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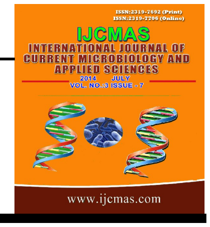

Original Research Article

Levels of polycyclic aromatic hydrocarbons (PAHS) in some Egyptian vegetables and fruits and their influences by some treatments

Abou-Arab, A.A.K.[1*], Abou-Donia, M. A. M.[1], El-Dars, F. M. S. E.[2], Ali, O. I. M.[2] and Hossam A. Goda[3]

[1]Food Toxicology and Contaminants, National Research Center, Egypt
[2]Chemistry Department, Faculty of Science, Helwan University, Cairo Governorate, Egypt
[3]Quality Control Manager, Luna for Perfumes and Cosmetics (Lunapac), Egypt
**Corresponding author*

A B S T R A C T

Keywords

PAHs, vegetables, fruits, washing, peeling.

The levels of PAHs in some Egyptian vegetables (potatoes and spinach) and fruits (apple and guava) that collected from different regions in Cairo were investigated. The PAHs' concentrations in samples were determined using gas chromatography-mass spectrometry. Data indicated that the highest concentration of total PAHs was detected in Spinach (8.977 µg/kg), followed by potatoes (6.196 µg/kg), apple (2.867 µg/kg) and guava (2.334 µg/kg). Washing with tap water and acetic acid solutions at 1% and 2% showed reduction of PAHs levels in investigated vegetables. Washing with tap water, 1% and 2% acetic acid solution reduced the amount of total and carcinogenic PAHs in spinach by 4.23 and 5.73%, 54.02 and 66.03% and 74.36 and 79.62%, respectively. The corresponding reduction in case of potatoes was 17.52 and 11.69%, 72.93 and 90.84% and 87.6 and 98.71%, respectively. Peeling of potatoes reduced the amount of total and carcinogenic PAHs by 93.85 and 93.18%, respectively, while boiling of peeled potatoes reduced total and carcinogenic PAHs by 98.39 and 97.19%, respectively. It could be recommended that careful washing of foodstuffs especially by acidic detergents, peeling process and boiling may be effective in reducing the daily intake of PAHs containing foods.

Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a group of chemicals composed of two or more fused aromatic rings that are formed during the incomplete combustion or high-temperature pyrolysis of coal, oil, gas, wood, fossil fuels, garbage, or other substances, such as tobacco and charbroiled meat (Grimmer and Boehnke, 1975).

Over 100 PAHs have been identified and occur as complex mixtures, never as individual component (ATSDR, 1995). However, only 16 compounds were selected as priority pollutants by the United States Environmental Protection Agency (USEPA) (Simko, 1991).

USEPA has classified benzo[a]anthracene, benzo[a]pyrene, benzo[a]fluoranthene, benzo[k]fluoranthene, chrysene, dibenzo[a,h]anthracene, and indeno[1,2,3-c,d]pyrene as probable human carcinogens (group B2). The International Agency for Research on Cancer (IARC) established that benzo[a]anthracene and benzo[a]pyrene are probable human carcinogens, whereas benzo[b]fluoranthene, benzo-[j] fluoranthene, benzo [k] fluoranthene, and indenol[1,2,3-c,d] pyrene are possible human carcinogens (Llobet et al., 2006). PAHs have been detected in many food products including cereals, potatoes, grain, flour, bread, vegetables, fruits, oils, and smoked or broiled meat and fish (Tuteja et al., 2011; Zohair, 2006; Bulder et al., 2006).

Seventy percentages of individuals are exposed to PAHs predominantly from dietary sources. PAHs are found in substantial quantities in some foods, depending on the mode of cooking, preservation, and storage (Purcaro et. al, 2006). Concentration of PAHs in uncooked food may vary from region to another according to the type of the product and the type and concentration of pollution in this region. Vegetables and fruits obtained from a polluted environment may contain higher PAHs concentrations than those obtained from non- polluted environment. Wang and Meresz (1982) reported that Benzo[a]pyrene, dibenz[a,h]anthracene, and chrysene were detected in vegetables grown near heavily travelled road. Thus, food may be contaminated by environmental PAHs that are present or during processing as drying, smoking and cooking like grilling, roasting and frying (Bulder et al., 2006).

PAHs can be harmful to human health under some circumstances. Several of the PAHs, including benzo [a] anthracene, benzo[a] pyrene, benzo [b] fluoranthene, benzo[j]fluoranthene, benzo[k] fluoranthene, chrysene, dibenz[a,h]anthracene, and indeno [1,2,3-c,d] pyrene have induced tumors in laboratory animals when they breathed these substances in the air, when they ate them, or when they had long periods of skin contact with them. Studies of people show that individuals exposed to PAHs in mixtures through breathing or skin contact for long periods and other compounds can also develop cancer (ATSDR, 1995).

During the last decades, increasing demand of food safety has stimulated research regarding the risk associated with consumption of contaminated foods (D'Mello, 2003). High-performance liquid chromatography with fluorescence detection (HPLC-FLD), gas chromatography with mass spectrometry (GC–MS), gas chromatography with flame ionization detector (GC-FID) and solid phase microextraction (SPME) followed by GC–MS are the most commonly techniques for PAHs determination (Kishikawa et al., 2003; Vigeas et al., 2012; Jira, 2004; Olatunji et al., 2014; Aguinaga et al., 2007).

The aim of the present work is to study the levels of polycyclic aromatic hydrocarbons (PAHs) in some Egyptian edible vegetables and fruits from different localities and their influences by some treatments as washing, peeling and boiling.

Materials and Methods

Chemicals and reagents

A mixture of 15 polyaromatic reference standards containing acenaphtene, acenaphthylene, anthracene, benzo(a) anthracene, benzo(a)pyrene, benzo(k) fluoranthene, benzo (ghi) perylene, chrysene, dibenzo (a,h) anthracene, fluoranthene, fluorene, indeno (1,2,3,-cd) pyrene, phenanthrene, pyrene and 2-

bromonaphthalene were purchased from Supleco Inc., USA., PAHs working solutions (10 µg/mL) was prepared from a stock solution of PAHs containing 200 µg/mL. Dichloromethane, n-hexane, cyclohexane, acetonirile (Pestiscan Chromatography grade), anhydrous sodium sulphate, acetone (BDH chemicals), florisil (Magnesium silicate) was obtained from Merck, Germany, Acetic acid.

Food Samples

A total of 78 vegetables samples belonging to two different species (potatoes and spinach) and 18 fruit samples belonging to two different species (apple and guava) were randomly collected during the period of January 2012 up to March 2012 to determine the concentrations of PAHs. The samples were quite representative since they collected from districts where foodstuffs were scattered throughout the different regions in Cairo. All of the samples were kept in a freezer at 4°C until analysis.

Quality assurance procedures and precautions were carried out to ensure reliability of the results, all materials used for processing were screened by dilute nitric acid, hot water, chromic acid, acetone and distilled water for possible removal of PAHs contamination according to the method of Tuteja et al. (2011).

Sample preparation, extraction and clean up

The different weights of samples were homogenized separately and 30 g of the fresh homogenate was mixed with 90 g of anhydrous sodium sulphate for extraction according to the method of Zohair (2006) using quick fit soxhelt unit for 24 h with 300 ml hexane: acetone (1:1, v/v) mixture. The samples were cleaned up using activated florisil (60/100 mesh) and anhydrous sodium sulphate and eluted by methylene chloride and n-hexane. The eluate was collected and evaporated to dryness by rotary evaporator at room temperature.

Instrumentation and analysis conditions

The dry eluate sample was dissolved in 1 mL n-hexane and injected into a Hewlett Packered Gas Chromatograph 5890 fitted with HP-5 fused silica capillary column (50 m x 0.2 mm i.d. x 0.3 µm film thickness) and connected to Hewlett Packered 5970 series mass selective detector. The carrier gas was helium at a flow rate of 1.0 mL/min. The injection port temperature was 275 ˚C with electron energy of 70 eV. The quadruple temperature was 280˚C. The instrument was tunned on perflorotributylamine (PFTBA). The oven programme was as follows; initial temperature 70 ˚C, continued for 5 min, followed by an increase to 290 ˚C at 3 ˚C/min, then finally hold for 30 min. Calibration was done using external standards (mixture of 15 compounds). The mass spectrometer was operated in selective ion monitoring mode using separate ions to identify and confirm compounds.

Experimental of PAHs detoxification

PAHs detoxification by washing

Samples of vegetables (spinach and potatoes) were separately washed with tap water or acetic acid solutions (1% and 2%). The washing procedure was carried out on naturally contaminated samples by high levels of PAHs.

PAHs detoxification by peeling

Samples of potatoes were peeled as applied at home. The peeling procedure was carried out on naturally contaminated samples by high levels of PAHs.

PAHs detoxification by boiling

Samples of vegetable (spinach and potatoes) were boiled for 10 min at 100°C on open flame. The boiling procedure was carried out on naturally contaminated samples by high levels of PAHs.

Recovery

Recovery results of PAHs from vegetables and fruits samples under investigation were studied according to the method of Chantara and Sangchan, (2009). The results showed that the recovery was ranged between 95 -97%. The average of triplicate analysis was calculated for each PAHs

Statistical analysis

The data obtained from this study was statistically subjected to analysis of variance (ANOVA) and means separation was by Snedecor and Cochran (1980). The least significant difference (L.S.D) value was used to determine significant difference between means and to separate means at ($P \leq 0.05$) using SPSS package version 15.0.

Results and Discussion

PAHs in some Egyptian vegetables and fruits

Concentrations of PAHs in different types of vegetables (potato and spinach) and fruits (guava and apple) which collected from different locations in Greater Cairo Urban Region (GCUR) were determined and data presented in Table 1 and illustrated in Fig 1. Data shows that PAHs levels in the samples collection are quite variable among the vegetables and fruits samples. Analysis of variance revealed that highly significant differences ($P \leq 0.005$) of PAHs levels were observed among the different samples collection. Data proved also that 2-bromonaphthalene, acenaphthylene, acenaphthene, fluorene and anthracene were not detected in spinach or guava samples. In contrast, potato samples contained acenaphthene, fluorene and anthracene at mean levels of 0.510, 0.271 and 1.470 µg/kg, respectively. However, acenaphthylene and fluorene were only found in the collected apple samples at mean values of 0.026 and 0.012 µg/kg, respectively. On the other hand, pyrene was not detected in spinach samples, but it was found in potato, guava and apple samples at mean concentration of 0.788, 0.565 and 0.138 µg/kg, respectively. Regarding to fluoranthene, it was not detected in potato or guava samples; however, it recorded mean values of 2.785 and 0.193 µg/kg in spinach and apple samples, respectively. With respect to benzo(k)fluorancene and benzo(ghi)perylene, data revealed that they were detected in spinach, guava and apple samples, while they not detected in potato (Table 1). The Table 1 shows also that indeno(1,2,3-cd)pyrene was not detected in the samples of potato, guava and apple, while it detected in spinach at mean level of 1.129µg/kg. The collected data indicated that the highest concentration of total PAHs was detected in spinach, while the highest concentration of total carcinogenic PAHs was detected in spinach. It was noticed from the results that the 3-4 rings PAHs were predominates in all samples collection.

The most important source of the contamination by PAHs is atmospheric pollution from industrial or motor vehicle emission. The mean concentrations of PAHs in different vegetables and fruits under investigation are quite variable. Total and carcinogenic PAHs in spinach are more than that present in potato, guava and apple, this explained by its greater surface contact to the ambient air during growth. These results agree with those reported by Lin and Zhu (2005) who showed that PAHs accumulated from air due to high surface area of tea leaves. Besides, Tuteja et al. (2011) and Bishnoi et al. (2006) reported that 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. Tuteja et al. (2011) showed also that the concentration of lower molecular weight PAHs compounds was found to be greater than higher molecular weight PAHs in all types of vegetables.

In the present study the mean total PAHs in vegetable and fruit samples collected from different locations ranged from 2.334 to 8.977 µg/kg. Similar results reported by Zohir (2006) who showed that total PAHs in Egyptian vegetables was ranged from 1.22 to 12.63 ppb. This indicates that PAHs levels in uncooked food largely depend on the origin of the food and can be subjected to regional variations. Ashraf and Salam (2012) reported that in the fruit vegetables, all the peels were found to be more contaminated than cores. However, in leafy vegetables, maximum PAHs level was shown by cabbage (8.34 µg/kg), which turned out to be more than any of the cores of fruit vegetables.

Additionally, Greenberg et al., (1990) proved that the level of benzo(a)pyrene in kale was in a range of 12.6-48.1 ng/g. While, Kazerouni et al., (2001) revealed that the highest level of benzo(a)pyrene was found in collards and kale with levels of 0.48 and 0.47 ng/g, respectively. These levels were higher than those detected in the present investigation. While for the fruit vegetables (like tomato, cucumber, eggplant, and bitter gourd) all the peels were found to be more contaminated than cores. For leafy vegetables, cabbage showed maximum PAHs (11.6 µg/kg) as compared to the cores of fruit vegetables (Ashraf et al., 2013).

In the present study, the ratio of fluoranthene to pyrene in apple shows that the incomplete combustion products via pyrolytic process and this in agreement with the results of Zohair (2006).

Detoxification of PAHs from some vegetables by washing

In plants and at home, vegetables are conveyed to the water flumes and washing with high pressure sprays. The effect of washing with tap water and acetic acid solutions at 1% and 2% on PAHs contents in contaminated spinach and potatoes were studied and data presented in Table 2 and illustrated in Fig. 2. The results indicated that washing of spinach generally caused reduction in total PAHs under investigation and carcinogenic PAHs compounds. In addition, the results revealed the efficient role of washing with acetic acid solutions at 1% and 2% in reduction of PAHs and carcinogenic compounds. Statistical analysis proved that significant differences ($P \leq 0.05$) were detected between the different washing solutions.

The results demonstrated that a variation in reduction of PAHs was observed with the different washing solutions. These differences increased as the levels of acetic acid increased. It was noticed that washing with 2% acetic acid decreased the levels of phenanthrene, fluoranthene, chrysene, benzo(a)anthracene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, benzo(ghi)perylene and indeno(1,2,3-cd)pyrene more efficiently than 1% acetic acid and more than with tap water.

PAHs contents of potatoes as affected by washing (tap water and acetic acid solutions 1% and 2%) were studied (Table 3 and Fig. 3). Data demonstrated that the different procedures of washing led to reduction in total and carcinogenic PAHs levels. The results showed that washing with tap water only caused a reduction in total PAHs under investigation and carcinogenic PAHs compounds by 17.52% and 11.69%, respectively.

In addition, the results revealed the efficient role of washing with acetic acid solutions at 1% and 2% in reduction of PAHs and carcinogenic compounds whichwere 72.93% and 90.84%, in this order at 1% acetic acid solution. The corresponding values with 2% acetic acid solution were 87.6% and 98.71%, respectively. Statistical analysis proved that significant differences ($P \leq 0.005$) were detected between the different washing solutions. These differences increased as the levels of acetic acid increased. Otherwise, the results demonstrated that, reduction of PAHs was observed with the different compounds due to the different washing treatments. Washing with tap water reduced the levels of acenaphthene, fluorene, anthracene, phenanthrene, pyrene, chrysene, benzo(a)anthracene, benzo(a)pyrene and dibenz(a,h)anthracene less than washing with 1% and 2% acetic acid solutions.

It could be observed that washing with acetic acid is more efficient than tap water in removal PAHs and washing with 2% was more efficient than 1% acetic acid which means that decreasing pH led to more reduction in PAHs levels. These results were in agreement with Pawar et al. (2013) study who reported that the second greatest rate of PAHs reduction was found at pH 6.0.

Detoxification of PAHs from some vegetables by Peeling

Some crops as potatoes can be peeled with different methods as the lye, mechanically and by hands. Thus, it could be reasonable to expect that such operations may cause some reduction of PAHs content in contaminated samples. The roles of peeling on PAHs with or without washing were investigated and the results are presented in Table 4 and illustrated in Fig. 4. The results demonstrated the efficient role of peeling process in reduction of PAHs from contaminated samples. The percentage of total and carcinogenic PAHs removed from potatoes was 93.85 and 93.18%, respectively. These percentages were increased to 96.44 and 98.82%, respectively when peeling process was followed by washing with tap water. Peeling of potatoes followed by washing with tap water decreased the levels of acenaphthene, fluorene, anthracene, phenanthrene, pyrene, chrysene, benzo(a)anthracene, benzo(a)pyrene and dibenz(a,h)anthracene more efficiently than peeling alone. The results proved that most PAHs contaminants were concentrated on the surface of the food and not completely penetrated inside the food. Therefore, peeling and washing reduce the values of PAHs in vegetables and fruits.
Wang and Meresz (1981) analyzed onions, beets, tomatoes, and soil for 17 PAHs, and found also that most of the PAHs contamination was in the peels. In addition, Vega et al. (2012) reported that in crops (apple and cactus stem), the values of PAHs were high over the surfaces for high and intermediate molecular weights, but the values declines with adequate washing or peeling. The waxy surface of vegetables and fruits can concentrate low molecular mass PAHs mainly through surface adsorption. The concentrations of PAHs are generally greater on plant surface (peel, outer leaves) than on internal tissue. Consequently, washing or peeling may remove a significant proportion of the total PAHs.

Table.1 Levels of PAHs in some Egyptian vegetable and fruit samples collected from Greater Cairo Urban Region (GCUR)

PAHs Compounds	Mean concentration (µg/kg) ± SD			
	Potato	spinach	Guava	Apple
2-Bromonaphthalene	ND	ND	ND	ND
Acenaphthylene	ND	ND	ND	0.026± 0.01
Acenaphthene	0.510 ± 0.03	ND	ND	ND
Fluorene	0.271 ± 0.02	ND	ND	0.012±0.01
Anthracene	1.470 ± 0.18	ND	ND	ND
Phenanthrene	0.800±0.06	2.326±0.17	0.337±0.02	0.475±0.05
Pyrene	0.788±0.08	ND	0.565±0.04	0.138±0.01
Fluoranthene	ND	2.785±0.21	ND	0.193±0.02
Chrysene**	0.525±0.04	0.197±0.02	0.230±0.02	0.250±0.01
Benzo(a)anthracene*	1.337±0.09	0.599±0.04	0.631±0.03	0.705±0.08
Benzo(k)fluorancene**	ND	0.602±0.03	0.139±0.01	0.594±0.03
Benzo(a)pyrene*	0.174±0.02	0.245±0.01	0.193±0.02	0.093±0.01
Dibenz(a,h)anthracene*	0.321±0.01	0.810±0.07	ND	ND
Benzo(ghi)perylene	ND	0.284±0.01	0.239±0.01	0.381±0.01
Indeno(1,2,3,-cd)pyrene**	ND	1.129±0.09	ND	ND
Total PAHs	6.196	8.977	2.334	2.867
Total Carcinogenic PAHs	2.357	3.582	1.193	1.642

ND: Not detectable. SD: Standard Deviation

* IARC Group 2a: Probably carcinogenic to human according to IARC.

** IARC group 2b: Possibly carcinogenic to humans according to IARC.

* & ** classified as carcinogenic to human by US EPA and WHO/IPCS.

Fig.1. Levels of PAHs in some Egyptian vegetable and fruit samples

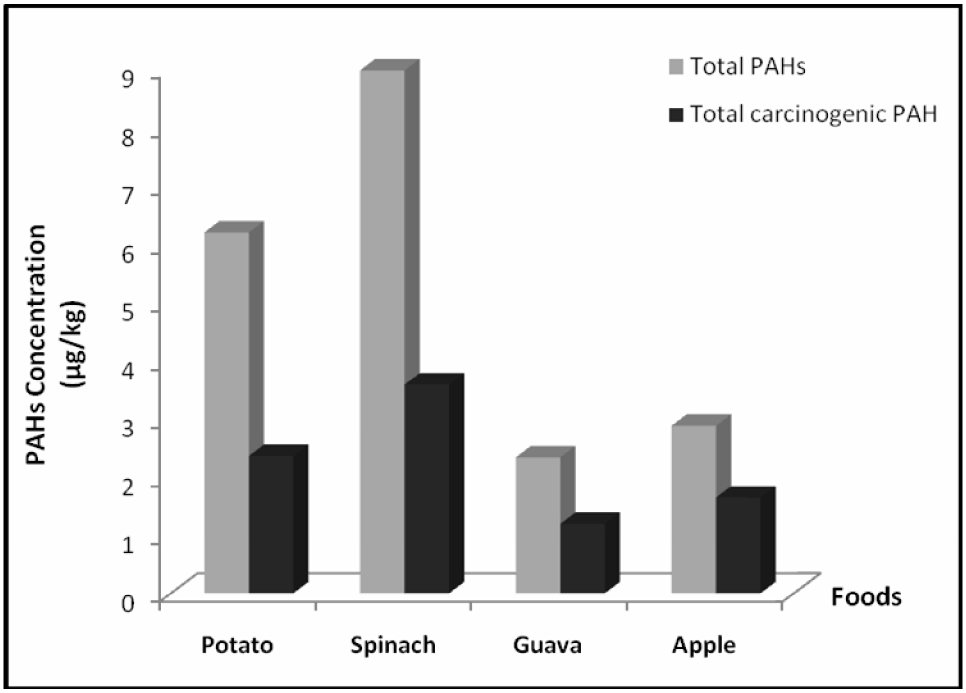

Fig.2 Mean levels (µg/kg) of PAHs and reduction percentage in spinach as affected by washing using tap water and acetic acid solutions (1 and 2%).

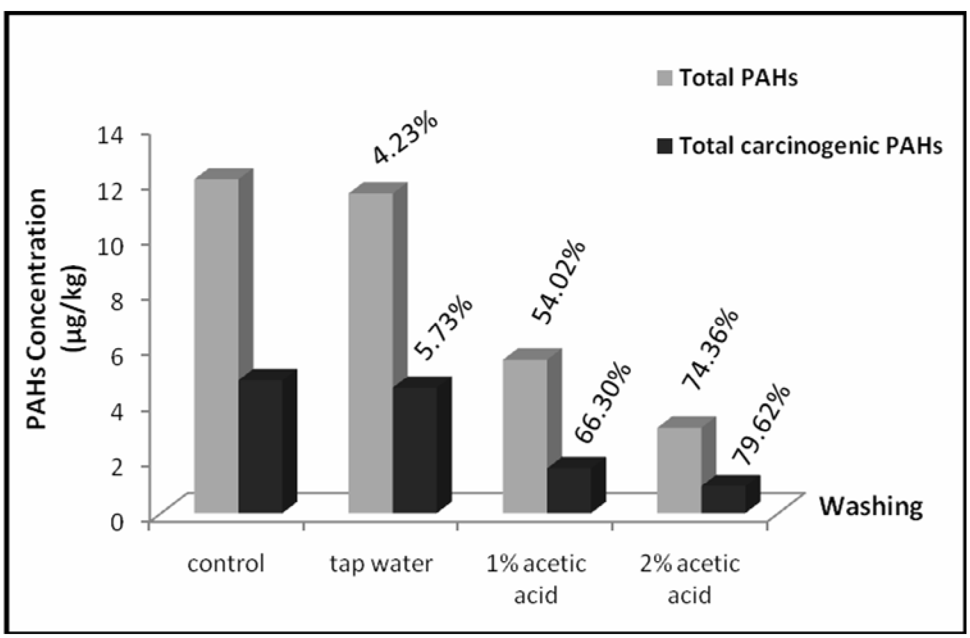

Table.2 Mean levels (µg/kg) of PAHs and reduction percentages in spinach as affected by washing using tap water and acetic acid solutions (1% and 2%).

PAHs Compounds	Mean concentration (µg/kg) ± SD			
	Control	washing with tap water	washing with 1% acetic acid	washing with 2% acetic acid
2-Bromonaphthalene	ND	ND	ND	ND
Acenaphthylene	ND	ND	ND	ND
Acenaphthene	ND	ND	ND	ND
Fluorene	ND	ND	ND	ND
Anthracene	ND	ND	ND	ND
Phenanthrene	3.071 ± 0.23	2.956 ± 0.18 (3.74%)***	1.918 ± 0.15 (37.54%)	1.055 ± 0.09 (65.65%)
Pyrene	ND	ND	ND	ND
Fluoranthene	3.872 ± 0.32	3.780 ± 0.25 (2.38%)	2.013 ± 0.18 (48.01%)	1.060 ± 0.11 (72.62%)
Chrysene**	0.192 ± 0.01	0.171 ± 0.02 (10.94%)	0.094 ± 0.01 (51.04%)	ND (100%)
Benzo(a)anthracene*	0.804 ± 0.06	0.724 ± 0.05 (9.95%)	0.075 ± 0.01 (90.67%)	0.039 ± 0.01 (95.05%)
Benzo(k)fluorancene**	0.837 ± 0.07	0.798 ± 0.07 (4.66%)	ND (100%)	ND (100%)
Benzo(a)pyrene*	0.368 ± 0.02	0.280 ± 0.01 (23.91%)	0.113 ± 0.01 (69.29%)	0.039 ± 0.01 (89.40%)
Dibenz(a,h)anthracene *	0.803 ± 0.06	0.761 ± 0.05 (5.23%)	0.321 ± 0.02 (60.02%)	0.090 ± 0.01 (88.79%)
Benzo(ghi)perylene	0.321 ± 0.29	0.293 ± 0.03 (8.72%)	ND (100%)	ND (100%)
Indeno(1,2,3,-cd)pyrene**	1.809 ± 0.21	1.803 ± 0.15 (0.33%)	1.019 ± 0.09 (43.67%)	0.813 ± 0.07 (55.06%)
Total PAHs	12.077	11.566 (4.23%)	5.553 (54.02%)	3.096 (74.36%)
Total carcinogenic PAHs	4.813	4.537 (5.73%)	1.622 (66.30%)	0.981 (79.62%)

ND: Not detectable. SD: Standard Deviation ***: Reduction percentage
* IARC Group 2a: Probably carcinogenic to human according to IARC.
** IARC group 2b: Possibly carcinogenic to humans according to IARC.
* & ** classified as carcinogenic to human by US EPA and WHO/IPCS.

Table.3 Mean levels (µg/kg) of PAHs and their reduction percentage in potatoes as affected by washing using tap water and acetic acid solutions (1% and 2%).

PAHs compounds	Mean concentration (µg/kg) ± SD			
	Control	washing with tap water	washing with 1% acetic acid	washing with 2% acetic acid
2-Bromonaphthalene	ND	ND	ND	ND
Acenaphthylene	ND	ND	ND	ND
Acenaphthene	1.091 ± 0.09	0.960 ± 0.05 (12.01%)	0.610 ± 0.02 (44.09%)	0.190 ± 0.02 (82.58%)
Fluorene	0.895 ± 0.07	0.405 ± 0.03 (54.75%)	ND (100%)	ND (100%)
Anthracene	2.091 ± 0.21	1.860 ± 0.17 (11.05%)***	1.010 ± 0.15 (51.7%)	0.690 ± 0.07 (67%)
Phenanthrene	1.189 ± 0.13	1.027 ± 0.09 (13.62%)	0.813 ± 0.08 (31.62%)	0.314 ± 0.04 (73.59%)
Pyrene	1.320 ± 0.09	0.968 ± 0.08 (26.67%)	ND (100%)	ND (100%)
Fluoranthene	ND	ND	ND	ND
Chrysene**	0.769 ± 0.06	0.581 ± 0.06 (24.45%)	0.031 ± 0.01 (95.97%)	0.022 ± 0.01 (97.14%)
Benzo(a)anthracene*	1.697 ± 0.16	1.604 ± 0.13 (5.48%)	0.029 ± 0.01 (98.24%)	ND (100%)
Benzo(k)fluorancene**	ND	ND	ND	ND
Benzo(a)pyrene*	0.473 ± 0.05	0.397 ± 0.04 (16.07%)	0.046 ± 0.01 (90.27%)	0.025 ± 0.01 (94.71%)
Dibenz(a,h)anthracene*	0.695 ± 0.07	0.627 ± 0.05 (9.78%)	0.227 ± 0.03 (67.34%)	ND (100%)
Benzo(ghi)perylene	ND	ND	ND	ND
Indeno(1,2,3,-cd)pyrene**	ND	ND	ND	ND
Total PAHs	10.220	8.429 (17.52%)	2.766 (72.93%)	1.241 (87.6%)
Total carcinogenic PAHs	3.634	3.209 (11.69%)	0.333 (90.84%)	0.047 (98.71%)

ND: Not detectable. SD: Standard Deviation *** Reduction percentage
[*] IARC Group 2a: Probably carcinogenic to human according to IARC.
[**] IARC group 2b: Possibly carcinogenic to humans according to IARC.
[* & **] classified as carcinogenic to human by US EPA and WHO/IPCS.

Table.4 Mean levels (µg/kg) of PAHs and reduction percentage in potatoes as affected by peeling and washing with tap water

PAHs compounds	Mean concentration (µg/kg) ± SD		
	Control	Peeled potatoes	Washing of peeled potatoes by tap water
2-Bromonaphthalene	ND	ND	ND
Acenaphthylene	ND	ND	ND
Acenaphthene	1.091 ± 0.09	0.030 ± 0.01 (97.25%)	0.019 ± 0.01 (98.26%)
Fluorene	0.895 ± 0.07	ND (100%) ***	ND (100%)
Anthracene	2.091 ± 0.22	0.210 ± 0.03 (89.96%)	0.190 ± 0.03 (90.91%)
Phenanthrene	1.189 ± 0.13	0.065 ± 0.008 (94.53%)	0.048 ± 0.01 (95.96%)
Pyrene	1.320 ± 0.09	0.076 ± 0.009 (94.24%)	0.064 ± 0.02 (95.15%)
Fluoranthene	ND	ND	ND
Chrysene**	0.769 ± 0.06	0.057 ± 0.006 (92.59%)	ND (100%)
Benzo(a)anthracene*	1.697 ± 0.16	0.075 ± 0.009 (95.58%)	ND (100%)
Benzo(k)fluorancene**	ND	ND	ND
Benzo(a)pyrene*	0.473 ± 0.05	0.017 ± 0.02 (96.41%)	0.013 ± 0.01 (97.25%)
Dibenz(a,h)anthracene*	0.695 ± 0.07	0.099 ± 0.01 (85.76%)	0.030 ± 0.01 (95.68%)
Benzo(ghi)perylene	ND	ND	ND
Indeno(1,2,3,-cd)pyrene**	ND	ND	ND
Total PAHs	10.220	0.629 (93.85%)	0.364 (96.44%)
Total carcinogenic PAHs	3.634	0.248 (93.18%)	0.043 (98.82%)

ND: Not detectable. SD: Standard Deviation ***: Reduction percentage
* IARC Group 2a: Probably carcinogenic to human according to IARC.
** IARC group 2b: Possibly carcinogenic to humans according to IARC.
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Fig.3 Mean levels (µg/kg) of PAHs and their reduction percentage in potatoes as affected by washing using tap water and acetic acid solutions (1% and 2%)

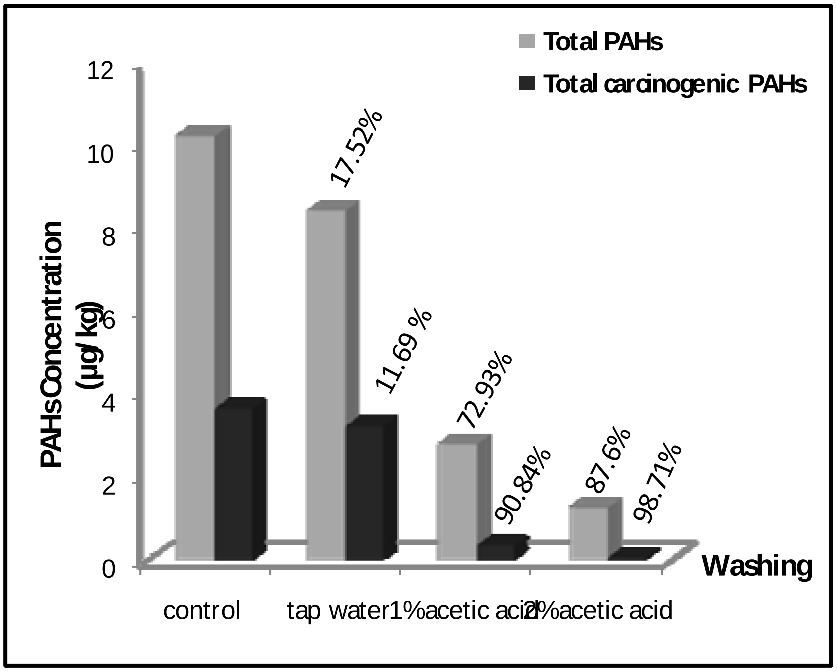

Fig.4 Mean levels (µg/kg) of PAHs and reduction percentage in potatoes as affected by peeling and washing with tap water

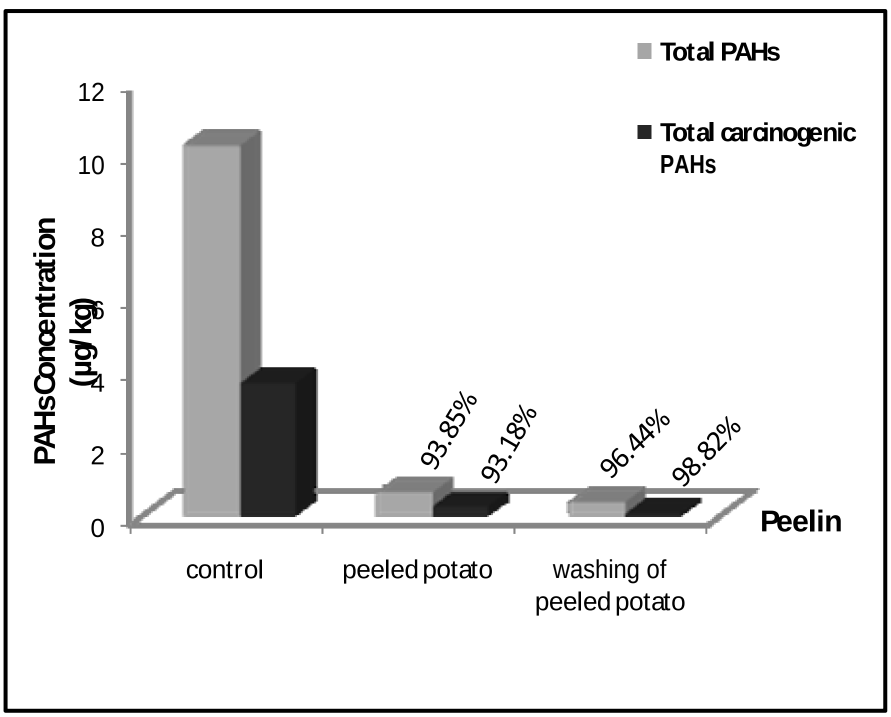

Table.5 Mean levels (µg/kg) of PAHs and reduction percentage in spinach as affected by boiling

PAHs Compounds	Mean concentration (µg/kg) ± SD	
	Control	Boiling
2-Bromonaphthalene	ND	ND
Acenaphthylene	ND	ND
Acenaphthene	ND	ND
Fluorene	ND	ND
Anthracene	ND	ND
Phenanthrene	3.071 ± 0.23	0.809 ± 0.09 (73.66%)***
Pyrene	ND	ND
Fluoranthene	3.872 ± 0.32	0.690 ± 0.05 (82.18%)
Chrysene**	0.192 ± 0.02	0.018 ± 0.01 (90.63%)
Benzo(a)anthracene*	0.804 ± 0.06	ND (100%)
Benzo(k)fluorancene**	0.837 ± 0.07	0.399 ± 0.04 (52.33%)
Benzo(a)pyrene*	0.368 ± 0.04	0.243 ± 0.03 (33.97%)
Dibenz(a,h)anthracene*	0.803 ± 0.06	0.006 ± 0.01 (99.25%)
Benzo(ghi)perylene	0.321 ± 0.29	0.127 ± 0.02 (60.44%)
Indeno(1,2,3,-cd)pyrene**	1.809 ± 0.21	ND (100%)
Total PAHs	12.077	2.292 (81.02%)
Total carcinogenic PAHs	4.813	0.666 (86.16%)

ND: Not detectable. SD: Standard Deviation *** Reduction percentage
* IARC Group 2a: Probably carcinogenic to human according to IARC.
** IARC group 2b: Possibly carcinogenic to humans according to IARC.
* & ** classified as carcinogenic to human by US EPA and WHO/IPCS.

Table.6 Mean levels (µg/kg) of PAHs and reduction percentage in potatoes as affected by boiling

PAHs compounds	Mean concentration (µg/kg) ± SD				
	Control	Boiled of shelled potato	Extract of boiling water of shelled potato	Boiled peeled potato	Extract of boiling water of peeled potato
2-Bromonaphthalene	ND	ND	ND	ND	ND
Acenaphthylene	ND	ND	ND	ND	ND
Acenaphthene	1.091 ± 0.09	0.300 ± 0.05 (72.50%)	0.419 ± 0.03 (91.59%)***	ND (100%)	ND (100%)
Fluorene	0.895 ± 0.07	ND (100%)	ND (100%)	ND (100%)	ND (100%)
Anthracene	2.091 ± 0.21	0.400 ± 0.03 (80.87%)	0.890 ± 0.09 (57.44%)	0.030 ± 0.01 (98.57%)	ND (100%)
Phenanthrene	1.189 ± 0.13	0.102 ± 0.01 (91.42%)	0.591 ± 0.06 (50.29%)	0.033 ± 0.01 (97.22%)	ND (100%)
Pyrene	1.320 ± 0.09	0.022 ± 0.01 (98.33%)	ND (100%)	ND (100%)	ND (100%)
Fluoranthene	ND	ND	ND	ND	ND
Chrysene**	0.769 ± 0.06	0.279 ± 0.03 (63.72%)	ND (100%)	0.102 ± 0.02 (86.74%)	ND (100%)
Benzo(a)anthracene*	1.697 ± 0.16	ND (100%)	ND (100%)	ND (100%)	ND (100%)
Benzo(k)fluorancene**	ND	ND	ND	ND	ND
Benzo(a)pyrene*	0.473 ± 0.05	0.017 ± 0.01 (96.41%)	0.018 ± 0.01 (96.19%)	ND (100%)	ND (100%)
Dibenz(a,h)anthrac-ene*	0.695 ± 0.07	0.130 ± 0.02 (81.29%)	ND (100%)	ND (100%)	ND (100%)
Benzo(ghi)perylene	ND	ND	ND	ND	ND
Indeno(1,2,3,-cd)pyrene**	ND	ND	ND	ND	ND
Total	10.220	1.250 (87.77%)	1.918 (81.23%)	0.165 (98.39%)	ND (100%)
Total carcinogenic PAHs	3.634	0.426 (88.28%)	0.018 (99.50%)	0.102 (97.19%)	ND (100%)

ND: Not detectable. SD: Standard Deviation ***: Reduction percentage

* IARC Group 2a: Probably carcinogenic to human according to IARC.

** IARC group 2b: Possibly carcinogenic to humans according to IARC.

* & ** classified as carcinogenic to human by US EPA and WHO/IPCS

Particle bound high molecular mass PAHs which remain on the surface are easily washed off whereas low molecular mass compounds which are in the vapour phase can penetrate the waxy layer of fruits and vegetables and are less efficiently removed by washing (European Commission, 2002).

Detoxification of PAHs from some vegetables by Boiling

Some Foods like vegetables may be cooked with different methods at home or plants. Each method has an important effect on PAHs levels in food. Boiling is a major method of home cooking which is very important for vegetables which helps to remove PAHs from leafy or ground vegetables. The role of boiling cooking process of spinach for 10 min at 100 °C was investigated and data are presented in Table 5. The results demonstrated the efficient role of boiling process in reduction percentage of PAHs from contaminated samples.

The percentage of total and carcinogenic PAHs removed from spinach was 81.02 and 86.16%, respectively. Boiling decreased the levels of phenanthrene, fluoranthene, chrysene, benzo(a)anthracene, benzo (k)fluoranthene, benzo(a)pyrene, dibenz (a,h)anthracene benzo(ghi)perylene and indeno(1,2,3-cd)pyrene. Also, the results in Table 6 proved the efficient role of boiling process on PAHs of shelled or peeled potatoes. The comparative percentages of total and carcinogenic PAHs removed from shelled potatoes were 87.77 and 88.28%, respectively. These percentages were increased to 98.39 and 97.19%, respectively when peeling process followed by boiling. Boiling of potatoes decreased the levels of acenaphthene, fluorene, anthracene, phenanthrene, pyrene, chrysene, benzo(a)anthracene, benzo(a)pyrene and dibenz(a,h)anthracene.

The present investigation proved that PAHs levels in street vended foodstuffs were quite variable; hence, there is a need for concerted efforts to improve the safety of street vended foods. The results showed the efficient role of washing with tap water in the reduction of PAHs from investigated foodstuffs. This reduction increased with acetic acid solutions at different levels. Also, peeling process was an efficient role for reducing PAHs content from the contaminated vegetables. This reduction is due to that, peeling process removed the adhered PAHs with the skin. Boiling process proved an important role on reducing PAHs levels from the contaminated vegetables. It could be recommended that careful washing of vegetables especially by acidic detergents and peeling process could be effective in reducing the daily intake of PAHs containing foods.

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