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Full Paper

Phytoremediation of anthracene- and fluoranthenecontaminated soil by *Luffa acutangula*

Khanitta Somtrakoon^{1,*}, Waraporn Chouychai² and Hung Lee³

¹Department of Biology, Faculty of Science, Mahasarakham University, Kantharawichai, Mahasarakham, Thailand 44150

² Biology Programme, Faculty of Science and Technology, Nakhonsawan Rajabhat University, Nakhonsawan, Thailand 60000

³ School of Environmental Sciences, University of Guelph, Guelph, Ontario, N1G 2W1, Canada

* Corresponding author, e-mail: khanitta.s@msu.ac.th

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Abstract: Phytoremediation of soil contaminated with anthracene and fluoranthene, either alone or together, by ridge gourd (Luffa acutangula) was investigated through laboratory pot experiments in a greenhouse for 45 days. The initial concentration of anthracene or fluoranthene was 100 mg kg⁻¹ when each was spiked alone. When spiked together, the initial concentration of each hydrocarbon was 50 mg kg⁻¹. The ridge gourd grew normally in anthracene-contaminated soil based on assessment of shoot growth at the end of the experiment. Fluoranthene spiked either alone or together with anthracene was toxic to the plant as shown by significantly reduced shoot and root growth, especially on day 45 after transplantation. Planting of ridge gourd was more effective in decreasing the amount of anthracene and fluoranthene from soil than un-planted control during the 45-day experiment. Only 0.5-1.8% and 3.1-14.1% of anthracene and fluoranthene respectively were detected in planted soil on day 45. In contrast, 27.7-48.2% and 46.9-73.8% of anthracene and fluoranthene respectively, spiked alone or together, remained in the control un-planted soil during the same period. The two aromatic hydrocarbons were neither detected in the shoot nor root tissue of the ridge gourd, which suggests that phytostimulation may be the most likely mechanism by which these hydrocarbons were removed from soil.

Keywords: phytoremediation, anthracene, fluoranthene, Cucurbitaceae, ridge gourd, Luffa acutangula

INTRODUCTION

The presence of polycyclic aromatic hydrocarbons (PAHs) in the environment is of serious concern due to their mutagenic and carcinogenic potential. The hydrophobicity of PAHs and their strong sorption onto the organic portion of soil particles contribute to their recalcitrance and persistence in the environment. While PAHs are found in air, water, soil and vegetation, soil and sediment are considered to be the ultimate sink of PAH contaminants in the environment [1, 2]. PAH contamination in soil increases the exposure risk of these compounds to living organisms. PAH contamination has been reported worldwide including Thailand. For example, the total concentration of PAHs bearing 3-7 rings was found to range between 6-8400 ng g⁻¹ in surface sediment (dry weight) of the coastal and riverine areas in the Gulf of Thailand and the mouth of Chao Praya River [3]. Anthracene and fluoranthene are selected as model PAHs in this study due to their toxic effect on various organisms [4-6]. These PAHs are listed as hazardous pollutants by the United States Environmental Protection Agency (USEPA.) [1, 7].

Phytoremediation refers to the use of plants and their associated microorganisms to clean up polluted areas. This technique can be effective for the remediation of large areas contaminated with diffuse pollutants [7]. Some plants in Pocaceae and Leguminaosae have been tested with some degree of success for remediation of soil contaminated with anthracene, fluoranthene and other PAHs. For example, the residual fluoranthene in soil planted with ryegrass decreased from 88.7 to 26.4 mg kg⁻¹ in 70 days [8]. Ryegrass also reduced the amount of anthracene and fluoranthene in a historically PAH-contaminated site from 6.0 to 2.2 and 103.5 to 38.6 mg kg⁻¹ respectively, after 18 months of cultivation [9]. Leguminosae such as alfalfa and white clover significantly promoted the degradation of pyrene in soil: only 191.55 and 183.58 mg kg⁻¹ (from initial concentration of 321.42 mg kg⁻¹) remained in soil after 70 days of cultivation with alfalfa and white clover respectively, as compared to 278.74 mg kg⁻¹ of pyrene remaining in unplanted soil [10]. Some of the other plants used in PAH phytoremediation include *Mimosa monancistra*, *Festuca arundinacea*, *Psophocarpus tetragonolobus*, *Zea mays*, *Zostera marina* and *Vicia faba* [11-15]. The extent of PAH removal by planting usually was greater than the unplanted control, but the efficiency may vary depending on the plant species, soil texture, soil pH and type of PAHs.

Plants of the Cucurbitaceae family have been used to remediate some organic pollutants such as PCBs, DDT, DDE and heptachlor [16-18]. For example, *Lagenaria siceraria* cultivar Hyotan was shown to decrease heptachlor epoxide from 0.376 to 0.050 μ g g⁻¹ dry soil [16]. Somtrakoon et al. [15] reported that cucumber (*Cucumis sativus*) was effective in removing anthracene and fluoranthene from soil. However, this plant was not tolerant of their toxicity and died after 25-30 days of transplantation. Other plants in the Cucurbitaceae family such as *Cucurbita pepo* and *Legenaria siceraria* have also been observed to accumulate some soil contaminants such as anthracene, fluoranthene, heptachlor epoxide and dioxin-like compounds [16, 17, 19]. Although, the toxicity of PAHs on ridge gourd (*Luffa acutangula*), another plant in the Cucurbitaceae family, has been reported [20], to our knowledge it has not been used to remediate PAH-contaminated sites. In this study we therefore undertake to investigate the potential of ridge gourd for remediating PAH-contaminated soil.

MATERIALS AND METHODS

Soil Preparation

Soil with no previous history of anthracene and fluoranthene contamination as verified by GC-MS analysis (described below) was obtained from Kookaew Temple, Kantharawichai district, Mahasarakham province, Thailand. The soil was air dried at room temperature ($29\pm1^{\circ}$ C) for at least 72 hr to constant weight before use. A sample of this soil was sent to Central Laboratory (Thailand) Co. for physical and chemical characterisation. It was of clay texture with a pH of 8.1 and electrical conductivity of 109.5 µs cm⁻¹, and contained 2.4% organic matter, 0.29% total nitrogen and 58.38 mg kg⁻¹ available phosphorus.

About 20% of the soil was spiked with anthracene (98%, Fluka), fluoranthene (99%, Fluka) or a mixture of the two dissolved in dichloromethane. After thorough mixing, the solvent was allowed to evaporate inside a fume hood at room temperature $(29\pm1^{\circ})$ for 48 hr. Then the spiked soil was added to the remaining 80% of unspiked soil and mixed thoroughly. The initial concentration of anthracene or fluoranthene in single-PAH-spiked soil was 100 mg kg⁻¹, while in mixed-PAH-spiked soil the concentration was 50 mg kg⁻¹ of each. Finally, the spiked soil samples were transferred to pots.

Seedling Preparation

Commercial seeds of ridge gourd (*Luffa acutangula*) were obtained from Chia Tai Group Co., Bangkok. Seeds were rinsed with sterile distilled water and immersed in distilled water for 3 hr. They were then germinated in moist soil spiked with anthracene, fluoranthene or a mixture of the two in experimental pots and kept at $29\pm1^{\circ}$ in a plant nursery which received natural sunlight. After 10 days, healthy plant seedlings with comparable sizes were picked and transplanted in pots with soil containing the same PAH or PAH combination as that used for germination.

Experimental Design

Pot experiments were performed in a plant nursery from March to May, 2012. In single and mixed PAH experiments, each pot containing spiked soil (1 kg dry weight) was planted individually with a 10-day-old seedling. Pots with ridge gourd seedlings in unspiked soil served as control. Other controls were soil spiked with anthracene, fluoranthene or their mixture but without any plants. Three independent replicates of each treatment were prepared in a completely randomised design and the total number of pots were 21. The detail of each treatment is described as follows:

- 1) Anthracene-spiked soil planted with ridge gourd 3 pots
- 2) Fluoranthene-spiked soil planted with ridge gourd 3 pots
- 3) Anthracene+fluoranthene-spiked soil planted with ridge gourd 3 pots
- 4) Anthracene-spiked soil without ridge gourd planting 3 pots (control for anthracene removal)
- 5) Fluoranthene-spiked soil without ridge gourd planting 3 pots (control for fluoranthene removal)
- 6) Anthracene+fluoranthene-spiked soil without ridge gourd planting 3 pots (control for anthracene and fluoranthene removal)
- 7) Unspiked soil planted with ridge gourd 3 pots (control for plant growth)

All pots were supplemented periodically with sterile distilled water to maintain the water content of the soil at about 60% for 45 days. The placement of pots in the nursery was changed randomly every week. One gram (dry weight) each of the rhizospheric soil and bulk soil from planted soil were carefully collected on day 20 and 45 for analysis of anthracene and fluoranthene

concentrations by gas chromatography - mass spectrometry (GC-MS). Soil samples from unplanted control treatments were also collected and analysed. The plants from single and mixed PAH pots were sampled on day 20 and 45 to determine the length, fresh weight and dry weight of shoot (including leaves and stem) and root. During removal of the plants from soil, the root was shaken gently to dislodge any loose soil into the rest of the soil in the pot and this was referred to as the bulk soil. The rhizospheric soil referred to the soil which remained tightly bound to the root system, and it was removed from the plant root by shaking in a plastic bag after a short period of air drying (about 12 hr). The root debris in the collected rhizospheric soil was removed by sieving.

PAH Extraction and Analytical Procedures

One gram of dried, PAH-containing soil was mixed with anhydrous sodium sulfate powder in 1:1 ratio. Fluorene (purity 99%, Fluka) was then added as internal standard (50 μ L of 200 mg L⁻¹ fluorene stock solution prepared in dichloromethane). The mixture was extracted with 180 mL of dichloromethane for 8 hr in a Soxhlet extractor and the solution obtained was evaporated at 60° to near dryness under reduced pressure. Anthracene and fluoranthene in the shoot and root of each plant were extracted in the same way. The shoot or root was dried in an incubator at 60° to constant weight before mixing with anhydrous sodium sulfate. Anthracene and fluoranthene concentrations in the dichloromethane extracts were determined using a gas chromatograph (Shimadzu GC AOC-5000) equipped with a mass spectroscopic detector (Shimadzu MS-QP2010) as described by Somtrakoon et al. [15].

Statistical Analysis

Per cent of each PAH remaining was expressed as the mean \pm SD. One-way ANOVA was used to test for statistical significance among treatments. Subsequent multiple comparisons of means were performed using the Turkey comparison method. Statistical significance was accepted at P<0.05.

RESULTS

General Health of Ridge Gourd Grown in PAH-Contaminated Soil

In unspiked control pots, the ridge gourd grew well, flourished and produced fruits between day 40-45 of transplantation. In soil spiked with anthracene, fluoranthene or anthracene + fluoranthene, the ridge gourd grew, but did not produce fruits until about 45 days after transplantation. The toxic effects of these PAHs were mostly manifested in the reduced shoot length. The shoot length of ridge gourd grown in PAH-spiked soil was shorter than that grown in unspiked soil (Figures 1a and 1b).

Shoot Growth and Root Growth of Ridge Gourd

The ridge gourd showed delayed growth in PAH-spiked soils, as evidenced by the shorter length and lower fresh and dry weight of its shoots, compared to those of the control plants on day 20 (Table 1). In anthracene-spiked soil, however, the growth of the ridge gourd caught up such that by day 45, the shoot length was similar to that of the control plant grown in unspiked soil, and the shoot fresh and dry weights also increased to values approaching those of the control plant. In contrast, in soil spiked with fluoranthene or anthracene + fluoranthene, the shoot length remained significantly shorter than that of the control plant on day 45 (Table 1). The shoot length of ridge gourd grown in fluoranthene and anthracene+fluoranthene mixture was only 68.7 and 87.0 cm

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respectively. In comparison, the shoot length of the control plant in unspiked soil was 106.2 cm. This is also reflected in the significantly lower shoot fresh weight (4.8 g and 5.6 g) and shoot dry weight (0.8 g and 0.8 g) of the plants grown for 45 days in soil with fluoranthene and anthracene+fluoranthene mixture respectively. In comparison, shoot fresh weight and dry weight of the control plant were 14.8 g and 2.6 g respectively) (Table 1).



Figure 1. Comparative shoot growth of ridge gourd after 45 days of transplantation in: (a) unspiked soil (left), anthracene-spiked soil (middle), and fluoranthene-spiked soil (right); (b) unspiked soil (left) and anthracene+fluoranthene-spiked soil (right) (ANT = anthracene, FLT = fluoranthene)

	Day 20			Day 45		
Soil	Shoot length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Shoot length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)
Unspiked (control)	$111.1 \pm 3.8a$	12.9 ± 0.9a	$1.2 \pm 0.2a$	$106.2 \pm 2.1a$	$14.8 \pm 3.0a$	$2.6 \pm 0.4a$
Anthracene-spiked	$33.0 \pm 2.2c$	$3.6 \pm 1.2b$	$0.4 \pm 0.1 b$	$108.3 \pm 3.0a$	$11.2 \pm 0.1a$	$2.0\ \pm 0.3a$
Fluoranthene-spiked	$52.6 \pm 2.8b$	$3.2 \pm 0.5b$	$0.5 \pm 0.1b$	$68.7 \pm 8.8c$	$4.8\pm0.4b$	$0.8\pm0.1b$
Anthracene+Fluoranthene-	$28.6 \pm 3.0c$	$2.2 \pm 0.8b$	$0.3 \pm 0.0b$	87.0 ± 5.8 cb	$5.6 \pm 1.2b$	$0.8\pm0.2b$
spiked						

Table 1. Shoot length, shoot fresh weight and shoot dry weight of ridge gourd grown in anthracene- and fluoranthene-spiked soil

Note: Different letters denote significant difference (P<0.05) in the same column.

Table 2. Root length, root fresh weight and root dry weight of ridge gourd grown in anthraceneand fluoranthene-spiked soil

		Day 20			Day 45	
Soil	Root length (cm)	Root fresh weight (g)	Root dry weight (g)	Root length (cm)	Root fresh weight (g)	Root dry weight (g)
Unspiked (control)	26.1 ± 1.1a	1.7 ± 0.5a	$0.09 \pm 0.1a$	74.5 ± 18.4a	5.8 ± 1.3a	$0.4 \pm 0.1a$
Anthracene-spiked	$24.7 \pm 1.2a$	$0.5 \pm 0.1 b$	$0.04\pm0.0b$	55.2 ± 2.9 ab	$2.9\pm0.9b$	$0.2 \pm 0.1 ab$
Fluoranthene-spiked	$28.5\pm2.3a$	$0.6 \pm 0.2b$	$0.03 \pm 0.0b$	$26.7 \pm 6.6c$	$0.8\pm0.1b$	$0.1 \pm 0.1b$
Anthracene+Fluoranthene-	$21.2 \pm 5.7a$	$0.4 \pm 0.0b$	$0.03 \pm 0.0b$	31.7 ± 2.0 bc	$1.5 \pm 0.0 \mathrm{b}$	$0.1 \pm 0.0b$
spiked						

Note: Different letters denote significant difference (P<0.05) in the same column.

The root of ridge gourd was adversely affected when the plant was grown in PAHcontaminated soil as compared to that of control plants grown in unspiked soil. This is readily seen in the low root weight (fresh and dry) of all the plants in PAH-spiked soil on both day 20 and 45 (Table 2). As for root length, the adverse effect of the PAHs was not apparent on day 20, but by day 45 the root length of all the plants grown in PAH-spiked soil was clearly shorter than that of the control plant in unspiked soil. The most severe effect is seen in the root length, root fresh weight and root dry weight of the plant grown in fluoranthene-spiked soil, which decreased to only 26.7 cm, 0.8 g and 0.1g respectively on day 45.

Anthracene and Fluoranthene in Plant Tissues

Anthracene and fluoranthene were not detected in any of the shoot and root samples of ridge gourd grown in PAH-spiked soil on day 20 or 45 (data not shown). The detection limit was 0.4 mg kg⁻¹ for each PAH by GC.

Anthracene Removal from Soil

Planting of ridge gourd in anthracene-spiked soil led to its significant removal irrespective of whether the soil was spiked with anthracene alone or in combination with fluoranthene. The rapid removal of anthracene in the planted soil was seen on day 20 when more than 87% of the spiked anthracene was removed from both the bulk and rhizospheric soils (Table 3). By day 45,

only about 0.5-1.8% of the initial anthracene remained. Anthracene in the rhizospheric soil was removed to a slightly greater extent than that in the bulk soil. In unplanted control soil, about 28-48% of the initial anthracene remained on day 45 (Table 3).

Treatments	% of anthracene remaining			
-	Day 20	Day 45		
Control (unplanted, soil spiked with ANT)	$104.9 \pm 21.3a$	$48.2\pm0.1a^{\boldsymbol{*}}$		
Planted, soil spiked with ANT				
Bulk soil	12.7±19.0b*	$1.8 \pm 0.4b^*$		
Rhizospheric soil	$4.7 \pm 5.7b^*$	$1.1 \pm 1.1b^*$		
Control (unplanted, soil spiked with ANT+FLT)	66.6 ± 25.0 ab	27.7 ± 32.7ab*		
Planted soil spiked with ANT+FLT				
Bulk soil	$4.8\pm2.9b\texttt{*}$	$1.2 \pm 0.0b*$		
Rhizospheric soil	$3.9\pm0.9b\texttt{*}$	$0.5 \pm 0.2b^{*}$		

Table 3. Percentages of anthracene remaining in soil planted with ridge gourd

Note: Initial concentration of anthracene (ANT) was 100 mg kg⁻¹ when spiked alone and 50 mg kg⁻¹ when spiked together with fluoranthene (FLT).

Different letters show significant difference (P < 0.05) between treatments on the same column. * Value is significantly different (P < 0.05) from that at day 0.

Table 4. Percentages of fluoranthene remaining in soil planted with ridge gourd

	% Fluoranthene remaining		
Soil	Day 20	Day 45	
Control (unplanted, spiked with FLT)	$82.8 \pm 40.7a$	$73.8 \pm 15.3a$	
Planted, spiked with FLT			
Bulk soil	$16.1 \pm 11.3b^*$	$14.1 \pm 4.6b^*$	
Rhizospheric soil	$15.0 \pm 1.8b^*$	$3.1 \pm 1.4b^*$	
Control (unplanted, spiked with ANT+FLT)	$84.2 \pm 19.7a$	$46.9 \pm 32.2a^*$	
Planted, spiked with ANT+FLT			
Bulk soil	9.3 ±4.4b*	$7.9 \pm 3.9b^{*}$	
Rhizospheric soil	$8.1 \pm 0.5b^{*}$	$5.5 \pm 3.7b^{*}$	

Note: Initial concentration of fluoranthene (FLT) was 100 mg kg⁻¹ when spiked alone and 50 mg kg⁻¹ when spiked together with anthracene.

Different letters show significant difference (P < 0.05) between treatments on the same column. * Value is significantly different (P < 0.05) from that at day 0.

Fluoranthene Removal from Soil

Fluoranthene, whether spiked alone or in combination with anthracene, was also rapidly removed from soil planted with the ridge gourd, although the extent of removal was not as fast or great compared to that for anthracene. On day 20, 8.1-16.1% of the spiked fluoranthene remained in planted soil (Table 4). By day 45, the amount of fluoranthene remaining declined further to 3.1-14.1%. The percentages of fluoranthene removal from the rhizospheric and bulk soils were not significantly different. In unplanted soil spiked with fluoranthene alone, 82.8% and 73.8% of fluoranthene remained on day 20 and 45 respectively. With fluoranthene and anthracene, the corresponding values were 84.2 and 46.9%.

DISCUSSION

Both anthracene and fluoranthene have been reported to adversely affect shoot and root growth of waxy corn, sweet corn and rice seedlings, fluoranthene being more toxic than anthracene [21]. In our study a similar toxic effect of anthracene and fluoranthene was also apparent in the decreased shoot and root lengths of ridge gourd on day 45. Some plants in the Cucurbitaceae family have been shown to stimulate PAH biodegradation in the rhizosphere, while others were reported to accumulate PAHs in their tissues [19, 22]. For example, cucumber (Cucumis sativus) was shown to enhance the removal of anthracene and fluorene from PAH-spiked soil [15]. The amounts of anthracene and fluorene remaining in its rhizospheric soil were only 9.5% and 4.6% respectively of the initial concentration on day 30 after transplantation. In comparison, the amounts of the two PAHs remaining in unplanted control soil on day 30 were 76.1% and 60.8% respectively. However, the plant was very sensitive to these PAH contaminants and was less healthy when grown together with winged bean (Z. mays) and finally died between 25-30 days after transplantation. In a different study, the rhizospheric soil of plants in the Cucurbitaceae family was found to be effective in removing a total of 16 PAH compounds, which decreased to the lowest amount of 1118.6 mg kg⁻¹ from 3306 mg kg⁻¹ in the control soil [22]. In another study, zucchini (*Curcubita pepo* Ravaen) planted in soil obtained from a coal gasification plant enhanced the removal of several PAHs after 90 days. The plant led to high extent of removal of fluorene (41%), anthracene (50%), fluoranthene (55%), pyrene (64%), benz(e)pyrene (60%) and benzo(k)fluoranthene (74%) (cf. 87%, 12%, 13%, 3.8%, 0% and 2.4% respectively in unplanted soil) [23].

The enhanced removal of anthracene and fluoranthene by ridge gourd observed in this study follows the same trend as shown by other plants. Kim et al. [24] reported that 89.8%, 77% and 76.1% of anthracene (initial concentration = 660-670 mg/kg) were removed from soil planted for 63 days with alfalfa, barley and tall fescue respectively. In comparison, about 72.4% was removed from unplanted soil and 71.4% from soil planted with orchard grass. In another study, planting with willow for 12 weeks led to 84% removal of fluoranthene (initial concentration = 3.3 mg/kg) from creosote-contaminated soil (cf. 75% removal in unplanted soil) [25]. In our study, the amounts of anthracene and fluoranthene removed from soil planted with ridge gourd for 45 days were more than 98.2 and 85.9% respectively (initial concentration = 100 mg/kg), while in unplanted soil the amounts removed were, respectively, 51.8 and 26.2%. Based on this results, ridge gourd could be an effective plant for PAH phytoremediation. Further studies are needed using other PAHs and by varying their concentrations to assess the plant's PAH phytoremediation potential.

In this study anthracene and fluoranthene seem to have been degraded by competent microorganisms in the rhizospheric soil of ridge gourd as well as bulk soil. While no specific microbial analysis had been done, the availability of these microorganisms in the soil is suggested

by the removal of some anthracene and fluoranthene from unplanted soil in the control pots. In the presence of the plant, the per cent degradation of anthracene and fluoranthene increased. Given that anthracene and fluoranthene were not accumulated by the plant, its cultivation in PAH-spiked soil must have provided suitable conditions for stimulating the degradation of PAHs by indigenous microorganisms. Thus, the significant enhancement of anthracene and fluoranthene removal by ridge gourd points to the value of phytoremediation in stimulating microbial activity to clean up PAH-contaminated soil.

PAHs are commonly found in mixtures in the environment. The degradation of individual PAHs may be affected by the presence of other PAHs. Both synergistic and antagonistic effects during degradation of PAH mixtures have been reported [26]. For example, Somtrakoon et al. [27] observed that *Burkholderia* sp. VUN10013 could degrade anthracene but not fluoranthene when each was supplied as the sole carbon source. However, when both compounds were supplied together, the presence of anthracene stimulated the degradation of fluoranthene by strain VUN10013 and the presence of fluoranthene reduced the extent of anthracene degradation. In this instance, anthracene was thought to induce enzymes needed for the transformation of fluoranthene [27]. There are examples where the presence of one PAH may impede the degradation of another PAH. For example, *Pseudomonas* sp. strain *S Ant Mu5* was reported to degrade anthracene was lowered when it was supplied together with fluorene. It was speculated that the inhibition of anthracene degradation might be due to the formation of toxic metabolite(s) during fluorene degradation [28].

Plants in the Cucurbitaceae family have been reported to accumulate PAHs and other organic pollutants in their tissues. For example, the root and shoot tissues of *Cucurbita pepo* ssp. *pepo* cv. Raven could accumulate pyrene from soils with the amount accumulated ranging between 9.6-36.7 μ g/plant [29], while *C. pepo* ssp. *pepo* cv. Gold Rush accumulated pyrene in both its shoot and root up to 16.0 μ g g⁻¹ and 1.7 μ g g⁻¹ respectively [30]. The vine of *Lagenaria siceraria* accumulated heptachlor epoxide with bioaccumulation factors of 1.0-5.2 [16]. *C. pepo* ssp. *texana* cv. Patty Green and *C. pepo* ssp. *pepo* cv. Black Beauty and Gold Rush also accumulated dioxin-like compounds [17], while *C. pepo* ssp. *pepo* cv. Black Beauty could accumulate anthracene and fluoranthene with bioaccumulation factors of 26.5 and 5.17 respectively [19]. Anthracene was reported to accumulate in lettuce and radish and the amount accumulated varied depending on the application method and plant species [31]. However, the ridge gourd in our study was not found to accumulate anthracene and fluoranthene.

CONCLUSIONS

Ridge gourd shows great promise of use in the phytoremediation of soil contaminated with anthracene and fluoranthene because of its ability to tolerate and grow in PAH-spiked soil. The enhanced degradation of anthracene and fluoranthene relative to that in control unplanted soil occurs in both the rhizospheric soil and bulk soil. Most of the anthracene and fluoranthene were effectively removed from soil during the 45-day experiment and the PAH degradation was most likely accomplished by competent microorganisms, in particular those residing in the rhizosphere. The precise mechanism(s) by which the ridge gourd can enhance the removal of anthracene and fluoranthene from soil warrants investigation.

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