Potted-plant/growth media interactions and capacities for removal of volatiles from indoor air

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ABSTRACT

The results of an investigation into the capacity of the indoor potted-plant/growth medium microcosm to remove air-borne volatile organic compounds (VOCs) which contaminate the indoor environment, using three plant species, *Howea forsteriana* Becc. (Kentia palm), *Spathiphyllum* Schott. 'Petite' (Peace Lily) and *Dracaena deremensis* Engl. 'Janet Craig' are presented. The VOCs selected were benzene and *n*-hexane, both common contaminants of indoor air. The findings provide the first comprehensive demonstration of the ability of the potted-plant system to act as an integrated biofilter in removing these contaminants. Under the test conditions used, it was found that the micro-organisms of the growth medium were the 'rapid-response' agents of VOC removal, the role of the plants apparently being mainly in sustaining the root micro-organisms.

INDEX TERMS

VOCs; Research strategy; Benzene; *n*-Hexane; Plants

INTRODUCTION

It is well established that 'outdoor' plants can absorb many toxic compounds from air, water or soil and detoxify or metabolize them (Sandermann, 1992; Giese et al., 1994). Leaf absorption and metabolism of air-borne VOCs such as benzene and toluene have been reported in a number of species, although the results have mainly been derived from experiments in which the VOCs have been applied at much higher concentrations than are likely to be found in reality (Ugrekhelidze et al., 1997; Collins et al., 2000). Giese et al. (1994) showed that both whole plants and isolated leaf cells of the spider plant (Chlorophytum comosum) and soybean (Glycine max) could absorb formaldehyde and metabolize it to carbon dioxide. Microorganisms are well known to be effective in the bioremediation of soil contaminated with organics, e.g. from oil spills (e.g. Siciliano and Germida, 1998, 1999; Li et al., 2000). They have also been used for the treatment of hydrocarbon vapours in 'biofilter reactors', in which the contaminated air is passed through a damp, porous medium which supports active microorganisms (Zhou et al., 1998; Yeom and Yoo, 1999). However, their possible role as a component of the indoor potted-plant system in removing VOCs, has not previously been investigated. Our own earlier test-chamber studies (Wood et al., 1997, 1999, 2000), using Howea forsteriana Becc. (Kentia palm) (Arecaceae), showed that potted specimens had the capacity to remove several times the maximum allowable Australian occupational exposure levels of benzene and n-hexane.

The aims of the current study have been to compare the removal capacity of potted *H. forsteriana* with those using two other internationally top-selling interior potted-plant species, *Spathiphyllum* Schott. Var. Petite (Peace Lily) (Araceae) and *Dracaena deremensis* Engl. Var. Janet Craig (Dracaenaceae), and to explore the respective roles of the plants and the potting mix micro-organisms in that process. The capacity for VOC removal was measured with potted specimens of each plant species, under light and dark regimes, and in both a standard potting mix and a standard hydroponic growth medium. Investigations into dose–response relationships, and the relative contributions to the removal process of the plant and the growth media micro-organisms, were also investigated. This is

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the first research undertaken to examine any of these matters systematically with respect to indoor potted-plant species.

METHODS

Initial experiments used plants grown in potting mix and under continuous light, which is commonly found in public indoor environments (e.g. hotels, shopping malls, office blocks, hospitals and airports). The potted-plants were then tested under dark conditions, after which the plants were removed and the potting mix placed back in the test chambers, in order to establish specifically the relative contributions of plant and potting mix to VOC removal rates. Other batches of plants were uprooted from their potting mix, transferred to a hydroponic medium, and tested in light and dark conditions as before, and once again removed to test the residual activity of the hydroponic medium. Since no previous studies on the role of indoor growth media micro-organisms in VOC removal have been carried out, the microbiological experiments reported here have been pilot studies only. Bacterial responses were chosen for investigation, since they were considered to be more likely to play a dominant role than the fungi, cyanobacteria or algae (Song *et al*., 1986; Leahy and Colwell, 1990).

Well established 12-month-old potted plants of each species were used, all 0.3–0.4 m tall, in 150 mm pots. Tissue-cultured Spathiphyllum 'Petite' and cutting-grown Dracaena 'Janet Craig' were obtained from Wood's Nursery, Kenthurst, NSW, and H. forsteriana seedlings from Mountain Range Nursery, Woonoona, NSW. Four replicate perspex static test chambers were used, 0.6 × 0.6 × 0.6 m (volume 0.216 m^3, 216 L). The chambers had perspex lids with stainless steel frames, sealed with adhesive foam rubber tape and held closed by six metal clips. Each chamber was equipped with rubber septa through which the VOC could be introduced and air samples withdrawn; a 0.5 m coil of copper tubing (i.d. 4 mm), through which water circulated from a thermostat bath at 23 ± 0.1°C; a 2.4 W fan to accelerate equilibration of the atmosphere; and a light box above (with an air gap of 5 cm), fitted with five 18 W fluorescent tubes designed for optimum plant growth (Wotan L 18/11 Maxilux Daylight, Ozram, Germany) (~120 μmol quanta m^{-2} s^{-1}).

Prior to each experiment, the inner surfaces of the chambers were swabbed thoroughly with 90% ethanol to clean and remove any traces of previously used test VOCs, and to reduce any incidence of microbial contamination. Test plants (4 replicates, 1 per chamber) were well watered and drained before being placed in the chamber. Benzene was Analar grade (BDH Chemicals Aust. Pty Ltd, Port Fairy, Vic.); *n*-hexane was Mallinkrodt Nanograde (Rhone-Poulenc, Clayton South, Vic.). For each VOC measurement, 1.0 mL of chamber air was withdrawn through the septum with a gas-tight syringe. Chambers were always sampled in duplicate (i.e. a total of eight readings). VOC levels were measured using a gas chromatograph (GC) (Shimadzu GC-8A). GC calibrations were performed using standard gas samples. Initial doses were 25 ppm benzene (80 mg m^{-3} at 1 atm, 25°C) and 100 ppm (353 mg m^{-3}) *n*-hexane. Lower limits of detection of the GC were found to be 0.2 ppm *n*-hexane and 0.1 ppm benzene. Experimental samplings were carried out at hourly, several hourly or daily intervals as required. Additional injections of VOC were performed as needed for the particular experiment 'Leak' tests were carried out immediately before and/or after experiments to correct for chamber leakage or any VOC adsorption/absorption on the test chamber apparatus. Losses of 2.7–3.8% d^{-1} for 25 ppm benzene and 1.6–3.0% d^{-1} for 100 ppm *n*-hexane were recorded, and results were corrected accordingly. No differences in loss rates were found between light and dark conditions, indicating that light-degradation of VOC was negligible. Leak tests with empty pots and containers, and with hydroponic aerators in operation, showed that VOC emissions from these articles were also negligible. A control test with 'virgin' (i.e. unused) potting mix was also made, using 25 ppm benzene as the VOC. To determine changes in the numbers of culturable bacteria in the potting mix following exposure of the potted-plants to benzene, substrate samples (10 g) were taken from each of four *Dracaena* 'Janet Craig' pots, both before and after one of the experiments outlined above. From these, serial suspensions were made in 0.1% w/v sodium pyrophosphate solution, and bacteria enumerated on spread plates of tenth-strength tryptic soy agar (TSA, Oxoid). Control samples were taken from the potting mix of plants placed in chambers for the same length of time but without benzene. No-treatment controls were also used; i.e. plants kept on the laboratory bench in ambient light conditions for the period of the experiment. The plates were incubated at room temperature (23 ± 1.5°C) for 4 d.

Second, to determine whether the culturable bacterial community derived from the potting mix was in fact capable of degrading benzene in the absence of the plants or substrate, 10^{-1} (w/w) potting mix suspensions were made, this time from *H. forsteriana* plants that had been shown to remove. Benzene

(5 ppm) was introduced into the jars and its concentration monitored by GC analysis of headspace gas samples taken by syringe through the septa. Data were corrected for losses of benzene related to the experimental apparatus or broth media.

Data Analysis

Means and standard errors were calculated for all data. Student's paired *t*-test was used to assess different removal rates in the same plants at different stages of the experimental sequence, and Student's *t*-test for unpaired data was used to compare different plant species, or the same species in the different growth media. Single factor analyses of variance (Microsoft Excel 5.0) were used to analyse the microbiological data. In reporting all the results, differences were regarded as significant where $p = 0.05$.

RESULTS

Rates of VOC removal per chamber (i.e. per potted-plant) for each species, in either potting mix or hydroponics, are shown in Figures 1 and 2. It can be seen that there were differences among the species in patterns of response to each VOC; nevertheless, there were strong and obvious similarities. This result indicates that, at least with these species and under these test conditions, neither continued absorption into the leaves through the stomates, nor concurrent light metabolism is of immediate importance to rates of disappearance of the VOC. This finding points strongly towards the primary role of the substrate micro-organisms in the process under this set of 'indoor' conditions. When a higher VOC dose was applied (50 ppm benzene and 150 ppm *n*-hexane, respectively), with the chambers still in the dark, it can be seen by inspection of the graphs (Figures 1 and 2) that removal rates usually increased further again (stage e). That is, the potted-plant microcosm could respond to, and cope with, the higher dose of either compound. Work is continuing to establish the upper limits of removal capacities of this microcosm.

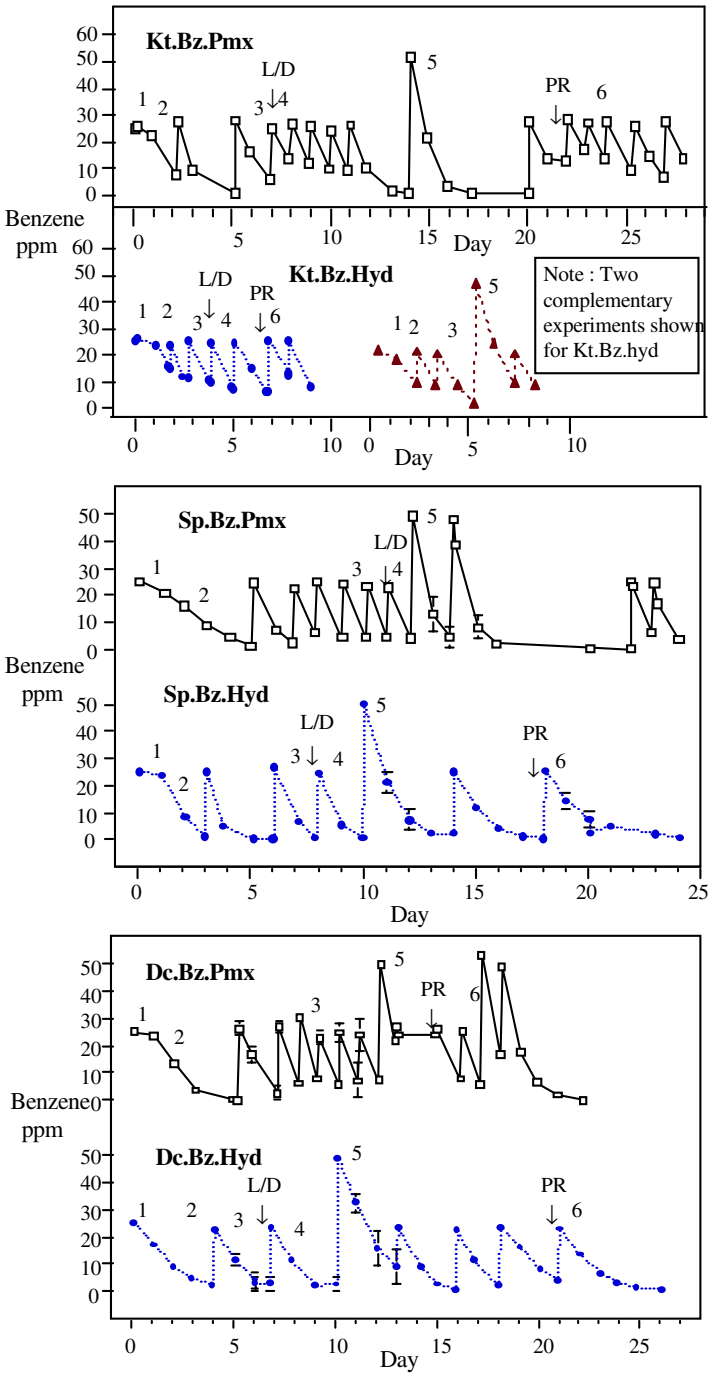

Figure 1 Benzene (Bz) levels in test chambers during experiments with three indoor plant species. Step increments in VOC concentration correspond to injections of benzene. Numbers 1–5 indicate Stages 1–5 of the protocol (see text). Kt = Kentia (Howea forsteriana); Sp = Spathiphyllum var,. Petite; Dc = Dracaenae deremensis; Pmx = potting mix; Hyd = hydroponics; L/D = change from light to dark; PR = plant removed and used substrate or medium returned to chamber. Each point mean ± SEM ($n = 4$).

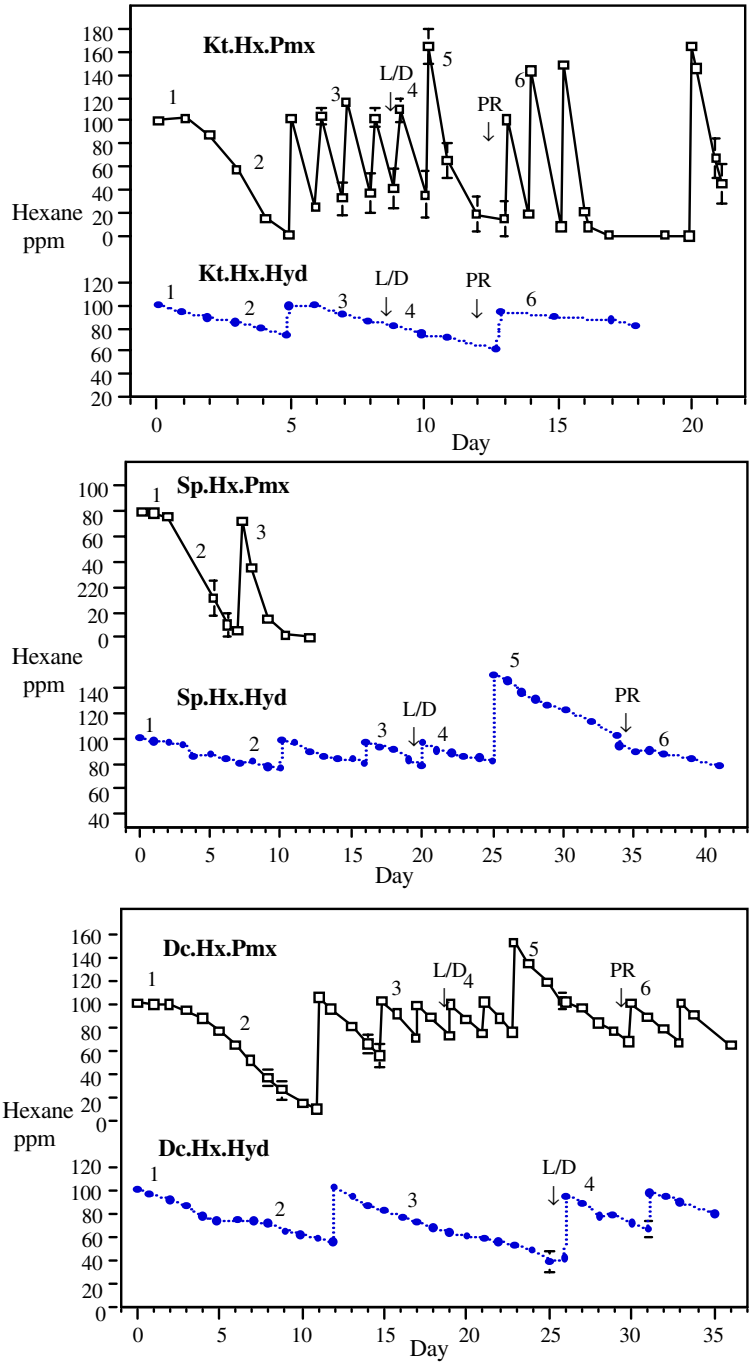

Figure 2 *n*-Hexane (Hx) levels in test chambers during experiments with three indoor plant species. Step incrememnts in VOC concentration correspond to injections of *n*-hexane. Numbers 1–5 indicate Stages 1–5 of the protocol (see text). Kt = Kentia (Howea forsteriana); Sp = Spathiphyllum var., Petite; Dc = Dracaena deremensis; Pmx = potting mix; Hyd = hydroponics; L/D = change from light to dark; PR = plant removed and used substrate or medium returned to chamber. Each point mean ± SEM (n = 4).

On placing 'soil-less' plants in hydroponics under conditions where transfer of soil particles was minimized (Figures 1 and 2) substantial removal activity was recorded with exposure to benzene, although rates were slower than in the potting mix. Removal of *n*-hexane was very slow. Once again, the eventual removal of the plant did not eliminate removal activity. These results again point to the

role of micro-organisms in the removal process. However, they also indicate that a complex of close relationships between plants and micro-organisms are involved in determining VOC-removing activity.

Effects of Benzene on Potting Mix Micro-organisms

Using potting mix samples from *Dracaena* 'Janet Craig' plants, no significant differences were found between total culturable bacterial numbers, scored as colony-forming units (cfu), following exposure to benzene. However, several types of bacteria were observed to either increase or decrease in numbers when the samples were exposed to benzene. In addition, several types of bacteria appeared in the cultures only after exposure to benzene. Thus, although no significant numerical alterations occurred in the total bacterial community as a result of benzene exposure, changes occurred in community structure, as increases and decreases of different taxa.

DISCUSSION

The results confirm, first, that the VOC removal is clearly a biological response, not merely an adsorption/absorption process, which would tend towards saturation. They also confirm that under these conditions, it is the micro-organisms of the growth medium that are the primary agents of rapid VOC removal, and that they can remain active for at least a week without the plant**.**

For benzene, the removal appears to be associated with micro-organisms closely associated with the root system, which are hence persistent on transfer to hydroponics. On the other hand, with *n*-hexane, it seems that the relevant micro-organisms may not be so tightly bound to the roots, and so are more effectively reduced in numbers on washing and placement in hydroponic conditions. These aspects need further investigation, along with differences among different potting and hydroponic media. Bacteria are well known to have the capability to degrade aromatic pollutants (e.g. Edwards and Grbic-Galic, 1992; Diáz and Prieto, 2000). The high level of efficiency and dose-related removal capacity shown by the bacteria here have not previously been reported. Comparisons among these plant species with each VOC point to different species having different communities and/or relationships with their root-zone micro-organisms. Therefore, since indoor air contains a dynamic mixture of gaseous pollutants, it seems that a mixture of potted-plant species is likely be the most effective in improving indoor air quality. This is in accord with common aesthetic and design principles used in interior plantscaping. The horticultural development of ornamental and crop species and their microflora is never-ending. It should be possible to develop improved indoor plant varieties and optimal growth media/microorganism complements, which will provide an enhanced capacity for cleaning indoor air, while continuing to beautify the indoor environment.

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