Kor. J. Hort. Sci. Technol. 28(3):476-483, 2010

Effect of Bacterial Population from Rhizosphere of Various Foliage Plants on Removal of Indoor Volatile Organic Compounds

Se-Chul Chun[1], Mung Hwa Yoo[2], Young Sook Moon[1], Mi Ho Shin[1], Ki-Cheol Son[2*], Ill-Min Chung[3], and Stanley J. Kays[4]

[1]Department of Molecular Biotechnology, Konkuk University, Seoul 143-701, Korea
[2]Department of Environmental Science, Konkuk University, Seoul 143-701, Korea
[3]Department of Applied Biological Science, Konkuk University, Seoul 143-701, Korea
[4]The Plant Center, Department of Horticulture, University of Georgia, Athens, GA 30602-7273, USA

Abstract. Total bacterial populations were cultured from the Hydroball cultivation media in the rhizospheres of 9 different plants including *Hedera helix* L. and *Dracaena deremensis* cv. Warneckii Compacta, etc. These cultured bacterial populations were studied to test if the bacterial populations in the plant growing pots may play a role on removal of volatile organic compounds (VOCs) such as benzene and toluene in the air. To meet this objective, first, we tested the possibility of removal of VOCs by the cultured total bacteria alone. The residual rates of benzene by the inoculation of total bacterial populations from the different plant growth media were significantly different, ranging from 0.741-1.000 of *Spathiphyllum wallisii* 'Regal', *Pachira aquatica*, *Ficus elastica*, *Dieffenbachia* sp. 'Marrianne' Hort., *Chamaedorea elegans*, compared to the control with residual rate of 0.596 (LSD, P=0.05). This trend was also similar with toluene, depending on different plants. Based on these results, we inoculated the bacterial population cultured from *P. aquatica* into the plant-growing pots of *P. aquatica*, *F. elastica*, and *S. podophyllum* inside the chamber followed by the VOCs injection. The inoculated bacteria had significant effect on the removal of benzene and toluene, compared to the removal efficacy by the plants without inoculation, indicating that microbes in the rhizosphere could play a significant role on the removal of VOCs along with plants.

***Additional key words*:** bacteria, inoculation, plant-microbe system

Introduction

Indoor air in metropolitan environments has become a major health consideration (Abbrittti and Muzi, 1995; American Lung Association, 2001). City air is always polluted, mainly from motor vehicles, and further chemicals like volatile organic compounds (VOCs) that make indoor air worse inside buildings (Brown, 1997; Brown et al., 1994). Since city residents often spend over 90% of their time indoors (Jenkins et al., 1992), the improvement of indoor air in urban environments has been strongly needed. The VOCs originated from both outdoor sources (mainly from fuel emissions, e.g. benzene) and indoor sources (e.g. from furnishings, machines, solvents, cleaning agents, clothes, cosmetics) (Zabiegata, 2006). The harmful effects of chemical mixtures have been recognized as components of 'sick building syndrome' or 'building related illness', particularly in air-conditioned buildings (Burge et al., 1987; Mendell and Smith, 1990). There have been reports that the species of VOCs are over three hundreds, generally as complex mixtures; although each compound is likely to be in very low concentration, the cocktail can produce synergistic effects, with symptoms of headache, respiratory problems and loss of concentration (National Occupational Health and Safety Commission (Aust.), 1991; Volkoff, 1995; Weschler and Shields, 1997).

There have been many reports that 'outdoor' plants can absorb many toxic compounds from air, water or soil and detoxify or metabolize them (Foyer et al., 1994; Sandermann, 1992; Schutle Hostede et al., 1987; Taylor et al., 1991). Number of plant species has been reported to absorb through leaf and metabolize air-borne VOCs such as benzene and toluene, although the results came from experiments in which the VOCs have been applied at much higher concentrations than are likely to be found in reality (Cape et al., 2000; Collins et al., 2000; Jen et al., 1995; Ugrekhelidze et al., 1997). In addition, a number of species of 'indoor' potted-

***Corresponding author:** kcson@konkuk.ac.kr

※ Received 8 September 2009; Accepted 31 January 2010. This work was supported by Konkuk University Research Fund in 2008.

plants have been reported to reduce concentrations of VOCs, as well as dust and other air-borne pollutants (Wolverton and Wolverton, 1993)

However, there have been only a few studies conducted on role of bacterial population on removal of VOCs. Wood et al. (2002) studied the effect of bacterial population in the potting mixture without plants on the removal of benzene and n-hexane, suggesting that microorganisms of the growth medium from the pots of *Howea forsteriana* are the primary agents of rapid VOCs removal. They inoculated potting mix suspensions from *H. forsteriana* plants into tenth-strength tryptic soy broth and then these bacterial suspensions were inoculated into the autoclaved vermiculite, and benzene and n-hexane were injected. The removal of benzene and n-hexane was significantly greater than the uninoculated control. However, their experiments in relation to microorganisms were conducted with only one bacterial population from potting mix of one plant species.

The objective of the present study was to determine the effect of total rhizobacterial populations of 9 indoor plants including *Hedera helix* L., *Dracaena deremensis* cv. Warneckii Compacta, and *Scindapsus aureus* Engler, etc. on removal of VOCs like benzene, toluene, and *m*, *p*, *o*-xylene. And their effect was also confirmed with inoculation of the total bacterial populations from the rhizosphere of *Pachira aquatica* into growing media with or without plants (*P. aquatica*, *Ficus elastica*, and *Syngonium podophyllum*) in the gas tight growth chamber.

Materials and Methods

The culture of total bacteria isolated from different plant growth media and their effect on removal of volatile organic compounds

Ten grams of Hydroball (0.5 mm in diameter, Jeil Ceramic Co., Masan, Korea) growth media from the rhizosphere of 9 plants (*H. helix*, *D. deremensis* cv. Warneckii Compacta, *F. elastica*, *P. aquatica*, *S. wallisii*, *Sansevieria trifasciata* Prain var. laurentii N. E. Br, *Chamaedorea elegans*, *F. benjamina* L., *S. podophyllum* Schott Albo-Virens, *Dieffenbachia* sp. 'Marrianne' Hort., and *Nephrolepis* exaltata Schott var. bostoniensis Davenport) were suspended with 90 mL of sterile water and serially diluted from 10^{-3} to 10^{-7}. One mL of each dilution series of the suspension was mixed with tryptic soy agar (TSA, Difco, USA) of Petri-dish plate and incubated at 28℃ for 24-28 hrs. Of these cultures, only bacterial cultures from 10^{-5} dilutions were used for their effects on the removal of VOCs such as benzene and toluene. One hundred μL of bacterial suspensions (absorbance at 600 nm = 2.0) was diluted with 5 mL and 1 mL of aliquots was inoculated onto solidified 20 mL TSA of glass bottle (diameter = 81 mm, height = 170 mm). The control has only TSA in a glass bottle. The inoculated bottles were sealed with septum (Sigma Korea, Seoul, Korea) and Parafilm (Parafilm, Chicago, IL, USA) and the VOCs mixture (benzene 0.36 $\mu l \cdot L^{-1}$, toluene 0.18 $\mu l \cdot L^{-1}$, *m,p*-xylene 0.976 $\mu l \cdot L^{-1}$, *o*-xylene 0.569 $\mu l \cdot L^{-1}$) was injected into the inoculated and control bottles with a syringe. The bottles inserted with gas were first checked for their initial gas concentrations with the gas chromatography (Model GC-14A, Dong-il Shimadzu, Seoul, Korea) right after injection and incubated at 28℃ for 24 hrs. The final concentrations of the VOCs were measured at 12 hrs after incubation.

After three replications per bacterial population, the results were combined before statistic analyses. Mean separation was analyzed with Sigma Stat Software ver. 2.0 (Systat Software, Inc., Point Richmond, USA).

The effect of plants and inoculation of bacteria into the plant-microbe system on removal of VOCs

Total rhizobacterial population of *P. aquatica* showed good efficacy on the removal of benzene than other rhizobacterial populations such as those from *F. elastica* and *Dieffenbachia* sp. (Table 1). Therefore, the bacterial population of *P. aquatica* was simply chosen to test the effect on the removal of VOCs when inoculated into plant-microbe system. The indoor plants used in this experiment were *P. aquatica*, *F. elastica*, and *S. podophyllum* which grew in the pots with 18 cm in diameter filled with Hydroball. The control had no plant but only Hydroball.

Effect of the above plants on the removal of VOCs was determined first, and then 500 ml of distilled water was irrigated into Hydroball of the plant pots followed by inoculation of bacterial suspension (Absorbance 2.0 at 600 nm) into Hydroball of the plant pots after 0.2 $g \cdot L^{-1}$ Technigro (24N:3.1P:4.2K; SunGro Chemicals, USA) was applied to the plants.

VOCs were measured every two hrs for 12 hrs after 4.0 ± 0.5 $\mu l \cdot L^{-1}$ of VOCs (benzene: toluene: *m,p*-xylene: *o*-zylene = 1:6:0.5:0.5, that is, 0.5 $\mu l \cdot L^{-1}$: 3.0 $\mu l \cdot L^{-1}$: 0.25 $\mu l \cdot L^{-1}$: 0.25 $\mu l \cdot L^{-1}$) was injected into the gas tight growth chamber. Gas leakage and absorption of the vacant chamber was 10.1% during the period. All plants were predisposed under 100 ± 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of light, and temperature and humidity were 25 ± 5℃ and 50 ± 10%, respectively, before the gas chamber experiment was started. The plants were maintained for 6 months in the greenhouse with irrigation once every other day. 0.2 $g \cdot L^{-1}$ Technigro (24N:3.1P:4.2K; SunGro Chemicals, USA) was applied to the plants once every other week. The plants were adjusted to the growth chamber environment

Table 1. Effect of total bacterial populations of plant cultivation media on reduction of VOCs.

Plant species	Benzene (μl·L^{-1})			Toluene (μl·L^{-1})			*m*,*p*-Xylene (μl·L^{-1})			*o*-Xylene (μl·L^{-1})			Total (μl·L^{-1})		
	Initial[y]	Final[x]	Red[w]	Initial	Final	Red	Initial	Final	Red	Initial	Final	Red	Initial	Final	Red
Control[z]	0.428	0.173	0.596c[v]	0.145	0.050	0.652b	1.185	0.081	0.931b	0.610	0.000	1.000	2.099	0.285	0.864b
S. trifasciata	0.390	0.121	0.691b	0.209	0.035	0.835b	1.006	0.052	0.948b	0.491	0.000	1.000	2.096	0.208	0.901b
D. deremensis	0.451	0.138	0.695b	0.315	0.030	0.906a	1.890	0.055	0.971b	0.984	0.009	0.990	3.640	0.232	0.936b
N. exalatata	0.553	0.167	0.697b	0.355	0.000	1.000a	2.291	0.186	0.919b	1.220	0.025	0.980	4.419	0.378	0.914b
S. wallisii	0.403	0.105	0.741a	0.210	0.000	1.000a	1.174	0.026	0.978b	0.557	0.000	1.000	2.344	0.131	0.944b
P. aquatic	0.633	0.114	0.820a	0.482	0.077	0.839b	4.253	0.013	0.997a	2.518	0.000	1.000	7.788	0.204	0.974a
F. elastica	0.357	0.028	0.922a	0.119	0.000	1.000a	0.829	0.000	1.000a	0.438	0.000	1.000	1.788	0.028	0.984a
S. aureus	0.229	0.071	0.690b	0.182	0.035	0.809b	1.224	0.043	0.965b	0.625	0.000	1.000	2.260	0.149	0.934b
Dieffenbachia sp.	0.235	0.000	1.000a	0.130	0.000	1.000a	0.798	0.000	1.000a	0.408	0.000	1.000	1.571	0.000	1.000a
C. elegans	0.159	0.000	1.000a	0.099	0.000	1.000a	0.558	0.000	1.000a	0.251	0.000	1.000	1.067	0.000	1.000a

[z]The concentration of VOCs (benzene, toluene, *m*,*p*-xylene) mixture before injection to the glass bottles was 0.36 μl·L^{-1} 0.18 μl·L^{-1}, 0.976 μl·L^{-1}, and 0.569 μl·L^{-1} for benzene, toluene, *m*,*p*-xylene, *o*-xylene, respectively.
[y]Initial concentrations were determined at 1 hr after the VOCs gas was injected into the inoculated glass bottle.
[x]Final concentrations were determined at 12 hrs after incubation of the inoculated glass bottle at 28℃.
[w]Residual rate was calculated by the equation of {1-(final concentration divided by initial concentration)}.
[v]Means followed by same letters are not significantly different within the column (LSD, *P*=0.05). Residual rate of *o*-xylene was too great to be compared.

(DF-95G-1485, Duri Science Inc., Seoul, Korea) for one week before the plants were tested for the removal of VOCs. Average light intensity was 100 μmol·m^{-2}·s^{-1}, and temperature and relative humidity were 24℃ and 60%, respectively, with day and night (14/10 hrs).

There were three replications per plant species and the results were combined before statistical analyses. Mean separation was analyzed with Sigma Stat software ver. 2.0 (Systat Software, Inc., Point Richmond, USA).

Bacteria past through the plant growth medium of the plant–microbe system of VOCs removal

Selective media were used for the test of the presence of *E. coli* and coliform, *Samonella* and *Staphyloccus*, which we regarded as some of the representative human pathogenic bacteria. In order to make *E. coli* and coliform selective medium, Coliform agar (Merk Korea Ltd., Seoul, Korea) of 13.25 g was completely dissolved into 500 mL of distilled water by placing the beaker into boiling water. Also, Rambach and Baird-Parker media for the test of the presence of *Samonella* and *Staphyloccus*, respectively, were made according to the instruction of the company (Merk Korea Ltd., Seoul, Korea).

Prepared agar plates as previously described were placed for 1 min in front of the fan in which air got past through the growth medium of the plant system of VOCs removal. There were three replications per type of agar. Control plates were placed in front of the fan in only the pots of Hydroball without plants and also the other control plates were exposed to air of three different laboratories of Life Science Building of Konkuk University for 12 hrs. All exposed plates of three kinds of selective media were incubated at 36℃ for 48hrs. Also the type cultures for three species were cultured for the comparative purpose. Dark blue to purple colonies on the Coliform agar were considered to be *E. coli* or Coliform bacteria. Red colonies on the Rambach agar were considered to be *Samonella*. Shiny, convex and black colonies with haloes on Baird-Parker agar were considered to be *Staphylococcus*.

Results and Discussion

Effect of total bacteria from different plant growth media on removal of volatile organic compounds

VOCs such as benzene, toluene and *m*,*p*-xylene were significantly reduced with inoculation of bacterial populations cultured from different plant growth media compared to the uninoculated control (Table 1) (LSD, *P*=0.05). And the loss of *o*-xylene in the control was too great to be compared to the other inoculated treatments.

Residual rate of benzene by total bacterial populations cultured from the growth media near the rhizosphere of *S. trifasciata*, *D. deremensis*, *S. aureus*, *N. exalatata* (0.691, 0.695, 0.690, 0.697, respectively) were significantly different from that of the control (0.596). Furthermore, residual rate of benzene by total bacterial populations cultured from near the rhizosphere of *S. wallisii*, *P. aquatica*, *F. elastica*, *Dieffenbachia* sp., and *C. elegans* (0.741, 0.820, 0.922, 1.000 and 1.000, respectively) was even greater than those of *S.*

trifasciata, *D. deremensis*, *S. aureus*, *N. exalatata* (Table 1) (LSD, P=0.05).

With regard to toluene, residual rates of *S. aureus*, *S. trifasciata*, and *P. aquatica* (0.809, 0.835, and 0.839, respectively) were similar to that of the control (0.652). However, residual rates of *D. deremensis* (0.906), and *N. exalatata*, *S. wallisii*, *F. elastica*, *Dieffenbachia* sp., and *C. elegans* (all of these as 1.000) were significantly different from that of the control (0.652).

In *m*,*p*-xylene, residual rates of *N. exalatata*, *S. trifasciata*, *S. aureus*, *D. deremensis*, and *S. wallisii* (0.919, 0.948, 0.965, 0.971, and 0.978, respectively) were not significantly different from that of the control (0.931). However, those of *P. aquatica*, *F. elastica*, *Dieffenbachia* sp., and *C. elegans* (0.997, 1.000, 1.000, and 1.000, respectively) were significantly different from that of the control (0.931).

On the other hand, the residual rate of *o*-xylene was too severe even in the control to compare residual rates between treatments.

Regarding *m*,*p*-xylene and o-xylene, there might be a leakage or natural degradation that could not be controlled in this experiment. We tried to reduce this possible leakage from the control treatment with septum and several layers of parafilm sealing. However, it was impossible to reduce residual rates of *m*,*p*-xylene and *o*-xylen in the control even with many repetitions. Thus, it is speculated that xylene may be degraded spontaneously or reacted with unknown chemical species in the TSA, considering that we washed the glass bottle completely with acetone, dried and autoclaved.

In all species of VOCs, initial concentration of the bottle inoculated with bacterial suspensions tends to be various depending on the different bacterial populations, specifically, this trend was more significant in relation to *m*,*p*-xylene and *o*-xylene.

Considering all the individual VOCs together (mixture of individual VOCs), residual rates (0.994-1.000) by total bacterial populations from the growth media of rhizosphere of *P. aquatica*, *F. elastica*, *Dieffenbachia* sp., and *C. elegans* (0.974, 0.984, 1.000 and 1.000, respectively) were significantly different from that of the control (0.864). Residual rates of total VOCs by *D. deremensis*, *N. exalatata*, and *S. wallissii*, were not significantly different from the control although there were significant differences in reduction of benzene and toluene. This was due to the statistical influence by insignificant difference of *m*,*p*-xylene and *o*-xylene. The present study clearly confirmed that bacteria alone could effectively remove VOCs.

Wood et al. (2002) studied the effect of total bacterial population through potting mixture on the removal of benzene and n-hexane and reported that 25 $\mu l \cdot L^{-1}$ of benzene was reduced down to 5 $\mu l \cdot L^{-1}$ within 5 days after incubation. Also, they reported that when the vermiculite that was used as growth medium to grow the plant *Howea* sp., was suspended in tryptic soy broth and then incubated for 4 days, 25 $\mu l \cdot L^{-1}$ of benzene was reduced down to less than 5 $\mu l \cdot L^{-1}$.

Formaldehyde, xylene and ammonia were speculated to be removed by plants and soil microorganisms (Wolverton and Wolverton, 1993). In addition, Radwan et al. (1998) reported that removal of oil in the dessert of Quait might be potentially attributed to microorganism of rhizosphere that utilized hydrocarbon.

The effect of plants and inoculation of total cultivated bacteria into plant-microbe system on removal of VOCs.

The growth media of Hydroball (0.5 mm in diameter, Jeil Ceramic Co. Korea) also absorbed a little amount of benzene, toluene, *m*,*p*-xylene and *o*-xylene. Consequently, the concentration of the respective VOCs was reduced down to approximately 0.450, 2.667, 0.171 and 0.130 $\mu l \cdot L^{-1}$, respectively, from the initial concentration at 12 hrs after injection. Background gas leakage and possible absorption of the gas tight empty growth chamber was 0.043, 0.333, 0.080 and 0.121 $\mu l \cdot L^{-1}$ for benzene, toluene, *m*,*p*-xylene and *o*-xylene, respectively. These were 8.6%, 11.1%, 32% and 48.2% losses from the initial concentration of the respective VOCs, which were in total of 4.0 $\mu l \cdot L^{-1}$ (benzene: toluene: *m*,*p*-xylene: *o*-zylene = 1:6:0.5:0.5, that is, 0.5 $\mu l \cdot L^{-1}$: 3.0 $\mu l \cdot L^{-1}$: 0.25 $\mu l \cdot L^{-1}$: and 0.25 $\mu l \cdot L^{-1}$). Residual rates of VOCs were more sharply decreased with Hydroball than in the empty growth chamber (Fig. 1, 2, and 3).

Although there were some differences in the decrease of residual rates depending on the types of VOCs, residual rate of VOCs in the treatment of Hydroball inoculated with bacteria was more significant compared to that of Hydroball alone without inoculation (Fig. 1, 2, and 3), indicating that bacteria might play a role on removal of the VOCs.

When three plant species of *P. aquatica*, *F. elastica*, and *S. podophyllum* were each placed inside the chamber, gas reduction was obviously clear although we considered background leakage and absorption described as previously. When there were plants in the pots, the removal effect of the VOCs was more significant than that of the VOCs of the Hydroball without plants (Fig. 1, 2, and 3). There have been many studies indicating that number of plant species could absorb through leaf and metabolize air-borne VOCs such as benzene and toluene, although the results came from experiments in which the VOCs have been applied at much higher concentration than are likely to be found in reality (Cape et al., 2000; Collins et al., 2000; Jen et al., 1995; Ugrekhelidze et al., 1997). Yoo et al. (2006) reported that the removal

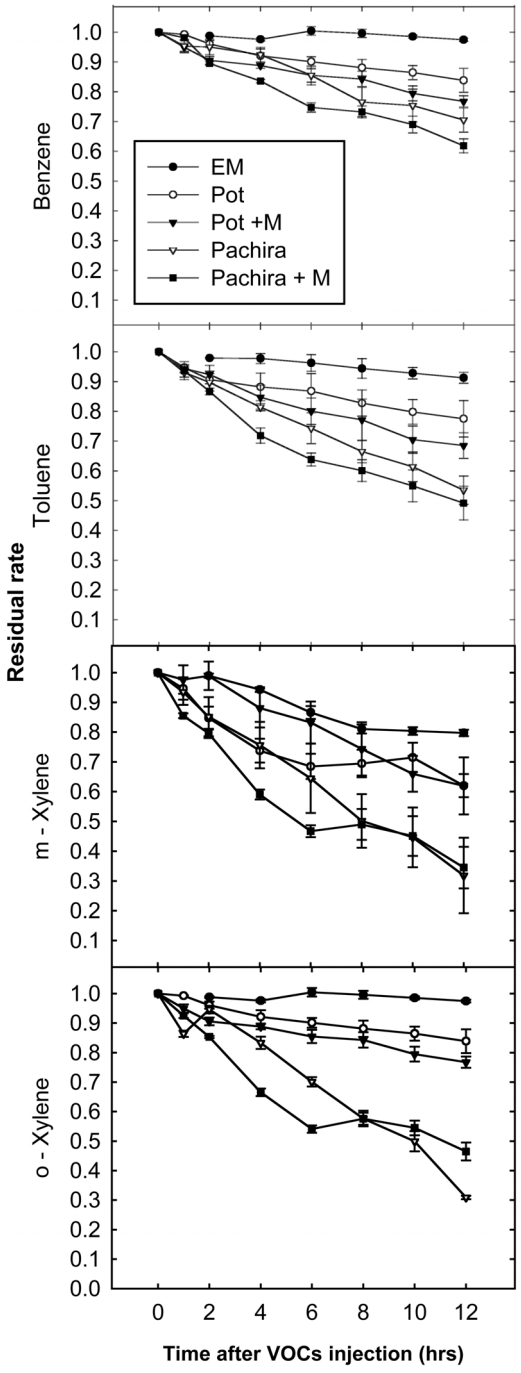

Fig. 1. Effect of *P. aquatica* and inoculation of total rhizobacterial population of *P. aquatica* on removal of volatile organic compounds. EM, empty growth chamber; Pot, with Hydroball but plant; Pot + M, Pot with Hydroball and inoculation of total rhizobacterial population of *P. aquatica*; Parchira, Pot planted with *P. aquatica*; Parchira + M, *P. aquatica* inoculated with total rhizobacterial population of *P. aquatica*. Final concentrations of VOCs were determined every 2 hrs for 12 hr period after injection of the initial VOCs except for the first 2 hrs. The concentration of the first 2 hrs was measured every hour but empty growth chamber. The initial concentration of the VOCs of the growth chamber, which were in total 4.0 $\mu l \cdot L^{-1}$ (benzene: toluene: *m*,*p*-xylene: *o*-zylene = 1:6:0.5:0.5, that is, 0.5 $\mu l \cdot L^{-1}$: 3.0 $\mu l \cdot L^{-1}$: 0.25 $\mu l \cdot L^{-1}$: 0.25 $\mu l \cdot L^{-1}$). Residual rate was calculated by the equation {1-(final concentration divided by initial concentration)}. Residual rate of 1.000 means that VOCs is completely removed.

by *S. wallisii*, *S. podophyllum*, and *H. helix* were more effective in benzene or toluene when exposed singly.

Furthermore, when bacterial suspensions were inoculated into three different plant species, the effect on reduction of benzene and toluene became greater than that of plants or Hydroball alone (Fig. 1, 2, and 3), indicating that both the plant itself and bacteria could play a role on removing VOCs. The reduction of *m*,*p*-xylene and *o*-xylene was significant from one to six hrs after the inoculation, compared to that

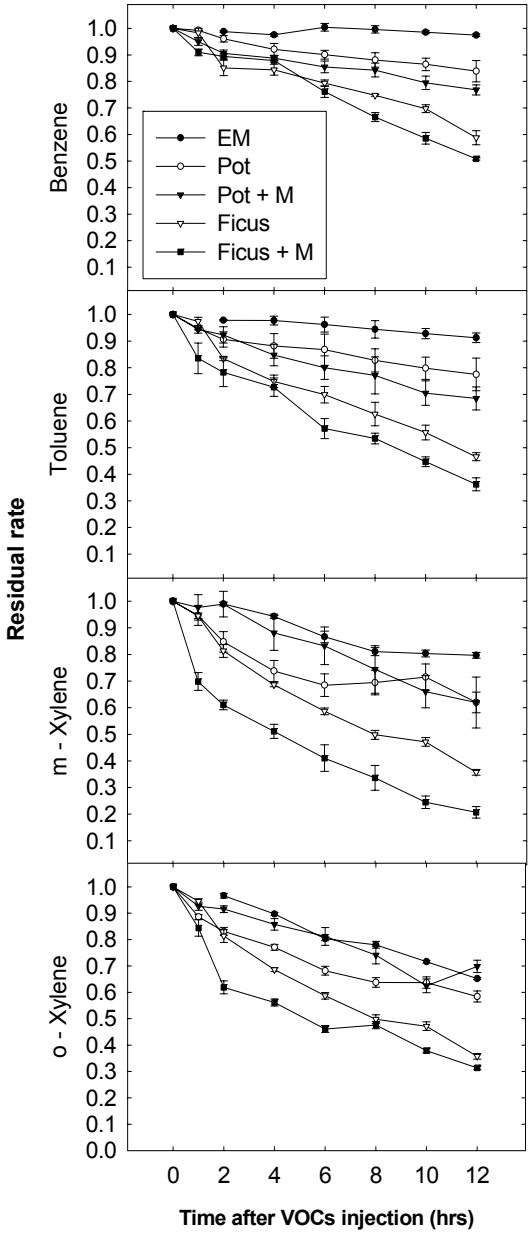

Fig. 2. Effect of *F. elastica* and inoculation of total rhizobacterial population of *P. aquatica* on removal of volatile organic compounds. EM, empty growth chamber; Pot, with Hydroball but plant; Pot + M, Pot with Hydroball and inoculation of total rhizobacterial population of *P. aquatica*; Parchira, Pot planted with *F. elastica*; Parchira + M, *F. elastica* inoculated with total rhizobacterial population of *P. aquatica*. The other experimental condition and procedures were identical to Figure 1.

in the control, and the removal effect was gradually reduced as the period of incubation became longer than 6 hrs.

A variety of plant species removed indoor air pollutants by the absorption of stomata, adsorption of leaf, soil surface, and soil microorganism. Wood et al. (2002) reported that the microorganisms of the growth medium are the primary agents of the rapid VOCs removal, and that they could remain active for at least a week without the plant. They also suggested that for benzene, the removal appeared to be associated with microorganisms closely associated with the root system, which might be hence persistent on transfer to hydrophonics. For the removal of formaldehyde, the aerial plant parts versus the root system of *F. japonica* and *F. benjamina* showed removal pattern differently during day (≈1:1) and night (1:11) (Kim et al, 2008). Bacteria are well known to have the capability to degrade aromatic pollutants (Diaz and Prieto, 2000; Edwards and Garbic-Galic, 1992; Hutchins, 1991; Leahy and Colwell, 1990).

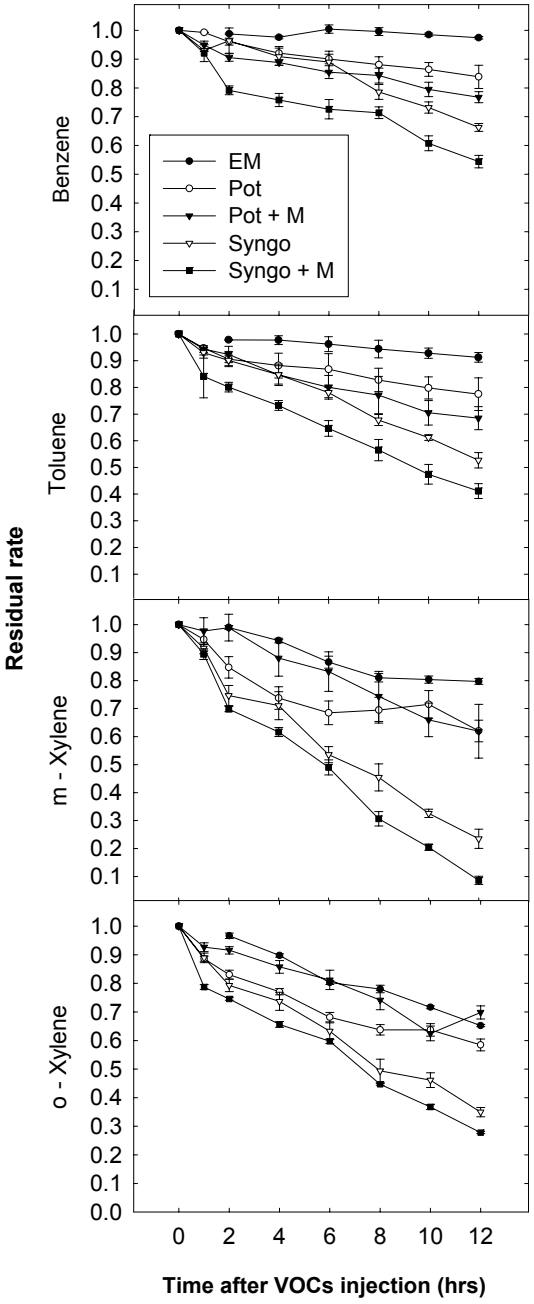

Fig. 3. Effect of *S. podophyllum* and inoculation of total rhizobacterial population of *P. aquatica* on removal of volatile organic compounds. EM, empty growth chamber; Pot, with Hydroball but plant; Pot + M, Pot with Hydroball and inoculation of total rhizobacterial population of *P. aquatica*; Parchira, Pot planted with *S. podophyllum*; Parchira + M, *S. podophyllum* inoculated with total rhizobacterial population of *P. aquatica*. The other experimental condition and procedures were identical to Figure 1.

The results in this study indicated that the microbial population of plant rhizosphere in the pot could play a role to remove the harmful VOCs which indoor and indoor plants could benefit to improve indoor air quality. At present we are studying effect of single bacterial isolates from the plant rhizophere on removal efficiency of VOCs such as benzene and toluene. If we could find better isolates to remove VOCs, those bacteria could be utilized to make plant-bacterial pot systems to improve air quality indoor.

Furthermore, the number of human pathogenic bacteria detected from the air that passed through the pot plant systems used in this experiment was not significantly different from

Table 2. Human pathogenic bacteria detected from the agar plate exposed to air flow through the apparatus of plant removal system for VOCs.

Treatment[z]	Number of bacteria (CFU/plate)		
	E.coli and Coliform	*Salmonella* spp.	*Staphylococcus* spp.
Control 1	0.0[y]	0.0	0.0
Control 2	0.3	0.0	0.0
Control 3	0.7	0.0	0.0
Hydroball	0.3	0.0	0.0
S. trifasciata	0.3	0.0	1.0
D. deremensis	0.0	0.0	0.0
N. exalatata	0.0	0.0	0.7
Rhapis excels	0.0	0.0	1.0
P. aquatica	0.0	0.0	1.0
F. elastica	0.0	0.0	0.3
F. benjamina	0.0	0.0	0.3
H. helix	0.0	0.0	0.3
S. podophyllum	1.0	0.0	0.3

[z]Control 1-3 are for the comparison of the treatments.
[y]There was no significant difference in the mean of CFU (colony forming unit) per plate placed in front of the fan where air passed through the growth medium of the different plant systems of VOCs removal (Dunnett's Control vs all others, P=0.05). The controls were open empty agar plates placed on laboratories for each bacterial species.

the controls, suggesting that the air passed through the rhizosphere of the Hydroball pot plant air circulation system may not have potential threat to people who are concerned with soil bacteria in the pot (Table 2).

Literature Cited

Abbritti, M.C. and G. Muzi. 1995. Indoor air quality and health effects in office buildings. University of Milano and International Center for Pesticide Safety, Milan, Italy, Vol. 1, pp. 185-195. In M. Maroni (ed.), Proceedings of Healthy Buildings '95, An International Conference on Healthy Buildings in a Mild Climate.

American Lung Association. 2001. In Air Quality. When you can't breathe, nothing else matters. www.lungusa.org/air/

Brown, S.K., M. Sim, M.J. Abramson, and C.N. Gray. 1994. Concentrations of volatile organic compounds in indoor air − A review. Indoor Air 4:123-134.

Brown, S.K. 1997. Volatile organic compounds in indoor air: sources and control. Chem. Australia, January/February:10-13.

Burge, S., A. Hedge, S. Wilson, B.J. Harris, and A. Robertson. 1987. Sick building syndrome: a study of 4373 office workers. Ann. Occup. Hygiene 31:493-504.

Cape, J.N., J. Binnie, N. Mackie, and U.M. Skiba. 2000. Uptake of volatile organic compounds by grass. In proceedings of third SETAC world Congress, 2000, Brighton, UK.

Collins, C.D., J.N. B. Bell, and C. Crews. 2000. Benzene accumulation in horticultural crops. Chemosphere 40:109-114.

Diaz, E. and M.A. Prieto. 2000. Bacterial promoters triggering biodegradation of aromatic pollutants. Curr. Opin. Biotech. 11:467-475.

Edwards, E.A. and D. Gabic-Galic. 1992. Complete mineralization of benzene by aquifer microorganisms under strictly anaerobic conditions. Appl. Environ. Microbiol. 58:2663-2666.

Foyer, C.H., P. Descourvieres, and K.J. Kunert. 1994. Protection against oxygen radicals: An important defense mechanism studied in transgenic plants. Plant, Cell and Environ. 17:507-523.

Hutchins, S.R. 1991. Biodegradation of monoaromatic hydrocarbons by aquifer microorganisms using oxygen, nitrate or nitrous oxide as the terminal electron acceptor. Appl. Environ. Technol. 57:2403-2407.

Jen, M.S., A.M. Hoylman, N.T. Edwards, and B.T. Walton. 1995. Experimental method to measure gaseous uptake of ^{14}C-toluene by foliage. Environ. Expt. Bot. 35:389-398.

Jenkins P.L., T.J. Phillips, E.J. Mulberg, and S.P. Hui. 1992. Activity patterns of Californians-Use of and proximity to indoor pollutant sources. Atmos. Environ. 26:2141-2148.

Kim, K.J., M.J. Kil, J.S. Seob, E.H. Yoo, K.C. Son, and S.J. Kays. 2008. Efficiency of volatile formaldehyde removal by indoor plants: contribution of aerial plant parts versus the root zone. J. Amer. Soc. Hort. Sci. 133:521-526.

Leahy, J.G. and R.R. Colwell. 1990. Microbial degradation of hydrocarbons in the environment. Microbiol. Rev. 54:305-315.

Mendell, M.J. and A.H. Smith. 1990. Consistent pattern of elevated symptoms in air-conditioned office buildings: A re-analysis of epidemiological studies. Amer. J. Pub. Health, 80:1193-1199.

National Occupational Health and Safety Commission (Australia). 1991. Exposure standards for atmospheric contaminants in the occupational environment. Australian Government Printing Service, Canberra, Australia.

Radwan, S.S., H. AL-Awadhi, N.A. Sorkhoh, and I.M. EL-Nemr. 1998. Rhizospheric hydrocarbon utilizing microorganisms as potential contributors to phytoremediation for the oily Kwaiti desert. Microbiol. Res. 153:247-251.

Sanderman, H.J.R. 1992. Plant metabolism of xenobiotiocs, Trends Biochem. Sci. 17:82-84.

Schulte-Hostede, S., N.M. Darrall, L.W. Blank, and A.R. Wellburn. 1987. Air Pollution and plant metabolism, Elsevier, NY, USA.

Systat Software, Inc., Point Richmond, USA

Taylor, G.E., L.F. Pitelka, and M.T. Clegg. 1991. Ecological genetics and air pollution, Springer Verlag, NY, USA.

Ugrekhelidze, D., F. Korte, and G. Kvestttadze. 1997. Uptake and transformation of benzene and toluene in plant tissues. Ecotoxicol. Environ. Safety 37:24-29.

Weschler, C.J. and H.C. Shields. 1997. Potential reactions among indoor air pollutants. Atmospheric Environ. 31:3487-3495.

Wolkoff, P. 1995. Volatile organic compounds - Sources, measurements, emissions and the impact on indoor air quality. Indoor Air. Suppl. No. 3.

Wolverton, B.C. and J.D. Wolverton. 1993. Plants and soil microorganisms - removal of formaldehyde, xylene and ammonia from the indoor environment. Jour. Mississippi Academ. Sci. 38:11-15.

Wood, R.A., R.L. Orwell, J. Tarran, F. Torpy, and M. Burchett. 2002. Potted-plant/growth media interactions and capacities for removal of volatiles from indoor air. J. Hort. Sci. Biotech. 77:120-129.

Yoo, M.H., Y.J. Kwon, K.C. Son., and S.J. Kays. 2006. Efficacy of indoor plants for the removal of single and mixed volatile organic pollutants and physiological effects of the volatiles on the plants. J. Amer. Soc. Hort. Sci. 131:452-458.

Zabiegata, B. 2006. Organic compounds in indoor environments. Polish J. Environ. Stud. 15:383-393.

다양한 관엽식물의 근권부 박테리아 집단이 실내 휘발성 유기화합물질의 제거에 미치는 영향

천세철[1] · **류명화**[2] · **문영숙**[1] · **신미호**[1] · **손기철**[2*] · **정일민**[3] · S.J. Kays[4]

[1]건국대학교 분자생명공학과, [2]건국대학교 환경과학과, [3]건국대학교 응용생물과학과, [4]미국 조지아대학교 원예학과

(*교신저자)

초 록. 실내식물 9종의 근권부 하이드볼 배지에서 배양된 세균집단이 공기중 벤젠과 같은 휘발성 유기화합물의 제거효과에 미치는 영향이 조사되었다. 여러 식물 근권부의 배양토에서 배양된 세균 집단은 벤젠을 제거할 수 있었는데, *Spathiphyllum wallisii* Regel, *Pachira aquatica*, *Ficus elastica*, *Dieffenbachia* sp. 'Marrianne' Hort., *Chamaedorea elegans* 식물들은 벤젠의 초기농도를 1.000으로 기준하였을 때, 세균 집단이 전혀 없는 배지의 대조구 초기 농도 대비 잔류율이 0.596이었으나 상기 언급한 식물들은 0.741-1.000으로서 벤젠의 농도를 현저히 감소시켰다(LSD, P=0.05). 이와 같은 경향은 식물의 종류에 따라 차이는 있었지만 톨루엔의 경우에도 비슷하게 나타났다. 이러한 결과를 바탕으로 *P. aquatic* 근권부의 배양토로부터 배양된 세균 집단을 *P. aquatica*, *F. elastica*, *S. podophyllum*에 접종하였을 때 접종하지 않은 식물들에 비하여 벤젠과 톨루엔을 현저히 제거하는 효과가 나타나, 근권부의 미생물 집단을 이용하여 공기 중 휘발성 유기화합물(VOC)을 제거할 수 있음을 보여 주었다.

추가 주요어 : 세균, 접종, 식물-미생물 시스템