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Polycyclic aromatic hydrocarbons (PAH) in foods and estimated PAH intake by the population of Catalonia, Spain: Temporal trend

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ABSTRACT

The concentrations of 16 polycyclic aromatic hydrocarbons (PAH) were determined in various foodstuffs randomly purchased in Catalonia (Spain) during November and December of 2008. Dietary intake of PAH was subsequently estimated according to age and sex for the general population of Catalonia. The current results were compared with those of previous studies performed in 2000 and 2006. The highest PAH levels corresponded to phenanthrene (18.18 μg/kg), naphthalene (13.31 μg/kg), and pyrene (8.46 μg/kg), whereas the lowest concentrations were those of dibenzo[*a,h*]anthracene (0.89 μg/kg), indeno[1,2,3-*c,d*]pyrene (0.94 μg/kg), and benzo[*k*]fluoranthene (1.00 μg/kg). With respect to the contribution of total carcinogenic PAH, benzo[*a*]pyrene contributed 47.77% or 48.22%, depending on the TEF value used. By food groups, the current highest levels of total PAH were detected in meat and meat products (38.99 μg/kg), followed by oils and fats (18.75 μg/kg), and dairy products (7.57 μg/kg). The highest contribution to PAH dietary intake corresponded to the group of meat and meat products (4.75 μg/day). The estimated mean dietary intake for a standard male adult (70-kg body weight) was 6.72 μg/day, a lower value than those found in our 2000 (8.42 μg/day), and 2006 surveys (12.04 μg/day). With regard to the results of other recent studies, the current PAH concentrations were comparatively lower.

1. Introduction

Polycyclic aromatic hydrocarbons (PAH) are a group of over 100 different compounds that have in common two or more fused aromatic rings. Most have low solubility in water, and generally they are very lipophilic, and they are formed because of incomplete combustion of different organic materials (Danyi et al., 2009). These environmental pollutants are found in air, water, soil and sediments (ATSDR, 1995; Bartos et al., 2009; Danyi et al., 2009; Zhang et al., 2009), generally occurring as ring complex mixture contaminants containing two or more of these compounds.

The presence of PAH in foodstuffs depends on the environmental concentrations of these pollutants, as well as the physiological and ecological characteristics of the product (Ramesh et al., 2004; Wenzl et al., 2006). In non-smokers, diet is the primary source of human to PAH (Lodovici et al., 1995; Phillips, 1999; Falcó et al., 2003), contributing to more than 70% of the total exposure (Gilbert, 1994; McGrath et al., 2007). The quantity coming from the diet depends largely on the way of cooking, and the potential food contamination, which originates from packaging materials and manufacturing (Guillen, 1994; Perelló et al., 2009).

The main health concern on PAH is due to the fact that some of them have been shown to be highly carcinogenic in laboratory animals, having been also implicated in different types of human cancers, mainly breast, lung, and colon, due a metabolic activation in mammalian cell to dioepoxides causing errors in DNA replication and mutation (US EPA, 2002; Yoon et al., 2007), which initiates the carcinogenic process (Janoszka et al., 2004). The US Environmental Protection Agency (EPA) has classified benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, chrysene, benzo[*k*]fluoranthene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene as probable human carcinogens (group B2) (US EPA, 2002). In turn, 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 indeno[1,2,3-*c,d*]pyrene are possible human carcinogens (IARC, 2004). On the other hand, the European Commission Regulation 1881/2006 of 19th December, 2006, in which there are listed maximum levels for benzo[*a*]pyrene in several foodstuffs, established different concentrations of benzo[*a*]pyrene depending on the respective foodstuff (EC, 2006).

In June–August 2000, we determined the concentrations of 16 PAH in a number of food samples acquired in Catalonia (NE, Spain) (Falcó

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et al., 2003). The dietary intake of PAH was subsequently estimated for the general population living in that Spanish region. The most important contribution to the dietary PAH intake corresponded to cereals, meat and meat products, and fish and shellfish. In March–April of 2005, we extended that survey by collecting samples of the 14 species of fish and shellfish most consumed in Catalonia and by measuring the levels of the same 16 PAH (Llobet et al., 2006; Domingo et al., 2007; Martí-Cid et al., 2007). In order to establish the evolution in the total dietary intake of PAH by the Catalan population, food items belonging to food groups, other than fish and shellfish, and also assessed in our 2000 survey were analyzed (Martí-Cid et al., 2008a). In 2008, we initiated a new survey whose main objective was to determine again the temporal trend of the dietary intake of PAH by the population of Catalonia. The results of this study are here presented and discussed.

2. Materials and methods

2.1. Sampling

In November–December 2008, samples of foodstuffs were purchased in 12 cities (Barcelona, Hospitalet de Llobregat, Vilanova i la Geltrú, Mataró, Sabadell, Terrassa, Girona, Tarragona, Reus, Tortosa, Lleida and Manresa) of Catalonia (Spain). Two hundred sixty food samples were purchased from each locality at 4 different places (local markets, small stores, supermarkets, and big grocery stores). The foods selected for PAH analysis are among the most consumed in Catalonia (Serra-Majem et al., 2003). Food samples included: meat (veal steak, hamburger, loin of pork, pork sausage, chicken breast, and steak and rib of lamb), and meat products (boiled ham, "frankfurt" sausage, salami, and cured ham); fish and shellfish (sardine, canned sardine, tuna, canned tuna, anchovy, mackerel, swordfish, salmon, hake, red mullet, sole, cuttlefish, squid, clam, mussel, and shrimp); vegetables (lettuce, tomato, cauliflower, string bean, onion, pepper, carrot, and eggplant); tubers (potato); fruits (apple, orange, pear, banana, mandarin, strawberry, and peach); eggs; milk (whole, and semi-skimmed); dairy products (1 composite for yoghurt, 3 composites for different types of cheese, and 1 composite for pudding–custard–cream); cereals (French bread, sandwich bread, rice, and pasta); pulses (lentils, haricot beans, chickpeas, and peas); oils and fats (olive oil, sunflower oil, margarine, and butter), and industrial bakery (croissant, cookie, and fairy cake). For each food item, two composite samples were prepared for analyses. Each composite sample consisted of 24 individual units. Only edible parts of each food item were selected for PAH analysis.

2.2. Analytical procedure

The concentrations of 16 PAH (naphthalene, acenaphtylene, acenaphtene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, indeno[1,2,3-*c,d*]pyrene, dibenzo[*a,h*]anthracene, and benzo[*g,h,i*]perylene) were analyzed according to the California Environmental Protection Agency Air Resources Board (CARB) method 429 (CARB, 1997). In each homogenized sample, an appropriate isotope-labeled extraction standard (deuterated PAH) was added in order to achieve the control of the all sample preparation process. Each PAH was extracted of the sample with hexane/acetone as solvent in accelerated solvent extraction (ASE). We carried out a chromatographic size exclusion to ensure proper cleaning and a good fractionation of the crude extract. The cleaned extracts were analyzed by isotope dilution high-resolution mass spectrometry (HRMS) combined with high-resolution gas chromatography (HRGC) using Agilent GCs coupled to Water Autospec Ultima HRMS systems with selected ion recording at resolution 8000. Certain isotopes were used as internal standards to determine the quantification of PAH. Previously, it was necessary to inject the sample onto non-polar DB5MS-type GC columns. The detection limit was between 0.025 μg/kg and 13 μg/kg, depending on the respective PAH. The percentages of recovery ranged between 4.1 and 147.7%. Sample preparations for analysis, and instrumentation, were widely detailed in previous reports (Falcó et al., 2003; Martí-Cid et al., 2008a; Perelló et al., 2009).

2.3. Dietary exposure estimates

Consumption data by the general population of Catalonia of the analyzed foodstuffs were taken from Serra-Majem et al. (2003). Total dietary intake of PAH for each food group was calculated by summing the results of multiplying the concentration in each specific food item by the amount (proportionally estimated) consumed of that food. Finally, total dietary intake was obtained by summing the respective intakes from each food group. For calculations, when a concentration was under the respective LOD, the value was assumed to be equal to one-half of the LOD (ND = 1/2 LOD).

2.4. Data analysis

Results were evaluated using the statistical software SPSS 15.0. The Levene test was applied to study the equality of variances. The statistical significance of differences was assessed by applying the Kruskal–Wallis test. A probability of 0.05 or lower ($p \leq 0.05$) was considered as significant.

3. Results and discussion

In a recent Scientific Opinion of the EFSA Panel on Contaminants in the Food Chain (CONTAM Panel) adopted on June 9, 2008 (EFSA, 2008), it was concluded that eight PAH, the seven considered as carcinogenic by the US EPA, plus benzo[*g,h,i*]perylene, either individually or in combination, should be considered as the only possible indicators of the carcinogenic potency of PAH in food. Although benzo[*g,h,i*]perylene had not been included in our previous surveys (Falcó et al., 2003; Martí-Cid et al., 2008a) the opinion of the CONTAM Panel was the reason because in the current study, this compound was also added to the group of carcinogenic PAH. For a possible comparison of the present results with those of the previous surveys, two sets of data, including 7 and 8 carcinogenic PAH are here reported.

The mean concentrations of 16 PAH in food samples acquired in various locations of Catalonia are shown in Table 1. Total PAH concentrations for all the analyzed food groups are also given. However, it is important to note that most concentrations were below the LODs. Among the single analyzed compounds, the most abundant were phenanthrene (18.18 μg/kg) and naphthalene (13.31 μg/kg), while the lowest levels corresponded to dibenzo[*a,h*]anthracene (0.89 μg/kg), indeno[1,2,3-*c,d*]pyrene (0.94 μg/kg), and benzo[*k*]fluoranthene (1.00 μg/kg).

By food groups, the current highest levels of total PAH were detected in meat and meat products (38.99 μg/kg), followed by oils and fats (18.75 μg/kg), and dairy products (7.57 μg/kg). By contrast, the food groups showing the lowest concentrations of total PAH were milk (0.47 μg/kg), tubers (0.73 μg/kg), and fruits (0.81 μg/kg). In general terms, the current values are lower than those found in our 2000 study (Falcó et al., 2003). It is interesting to remark the important decrease of PAH levels in cereals (14.45 μg/kg vs. 1.27 μg/kg in the current survey). Only in the group of meat and meat products, higher values could be seen (13.43 μg/kg vs. 38.99 μg/kg). The statistical comparison with the results of the 2006 survey (Martí-Cid et al., 2008a) shows a decreasing trend of the total PAH levels for most food groups (Table 2). Significant differences were found in fish and shellfish ($p<0.01$), tubers ($p<0.01$), milk ($p<0.001$), cereals ($p<0.001$), pulses ($p<0.001$), oil and fats ($p<0.01$) and industrial bakery ($p<0.01$). However, PAH levels in meat and meat products increased significantly ($p<0.05$). Regarding benzo[*a*]pyrene, it is interesting to remark that significant reductions were observed in vegetables ($p<0.05$), tubers ($p<0.01$), dairy products ($p<0.05$), and industrial bakery ($p<0.01$), while a significant increase was noted in pulses ($p<0.05$).

In general terms and with the exception of vegetables, the current concentrations concerning carcinogenic PAH are lower than those observed in our 2006 study (Martí-Cid et al., 2008a). As above commented, the foodstuffs collected in the 12 Catalan cities were quite random. Therefore, the PAH levels are not necessarily related with the place in which samples were purchased.

The contribution of each food group to the total PAH levels is depicted in Fig. 1. Meat and meat products (49.2%) contributed with approximately one-half of the total, followed by oils and fats (23.7%), and dairy products (9.6%). According to these results, the specific contributions of each group were similar to those observed in our previous surveys. PAH concentrations in the 2000 and 2008 (current) studies were 62.76 μg/kg, 108.2 μg/kg and 79.23 μg/kg, respectively (Falcó et al., 2003; Martí-Cid et al., 2008a).

De Vos et al. (1990) analyzed various food samples from the Dutch diet. Benzo[*a*]pyrene levels were higher than our current concentrations. For example, butter and margarine were 0.6 and 1.4 μg/kg, whereas we found levels of 0.48 and 0.50 μg/kg, respectively (concentrations below the LODs). In a recent survey by Rojo-Camargo and Toledo (2003) in which

Table 1
Concentrations of PAH in food samples from Catalonia, Spain.[a]

	Naphthalene	Acenaphtylene	Acenaphtelene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo[*a*]-anthracene	Chrysene	Benzo[*b*]-fluoranthene	Benzo[*k*]-fluoranthene	Benzo[*a*]-pyrene	Indeno [1,2,3-*c*,*d*]-pyrene	Dibenzo-[*a*,*h*] anthracene	Benzo-[*g*,*h*,*i*]-perylene	Total PAH	Σ7 Carcinogenic PAH	Σ8 Carcinogenic PAH
Veal steak	<0.80	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	0.07	1.25	0.22	0.29
Hamburger	<0.81	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.23	0.23	0.26
Loin of pork	<0.78	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	1.18	0.22	0.25
Pork sausage	<0.79	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	0.05	<0.06	0.06	<0.06	<0.06	<0.06	1.25	0.27	0.30
Chicken breast	<0.82	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.25	0.23	0.26
Lamb	<0.84	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.26	0.23	0.27
Boiled ham	<0.81	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.22	0.23	0.26
Frankfurt	2.60	2.40	0.14	1.63	3.34	1.19	0.94	1.09	0.16	0.12	0.00	<0.06	0.06	<0.06	<0.06	<0.06	13.86	0.51	0.54
Salami	19.00	18.00	2.55	18.00	155.00	32.00	50.50	55.50	4.65	5.10	2.15	0.62	1.10	0.28	<0.11	0.42	364.91	13.95	14.36
Cured ham	<0.83	<0.17	0.17	<0.17	0.64	<0.17	<0.17	0.64	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	2.47	0.23	0.27
Meat and meat products	**2.48**	**2.10**	**0.34**	**2.03**	**15.95**	**3.38**	**5.21**	**5.78**	**0.51**	**0.55**	**0.25**	**0.09**	**0.14**	**0.06**	**0.03**	**0.07**	**38.99**	**1.63**	**1.71**
Fresh sardine	<0.83	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	0.05	<0.07	<0.07	0.08	1.32	0.25	0.33
Canned sardine	<0.81	<0.16	0.21	<0.16	<0.16	<0.16	<0.16	0.47	0.06	0.07	<0.07	<0.07	<0.07	<0.07	<0.07	0.12	1.89	0.30	0.41
Sardine	<1.64	<0.33	0.29	<0.33	<0.33	<0.33	<0.33	0.55	0.10	0.10	<0.13	<0.13	0.09	<0.13	<0.13	0.19	3.21	0.55	0.74
Fresh tuna	<0.83	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	0.08	4.25	0.27	0.35
Canned tuna	<2.01	<0.41	0.24	<0.41	<0.41	<0.41	0.58	0.76	0.13	0.20	0.11	<0.16	<0.16	<0.16	<0.16	<0.16	4.25	0.77	0.85
Tuna	<2.84	<0.57	0.33	<0.57	<0.57	<0.57	0.66	0.85	0.16	0.23	0.14	<0.23	<0.23	0.15	<0.23	0.16	5.58	1.03	1.20
Anchovy	<0.76	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	1.16	0.21	0.24
Mackerel	<0.76	0.13	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	1.20	0.21	0.24
Swordfish	<0.80	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	1.22	0.22	0.26
Salmon	<0.80	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	1.22	0.23	0.26
Hake	<0.80	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	1.22	0.23	0.26
Red mullet	<0.81	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	0.06	<0.06	<0.08	<0.06	<0.06	<0.06	1.30	0.30	0.33
Sole	<0.76	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	1.15	0.21	0.24
Cuttlefish	<0.82	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.25	0.23	0.26
Squid	<0.77	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	<0.06	<0.06	<0.06	<0.11	<0.06	<0.06	1.20	0.24	0.27
Clam	<0.78	<0.16	<0.16	<0.16	0.33	<0.16	1.20	0.98	0.36	0.54	0.36	0.13	0.11	0.12	<0.06	0.12	4.98	1.64	1.76
Mussel	<0.79	0.26	<0.16	0.13	0.59	0.42	2.90	3.60	0.64	1.50	1.95	0.70	0.34	0.27	0.14	0.51	14.34	5.46	5.97
Shrimp	<0.82	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.23	0.23	0.26
Fish and shellfish	**0.50**	**0.12**	**0.11**	**0.10**	**0.15**	**0.12**	**0.41**	**0.48**	**0.11**	**0.19**	**0.20**	**0.09**	**0.07**	**0.07**	**0.04**	**0.09**	**2.864**	**0.78**	**0.88**
Lettuce	<0.61	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.92	0.17	0.19
Tomato	<0.60	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.91	0.17	0.19
Cauliflower	<0.59	<0.12	<0.12	<0.12	0.35	0.10	<0.12	1.32	0.38	0.28	0.19	0.04	0.39	<0.05	<0.05	0.42	4.08	1.34	1.76
String bean	<0.49	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.74	0.14	0.16
Onion	<0.47	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.71	0.13	0.15
Pepper	<0.49	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.74	0.13	0.15
Carrot	<0.63	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.95	0.18	0.20
Eggplant	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.75	0.14	0.16
Vegetables	**0.27**	**0.05**	**0.05**	**0.05**	**0.09**	**0.06**	**0.05**	**0.21**	**0.07**	**0.05**	**0.04**	**0.02**	**0.07**	**0.02**	**0.02**	**0.07**	**1.22**	**0.30**	**0.37**
Potato	<0.49	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.73	0.13	0.15

Tubers	**0.24**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.73**	**0.13**	**0.15**
Apple	<0.49	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.74	0.14	0.16
Orange	<0.49	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.74	0.14	0.16
Pear	<0.65	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.98	0.18	0.21
Banana	<0.47	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.71	0.13	0.15
Mandarin	<0.51	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.76	0.14	0.16
Strawberry	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.75	0.14	0.16
Peach	<0.66	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	1.01	0.19	0.21
Fruits	**0.27**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.81**	**0.15**	**0.17**
Hen eggs	<2.40	<0.48	<0.48	<0.48	<0.48	<0.48	<0.48	<0.48	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19	<0.19	3.62	0.67	0.76
Eggs	**1.20**	**0.24**	**0.24**	**0.24**	**0.24**	**0.24**	**0.24**	**0.24**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**3.62**	**0.67**	**0.76**
Whole milk	<0.31	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.47	0.09	0.10
Semi skimmed milk	<0.31	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.48	0.09	0.10
Milk	**0.16**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.47**	**0.09**	**0.10**
Yoghurt	<0.43	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.65	0.12	0.14
Cheese I	<6.90	<1.44	<1.44	<1.44	<1.44	<1.44	<1.44	<1.44	<0.57	<0.57	<0.57	<0.57	<0.57	<0.57	<0.57	<0.57	10.75	2.00	2.28
Chesse II	<7.90	<1.53	<1.53	<1.53	<1.53	<1.53	<1.53	<1.53	<0.61	<0.61	<0.61	<0.61	<0.61	<0.61	<0.61	<0.61	11.75	2.14	2.44
Chesse III	<8.45	<1.69	<1.69	<1.69	<1.69	<1.69	<1.69	<1.69	<0.67	<0.67	<0.67	<0.67	<0.67	<0.67	<0.67	<0.67	12.80	2.33	2.66
Pudding–custard–cream	<1.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	1.89	0.34	0.39
Dairy products	**0.63**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**7.57**	**1.38**	**1.58**
French bread	<0.84	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.28	0.23	0.27
Sandwich bread	<0.82	<0.17	<0.37	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.35	0.23	0.26
Rice	<0.79	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	1.19	0.22	0.25
Pasta	<0.83	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.25	0.23	0.26
Cereals	**0.41**	**0.08**	**0.11**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**1.27**	**0.23**	**0.26**
Lentil	<1.54	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	2.30	0.41	0.47
Haricot bean	<1.46	<0.29	<0.29	<0.29	<0.29	<0.29	<0.29	<0.29	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	<0.12	2.20	0.40	0.46
Chickpea	<0.50	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.75	0.14	0.16
Pea	<0.51	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.76	0.14	0.16
Pulses	**0.50**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**	**1.50**	**0.27**	**0.31**
Olive oil	<12.50	<2.50	<2.50	<2.50	<2.50	<2.50	<2.50	<2.50	<0.98	<0.98	<0.98	<0.98	<0.98	<0.98	<0.98	<0.98	18.92	3.43	3.92
Sunflower oil	<12.50	<2.45	<2.45	<2.45	<2.45	<2.45	<2.45	<2.45	<0.98	<0.98	<0.98	<0.98	<0.98	<0.98	<0.98	<0.98	18.75	3.43	3.92
Margarine	<13.00	<2.50	<2.50	<2.50	<2.50	<2.50	<2.50	<2.50	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	19.25	3.50	4.00
Butter	<12.00	<2.35	<2.35	<2.35	<2.35	<2.35	<2.35	<2.35	<0.96	<0.96	<0.96	<0.96	<0.96	<0.96	<0.96	<0.96	18.07	3.36	3.84
Oils and fats	**6.25**	**1.23**	**1.23**	**1.23**	**1.23**	**1.23**	**1.23**	**1.23**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	**18.75**	**3.43**	**3.92**
Croissant	<0.84	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.28	0.23	0.27
Cookie	<0.83	<0.17	0.19	0.14	<0.17	<0.17	<0.17	<0.17	0.06	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.46	0.26	0.30
Fairy cake	<0.82	<0.17	0.30	0.15	<0.17	<0.17	<0.17	<0.17	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	<0.07	1.54	0.23	0.26
Industrial bakery	**0.41**	**0.08**	**0.19**	**0.13**	**0.08**	**0.08**	**0.08**	**0.08**	**0.04**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**1.43**	**0.24**	**0.28**
Total	13.31	4.26	2.63	4.21	18.18	5.55	7.66	8.46	1.49	1.59	1.29	1.00	1.08	0.94	0.89	1.03	79.23	9.31	10.49

Data in bold are the specific food groups, as well as the mean concentrations of PAH concerning each group.

[a] Data are given in μg/kg fresh weight. The upper value was calculated assuming that when a congener was below the detection limit the concentration was equal to one-half of the respective limit of detection.

Table 2
Concentrations of PAH in food samples from Catalonia, Spain. Data from the 2000, 2006 and 2008 (current) surveys.

PAH (μg/kg)	Meat and meat products			Fish and shellfish			Vegetables			Tubers			Fruits			Eggs		
	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008
Benzo[*a*]pyrene	0.10	0.13	0.14	0.24	0.14	0.07	0.01	0.02	0.07	0.06	0.03	0.02	0.01	0.02	0.02	0.02	0.09	0.10
7 Carcinogenic PAH[a]	0.21	0.32	0.26	0.39	0.34	0.15	0.03	0.05	0.10	0.13	0.07	0.04	0.03	0.05	0.05	0.06	0.30	0.22
8 Carcinogenic PAH[b]	0.21	0.31	0.24	0.39	0.35	0.16	0.03	0.06	0.10	0.13	0.07	0.05	0.03	0.05	0.05	0.06	0.32	0.23
Sum of 16 PAH	13.43	25.56	38.99	7.89	8.01	2.87	0.89	1.73	1.22	3.61	1.21	0.73	0.95	1.05	0.81	2.42	8.56	3.62
	Milk			Dairy products			Cereals			Pulses			Oils and fats			Industrial bakery		
	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008
Benzo[*a*]pyrene	0.01	0.06	0.01	0.08	0.08	0.20	0.26	0.05	0.03	0.06	0.03	0.04	0.27	0.50	0.49	NA	0.12	0.03
7 Carcinogenic PAH[a]	0.03	0.18	0.03	0.16	0.18	0.46	0.49	0.13	0.08	0.11	0.07	0.09	0.48	1.15	1.13	NA	0.29	0.08
8 Carcinogenic PAH[b]	0.03	0.20	0.03	0.16	0.18	0.46	0.49	0.14	0.08	0.12	0.08	0.09	0.47	1.19	1.18	NA	0.30	0.08
Sum of 16 PAH	1.53	2.58	0.47	6.64	4.08	7.57	14.45	20.44	1.27	2.74	7.96	1.50	8.68	23.48	18.75	NA	11.22	1.43

NA (Not analyzed in 2000).

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).

[b] Carcinogenic PAH, according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Brazilian vegetables and fruits were analyzed, PAH levels were higher than those of the present study. Something similar occurred in a study by Kazerouni et al. (2001), with the exception of some samples such as margarine (0.12 μg/kg). In another recent survey (Perelló et al., 2009), we determined the levels of a number of PAH in various uncooked and cooked food samples. In uncooked samples, all PAH levels were higher than those of the present study. In contrast, in another study also performed in Catalonia, Fontcuberta et al. (2006) reported a value of 59 μg/kg for total PAH. In the present survey, total PAH was higher, 79.2 μg/kg, but similar to the levels reported by Loutfy et al. (2007) (11.7–154.3 μg/kg). Benzo[*a*]pyrene, is a subject of a notable concern due to its carcinogenic potential (Yoon et al., 2007). Dennis et al. (1991) found similar concentrations of this pollutant to those of our study. However, slightly lower values were noted in meat and meat products (0.05 μg/kg), a group for which our PAH level was higher (0.14 μg/kg).

Table 3 summarizes data on the daily intakes of the analyzed food groups for 4 age groups (children, adolescents, adults, and seniors) and according to gender. A comparison with our previous (2000 and 2006) studies (Falcó et al., 2003; Llobet et al., 2006; Martí-Cid et al., 2008a) is also given. It is important to note that the LODs concerning our previous surveys and the current study are similar. Generally, it can be noted that females ingested less PAH (mainly senior females). The differences in food habits between genders could explain these results. Men consume usually more meat, and oils and fats than women, which are the food groups where the highest concentrations of PAH were found (Cucó et al., 2001). Compared with our 2006 market basket study (Martí-Cid et al., 2008a), a decreasing trend can be seen in all food groups, with the exception of meat and dairy products. In the 2006 and 2008 surveys, we used the data on food consumption of Serra-Majem et al. (2003), together with other recently published data. However, in the 2000 survey, food consumption information was obtained from Cucó et al. (2001) and Capdevila et al. (2000). Total daily food intake reported by these authors (Capdevila et al., 2000) was slightly higher than that of Serra-Majem et al. (2003).

Tables 4a–4h show, for each age and gender group, the total dietary intakes of benzo[*a*]pyrene, the sum of the PAH considered as probable human carcinogens by the US EPA (2002) and by Larsen and Larsen (1998), and the sum of the 16 PAH here analyzed. The total dietary intake of benzo[*a*]pyrene was expressed in micrograms per kilograms of body weight per day. Due to its importance as one of the most potent animal carcinogenic PAH, benzo[*a*]pyrene is the most widely known and studied. The decreasing trend found for this compound has an exception in the senior groups. When the dietary intake of the sum of the 16 PAH analyzed was expressed in micrograms per day the results were the following: boys (6.051), girls (5.441), adolescents-boys (8.278), adolescents-girls (5.605), male adults (6.705), female adults (3.918), male seniors (3.560), and female seniors (2.683). Although not statistically evaluated, in comparison with the results of our previous surveys (Falcó et al., 2003; Martí-Cid et al., 2008a) a decreasing tendency in the total PAH intake was observed for all age groups.

In order to estimate the potency of a PAH fraction of a mixture, the total number of B[*a*]P equivalents of the mixture is multiplied by the potency for B[*a*]P (US EPA, 2002; Yoon et al., 2007). The toxic equivalency factors (TEFs) adopted by the US EPA (2002) provide values for benzo[*a*]anthracene TEF = 0.1, chrysene TEF = 0.001, benzo[*b*]fluoranthene TEF = 0.1, benzo[*k*]fluoranthene TEF = 0.01, benzo[*a*]pyrene TEF = 1, dibenzo[*a,h*]anthracene TEF = 1, and indeno[1,2,3-*c,d*]pyrene TEF = 0.1. In turn, Larsen and Larsen (1998) included the same PAH than the US EPA, although with different TEF values and adding also benzo[*g,h,i*]perylene. TEF values were used to calculate PAH as benzo[*a*]pyrene equivalents for a standard adult male (70-kg body weight) living in Catalonia. This approach estimates the potency of B[*a*]P and expresses the environmental levels of other PAH as "B[*a*]P equivalents". With respect to the carcinogenic risk associated with the dietary intake of PAH, on the basis of animal carcinogenicity data, an acceptable daily intake of benzo[*a*]pyrene was computed as the quantity that would be associated with a $1/10^6$ increase in risk of cancer for an adult of 70 kg (Santodonato et al., 1981; Falcó et al., 2003). Non-carcinogenic PAH were given a TEF = 0 (Nisbet and LaGoy, 1992; Yoon et al., 2007). According to the results of the present study, the estimated total daily intake of benzo[*a*]pyrene would be associated with $4.5/10^6$ increase in the risk for the development of cancer in a male adult with a body weight of 70 kg.

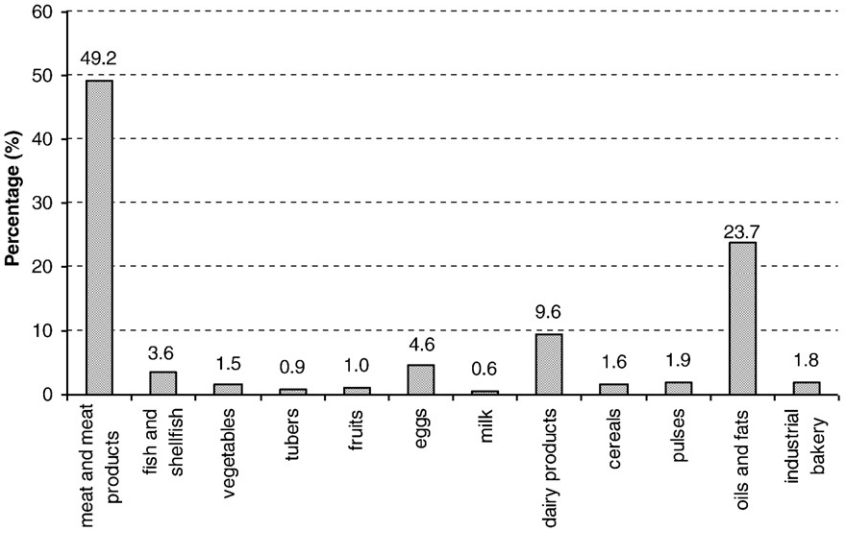

Fig. 1. Contribution (%) of 16 PAH to the total PAH concentration for each food group.

Table 3
540 Daily intake of PAH by various population groups of Catalonia, Spain. Data from the 2000, 2006 and 2008 541 (current) surveys.

Body weight (kg)	Boys			Girls			Boys adolescents			Girls adolescents			Male adults			Female adults			Male seniors			Female seniors		
	24			24			56			53			70			55			65			60		
	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008	2000	2006	2008
Meat and meat products	1.88	3.76	4.29	1.88	3.76	3.85	2.24	4.14	6.46	2.24	2.63	3.98	2.49	3.28	4.75	1.68	1.63	2.12	1.53	1.32	1.54	1.53	0.96	1.02
Fish and shellfish	0.41	0.46	0.15	0.41	0.46	0.13	0.49	0.25	0.12	0.49	0.21	0.11	0.73	0.34	0.17	0.63	0.37	0.17	0.63	0.37	0.16	0.63	0.28	0.12
Vegetables	0.11	0.24	0.18	0.11	0.24	0.17	0.14	0.19	0.12	0.14	0.21	0.16	0.20	0.34	0.20	0.18	0.38	0.24	0.17	0.35	0.30	0.17	0.31	0.28
Tubers	0.23	0.08	0.05	0.23	0.08	0.04	0.28	0.10	0.06	0.28	0.09	0.05	0.27	0.09	0.05	0.21	0.06	0.04	0.25	0.08	0.05	0.25	0.07	0.04
Fruits	0.19	0.17	0.15	0.19	0.17	0.13	0.19	0.13	0.09	0.19	0.13	0.10	0.22	0.20	0.16	0.21	0.21	0.17	0.25	0.32	0.28	0.25	0.26	0.23
Eggs	0.06	0.23	0.10	0.06	0.23	0.09	0.06	0.22	0.09	0.06	0.19	0.08	0.08	0.27	0.11	0.06	0.20	0.08	0.06	0.20	0.09	0.06	0.17	0.07
Milk	0.47	0.28	0.07	0.47	0.28	0.06	0.41	0.85	0.12	0.41	0.60	0.10	0.33	0.40	0.07	0.39	0.41	0.09	0.39	0.31	0.09	0.39	0.29	0.10
Dairy products	0.76	0.26	0.26	0.76	0.26	0.23	0.81	0.11	0.27	0.81	0.11	0.25	0.70	0.14	0.29	0.61	0.12	0.25	0.48	0.12	0.23	0.48	0.07	0.14
Cereals	2.9	3.93	0.26	2.90	3.93	0.23	3.19	6.01	0.34	3.19	4.57	0.26	2.98	5.47	0.28	2.00	3.53	0.20	2.26	4.74	0.24	2.26	3.22	0.17
Pulses	0.07	0.21	0.04	0.07	0.21	0.04	0.07	0.19	0.05	0.07	0.12	0.03	0.07	0.22	0.05	0.06	0.14	0.04	0.06	0.23	0.06	0.06	0.24	0.05
Oils and fats	0.29	0.55	0.46	0.29	0.55	0.42	0.31	0.74	0.45	0.31	0.67	0.40	0.36	0.85	0.51	0.27	0.76	0.46	0.25	0.82	0.50	0.25	0.73	0.45
Industrial bakery		0.44	0.06		0.44	0.05		0.91	0.11		0.64	0.09		0.46	0.06		0.42	0.06		0.32	0.03		0.30	0.04
Total intake																								
(μg/day)	7.37	10.61	6.06	7.37	10.61	5.40	8.20	13.83	8.28	8.20	10.16	5.61	8.42	12.04	6.72	6.29	8.24	3.93	6.33	9.19	3.58	6.33	6.89	2.70
(μg/kg body weight/day)	0.31	0.44	0.25	0.31	0.44	0.20	0.15	0.25	0.15	0.15	0.19	0.11	0.12	0.17	0.10	0.11	0.15	0.07	0.10	0.14	0.06	0.11	0.11	0.04

Table 5 shows the percentages of contribution of carcinogenic PAH in the diet. The highest contribution corresponded mainly to benzo[*a*]pyrene (48.22%), followed by dibenzo[*a,h*]anthracene (34.45%) (47.77% and 37.54% when using the TEFs suggested by Larsen and Larsen, 1998). This is in agreement with the results found in the 2000 study (Falcó et al., 2003). The food group showing the greatest contribution of PAH was meat and meat products (4.75 μg/day), followed by oils and fats (0.51 μg/day).

Table 6 summarizes data from some international studies concerning dietary exposure to PAH for male adults, an information that is rather limited. De Vos et al. (1990) estimated the daily intake of PAH for the population of the Netherlands, being 5–17 μg. In the United Kingdom, an intake of 3.7 μg/day was reported by Phillips (1999). For a male adult living in Catalonia, the current intake of PAH, 6.72 μg/day is of the same order of those values (De Vos et al., 1990; Phillips, 1999), being lower than that estimated in our previous surveys in Catalonia: 8.4 μg/day (Falcó et al., 2003) and 12.0 μg/day (Martí-Cid et al., 2008a). In an epidemiological study in which 200 food items were analyzed and the daily intake of benzo[*a*]pyrene was estimated, it was observed that intake ranged from 0.04 to 0.06 μg/day (Kazerouni et al., 2001). This is a similar range than that found for the population of Catalonia. The notable differences in dietetic habits for different countries (De Vos et al., 1990; Phillips, 1999; Kazerouni et al., 2001) would explain the differences among studies.

Yoon et al. (2007) quantified the time-weighted, lifetime average, daily intake (LADI) of 14 PAH through food ingestion, and estimated the excess cancer risk based on lifetime dietary PAH intake in South Korea. Twenty-seven different food commodities were selected from the 2001 Korean National Health and Nutrition survey based on their frequent consumption and high PAH level. The highest total TEQ level of PAH in foods was detected in roasted liver, 1.2 μg TEQ/kg. The estimated LADI of PAH was 3.22/10^3 μg/kg/day for carcinogenic effects, being higher in the younger age groups than in the older groups. The dietary excess cancer risk estimated using the cancer potency of benzo[*a*]pyrene (7.3 $(mg/kg/day)^{-1}$) was 2.3/10^5. In turn, Nwaneshiudu et al. (2007) determined the risks due to PAH exposure from food consumption for the population of Azerbaijan using deterministic and probabilistic methods. The most prevalent pathways of PAH exposure from the dietary patterns of the Azerbaijani population were bread and bakery products, milk and dairy products, and egg products. Child risks were consistently four to seven times higher in magnitude than adult risks. In a recent study, Reinik et al. (2007) determined the content of 12 PAH in 322 meat products consumed by children and the general Estonian population. The average intake of PAH by children from meat products was found to be 192 ng/day, while maximum intake values were estimated to be up to 1575 ng/day. Mean intakes by the general population from the consumption of meat products were 29 and 346 ng/day, for B[*a*]P and total PAH, respectively.

Recently, Cirillo et al. (2009) analyzed the levels of PAH in fresh-catch, farmed, and frozen marine fish marketed in Campania, Italy. In all the organisms analyzed, 16 PAH were found at detectable levels, with a total PAH content ranging between 0.82 and 134.28 ng/g. Benzo[*a*]pyrene was detected in 66% of the aquaculture, 35% of the fresh catch, and 24% of the frozen species, at concentrations varying from 0.03 to 9.18 ng/g. The contribution of fish to the daily consumption of the non-carcinogenic PAH was considered low. For benzo[*a*]pyrene, the estimated daily intake was considerably lower than the doses considered carcinogenic for experimental animals by the European Union Scientific Committee on Food (SCF, 2002). In turn, in order to assess the dietary intake of PAH by Kuwaiti population, concentrations of various PAH were determined in edible tissues of commercially important seafood (fish and shrimp) samples collected from fish markets in 2005 (Alomirah et al., 2009). Naphthalene, phenanthrene, fluoranthrene, pyrene, benzo[*a*]anthracene, and chrysene were routinely detected in all samples analyzed. The concentrations of ΣPAH ranged between 30 and 247 ng/g dry wt. with yellow fin sea bream imported from Iran exhibiting the highest concentration followed by Nile tilapia imported from Egypt (218 ng/g dry wt.), and then by locally caught silver pomfret (142 ng/g dry wt.), and Jinga shrimp (139 ng/g dry wt.). The mean exposures for the average adult Kuwaiti consumer to ΣPAH and benzo[*a*]pyrene equivalents were estimated to be 1.3 μg/day and 0.0013 μg/day, respectively.

According to the present survey, the current average dietary intake of total PAH for a standard male adult living in Catalonia is 6.72 μg/day. Compared to the estimated exposure to 2–5 μg/day of PAH per packet of cigarettes for a regular smoker, that value is clearly higher. Although smokers are much exposed to PAH than non-smokers, for humans the main source of PAH is the diet (Ibáñez et al., 2005).

In summary, the results of the present study seem to show an important decreasing trend in the dietary exposure to PAH for the population living in Catalonia (Falcó et al., 2003; Martí-Cid et al., 2008a). It can be due to the general reduction of industrial and traffic emissions (Wang et al., 2009), which has also shown a decreasing trend in the atmospheric PAH levels (Meijer et al., 2008).This is in agreement with the results of other recent studies on environmental pollutants in foodstuffs, which also corroborate this trend. Metals (Martí-Cid et al., 2009; Pereira et al., 2009), and dioxins and furans (Llobet et al., 2008; Martí-Cid et al., 2008b) would be among them. Taking into account the health concern of these environmental pollutants, it would be necessary to maintain a surveillance program to establish the trend of PAH concentrations in foodstuffs, as well as that for human dietary intake.

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Table 4a
Mean dietary intakes of PAH by children (boys) living in Catalonia, Spain.

PAH	Mean dietary intake (μg/day) for food group												Total dietary	
	Meat and meat products	Fish and shellfish	Vegetables	Tubers	Fruits	Eggs	Milk	Dairy products	Cereals	Pulses	Oils and fats	Industrial bakery	μg/day	μg/kg of body wt/day
Benzo[*a*]pyrene	0.017	0.004	0.010	0.001	0.004	0.003	0.002	0.007	0.007	0.001	0.012	0.001	0.068	0.003
7 Carcinogenic PAH[a]	0.189	0.031	0.045	0.009	0.025	0.019	0.012	0.048	0.047	0.008	0.084	0.010	0.526	0.022
8 Carcinogenic PAH[b]	0.183	0.036	0.056	0.010	0.028	0.021	0.014	0.055	0.053	0.009	0.096	0.011	0.573	0.024
Sum of 16 PAH	4.286	0.149	0.185	0.048	0.134	0.102	0.067	0.261	0.255	0.043	0.463	0.058	6.051	0.252

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).
[b] Carcinogenic PAH according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Table 4b
Mean dietary intakes of PAH for children (girls) living in Catalonia, Spain.

PAH	Mean dietary intake (μg/day) for food group												Total dietary	
	Meat and meat products	Fish and shellfish	Vegetables	Tubers	Fruits	Eggs	Milk	Dairy products	Cereals	Pulses	Oils and fats	Industrial bakery	μg/day	μg/kg of body wt/day
Benzo[*a*]pyrene	0.016	0.003	0.009	0.001	0.003	0.002	0.002	0.006	0.006	0.001	0.011	0.001	0.061	0.003
7 Carcinogenic PAH[a]	0.170	0.028	0.041	0.008	0.022	0.017	0.011	0.043	0.042	0.007	0.076	0.009	0.473	0.020
8 Carcinogenic PAH[b]	0.165	0.032	0.050	0.009	0.026	0.019	0.013	0.049	0.048	0.008	0.086	0.010	0.515	0.021
Sum of 16 PAH	3.854	0.134	0.166	0.044	0.121	0.092	0.060	0.234	0.229	0.039	0.416	0.052	5.441	0.227

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).
[b] Carcinogenic PAH according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Table 4c
Mean dietary intakes of PAH for adolescents (males) living in Catalonia, Spain.

PAH	Mean dietary intake (μg/day) for food group												Total dietary	
	Meat and meat products	Fish and shellfish	Vegetables	Tubers	Fruits	Eggs	Milk	Dairy products	Cereals	Pulses	Oils and fats	Industrial bakery	μg/day	μg/kg of body wt/day
Benzo[*a*]pyrene	0.025	0.003	0.007	0.002	0.002	0.002	0.003	0.007	0.009	0.001	0.012	0.003	0.075	0.001
7 Carcinogenic PAH[a]	0.277	0.026	0.030	0.011	0.016	0.017	0.021	0.049	0.062	0.010	0.082	0.020	0.622	0.011
8 Carcinogenic PAH[b]	0.193	0.029	0.038	0.012	0.018	0.020	0.024	0.056	0.071	0.011	0.094	0.023	0.590	0.011
Sum of 16 PAH	6.456	0.116	0.122	0.060	0.085	0.093	0.115	0.269	0.339	0.055	0.454	0.113	8.278	0.148

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).
[b] Carcinogenic PAH according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Table 4d
Mean dietary intakes of PAH for adolescents (females) living in Catalonia, Spain.

PAH	Mean dietary intake (μg/day) for food group												Total dietary	
	Meat and meat products	Fish and shellfish	Vegetables	Tubers	Fruits	Eggs	Milk	Dairy products	Cereals	Pulses	Oils and fats	Industrial bakery	μg/day	μg/kg of body wt/day
Benzo[*a*]pyrene	0.016	0.003	0.010	0.001	0.002	0.002	0.003	0.006	0.007	0.001	0.010	0.002	0.064	0.001
7 Carcinogenic PAH[a]	0.176	0.021	0.041	0.010	0.017	0.015	0.018	0.045	0.048	0.006	0.073	0.015	0.486	0.009
8 Carcinogenic PAH[b]	0.198	0.025	0.052	0.011	0.020	0.017	0.021	0.052	0.055	0.007	0.084	0.017	0.557	0.011
Sum of 16 PAH	3.978	0.114	0.156	0.053	0.093	0.082	0.098	0.247	0.261	0.034	0.403	0.085	5.605	0.106

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).
[b] Carcinogenic PAH according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Table 4e
Mean dietary intakes of PAH for male adults living in Catalonia, Spain.

PAH	Mean dietary intake (μg/day) for food group												Total dietary	
	Meat and meat products	Fish and shellfish	Vegetables	Tubers	Fruits	Eggs	Milk	Dairy products	Cereals	Pulses	Oils and fats	Industrial bakery	μg/day	μg/kg of body wt/day
Benzo[*a*]pyrene	0.019	0.004	0.011	0.001	0.004	0.003	0.002	0.008	0.007	0.001	0.013	0.002	0.076	0.001
7 Carcinogenic PAH[a]	0.209	0.034	0.050	0.010	0.028	0.021	0.014	0.053	0.052	0.009	0.093	0.011	0.583	0.008
8 Carcinogenic PAH[b]	0.203	0.039	0.062	0.011	0.031	0.024	0.016	0.060	0.059	0.010	0.106	0.012	0.635	0.009
Sum of 16 PAH	4.750	0.165	0.205	0.054	0.149	0.113	0.074	0.289	0.283	0.048	0.513	0.064	6.705	0.096

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).
[b] Carcinogenic PAH according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Table 4f
Mean dietary intakes of PAH for female adults living in Catalonia, Spain.

PAH	Mean dietary intake (μg/day) for food group												Total dietary	
	Meat and meat products	Fish and shellfish	Vegetables	Tubers	Fruits	Eggs	Milk	Dairy products	Cereals	Pulses	Oils and fats	Industrial bakery	μg/day	μg/kg of body wt/day
Benzo[*a*]pyrene	0.010	0.004	0.014	0.001	0.004	0.002	0.002	0.006	0.005	0.001	0.012	0.001	0.064	0.001
7 Carcinogenic PAH[a]	0.102	0.038	0.061	0.007	0.029	0.015	0.017	0.045	0.036	0.008	0.084	0.010	0.453	0.008
8 Carcinogenic PAH[b]	0.155	0.044	0.076	0.008	0.034	0.018	0.020	0.052	0.041	0.009	0.096	0.011	0.563	0.010
Sum of 16 PAH	2.122	0.168	0.244	0.039	0.159	0.084	0.093	0.248	0.197	0.043	0.464	0.058	3.918	0.071

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).
[b] Carcinogenic PAH according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Table 4g
Mean dietary intakes of PAH for male seniors living in Catalonia, Spain.

PAH	Mean dietary intake (μg/day) for food group												Total dietary	
	Meat and meat products	Fish and shellfish	Vegetables	Tubers	Fruits	Eggs	Milk	Dairy products	Cereals	Pulses	Oils and fats	Industrial bakery	μg/day	μg/kg of body wt/day
Benzo[*a*]pyrene	0.008	0.004	0.021	0.001	0.007	0.002	0.002	0.006	0.006	0.001	0.013	0.001	0.073	0.001
7 Carcinogenic PAH[a]	0.078	0.038	0.081	0.009	0.048	0.016	0.017	0.043	0.044	0.011	0.091	0.006	0.481	0.007
8 Carcinogenic PAH[b]	0.148	0.043	0.104	0.010	0.054	0.018	0.019	0.049	0.051	0.013	0.104	0.006	0.619	0.010
Sum of 16 PAH	1.545	0.162	0.297	0.047	0.258	0.085	0.091	0.233	0.242	0.062	0.504	0.034	3.560	0.055

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).
[b] Carcinogenic PAH according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Table 4h
Mean dietary intakes of PAH for female seniors living in Catalonia, Spain.

PAH	Mean dietary intake (μg/day) for food group												Total dietary	
	Meat and meat products	Fish and shellfish	Vegetables	Tubers	Fruits	Eggs	Milk	Dairy products	Cereals	Pulses	Oils and fats	Industrial bakery	μg/day	μg/kg of body wt/day
Benzo[*a*]pyrene	0.006	0.003	0.020	0.001	0.006	0.002	0.003	0.004	0.004	0.001	0.012	0.001	0.062	0.001
7 Carcinogenic PAH[a]	0.057	0.024	0.077	0.008	0.040	0.013	0.018	0.026	0.030	0.009	0.081	0.006	0.389	0.006
8 Carcinogenic PAH[b]	0.206	0.028	0.098	0.009	0.045	0.015	0.021	0.029	0.035	0.010	0.093	0.007	0.596	0.010
Sum of 16 PAH	1.019	0.116	0.278	0.042	0.214	0.073	0.099	0.139	0.166	0.050	0.449	0.038	2.683	0.045

[a] Carcinogenic PAH include benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, chrysene, dibenzo[*a,h*]anthracene, and indeno[1,2,3-*c,d*]pyrene, which are probable human carcinogens according to the US EPA (2002).
[b] Carcinogenic PAH according to Larsen and Larsen (1998), include also benzo[*g,h,i*]perylene.

Table 5
Mean dietary intake of PAH considered as probable human carcinogens, benzo[*a*]pyrene (B[*a*]P) equivalents, and percentages contribution to B[*a*]P equivalents.[a]

PAH	Intake (μg/day)[a]	TEF (US EPA, 2002)	Intake of B[*a*]P equivalents (μg/day)	B[*a*]P (%)[b]	TEF (Larsen and Larsen, 1998)	Intake of B[*a*]P equivalents (μg/day)	B[*a*]P (%)[b]
Benzo[*a*]anthracene	0.121	0.1	0.012	7.67	0.005	0.001	0.38
Chrysene	0.126	0.001	0.000	0.08	0.03	0.004	2.37
Benzo[*b*]fluoranthene	0.087	0.1	0.009	5.52	0.1	0.009	5.46
Benzo[*k*]fluoranthene	0.062	0.01	0.001	0.40	0.05	0.003	1.96
Benzo[*a*]pyrene	0.076	1	0.076	48.22	1	0.076	47.77
Dibenzo[*a,h*]anthracene	0.054	1	0.054	34.45	1.1	0.060	37.54
Indeno[1,2,3-*c,d*]pyrene	0.058	0.1	0.006	3.67	0.1	0.006	3.63
Benzo[*g,h,i*]perylene	0.070	–	–	–	0.02	0.001	0.89
Total	0.583		0.157	100		0.159	100

[a] Calculated for a male adult (with a body weight of 70 kg) living in Catalonia, Spain.
[b] Percentages of contributions to the B[*a*]P equivalents. The B[*a*]P equivalents are the sums of the results of multiplying the intake of each of the respective seven or eight PAH by their respective TEFs.

Table 6
Summary of total daily intake (PAH) from various surveys.

Country	Year of publication	Total intake (μg/day)	Reference
Catalonia (Spain)	2008	12	Martí-Cid et al. (2008a,b)
Spain	2005	8.4	Yoon et al. (2007)
Catalonia (Spain)	2003	8.6	Falcó et al. (2003)
United Kingdom	1999	3.7	Phillips (1999)
The Netherlands	1990	5–17	De Vos et al. (1990)

References

Alomirah H, Al-Zenki S, Husain A, Ahmed N, Al-Rashdan A, Gevao B, et al. Dietary exposure to polycyclic aromatic hydrocarbons from commercially important seafood of the Arabian Gulf. J Food Agric Environ 2009;7:9-15.

ATSDR, Agency for Toxic Substances and Disease Registry. Polycyclic aromatic hydrocarbons., Atlanta, Ga: US 1995. Available at: http://www.atdsr.cdc.gov/toxpro.les/phs69.html.

Bartos T, Cupr P, Klánová J, Holoubek I. Which compounds contributed most to elevated airborne exposure and corresponding health risks in the Western Balkans? Environ Int 2009;35:1066–71.

Capdevila F, Llop D, Guillén N, Luque V, Pérez S, Sellés V, et al. Food intake, dietary habits and nutritional status of the population of Reus (Catalonia, Spain) (X): evolution of the diet and macronutrients contribution to energy intake (1983–1999), by age and sex. Consumo, hábitos alimentarios y estado nutricional de la población de Reus (X): Evolución de la ingestión alimentaria y de la contribución de los macronutrientes al aporte energético (1983–1999), según edad y sexo. Med Clin 2000;115:7-14 in Spanish.

CARB Method 429. Determination of polycyclic aromatic hydrocarbons (PAH) emissions from stationary sources. California Air Resources Board, Sacramento, CA. 1997.

Cirillo T, Montuori P, Mainardi P, Russo I, Triassi M, Amodio-Cocchieri R. Multipathway polycyclic aromatic hydrocarbon and pyrene exposure among children living in Campania (Italy). J Environ Sci Health Part A 2009;41:2089–107.

Cucó G, Arija V, Martí-Henneberg C, Fernández-Ballart J. Food and nutritional profile of high energy density consumers in an adult Mediterranean population. Eur J Clin Nutr 2001;55:192–9.

Danyi S, Bose F, Brasseur C, Schneider YJ, Larondelle Y, Pussemier L, et al. Analysis of EU priority polycyclic aromatic hydrocarbons in food supplements using high performance liquid chromatography coupled to an ultraviolet, diode array or fluorescence detector. Anal Chem Acta 2009;633:293–9.

De Vos RH, Van Dokkum W, Schouten A, De Jong-Berkhout P. Polycyclic aromatic hydrocarbons in Dutch total diet samples (1984–1986). Food Chem Toxicol 1990;28:263–8.

Dennis MJ, Massey RC, Cripps G, Venn I, Howarth N, Lee G. Factors affecting the polycyclic aromatic hydrocarbon content of cereals, fats and other food products. Food Addit Contam 1991;8:517–30.

Domingo JL, Bocio A, Martí-Cid R, Llobet JM. Benefits and risks of fish consumption: part II. RIBEPEIX, a computer program to optimize the balance between the intake of omega-3 fatty acids and chemical contaminants. Toxicology 2007;230:227–33.

EFSA. European Food Safety Agency. Polycyclic Aromatic Hydrocarbons in Food. Scientific Opinion on the Panel on Contaminants in the Food Chain (Question No EFSA-Q-2007-136). EFSA J 2008;724:1-114.

European Commission (EC) Regulation No 1881/2006 of 19th December, 2006, setting maximum levels for certain contaminants in foodstuffs. http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:364:0005:0024:EN:PDF.

Falcó G, Domingo JL, Llobet JM, Teixidó A, Casas C, Müller L. Polycyclic aromatic yydrocarbons in foods: human exposure through the diet in Catalonia, Spain. J Food Prot 2003;66:2325–31.

Fontcuberta M, Arqués JF, Martinez M, Suárez A, Villalba JR, Centrich F, et al. Polycyclic aromatic hydrocarbons in food samples collected in Barcelona, Spain. J Food Prot 2006;69:2024–8.

Gilbert J. The fate of environmental contaminants in the food chain. Sci Total Environ 1994;143:103–11.

Guillen MD. Polycyclic aromatic compounds: extraction and determination in food. Food Addit Contam 1994;11:669–84.

IARC, International Agency for Research of Cancer. Overall evaluations of carcinogenicity: an updating of IARC monographs. Int Agency Res Cancer 2004;7.

Ibáñez R, Agudo A, Berenguer A, Jakszyn P, Tormo MJ, Sanchéz MJ, et al. Dietary intake of polycyclic aromatic hydrocarbons in a Spanish population. J Food Prot 2005;68:2190–5.

Janoszka B, Warzecha L, Blaszczyk U, Bodzek D. Organic compounds formed in thermally treated high-protein food. Part I: polycyclic aromatic hydrocarbons. Acta Chromatica 2004;14:115–28.

Kazerouni N, Sinha R, Hsu CH, Greenberg A, Rothman N. Analysis of 200 food items for benzo[a]pyrene and estimation of its intake in an epidemiologic study. Food Chem Toxicol 2001;39:423–36.

Larsen JC, Larsen PB. Chemical carcinogens. In: Hester RE, Harrison RM, editors. Air pollution and health. Cambridge, UK: Royal Society of Chemistry; 1998. p. 33–56.

Llobet JM, Falcó G, Bocio A, Domingo JL. Exposure to polycyclic aromatic hydrocarbons through consumption of edible marine species in Catalonia, Spain. J Food Prot 2006;69:2493–9.

Llobet JM, Martí-Cid R, Castell V, Domingo JL. Significant decreasing trend in human dietary exposure to PCDD/PCDFs and PCBs in Catalonia, Spain. Toxicol Lett 2008;178:117–26.

Lodovici M, Dolara P, Casalini C, Ciappellano S, Testolin G. Polycyclic aromatic hydrocarbon contamination in the Italian diet. Food Addit Contam 1995;12:703–13.

Loutfy N, Fuerhacker M, Tundo P, Raccanelli S, Ahmed MT. Monitoring of polychlorinated dibenzo-p-dioxins and dibenzofurans, dioxin-like PCBs and polycyclic aromatic hydrocarbons in food and feed samples from Ismailia city, Egypt. Chemosphere 2007;66:1962–70.

Martí-Cid R, Bocio A, Llobet JM, Domingo JL. Intake of chemical contaminants through fish and seafood consumption by children of Catalonia, Spain: health risks. J Food Prot 2007;45:1968–74.

Martí-Cid R, Llobet JM, Castell V, Domingo JL. Evolution of the dietary exposure to polycyclic aromatic hydrocarbons in Catalonia, Spain. Food Chem Toxicol 2008a;46:3163–71.

Martí-Cid R, Bocio A, Domingo JL. Dietary exposure to PCDD/PCDFs by individuals living near a hazardous waste incinerator in Catalonia, Spain: temporal trend. Chemosphere 2008b;70:1588–95.

Martí-Cid R, Perelló G, Domingo JL. Dietary exposure to metals by individuals living near a hazardous waste incinerator in Catalonia, Spain: temporal trend. Biol Trace Elem Res 2009;131:245–54.

McGrath TE, Wooten JB, Geoffrey Chan W, Hajaligol MR. Formation of polycyclic aromatic hydrocarbons from tobacco: the link between low temperature residual solid (char) and PAH formation. Food Chem Toxicol 2007;45:1039–50.

Meijer SN, Sweetman AJ, Halsall CJ, Jones KC. Temporal trends of polycyclic aromatic hydrocarbons in the U.K. atmosphere: 1991–2005. Environ Sci Technol 2008;42:3213–8.

Nisbet IC, LaGoy PK. Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs). Regul Toxicol Pharmacol 1992;19:290–300.

Nwaneshiudu OC, Autenrieth RL, McDonald TJ, Donnelly KC, Degollado ED, Abusalih AA. Risk of polycyclic aromatic hydrocarbon (PAH) exposure from ingested food: the Azerbaijan case study. J Environ Sci Health Part B 2007;42:201–9.

Pereira MG, Walker LA, Best J, Shore RF. Long-term trends in mercury and PCB congener concentrations in gannet (*Morus bassanus*) eggs in Britain. Environ Pollut 2009;157:155–63.

Perelló G, Martí-Cid R, Castell V, Llobet JM, Domingo JL. Concentrations of polybrominated diphenyl ethers, hexachlorobenzene and polycyclic aromatic hydrocarbons in various foodstuffs before and after cooking. Food Chem Toxicol 2009;47:709–15.

Phillips DH. Polycyclic aromatic hydrocarbons in the diet. Mutat Res 1999;443:139–47.

Ramesh A, Walker SA, Hood DB, Guillén MD, Schneider K, Weyand EH. Bioavailability and risk assessment of orally ingested polycyclic aromatic hydrocarbons. Int J Toxicol 2004;23:301–33.

Reinik M, Tamme T, Roasto M, Juhkam K, Tenno T, Kiis A. Polycyclic aromatic hydrocarbons (PAHs) in meat products and estimated PAH intake by children and the general population in Estonia. Food Addit Contam 2007;2:429–37.

Rojo-Camargo MC, Toledo MCF. Polycyclic aromatic hydrocarbons in Brazilian vegetables and fruits. Food Control 2003;14:49–53.

Santodonato J, Howard P, Basu D. Health and ecological assessment of polynuclear aromatic hydrocarbons. J Environ Pathol Toxicol 1981;5:1-364.

SCF, Scientific Commission on Food. Opinion of the Scientific Commission on Food on the risks to human health of PAHs in food, expressed on December 4, 2002. Available at: http://ec.europa.eu/food/fs/sc/scf/out153_pdf.

Serra-Majem L, Ribas L, Salvador G, Castells C, Serra J, Jover L, Treserras R, Farran A, Román B, Raidó B, Taberner JL, Salleras L, Ngo J. Avaluació de l'estat nutricional de la població catalana 2002–2003. Evolució dels hàbits alimentaris i del consum d'aliments i nutrients a Catalunya (1992–2003), 2003 (in Catalan).

US EPA. Polycyclic Organic Matter. Environmental Protection Agency, Washington, DC. 2002. Available at: http://www.epa.gov/ttn/atw/hlthef/polycycl.html.

Wang LC, Lin LF, Lai SO. Emissions of polycyclic aromatic hydrocarbons from fluidized and fixed bed incinerators disposing petrochemical industrial biological sludge. J Hazard Mater 2009;168:438–44.

Wenzl T, Simon R, Anklam E, Kleiner J. Analytical methods for polycyclic aromatic hydrocarbons (PAHs) in food and the environment needed for new food legislation in the European Union. TrAC-Trends Anal Chem 2006;25:716–25.

Yoon E, Park K, Lee H, Yang JH, Lee C. Estimation of excess cancer risk on time-weighted lifetime average daily intake of PAHs from food ingestion. Hum Ecol Risk Assess 2007;13:669–80.

Zhang P, Song J, Yuan H. Persistent organic pollutant residues in the sediments and mollusks from the Bohai Sea coastal areas, North China: an overview. Environ Int 2009;35:632–46.