossfeldiana*, *Dracaena deremensis 'Lemon lime'*, *Dracaena sanderiana*, *Codiaeum variegatum*, *Chlorophytum comosum*, *Cordyline fruticosa* and *Aglaonema commutatum*.

2. Materials and methods

2.1. Screening plants for toluene and ethylbenzene removal

The twelve plant species were purchased from ornamental plant shops in Thailand. In order to get all test plants of similar leaf area, the twelve plant species leaf areas were measured by graph paper. The leaf area of 0.013 m^2 was chosen for the experiment. Before initiating the experiments, plants were cleaned with tap and distilled water to disperse soil particles. Cultures of plants were maintained in plastic pots (0.1×0.1 m^2) that contained 200 g of soil and coco coir (1:1) as growth media. Furthermore, the pot was covered by aluminum foil to avoid other factors such as soil and pot absorption.

2.2. Fumigation experiment

Glass chambers with volume 15.6 L were used for plant fumigation. Three replicate chambers were used in each treatment. The lids of chambers were modified to two separated ports, the injection port and the sampling port, and the tip of each port contained a rubber septum. Afterward, the same average leaf areas of each plant were placed into each chamber which were then closed and sealed by paraffin tape at room temperature (32 ± 5 °C) and a pressure of 760 mmHg with 12 h of light and dark cycles. Then toluene or ethylbenzene was injected to generate the concentration of 20 ppm or 12 μmol inside the chamber. In addition, controls consisting of pollutant gases without plants were used to evaluate the photodegradation.

2.3. Gas analysis

The toluene or ethylbenzene concentrations were analyzed by a gas chromatography flame ionization detector (GC-FID) model GC-430 from Bruker column: VF-1ms, 15 m × 0.25 mm, i.d. 0.25 μm. The experimental conditions for GC-FID were 100 °C injection temperature, 130 °C column temperature and 150 °C detector temperature.

2.4. Stomata number, cuticle and phytotoxic analysis

The stomata number of plants was analyzed by using nail varnish to copy the pattern of stomata on the leaves. The appearance and number of stomata were analyzed by a light microscope. The cuticle of plants was extracted by hexane. The leaves (0.013 m^2) were immersed in 300 ml of hexane for 24 h. There were three replicates in each treatment. Then the solution was filtered and evaporated for removing the hexane from the wax. The weight of the cuticle was analyzed by an analytical balance.

The photosynthesis of plant leaves was measured and the toxicity of toluene and ethylbenzene on each plant was observed. In this experiment, leaf Fv/Fm ratios were measured to give information on potential photosynthetic efficiency or the potential quantum yield of PSII between control and treated plants. Fm is the fluorescence to a maximum value, while Fv is the variable fluorescence. Photosynthesis in the control and the treated plants was determined by measurement with an FMS-2 portable pulse-modulated fluorometer. Leaves were clipped and allowed 5 min for darkness adaptation before measurements were carried out.

2.5. Effect of cuticle on toluene and ethylbenzene removal efficiency

Cuticle was extracted from a 0.013 m^2 leaf area of the highest and lowest toluene and ethylbenzene removal efficiency plants by hexane and transferred onto an aluminum plate (size ~0.013 m^2). Hexane was evaporated and wax was then fumigated with 20 ppm of toluene or ethylbenzene to study the removal efficiency. There were three replicates in each treatment. The gas sample was taken from a fumigation chamber at 72 h to be analyzed by GC.

2.6. Composition of cuticular wax analysis

Cuticular wax of the twelve plants was analyzed. Leaves of the selected plants were immersed in hexane for 24 h to remove the waxes. After extraction, wax samples were evaporated to remove hexane and to concentrate them. Then the samples were dissolved in 10 ml of hexane, bis(trimethylsilyl)-rifluoroacetamide (BSTFA) with 1 percent Trimethylchlorosilane (TMCS) [10], and derivatized at 60 °C for 30 min. 0.5 μL of the sample was injected and then analyzed by gas chromatography–mass spectroscopy (GC–MS). GC–MS analysis was performed using a GC-8000 GC–MS system equipped with a 30 m × 320 μm × 1 μm film thickness, DB-5 capillary column with helium as the carrier gas. 0.5 μl was injected with a split mode 1:100. The temperature programming was 80 °C as the initial temperature, then 7 °C/min to 150 °C and 10 °C/min to 250 °C, holding for 20 min. The electron impact technique (70 eV) was used and scanned at 30–50 amu conditions for mass analysis.

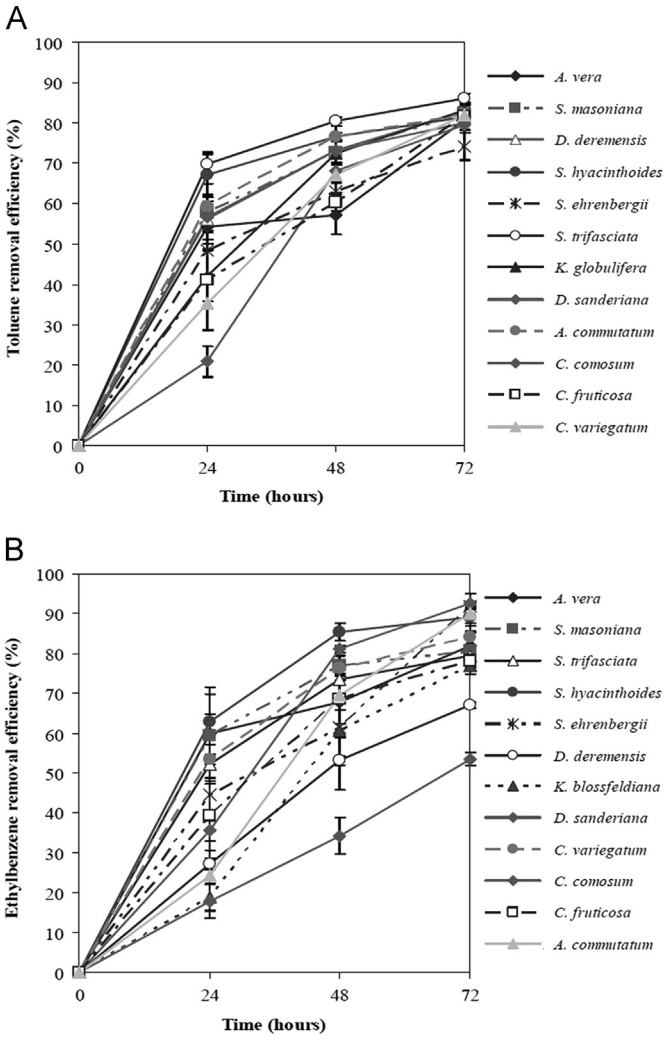

Fig. 1. Toluene (A) and ethylbenzene (B) removal efficiency of twelve plant species at 24, 48 and 72 h.

2.7. Statistical analysis

A completely randomized design was used for the experiments. The data were statistically analyzed using a one way analysis of variance (ANOVA), SPSS version 20. Significantly different means were assessed by Duncan's multiple range tests at a 95 percent confidence level.

3. Results and discussion

3.1. Screening plant for toluene and ethylbenzene removal

Twelve plant species were obtained from commercial sources and were screened for their ability to remove toluene and ethylbenzene volatile compounds. In this experiment we found that 2–4 percent of toluene or ethylbenzene was lost through photodegradation. The results for comparative rates and final removal of toluene and ethylbenzene across the twelve species showed convergent trends over 72 h (Fig. 1A). The final removal of toluene averaged ~77 percent of the dose across twelve plant