POLYCYLIC AROMATIC HYDROCARBONS IN CHICKEN EGGS IN VIETNAM: OCCURRENCE, DISTRIBUTION AND RISK ASSESSMENT

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TÓM TẮT

MỘT SỐ HYDROCARBON THƠM ĐA VÒNG TRONG TRỨNG GÀ TẠI VIỆT NAM: SỰ XUẤT HIỆN, PHÂN BỐ VÀ ĐÁNH GIÁ RỦI RO

Hydrocarbon thơm đa vòng là nhóm hợp chất tương đối bền, dễ dàng phát tán trong môi trường thông qua quá trình lắng đọng, đồng thời xâm nhập vào chuỗi thức ăn và gây ra những tác hại lâu dài đối với sinh vật sống. Tuy nhiên, các nghiên cứu phân tích hàm lượng PAH trong thực phẩm (trứng gà) còn chưa được quan tâm ở Việt Nam. Phương pháp phân tích PAH trong trứng gà được phát triển bằng việc sử dụng kỹ thuật chiết QuEChERS cải tiến kết hợp kỹ thuật sắc ký khí ghép nối hai lần khối phổ (GC-MS/MS). Giới hạn phát hiện và định lượng của phương pháp lần lượt từ 0,02–0,04 ng/g và 0,10–0,90 ng/g. Hiệu suất thu hồi của các PAH nằm trong khoảng 82,2–103,5%, với giá trị lệch chuẩn tương đối nhỏ hơn 15%. Phương pháp được áp dụng trong phân tích 100 mẫu trứng gà thuộc hai nhóm gà thả rông và gà nuôi chuồng, với hàm lượng PAH trong lòng đỏ và lòng trắng dao động trong khoảng 15,8–50,5 ng/g và 2,4–13,1 ng/g lipid. Đồng thời, kết quả phân tích mẫu trứng cho thấy sự phân bố PAH trong các phần trứng gà có liên quan đến giá trị log kow và tỷ lệ thành phần lipid. Chỉ số rủi ro (HQ) được xác định thông qua hàm lượng tiêu thụ ước tính hằng ngày đều nhỏ hơn 1, chứng tỏ mức độ rủi ro trực tiếp đối với sức khỏe con người thông qua việc tiêu thụ trứng gà tại Việt Nam là không đáng kể.

Từ khóa: *Hydrocarbon thơm đa vòng, QuEChERS, GC-MS/MS, trứng gà, Việt Nam.*

1. INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are persistent organic pollutants established from at least two aromatic rings without heteroatoms or substituents [1]. PAHs possess all the characteristics of aromatic hydrocarbons as a result of their structure, which is made up of benzene rings. The toxicity of PAHs is defined by their molecular structure, which may cause prenatal abnormalities, cancer, and immunotoxicity in numerous organisms, including microbes, animals, and humans [2]. Notably, the concentration, accumulation, exposure mechanism, and characteristics of PAHs are the main variables that influence their impact on human health. Besides, the cancer risk of PAHs is assessed to increase gradually via inhalation, skin exposure, and ingestion [3]. The primary sources of PAHs emissions are human activities and natural sources, most frequently the incomplete combustion of organic materials followed by release into the environment. The presence of PAHs has also been found in foods, including fish, tea, meat products, fruits and vegetables [4]. Due to the various existences of PAHs in the environment and their negative effects, the

regulation on PAHs concentration thresholds has been proposed. PAHs are chemical in drinking water for which the European Union (EU) has established a total concentration of B[b]F, B[k]F, B[ghi]F, IP accordingly not be higher than 0.10 µg/L and B[a]P level not exceed 0.01 µg/L [5]. In 2020, the Commission Regulation issued regulation No. 1255/2020 on the maximum levels of PAH4 (benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[a]pyrene) in smoked meat products/ fish is not to exceed 30 µg/kg. Furthermore, the newer regulation established the maximum allowable levels in plant-based powders for BaP and PAH4 at 5.0 and 50 µg/kg, respectively [6]. Several investigations conducted in Vietnam have shown the existence of PAHs in both environmental samples and in food that is directly ingested by humans [4, 7, 8]. The total concentrations of 22 PAHs were observed in the range of 52–920 ng/g dry weight in surface sediments in Hanoi [4, 8]. For various food samples, average levels of 18 PAHs were found in the ranges of 9.3–9.6 µg/kg (instant noodles), 0.22–2.48 µg/kg (pastries), 5.14–23.32 µg/kg (tea) or 1.43–25.2 µg/kg (grilled meat) [4]. Nevertheless, there is a lack of studies about their existence in animal-derived foods. Notably, controlling the level of PAHs in laying hen eggs is urgent since Vietnam still has insufficient regulations governing the food safety derived from animals. The aims of this study include: (1) analyzing the PAHs concentration in chicken egg samples; (2) evaluating the PAHs distribution in the albumen and yolk; and (3) estimating the exposure risk to human health via chicken egg consumption.

2. MATERIALS AND METHODS

2.1. Chemical and reagents

The mixture standard of 16 PAHs (QTM PAH Mix 2000 µg/mL each component in dichloromethane) including naphthalene, acenapthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[g,h,i]perylene, dibenz[a,h]anthracene, indenol[1,2,3-c,d]pyrene were supplied by Merck (Darmstadt, Germany). The isotopic standards were provided by Dr. Ehrenstorfer GmbH (Augsburg, Germany), consisting of benzo[a]anthracence-$^{13}C_6$ and benzo[g,h,i]pyrylene-$^{13}C_{12}$. Organic solvents (*n*-hexane, acetonitrile (MeCN)) were purchased from Merck. Ultra-pure water (UPW) was provided by the Milli-Q-Integral system from Merck Millipore (Burlington, MA, USA). $MgSO_4$ and NaCl salts were purchased from Merck. The purified materials (PSA, C18) were supplied by Agilent (Santa Clara, CA, USA).

2.2. Sample collection

In 2023, 100 chicken egg samples were purchased in batches in Hanoi, which were classified into two groups, including battery-cage (n = 47) and free-range (n = 53). Chicken eggs are carefully separated into yolk and albumen, then were contained in aluminum foil tarts that have been previously rinsed with methanol. The egg yolk must be separated intact without breaking the surrounding membrane. The egg samples were stored at -20 °C until analysis. The same methodology as in the prior study was applied to measure the lipid content in albumen or yolk [9].

2.3. GC-MS/MS

The GC-MS/MS system included a Trace GC 1310 gas chromatograph, a TriPlus RSH autosampler, and a TSQ Dashboard 9000 mass spectrometer (Thermo Fisher Scientific, Waltham, MA, USA). A DB5-MS column (30m × 0.25mm, 0.25 µm) was utilized to separate the PAHs. The temperature gradient program is illustrated as follows: maintain at 70 °C for 1 min, rapidly increase to 150 °C (25 °C/min), then gradually increase to 200 °C (3 °C/min), and finally increase to 280 °C (8 °C/min, hold 13 min). The total analysis time was 45 minutes. Helium gas was employed as a carrier gas at a rate of 1 mL/min. In splitless mode, the injection volume was 1 µL. The triple quadrupole mass spectrometer was used in electron ionization mode with an energy of 70 eV. The temperatures assigned to the inlet, transfer line and ion source were 250 °C, 280 °C, and 230 °C, respectively. The mass analyzer parameters were based on the previous study [4].

2.4. Sample preparation

The QuEChERS extraction method was applied based on a previous study and some modifications [4]. Briefly, 1 g of the freeze-yolk or albumen sample was transferred to a 50-mL centrifuge tube. Afterward, 10 µL of isotopic standard (50 µg/g) were added to the tube and allowed to

equilibrate for 15 min. Then, a 10 mL solvent containing UPW:MeCN (v/v, 9/10) was transferred to the tube and it was vortexed for 1 min. A mixture of 4 g $MgSO_4$ and 1 g NaCl was also added, gently shaken and vortexed for 5 mins. Subsequently, the sample tube was centrifuged at 7000 × g for 10 min. Then, 5 mL of the supernatant was collected, transferred and vortexed for 2 minutes in another falcon tube containing 200 mg primary secondary amine (PSA) and 200 mg C18. Then, the tube was immediately centrifuged for 5 mins at 7000 × g. After that, 3 mL of the supernatant was concentrated to dryness under a stream of nitrogen gas at 1 °C and reconstituted with 1 mL of *n*-hexane. The extract was lastly filtered through a 0.22-µm PTFE membrane into a dark glass vial before GC-MS/MS analysis.

2.5. Method validation

The method for determining PAHs in egg sample by GC-MS/MS system was validated in accordance with the European Commission (SANTE/11312/2021). A linear range was established in the range of 1-100 ng/mL, with all regression coefficients (R^2) obtained being greater than 0.995. Repeatability and reproducibility were evaluated through the relative standard deviation (RSD) at three spiked concentration levels in egg blank samples. The experiment was repeated six times at each spiked concentration level and continuously for three days. The observed RSD was within the permitted range of 2.1–10.5 (less than 15%). The method detection limit (MDL) was determined via PAHs quantification of the egg sample with an S/N ratio of at least 3. The PAHs standard solution mixture was spiked into the egg sample, which ensured that no PAHs signals were detected previously. The method quantification limit (MQL) was calculated as $MQL = 10 \times SD_{blank}$. The MDL and MQL for PAHs were in the range of 0.02–0.04 ng/g and 0.10–0.90 ng/g, respectively. Likewise, the matrix effect was recorded in the range of -7.2–11.2%, aligning with the guidance given in SANTE/11312/2021.

2.6. Health risk assessment

The exposure risk of PAHs to human health via chicken egg consumption was evaluated by risk category [3]. For PAHs non-carcinogenic hazards, the average daily dose (ADD) was calculated according to formula (1):

$$\mathrm{ADD} = \frac{C \times IR}{BW} \quad (1)$$

For PAHs carcinogenic hazards, the lifetime average daily dose was estimated based on formula (2):

$$\mathrm{LADD} = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (2)$$

Then, Hazard Quotients (HQ, %) for non-carcinogenic PAHs were determined as follows:

$$HQ = \frac{ADD}{RfD} \times 100\% \quad (3)$$

Where C is the mean concentration for each PAH (mg/kg), while B[a]P is calculated using the equivalent concentration C B[a]P = C × TEF; IR is the digestion rate of food (kg/day); EF is exposure frequency (day/year) assuming a consumption level of 365 days; ED is exposure duration (years), with a value of 7.0 years for children and 34.5 years for adults; AT is the average time (70 years × 365 days); RfD is the chronic oral reference dose (mg/kg-day). BW applicable to children and adults is 15 kg and 60 kg, respectively.

3. RESULTS AND DISCUSSION

3.1. PAHs in chicken eggs

The results of PAHs concentration in yolk and albumen of the collected chicken egg samples were presented in Table 1. The yolk/albumen weight ratio data were gathered to determine PAHs levels in whole eggs. The PAHs level in whole eggs was estimated as follows: $[PAH]_{whole\ egg} = [PAH]_{yolk} \times \%m_{yolk} + [PAH]_{albumen} \times \%m_{albumen}$. Yolk and albumen had respective average weight ratios of 32% and 68%. Besides, PAHs concentration was converted from initial data (ng/g-ww) to processed data (ng/g-lw) according to the formula: $Conc._{(lw)} = \frac{Conc._{(ww)}}{lipid\ content\ (\%)}$. Whereby, the albumen and yolk had typical lipid content ratios of 30% and 0.2%, respectively. Overall, most PAHs were detected in both yolk and albumen. As a result, 12 of 16 PAHs were observed to have detection frequencies (DF) greater than 50% for yolk and whole eggs. On the other hand, 4 of 16 PAHs, including NaP, ACNP, ACP and Fl had DF < 30%, with the mean level not exceeding 1.95 ng/g-lw. The ΣPAHs concentrations in yolk and albumen were 15.8–50.5 ng/g-lw (with a mean of 30.5 ng/g-lw) and 2.4–13.1 ng/g-lw (with a mean of 7.59 ng/g-lw), respectively. Notably, B[ghi]P, DBA, IP were

compounds found in high concentrations in both yolk and albumen. Meanwhile, NaP, ACNP, ACP, Fl had DF ranging from 2–8% in the yolk to 2–9% in whole eggs, which was negligible or not detected in the albumen fraction (0–2%). The PAHs concentration in chicken eggs was found to be lower than in seabird eggs in Northwest Iberian, with a concentration range (mean) of 48.6–747.1 µg/kg-dw (187.1 µg/kg-dw) [5]. The comparable ΣPAHs level reported was substantially inferior to that of chicken eggs examined during multiple weeks of gathering in Minas Gerais, Brazil (0.926–1.668 µg/g) [10]. These results suggested that the PAHs distribution in chicken egg fractions was influenced by logarithm of *n*-octanol/water partition coefficient (log K_{OW}). Whereas more polar molecules were detected in albumen, lipophilic compounds commonly existed in yolk [11]. As a result, PAHs chemicals with a larger log K_{OW} typically spreaded mostly in the hydrophobic phase, which was in keeping with the greater lipid composition level in yolk. Notably, there had been a lack of studies indicating the PAH distribution in egg fractions. Nevertheless, this distribution was noted for a number of other categories of organic pollutant substances. For instance, tissues absorbed up to 80% of the yolk's lipid content, with higher PBDEs and PCBs concentrations exhibiting a higher log K_{OW} [12]. On the other hand, OPEs were more concentrated in albumen. Although egg metabolism normally enhanced compound polarity and lowers lipophilicity, OPEs metabolism tended to accumulate in the yolk due to protein formation in the yolk and albumen synthesis [11]. To provide a clearer representation of the findings, PAHs were split into five groups: di-, tri-, tetra-, penta-, and hexa-cyclic. Significant variations in the PAHs group concentration and kind of egg were discovered (*t*-test, $p<0.05$). For instance, there was a noticeable variation between battery-cage and free-range chicken eggs in terms of the mean level of tri-cyclic, tetra-cyclic, and hexa-cyclic. It further emerged the average concentrations of PAHs varied throughout each group. The existence of PAHs in the ecological environment (soil, surrounding air) and the chicken-growing procedure (water, poultry feed) could represent an explanation of these discrepancies [13]. These exposure sources were more likely for free-range hens than for battery-cage hens [14]. Furthermore, the predominant existence of larger PAHs (≥4 cyclics) was considered to be more challenging to metabolize than less cyclic PAHs.

Table 1. Detection frequency (DF, %) and concentration (ng/g-lw) of PAHs in albumen, yolk and whole egg samples from Hanoi, Vietnam.

Compound	Yolk		Albumen		Whole egg	
	DF (%)	Range *(Mean)*	DF (%)	Range *(Mean)*	DF (%)	Range *(Mean)*
NaP	2	1.5 – 2.4 *(1.95)*	0	<MDL	2	0.48 – 0.77 *(0.62)*
ACNP	6	0.6 – 1.6 *(1.02)*	1	0.6	7	0.19 – 0.51 *(0.34)*
ACP	7	0.5 – 3.1 *(1.76)*	1	1.0	8	0.16 – 0.96 *(0.59)*
Fl	8	0.5 – 3.1 *(1.43)*	2	0.5 – 1.0 *(0.75)*	9	0.16 – 1.17 *(0.52)*
PHN	85	0.1 – 3.1 *(1.72)*	31	0.5 – 2.0 *(0.89)*	86	0.03 – 2.03 *(0.76)*
AN	91	0.2 – 4.0 *(1.78)*	35	0.5 – 1.7 *(0.94)*	95	0.06 – 1.83 *(0.78)*
Py	100	0.3 – 3.8 *(1.64)*	47	0.5 – 1.9 *(0.80)*	100	0.10 – 1.76 *(0.78)*
FLA	88	0.1 – 5.2 *(2.21)*	54	0.5 – 2.1 *(0.95)*	93	0.03 – 2.90 *(1.04)*
Chy	92	0.1 – 6.1 *(2.23)*	55	0.5 – 2.1 *(1.11)*	97	0.10 – 2.77 *(1.12)*
B[a]A	93	0.3 – 6.3 *(2.80)*	74	0.3 – 3.0 *(1.02)*	98	0.10 – 2.71 *(1.38)*
B[b]F	95	0.7 – 6.5 *(2.56)*	67	0.5 – 2.4 *(1.03)*	99	0.29 – 3.10 *(1.26)*
B[k]F	97	0.3 – 6.0 *(2.81)*	73	0.4 – 2.6 *(1.02)*	100	0.19 – 2.62 *(1.38)*
B[a]P	96	0.3 – 7.0 *(2.93)*	75	0.1 – 2.5 *(0.98)*	99	0.13 – 2.63 *(1.42)*
B[g,h,i]P	94	0.2 – 6.4 *(3.05)*	76	0.3– 3.0 *(1.15)*	99	0.22 – 3.06 *(1.53)*
DBA	97	0.4 – 8.7 *(3.83)*	74	0.3 – 3.0 *(1.10)*	99	0.13 – 3.96 *(1.78)*
IP	97	0.2 – 9.4 *(4.36)*	72	0.3 – 3.0 *(1.16)*	98	0.06 – 4.47 *(1.96)*
ΣPAHs	100	15.8 – 50.5 (30.5)	100	2.4 – 13.1 (7.59)	100	9.07 – 22.8 (14.9)

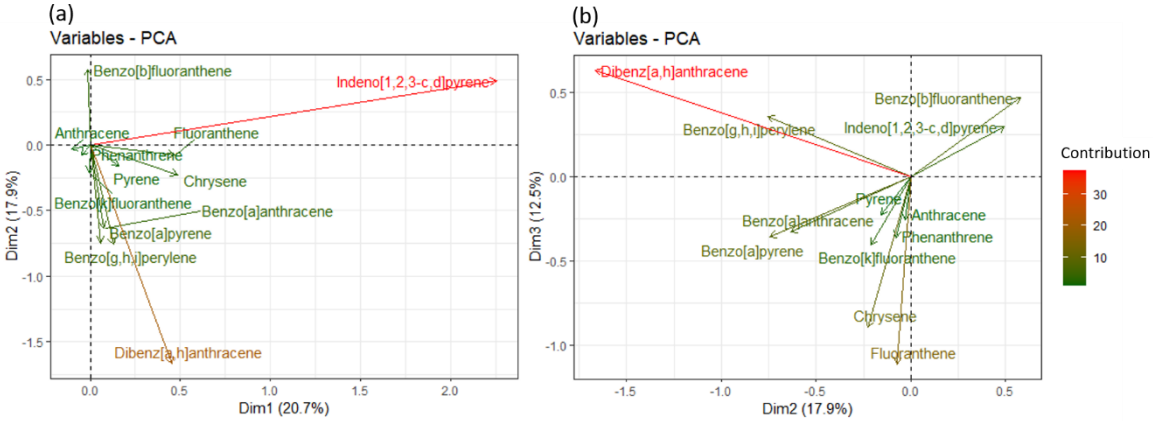

Figure 1. The variable loadings are represented by the principal component analysis (PCA) of PAHs.

For 12 PAHs (DF > 50%) in all egg samples, principal component analysis (PCA) was applied in order to indicate the relationship between poultry production methods and PAHs chemicals (Figure 1). The first three PCs explained 51.1% of the total sample variance. Of which PC1, PC2, PC3 accounted for 20.7%, 17.9% and 12.5%, respectively. As a result, indeno[1,2,3-c,d]pyrene (IP), dibenz[a,h]anthracene (DBA) and fluoranthene (FLA) function as predominant key loadings in the first three PCs, respectively. In detail, the recorded percentage explaining the variance of IP, DBA, FLA in PC1, PC2, PC3 were 87.5%, 54.0% and 35.5%, respectively. These three PAHs were harder to eliminate from the poultry body that they accumulated and entered the following products due to their multiple-ring structure [6]. Furthermore, IP, DBA and FLA contributed significant variance percentages, meaning that even a slight variation in their concentration in chicken feed might impact the coordinates of sample points position on the PC score-plot. Thus, more investigations were required to testing the PAHs presence in animal feed due to their high toxicity.

3.2. Dietary exposure to PAHs

The average daily dose (ADD) and the lifetime average daily dose (LADD) by age group were estimated and presented in Table S1. For non-carcinogenic effects, the average daily dose varied from 7.74E-09 to 5.71E-07 mg/kg-day and 1.93E-09 to 1.43E-07 mg/kg-day for children and adults, respectively. B[g,h,i]P had the highest ADD value, followed by FLA and Py, while NaP had the lowest value. Comparably, the lifetime average daily dosage for carcinogenic effects was 4.17E-08–8.41E-08 mg/kg-day in children and 5.13E-08–1.04E-07 mg/kg-day in adults. The PAHs in this category with the highest LADD were DBA and IP, whereas Chy had the lowest. Overall, the estimated ADD was stronger in children than adults, which was the opposite for LADD. The estimated exposure parameters between two PAHs groups and by age group were examined without statistically significant differences (p<0.05). Hazard Quotient (HQ) was observed for the group of PAHs non-carcinogenic hazards in the range of 9.67E-06–1.09E-03 mg/kg-day. HQ values were significantly less than 1, indicating a low potential that consuming chicken eggs in Vietnam directly endangers human health.

4. CONCLUSION

This study provided an effective method for accurately and sensitively analyzing PAHs in chicken egg samples. The recovery efficiency of PAHs was in the range of 82.2–103.5% (RSD<15%). The study then evaluated the distribution of PAHs in chicken egg parts of two free-range and battery-cage species. The findings indicated that naphthalene, acenaphthylene, acenaphthene and fluorene had poor detection frequencies (DF<10%), while the remaining PAHs had greater detection frequencies (DF>50%). There was a significant variance in the mean concentration of ΣPAHs between the two types of chicken eggs (p<0.05). The PAHs level determined in chicken egg samples was found to be acceptable; even so, further reporting requirements and stringent control procedures would be essential in the future.

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Supplementary Information

Table S1. The parameters for analyzing PAHs on GC-MS/MS system.

Abbreviations	Compound	R.T (min)	Precursor ion (m/z)	Products ion (m/z)	CE (V)	Remark
NaP	Naphthalene	6.11	128	127 (102)	15 (20)	Q (C)
ACNP	Acenaphthylene	9.14	154	153 (152)	13 (20)	Q (C)
ACP	Acenaphthene	9.65	152	151 (150)	16 (20)	Q (C)
Fl	Fluorene	11.42	166	154 (164)	16 (24)	Q (C)
PHN	Phenanthrene	15.85	178	176 (172)	26 (18)	Q (C)
AN	Anthracene	16.13	178	176 (152)	30 (28)	Q (C)
Py	Pyrene	24.23	202	200 (152)	20 (16)	Q (C)
FLA	Fluoranthene	23.08	202	200 (88)	32 (8)	Q (C)
Chy	Chrysene	29.57	228	226 (202)	12 (32)	Q (C)
B[b]F	Benzo[b]fluoranthene	33.07	252	250 (248)	30 (34)	Q (C)
B[a]A	Benzo[a]anthracene	29.46	228	226 (202)	28 (32)	Q (C)
B[k]F	Benzo[k]fluoranthene	32.98	253	251 (250)	32 (28)	Q (C)
B[a]P	Benzo[a]pyrene	34.09	252	250 (226)	34 (32)	Q (C)
B[g,h,i]P	Benzo[g,h,i]perylene	39.21	276	274 (250)	24 (38)	Q (C)
DBA	Dibenz[a,h]anthracene	39.50	278	276 (252)	32 (26)	Q (C)
IP	Indeno[1,2,3-c,d]pyrene	40.68	276	274 (250)	30 (36)	Q (C)
B[a]A-$^{13}C_6$	Benzo[a]anthracene-$^{13}C_6$	29.46	234	232 (208)	30 (35)	Q (C)
B[g,h,i]-$^{13}C_{12}$	Benzo[g,h,i]pyrylene-$^{13}C_{12}$	39.21	288	286 (261)	30 (40)	Q (C)

Table S2. List of method validation parameters results.

PAHs	Linear range (ng/mL)	R^2	Recovery (%)			RSD_R (RSD_{wr}, %)			MDL (ng/g)	MQL (ng/g)	ME (%)
			10 ng/g	20 ng/g	50 ng/g	10 ng/g	20 ng/g	50 ng/g			
NaP	1-100	0.9993	104.9	98.8	91.5	9.9 (8.6)	7.1 (6.1)	5.0 (3.0)	0.03	0.90	-5.2
ACNP	1-100	0.9994	89.8	91.2	88.1	4.1 (9.9)	6.7 (5.1)	4.7 (6.7)	0.02	0.15	4.3
ACP	1-100	0.9997	95.5	101.3	95.2	5.1 (9.5)	9.1 (5.7)	5.9 (6.5)	0.02	0.20	10.3
Fl	1-100	0.9990	103	97.1	99.7	6.2 (4.4)	7.4 (6.7)	4.8 (5.2)	0.02	0.25	11.2
PHN	1-100	0.9998	99.3	97.6	96.5	6.6 (4.2)	7.8 (8.5)	4.6 (7.5)	0.03	0.10	6.2
AN	1-100	0.9991	100.9	98.7	103.5	9.3 (7.0)	8.1 (3.1)	6.5 (5.9)	0.03	0.15	8.0
Py	1-100	0.0989	98.3	89.6	98.2	3.0 (4.6)	7.1 (5.4)	8.7 (4.2)	0.03	0.20	9.2
FLA	1-100	0.9998	89.4	95.7	99.9	7.5 (8.5)	5.1 (5.3)	4.3 (5.0)	0.04	0.10	-3.2
Chy	1-100	0.9995	92.8	97.9	96.2	3.3 (5.1)	9.0 (6.3)	6.2 (6.1)	0.04	0.10	-7.2
B[a]A	1-100	0.9986	92.8	85.8	88.4	8.8 (9.5)	9.9 (4.8)	8.7 (9.9)	0.04	0.10	10.3
B[b]F	1-100	0.9995	101.5	95.9	101.9	3.3 (8.9)	4.6 (9.8)	6.1 (10)	0.03	0.25	5.2
B[k]F	1-100	0.9986	87.5	94.4	98.9	5.6 (8.3)	8.1 (8.9)	7.9 (4.3)	0.03	0.20	10.0
B[a]P	1-100	0.9987	96.8	102.4	95.6	3.5 (9.8)	5.8 (3.6)	5.4 (5.0)	0.03	0.15	8.3
B[g,h,i]P	1-100	0.9990	93.4	87.7	82.2	9.3 (3.5)	3.6 (7.4)	5.4 (4.5)	0.02	0.15	-2.2
DBA	1-100	0.9991	95.9	101.9	87.8	5.4 (8.3)	3.1 (8.2)	8.6 (3.8)	0.04	0.20	8.3
IP	1-100	0.9992	95.3	88.6	97.3	3.2 (3.4)	4.1 (7.6)	7.7 (4.7)	0.02	0.15	9.3

RSD_R: Repeatability, RSD_{wr}: Reproducibility.

Table S3: Estimated exposure parameters for children and adults.

Non-carcinogenic hazards	ADD (mg/kg-day)		HQ		Carcinogenic hazards	LADD (mg/kg-day)	
	Children	Adults	Children	Adults		Children	Adults
NaP	7.74E-09	1.93E-09	3.87E-05	9.67E-06	Chy	4.17E-08	5.13E-08
ACNP	1.21E-08	3.03E-09	n.a	n.a	B[a]A	5.20E-08	6.40E-08
ACP	2.48E-08	6.21E-09	4.14E-05	1.03E-05	B[b]F	4.85E-08	5.98E-08
Fl	2.27E-08	5.66E-09	5.66E-05	1.42E-05	B[k]F	5.43E-08	6.69E-08
PHN	2.90E-07	7.26E-08	n.a	n.a	B[a]P	5.60E-08	6.90E-08
AN	3.22E-07	8.05E-08	1.07E-04	2.68E-05	DBA	7.40E-08	9.11E-08
Py	3.26E-07	8.16E-08	1.09E-03	2.72E-04	IP	8.41E-08	1.04E-07
FLA	3.87E-07	9.68E-08	9.68E-04	2.42E-04			
B[g,h,i]P	5.71E-07	1.43E-07	n.a	n.a			

Note: n.a: not available