



Journal of Environmental Science and Technology

ISSN 1994-7887

science
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Quantification of Polycyclic Aromatic Hydrocarbons in Leafy and Underground Vegetables: A Case Study Around Panipat City, Haryana, India

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ABSTRACT

Food ingestion is the most important means of human exposure to Polycyclic Aromatic Hydrocarbons (PAHs). The Polycyclic Aromatic Hydrocarbons (PAHs) were observed in all vegetables which is matter of great concern because diet is the major source of human exposure to PAHs and major dietary source of human are cereals and vegetables. Our main objective of investigation was to assess the concentration of individual PAHs compounds in leafy and underground vegetable samples. In the present study the PAHs concentrations were determined by using High Performance Liquid Chromatography (HPLC). All the samples were collected from 9 different agriculture fields around Panipat city, Haryana and PAHs concentration was identified in all the vegetables (leafy and underground) and soil (0-10 cm upper layer). The total PAHs concentration in leafy vegetables, underground vegetables and soil ranged from 31.86 to 85.55, 22.89 to 37.73 and 130.18 to 175.98 $\mu\text{g kg}^{-1}$ dry weight, respectively. The dominant PAHs in soil and vegetable samples were Naphthalene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene, Fluoranthene and Pyrene. The concentration of lower-molecular weight PAHs compounds were found to be greater than higher molecular weight PAHs in all types of vegetables. Leafy vegetables are found to be more contaminated with higher concentration of PAHs as compared to underground vegetables.

Key words: PAHs, ultrasonicator, UV-detector, C-18 material, acetonitrile

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are a class of toxic xenobiotic fused-ring aromatic compounds consisting of hydrocarbon molecules of two or more fused benzene and/or pentacyclic rings in linear, angular or cluster formation (Muckian *et al.*, 2007). Polycyclic Aromatic Hydrocarbons (PAHs), as a result of the incomplete combustion of organic matter, emission sources, automobile exhaust, coal-fired electricity, generating power-plants, domestic matter and area source matter are ubiquitous in environment (Zhang *et al.*, 2006). More than 100 PAHs have been characterized in nature, sixteen of which were classified as priority pollutants according to the US Environment Protection Agency (Bishnoi *et al.*, 2005). Several of these compounds are carcinogenic

and/or mutagenic therefore, they may pose a human health threat. Karami-Varnamkhasti *et al.* (2008) reported mortality of juvenile anglefish (*Pterophyllum scalare*) exposed to six different concentrations of naphthalene, anthracene, phenanthrene and pyrene. Abdelmeguid *et al.* (2009) also reported sever effect of Polycyclic Aromatic Hydrocarbons (PAHs) in major ultrastructural changes of hepatopancreas of *Palaemon serratus*. In addition, they are lipophilic and may accumulate in vegetation (Kipopoulou *et al.*, 1999) that could indirectly cause human exposure through food consumption (Juhasz and Naidu, 2000). In most of cases, diet is the main source of human exposure to these pollutants. The occurrence of PAHs in variety of plants has been demonstrated (Wennrich *et al.*, 2001). Vegetables and in particular leafy vegetables, can act as an indicator of human exposure to PAHs (Zhang *et al.*, 2004). It is suggested that PAHs present in water soluble fraction may modify the availability absorption and/or passive uptake of Na⁺ in *Paspalum conjugatum* (Ibemesim, 2010). It has also been reported that PAHs are present in cereals, grains, flour, bread, vegetables, fruits, fish, meat, processed or pickled foods and contaminated cow's milk or human breast milk (FSA, 2002; White *et al.*, 2002; Falco *et al.*, 2003). Cereals and cereals products, milk, vegetables and fruits are the highest contributors to total PAHs intake. These contaminants may enter and accumulate in agriculture soil and crops through irrigation and atmospheric sink and will directly threaten food safety (Li *et al.*, 2008). Since these products are the most important dietary component. In India until now studies dealing with the detection of PAHs residues in leafy and underground vegetables are still lacking. Moreover, information on PAHs burden of leafy and underground vegetable in this region is scarce. Therefore, we attempted to assess the concentration of individual PAHs compounds in leafy and underground vegetable samples collected from 9 different agriculture fields of Panipat City.

MATERIALS AND METHODS

Chemicals: All chemicals, except PAHs, were purchased from Merck (Darmstadt, Germany) in highest purity grade available. Hexane, benzene and acetonitrile were analytical reagent grade and redistilled in all glass apparatus. Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Chrysene, Benzo [a] anthracene, Benzo [b] fluoranthene, Benzo [k] fluoranthene, Benzo [a] pyrene, Dibenzo [a, h] anthracene, Indeno [1, 2, 3-c d] pyrene, Benzo [g, h, i] perylene (All with 99.0% analytical standards) were purchased from Sigma Aldrich chemicals (Germany).

Cleaning of glassware: All the glassware were first cleaned with detergent and left under running water for about ½ h; placed in dilute nitric acid solution for 12 h to remove the inorganic and organic impurities, then rinsed with chromic acid for 4 h to destroy the organic impurities. Thereafter, all the glassware was washed up to 30 min with hot water to remove the nitric and chromic acids residuals. All the glassware were further washed with double distilled water and rinsed with acetone and dried in oven at 180°C overnight.

Sample collection and analytical methodology: Soil samples and leafy vegetables like spinach, white gourd, fenugreek, chilli, ribbed gourd, cauliflower and underground vegetables like potato, radish and turnip were collected randomly from 9 different agriculture fields of Asan Khurd, Shodhapur, Munark, Dohar, Bapauli, Faridpur, Didwari, Kohand, Baberpur Mandi area around Panipat city, Haryana on 5th march 2008. The soil samples were collected from 0 to 10 cm depth with the help of auger. Utmost care has taken to avoid contamination while collecting the

samples. For this the soil auger was washed with normal and then with distilled water and wiped clean between two samplings.

Residual PAHs were extracted on ultrasonicator and on rotary evaporator (Varian) twice with n-hexane, centrifuged for 15 min at 12000 rpm and filtered with syringe filters (0.45 µm). Cleanup procedure was carried out using chromatographic column. Extracts were analyzed by High Performance Liquid Chromatography (HPLC) equipped with UV detector. Analytical column (250 mm long, 4.6 mm dia) was packed with totally porous spherical C-18 material (packed size 5 µm). Acetonitrile water mixture (75:25) was used as mobile phase at a flow rate of 1.0 mL per min. Sample of (20 µL) was injected into column through the sample loop. UV-detector set at 254 nm for compound detection. Stock solution of PAHs standards were prepared by dissolving PAH analytical standard (200 to 1000 ppm) in acetonitrile. Working standard (10 ppm) PAHs mixture was prepared by suitable dilution of stock solution with acetonitrile. Calibration graphs at several dilution of standard mixture of individual compounds of PAHs were used for determining the retention time and studying the linearity of detector. PAHs concentration was calculated by comparing the peak areas of the sample chromatogram with that of peak area of standard chromatogram:

$$\text{Concentration of PAHs in sample } (\mu\text{g mL}^{-1}) = \frac{\text{Peak area of chromatogram of sample}}{\text{Peak area of chromatogram of standard PAHs compound}} \times \text{Conc. of stds. of PAHs compound}$$

[Student's t-test (Two-sample assuming unequal variances) was applied to compare the individual and paired two samples for means was applied to the total mean concentrations of PAHs found in leafy and underground vegetables.

RESULTS AND DISCUSSION

Analytical characteristics of standards: The analytical characteristics of the proposed method for standards of PAHs, PAHs concentration in soil and vegetable (leafy and underground) samples are summarized in Table 1-4. Sixteen PAHs concentration were studied in the range of 10-100 ng per injection. Linearity was found in all cases with Regression Coefficient (R^2) close to 0.999. Relative Standard Deviation (RSD), Detection Limit (DL) and Quantification limits were in the range of 0.4 to 7%, 0.0006 to 0.174 and 0.002-1.75 ng per injection, respectively is specified in Table 1.

PAHs concentration in soil samples: The total mean concentration of sixteen PAHs in soil samples (Table 2) of 9 different agriculture fields around Panipat city was found to be 151.02 µg kg⁻¹ and the mean concentration of individual PAHs namely Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Chrysene, Benzo [a] anthracene, Benzo [b] fluoranthene, Benzo [k] fluoranthene, Benzo [a] pyrene, Dibenzo [a, h] anthracene, Indeno [1, 2, 3-c, d] pyrene, Benzo [g, h, i] perylene was found to be 37.80, 20.00, ND (Not Detected), 16.97, 15.26, 20.35, 12.58, 10.64, 3.68, 3.81, 3.13, 4.19, 1.89, 0.90, ND, 1.13 µg kg⁻¹ dry weight of soil, respectively shown in Table 2. The total PAHs concentration in agricultural soil was higher than background (1 µg kg⁻¹) and moderate level contamination concentration (20 µg kg⁻¹) which is given by Canadian standards (MacDonald *et al.*, 2000). The maximum contamination limit of total PAHs in soil according to soil quality standard for soil (U.S. Fish and wildlife service) is 200 µg kg⁻¹ dry weight and require immediate cleanup.

Table 1: Analytical characteristics of chromatographic method

Peak	PAHs	t_R (min)	DL (ng/inj.)	Quantification		R.S.D.(%)
				limit (ng/inj.)	R^2	
1	NA	4.34	0.174	0.580	0.992	4.40
2	ACEY	5.58	0.023	0.078	0.9991	1.36
3	ACE	6.63	0.052	1.75	0.9977	1.50
4	FLU	7.83	0.002	0.0087	0.9999	1.70
5	PH	8.97	0.009	0.032	0.9897	4.00
6	AN	9.83	0.0006	0.002	0.9915	0.40
7	FA	11.72	0.035	0.117	0.9988	0.50
8	PY	13.45	0.071	0.239	0.9993	2.90
9	B(a)A	17.48	0.0016	0.0054	0.9991	7.00
10	CHR	25.67	0.0024	0.008	0.9994	3.70
11	B(b)F	25.87	0.0017	0.0056	0.9992	1.30
12	B(k)F	26.65	0.0023	0.0078	0.9941	6.40
13	B(a)P	30.18	0.022	0.074	0.9995	4.40
14	D(a,h)A	35.67	0.074	0.24	0.9994	2.20
15	B(g,h,i)P	44.92	0.030	0.122	0.9894	4.50
16	I(1,2,3-cd)P	44.92	0.016	0.05	0.9991	1.90

NA: Naphthalene, ACEY: Acenaphthylene, ACE: Acenaphthene, FLU: Fluorene, PH: Phenanthrene, AN: Anthracene, FA: Fluoranthene, PY:pyrene, B (a): A-benzo (a) anthracene, CHR: Chrysene, B (b) F: Benzo (b) fluoranthene, B (k) F: benzo (k) fluoranthene, B (a) P: Benzo (a) pyrene, D (a, h) A:Dibenzo (a, h) anthracene, B (g,h,i) P: Benzo (g, h, i) perylene, I (1, 2, 3-cd) P: Indeno (1, 2, 3-cd) pyrene. t_R : Retention time, DL: Detection limit, QL: Quantification limit, R.S.D: Relative standard deviation

Table 2: Concentration of PAHs ($\mu\text{g kg}^{-1}$ d.w) in soil samples

PAHs	1	2	3	4	5	6	7	8	9	Mean
NAP	45.08	32.45	33.41	43.06	35.07	45.77	42.16	30.95	32.29	37.80
ACEY	22.45	20.21	17.00	ND	25.05	25.40	23.30	22.28	24.38	20.00
FLU	18.34	17.33	17.02	16.82	19.88	12.33	15.00	19.24	16.80	16.97
ACE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PH	15.80	14.52	15.39	14.10	13.66	ND	12.83	18.26	15.33	15.26
AN	21.61	23.49	20.61	20.53	15.61	22.65	21.62	23.59	13.51	20.35
FA	15.72	15.77	12.34	13.59	14.36	11.37	11.45	13.51	5.16	12.58
PY	17.76	11.64	18.14	10.53	7.30	8.44	7.15	8.14	6.72	10.64
CHR	4.43	4.23	2.13	3.34	5.42	3.64	3.30	4.55	2.12	3.68
B (a) A	4.24	3.64	2.51	3.11	4.58	5.18	3.76	4.53	2.77	3.81
B (b) F	2.94	3.01	3.03	2.92	3.42	4.14	2.93	2.95	2.91	3.13
B (k) F	4.65	4.82	4.75	4.67	0.89	6.72	3.73	4.71	2.83	4.19
B (a) P	1.83	1.42	1.58	1.78	0.33	2.19	1.93	3.56	2.43	1.89
D (a,h) A	0.25	0.13	1.01	0.84	0.50	0.11	1.77	2.22	1.30	0.90
I (1,2,3-cd) P	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
B (g,h,i) P	0.88	0.32	1.66	2.41	0.55	0.37	0.98	1.43	1.63	1.13
Σ PAHs	175.98	152.98	150.58	137.7	151.62	148.31	151.91	159.92	130.18	151.02

ND: Not Detected, 1. Asan Khurd 2. Shodhapur 3. Munark 4. Dohar 5. Bapauli 6. Faridpur 7. Didwari 8. Kohand 9. Baberpur Mandi

It is suggested that concentrations of PAHs in agricultural soil may be substantially and persistently increased when sewage sludge, farmyard manure, compost or composted waste sewage sludge mixtures are applied (Smith, 1996; Wilcke, 2000; Cai *et al.*, 2002, 2003; Mo *et al.*, 2005; Zohair *et al.*, 2006). Reid *et al.* (2000), Semple *et al.* (2003) and Doick *et al.* (2005) stated that the fate of PAHs in the soil is affected by factors such as weather and climate, biological diversity and

abundance, the amount and the nature of the soil minerals and organic matter and pollutant properties such as solubility, polarity, hydrophobicity, liphilicity and molecular structure. This might explain the differences in PAHs concentrations between soil samples that are not in close proximity, as well as variation in PAHs concentrations of the same site. Al-Turki (2009) suggested microbial decontamination of PAHs contaminated soil is suitable, efficient, economic and good alternative than physicochemical treatment. Mahesh *et al.* (2006) suggested that biodegradation is the best method in controlling PAH pollution effectively. The PAHs levels in our agriculture soil samples are found to be more or less similar than other data found in different regions of the world. Chen *et al.* (2005) found 16 EPA PAHs in vegetable soils of Guangzhou metropolitan area were in the range of 42-791 $\mu\text{g kg}^{-1}$, with exception of 3,077 $\mu\text{g kg}^{-1}$ of concentration in one sample. Zhang *et al.* (2005) also reported means of total PAHs of 31.1 $\mu\text{g kg}^{-1}$ in farmland and 169 $\mu\text{g kg}^{-1}$ in urban area from populous Hong Kong. Higher sums of 16 EPA PAHs were reported in some temperate soils, such as 818.2 $\mu\text{g kg}^{-1}$ in Tianjian and 236 $\mu\text{g kg}^{-1}$ in agricultural soil of South Korea (Nam *et al.*, 2003).

PAHs concentration in leafy and underground vegetables: Total mean PAHs concentration were found to be 72.69, 85.55, 54.33, 31.86, 55.24 and 65.02 $\mu\text{g kg}^{-1}$ dry weight in spinach, white gourd, fenugreek, chilli, ribbed gourd and cauliflower, respectively (Table 3). The mean concentrations of Naphthalene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene and Fluoranthene are 15.41, 24.53, 5.4, 7.51, 5.16 and 4.5 $\mu\text{g kg}^{-1}$ in spinach; 19.25, 26.53, 3.60, 6.08, 10.65 and 9.31 $\mu\text{g kg}^{-1}$ in white gourd; 12.4, 16.27, 3.27, 9.70, 5.54 and 2.91 $\mu\text{g kg}^{-1}$ in Fenugreek; 11.70, 8.57, 1.37, 5.36, 0.04 and 1.82 $\mu\text{g kg}^{-1}$ in chilli; 11.08, 13.66, 6.46, 2.33, 5.75 and 4.57 $\mu\text{g kg}^{-1}$ in ribbed gourd; 9.20, 15.30, 5.70, 2.37, 10.81 and 8.80 $\mu\text{g kg}^{-1}$ in Cauliflower, respectively. This is due to uptake of volatilized PAHs from ambient air is main pathway into plant

Table 3: Concentration of PAHs in leafy vegetables of Panipat ($\mu\text{g kg}^{-1}$ d.w)

PAHs	Spinach	White gourd	Fenugreek	Chilli	Ribbed gourd	Cauliflower
NA	15.41±3.12	19.25±1.86	12.4±0.11	11.70±1.79	11.08±0.92	9.20±1.40
ACEY	24.53±4.3	26.53±1.37	16.27±2.12	8.57±0.36	13.66±0.08	15.30±0.09
FLU	5.4±0.87	3.60±0.55	3.27±0.05	1.37±0.08	6.46±0.44	5.70±0.08
PH	7.51±0.08	6.08±0.66	9.70±1.09	5.36±0.03	2.33±0.13	2.37±0.59
AN	5.16±0.58	10.65±0.25	5.54±0.22	0.04±0.011	5.75±0.24	10.81±0.57
FA	4.5±0.27	9.31±0.09	2.91±0.67	1.82±0.21	4.57±0.42	8.80±0.80
PY	2.5±0.3	1.3±0.07	1.22±0.34	0.38±0.11	1.55±0.12	5.53±1.15
CHR	2.5±0.3	3.60±0.92	1.1±0.01	ND	0.53±0.11	0.85±0.59
B(a)A	0.25±0.02	ND	0.2±0.45	0.33±0.06	3.45±0.38	3.94±0.79
B(b)F	ND	ND	ND	ND	ND	ND
B(k)F	1.32±0.07	ND	ND	ND	ND	ND
B(a)P	2.91±0.67	0.38±0.013	0.43±0.24	2.0±0.09	2.83±0.09	1.50±0.4
D(a,h)A	ND	4.80±0.34	ND	ND	1.91±0.03	ND
I(1,2,3-cd)P	ND	ND	1.29±0.01	ND	1.12±0.01	0.90±0.11
B(g,h,i)P	0.7±0.06	0.05±0.001	ND	0.29±0.01	ND	0.12±0.01
?PAHs	72.69	85.55	54.33	31.86	55.24	65.02

NA: Naphthalene, ACEY: Acenaphthylene, ACE: Acenaphthene, FLU: Fluorene, PH: Phenanthrene, AN: Anthracene, FA: Fluoranthene, PY-pyrene, B (a) A-benzo (a) anthracene, CHR: Chrysene, B (b) F: Benzo (b) fluoranthene, B (k) F: Benzo (k) fluoranthene, B (a) P: Benzo (a) pyrene, D (a, h) A: Dibenzo (a, h) anthracene, I (1, 2, 3-cd) P: Indeno (1, 2, 3-cd) pyrene, B (g,h,i) P: Benzo (g, h, i) perylene, ND: Not detected

foliage (Simonich and Hites, 1995). The higher concentration in green leafy vegetables could be explained by their greater contact surface to the ambient air during growth. Lin *et al.* (2007) reported that tea leaves possess high surface area, so they may accumulate PAHs, especially from air. Lower molecular weight PAHs were absorbed by plants more readily than higher molecular weight PAHs. The dominance of lower molecular weight PAHs in vegetables may be due to their greater water solubility, volatility and bioavailability (Tao *et al.*, 2004). Unleaded vehicular emissions were estimated as a source of low molecular weight compounds. Oil refineries, unleaded vehicular Pollution, wood preservative and creosote production activities, sewage sludges, domestic combustion are major contributor of 3-4 ring compounds (Bishnoi *et al.*, 2005). Foliage PAHs are independent of soil PAHs concentration due to insignificance of root uptake mechanism and dominant role of atmosphere in supplying PAH compounds.

The mean concentration of Pyrene, Chrysene, Benzo (a) anthracene, Benzo (k) fluoranthene, Benzo (a) pyrene, Dibenzo (a, h) anthracene, Indeno (1, 2, 3-cd) pyrene and Benzo (g, h, i) perylene was found to be 2.5, 2.5, 0.25, ND, 1.32, 2.91, ND, ND and 0.7 $\mu\text{g kg}^{-1}$ in Spinach; 1.3, 3.60, ND, ND, ND, 0.38, 4.80, ND and 0.05 $\mu\text{g kg}^{-1}$ in white gourd; 1.22, 1.1, 0.2, ND, ND, 0.43, ND, 1.29 and ND in Fenugreek; 0.38, ND, 0.33, ND, ND, 2.0, ND, ND and 0.29 in chilli; 1.55, 0.53, 3.45, ND, ND, 2.83, 1.91, 1.12 and ND in ribbed gourd; 5.53, 0.85, 3.94, ND, ND, 1.50, ND, 0.90 and 0.12 in cauliflower, respectively. Benzo (b) fluoranthene was not detected in leafy vegetables. The high molecular weight compounds have lower water solubility and have a low potential for root uptake from the soil. Wood combustion may generate ashes with significant amounts of PAHs (Kim *et al.*, 2003). Unregulated fires have been considered as a source of high molecular weight compounds.

Three underground vegetable samples i.e., Potato, Raddish and Turnip were analyzed for the PAHs concentration. The total mean concentration of PAHs was found to be 37.73, 36.32 and 22.89 $\mu\text{g kg}^{-1}$ dry weight, respectively (Table 4). The mean concentrations of Naphthalene, Acenaphthylene, Fluorene, Phenanthrene, Anthracene and Fluoranthene are 8.88, 16.25, 2.90, 4.30, 2.20 and 0.74 $\mu\text{g kg}^{-1}$ in Potato; 15.56, 9.20, 2.56, 4.79, 1.17 and 1.00 $\mu\text{g kg}^{-1}$ in Raddish; 5.53, 8.68, 0.38, 2.73, 1.22 and 0.14 $\mu\text{g kg}^{-1}$ in Turnip, respectively. In underground vegetables uptake of PAHs from soil takes place through adsorption of PAHs to root surface and root tissue. The lower molecular weight compounds contribute to significant extent. This may be due to their higher water solubility which is responsible for higher uptake by plant. The mean concentration of Pyrene, Chrysene, Benzo (a) anthracene, Benzo (b) fluoranthene, Benzo (k) fluoranthene, Benzo (a) pyrene, Dibenzo (a, h) anthracene, Indeno (1, 2, 3-cd) pyrene and Benzo (g, h, i) perylene are 0.45, ND, 0.22, ND, ND, 1.60, ND, ND and 0.19 $\mu\text{g kg}^{-1}$ in potato; 0.27, ND, 0.16, 0.2, ND, 1.1, ND, ND and 0.31 $\mu\text{g kg}^{-1}$ in raddish; 0.07, 2.53, ND, 0.47, 0.21, 0.85, 0.08, ND and ND $\mu\text{g kg}^{-1}$ in Turnip, respectively. Chrysene is not detected in underground vegetables. More than 4-ring compounds were detected with lower concentration due to their high octanol coefficient and low aqueous solubility. Compounds with high $\log K_{ow}$ are tightly bound to organic fraction in soil which renders less available for degradation, leaching, volatilization and plant uptake (Jones, 1991).

The 16 EPA PAHs levels in our vegetable samples were found to be more or less similar to other regions. Kipopoulou *et al.* (1999) found 16 EPA PAH values in range of 25-294 $\mu\text{g kg}^{-1}$ in the inner tissue of leafy vegetables and 48-94 $\mu\text{g kg}^{-1}$ in root vegetables in a Greek industrial area. From a Spanish area with an important number of chemical and petrochemical industries, Nadal *et al.* (2004) reported 16 PAHs concentrations of 28, 58 and 179 $\mu\text{g kg}^{-1}$ in chard samples from unpolluted, industrial and residential area, respectively. Camargo and Toledo (2003) reported that

Table 4: Concentration of PAHs in underground vegetables of Panipat ($\mu\text{g kg}^{-1}$ d.w)

PAHs	Potato	Raddish	Turnip
NA	8.88 \pm 0.07	15.56 \pm 0.13	5.53 \pm 1.15
ACEY	16.25 \pm 0.03	9.20 \pm 1.40	8.68 \pm 2.39
ACE	ND	ND	ND
FLU	2.90 \pm 0.71	2.56 \pm 0.27	0.38 \pm 0.05
PH	4.30 \pm 0.28	4.79 \pm 0.03	2.73 \pm 0.02
AN	2.20 \pm 0.23	1.17 \pm 0.63	1.22 \pm 0.87
FA	0.74 \pm 0.03	1.00 \pm 0.30	0.14 \pm 0.05
PY	0.45 \pm 0.07	0.27 \pm 0.09	0.07 \pm 0.02
CHR	ND	ND	2.53 \pm 0.72
B (a) A	0.22 \pm 0.03	0.16 \pm 0.02	ND
B (b) F	ND	0.2 \pm 0.45	0.47 \pm 0.52
B (k) F	ND	ND	0.21 \pm 0.03
B (a) P	1.60 \pm 0.18	1.1 \pm 0.01	0.85 \pm 0.59
D(a,h) A	ND	ND	0.08 \pm 0.04
I (1,2,3-cd) P	ND	ND	ND
B (g,h,i) P	0.19 \pm 0.01	0.31 \pm 0.05	ND
Σ AHs	37.73	36.32	22.89

NA-Naphthalene, ACEY: Acenaphthylene, ACE: Acenaphthene, FLU: Fluorene, PH: Phenanthrene, AN: Anthracene, FA: Fluoranthene, PY-pyrene, B (a) A-benzo (a) anthracene, CHR: Chrysene, B (b) F: Benzo (b) fluoranthene, B (k) F: Benzo (k) fluoranthene, B (a) P: Benzo (a) pyrene, D (a, h) A: Dibenzo (a, h) anthracene, I (1, 2, 3-cd) P: Indeno (1, 2, 3-cd) pyrene, B (g,h,i) P: Benzo (g, h, i) perylene, ND- Not detected

Table 5: Comparison of mean concentration of PAHs ($\mu\text{g kg}^{-1}$ d.w) in vegetables

PAHs	Leafy vegetables	Underground vegetables
NA	13.17	9.99 [*] t = 0.966
ACEY	17.47	11.37 [*] t = 1.64
ACE	ND	ND
FLU	4.3 ^{**}	1.94 ^{**} t = 2.13
PH	5.55	3.94 [*] t = 1.21
AN	6.32 ^{**}	1.53 ^{**} t = 2.86
FA	5.31 ^{**}	0.62 ^{**} t = 3.66
PY	2.08	0.26 [*] t = 2.42
CHR	1.43	0.84 [*] t = 0.58
B (a) A	1.36	0.12 [*] t = 1.65
B (b) F	ND	0.22 [*] t = 1.64
B (k) F	0.22	0.07 [*] t = 0.65
B (a) P	1.67	1.18 [*] t = 0.97
D (a,h) A	1.11	0.02 [*] t = 1.36
I (1,2,3-cd) P	0.55	ND [*] t = 2.19
B (g,h,i) P	0.19	0.16 [*] t = 0.18
Σ Mean conc.	60.73 ^{**} t=3.65	32.26 ^{**} t = 3.65

*Indicates that value are not statistically significant ($p < 0.05$) based on t-test. **Indicates that values are statistically significant ($p < 0.05$) based on t-test. NA: Naphthalene, ACEY: Acenaphthylene, ACE: Acenaphthene, FLU: Fluorene, PH: Phenanthrene, AN: Anthracene, FA: Fluoranthene, PY: Pyrene, B (a) A: Benzo (a) anthracene, CHR- Chrysene, B (b) F: Benzo (b) fluoranthene, B (k) F: Benzo (k) fluoranthene, B (a) P: Benzo (a) pyrene, D (a, h) A: Dibenzo (a, h) anthracene, I (1, 2, 3-cd) P: Indeno (1, 2, 3-cd) pyrene, B (g,h,i) P: Benzo (g, h, i) perylene. ND: Not detected

the sums of 16 PAHs were 13.53 $\mu\text{g kg}^{-1}$ in lettuce, 9.50 $\mu\text{g kg}^{-1}$ in tomato, 8.86 $\mu\text{g kg}^{-1}$ in cabbage collected around the metropolitan area of Campinas, Brazil. Bishnoi *et al.* (2006) found 16 EPA PAH values in range of 122.69-195.01 $\mu\text{g kg}^{-1}$ in the leafy vegetables and 59.78-128.47 $\mu\text{g kg}^{-1}$ in underground vegetables collected from various places of Mumbai city, India.

Comparison of mean concentration of PAHs ($\mu\text{g kg}^{-1}$) in leafy and underground vegetables: The total mean concentration of PAHs in Leafy and underground vegetables were found to be 32.26 and 60.73 $\mu\text{g kg}^{-1}$, respectively (Table 5). Student's t-test reveals that there is a significant difference between the mean concentration of PAHs in leafy and underground vegetables ($t = 3.65$, $p < 0.05$). The concentration of lower molecular weight compounds of PAHs was found to be greater than higher molecular PAHs which could be due to their difference in solubility. Leafy vegetables are found to be more contaminated with higher concentration of PAHs as compared to underground vegetables due to their greater surface area which is responsible to trap higher concentration of PAHs (Bishnoi *et al.*, 2005).

CONCLUSION

From the above results following conclusions are drawn: 1. The concentration of PAHs in the soil samples is more than the background (1 $\mu\text{g kg}^{-1}$) and moderate level contamination concentration (20 $\mu\text{g kg}^{-1}$) which is given, by Canadian standard the mean concentration of sixteen PAHs was found to be 151.02 $\mu\text{g kg}^{-1}$ dry weight in soil 2. The accumulation of lower molecular weight compounds of PAHs is more than higher molecular weight PAHs. 3. Leafy vegetables are more contaminated with higher concentration of PAHs as compared to underground vegetables, as the total mean concentration of PAHs in Leafy and underground vegetables are 60.51 and 32.86 $\mu\text{g kg}^{-1}$ dry weight, respectively.

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