

Supporting Information for

Occurrence and distribution of phthalates in sanitary napkins from six countries: implications for women's health

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This file has 16 pages and includes three figures and six tables.

Section S1

Instrumental Analysis. The quantitative analysis of the phthalates was carried out using an Agilent 7890A GC system and a 5975C inert mass selective detector (Agilent Technologies, Santa Clara, CA, USA) equipped with silica capillary column (HP-5MS, 30 m \times 0.25 mm \times 0.25 μ m, Agilent). The oven temperature was programmed from 60 $^{\circ}$ C (held for 1.0 min) to 220 $^{\circ}$ C at 20 $^{\circ}$ C/min (held for 1.0 min), and increased to 280 $^{\circ}$ C at 5 $^{\circ}$ C/min (held for 4.0 min). The injector temperature was 250 $^{\circ}$ C. The ion source, transmission line, quadrupole temperatures were held at 230 $^{\circ}$ C, 280 $^{\circ}$ C and 230 $^{\circ}$ C, respectively. The helium mobile phase flow rate was 1.0 mL/min. The injector was used in the splitless mode.

Quality control and quality assurance. Target analytes were identified if the GC retention time and ion abundance ratio matched those for the authentic corresponding standard. Quantitation was performed using the internal calibration method based on five-point calibration curve for individual phthalates. Benzyl benzoate was used as internal standards for the quantification of phthalates. Linearity was tested by injecting replicate standards at seven different concentration levels. The correlation coefficients (R^2) of the calibration curve were higher than 0.995. Within our experiments, relative standard deviations (RSDs) for consecutive injections of standard solutions at different concentration levels were lower than 8.0%.

A procedural blank, a spiked blank, and matrix-spiked sample were processed with each batch of 10 sanitary napkin samples, to monitor the method performance and matrix effects. Only small concentrations of DMP, DiBP and DEHP were found in procedural blanks, and they were appropriately subtracted from those in the sample extracts. The recoveries of the 15 target phthalates in spiked matrixes ranged from 81.9% to 107%. The limit of quantitation (LOQ) was calculated using a signal-to-noise ratio of 10:1. The LOQs of 15 phthalates ranged from 0.50 to 4.29 ng/g. In this study, sample concentrations below LOQ were replaced with one half of the LOQ in statistical analysis. Reported concentrations were not corrected for surrogate recovery in this

50 study.

Section S2

Calculations of exposure doses and risks. Based on the phthalate concentrations measured in sanitary napkin in this study, the daily exposure dose (DED) of these chemicals through dermal/transmucosal absorption for females was estimated by the following equation 1.¹ Here, the exposure to sanitary napkins is unified as dermal exposure to simplify the expression of the whole manuscript.

$$DED = \frac{C_i \times T \times N \times D \times A \times Y}{BW \times 30 \times L} \quad (1)$$

The equation 1 involved the concentration of phthalate from sanitary napkin (C_i , ng/g), the weight of sanitary napkin (T , g), the numbers of sanitary napkins used per day (N), the number of days per month that women use sanitary napkins (D , day), the dermal absorption rate of phthalate in product (A , %), the number of years in the life of the average woman (Y , year), the average woman's weight (BW , kg) and the life years of the average woman (L , year). 30 is the number of days in a month. Values of all the parameters used in the DED estimation are given in Table S4.

The non-carcinogenic risks to women associated with absorption of phthalates in the sanitary napkins was estimated using the hazard quotient (HQ). The cumulative risk assessment for phthalates based on an assumption that these chemicals share a common mechanism of action. And the cumulative non-carcinogenic risks were estimated by the hazard index (HI), which is a sum of HQ of individual phthalate. The HQ can be estimated using the equation 2.

$$HQ = \frac{DED}{RfD} \quad (2)$$

Where RfD is the dermal reference dose of the individual phthalate.

The carcinogenic risk (CR) of BzBP and DEHP for women from sanitary napkins was conducted as follow equation 3.

$$CR = DED \times CFS \quad (3)$$

Where CFS is the slope factor for dermal exposure to the individual phthalate.

In this study, the dermal RfD of DMP, DEP, DnBP, DnOP, BzBP and DEHP were

78 assumed to be equal to their corresponding oral RfD, respectively. The dermal CFS of
79 BzBP and DEHP were also assumed to be equal to their corresponding oral CFS,
80 respectively. Values of the parameters used in our risk assessment are given in Table
81 S4.

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85 **Table S1. Select Physicochemical Properties of Target Phthalates in This Study**

CAS No.	Name	Abbreviation	Molecular weight	Log K_{ow} ^a	Log K_{oa} ^a
131-11-3	dimethyl phthalate	DMP	194.2	1.61	7.01
84-66-2	diethyl phthalate	DEP	222.2	2.54	7.55
84-69-5	di(isobutyl) phthalate	DiBP	278.4	4.27	8.54
84-74-2	di- <i>n</i> -butyl phthalate	DnBP	278.4	4.27	8.54
117-82-8	bis(2-methoxyethyl) phthalate	DMEP	282.3	1.11	9.766
84-63-9	bis(4-methyl-2-pentyl) phthalate	BMPP	334.5	6.28	10.089
605-54-9	bis(2-ethoxyethyl) phthalate	DEEP	310.3	2.10	10.51
131-18-0	di- <i>n</i> -pentyl phthalate	DPP	306.4	5.62	9.674
85-68-7	benzyl butyl phthalate	BzBP	312.4	4.73	9.018
117-83-9	bis(2- <i>n</i> -utoxyethyl) phthalate	DBEP	366.5	4.06	11.977
84-61-7	dicyclohexyl phthalate	DCHP	330.4	6.20	11.588
117-81-7	bis(2-ethylhexyl) phthalate	DEHP	390.6	7.60	12.577
68515-49-1	diisodecyl phthalate	DiDP	446.7	9.46	11.52
117-84-0	di- <i>n</i> -octyl phthalate	DnOP	390.6	8.10	12.079
84-76-4	di- <i>n</i> -nonyl phthalate	DNP	418.7	9.52	12.570

86 ^a Log K_{ow} , Log K_{oa} values using the Estimation Program Interface (EPI) Suite (V4.11). [https://www.epa.gov/tsca-screening-tools/download-epi-suite-tm-estimation-](https://www.epa.gov/tsca-screening-tools/download-epi-suite-tm-estimation-program-interface-v411)
87 [program-interface-v411](https://www.epa.gov/tsca-screening-tools/download-epi-suite-tm-estimation-program-interface-v411).
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89 **Table S2. Information on Sanitary Napkin Samples Analyzed in This Study**

Sale sites	Brands–types	Samples/composite samples	Fragrances	Unit price (per piece) ^a	Production sites
Japan	Brand J1–1	10/2	Unscented	Low-price	Japan
Japan	Brand J1–2	10/2	Unscented		Japan
Japan	Brand J2–3	10/2	Unscented		Japan
Japan	Brand J2–4	10/2	Unscented		Japan
Japan	Brand J3–5	10/2	Scented		Japan
Japan	Brand J3–6	10/2	Unscented		Japan
South Korea	Brand H1–1	10/2	Unscented	High-price	South Korea
South Korea	Brand H1–2	10/2	Unscented		South Korea
South Korea	Brand H1–3	10/2	Unscented		South Korea
South Korea	Brand H1–4	10/2	Unscented		South Korea
South Korea	Brand H2–5	10/2	Scented		South Korea
South Korea	Brand H3–6	10/2	Unscented		South Korea
USA	Brand U1–1	10/2	Scented	High-price	USA
USA	Brand U1–2	10/2	Unscented		USA
USA	Brand U1–3	10/2	Unscented		USA
USA	Brand U2–4	10/2	Unscented		Canada
USA	Brand U3–5	10/2	Unscented		Canada
USA	Brand U4–6	10/2	Scented		Canada
UK	Brand K1–1	10/2	Unscented	Low-price	Italy
UK	Brand K2–2	10/2	Unscented		UK
UK	Brand K3–3	10/2	Unscented		UK
UK	Brand K4–4	10/2	Unscented		UK
UK	Brand K5–5	10/2	Unscented		Spain

UK	Brand K6–6	10/2	Unscented		Taiwan, China
Australia	Brand A1–1	10/2	Unscented	High-price	Australia
Australia	Brand A2–2	10/2	Unscented	High-price	Vietnam
Australia	Brand A3–3	10/2	Unscented	High-price	UK
Australia	Brand A4–4	10/2	Unscented	High-price	Vietnam
Australia	Brand A5–5	10/2	Unscented		Thailand
Australia	Brand A6–6	10/2	Unscented	High-price	China
Germany	Brand G1–1	10/2	Unscented	Low-price	Germany
Germany	Brand G2–2	10/2	Unscented	Low-price	Germany
Germany	Brand G3–3	10/2	Unscented	Low-price	Germany
Germany	Brand G3–4	10/2	Scented	Low-price	Germany
Germany	Brand G4–5	10/2	Unscented		Belgium
Germany	Brand G4–6	10/2	Unscented		Germany

^a The samples were ranked as top 20% and bottom 20% based on the unit price of the sanitary napkins, and classed them as high-price and low-price products, respectively. Prior to classification, the unit price of all samples was standardized in Renminbi.

93 **Table S3.** Spearman's Correlation Matrix Between the Concentrations of Phthalates in Sanitary Napkins from Six Countries ($n=72$)

	DMP	DEP	DiBP	DnBP	DMEP	BMPP	DEEP	DPP	BzBP	DBEP	DCHP	DEHP	DiDP	DnOP
DEP	0.197	1												
DiBP	0.477**	0.414**	1											
DnBP	0.482**	0.194	0.631**	1										
DMEP	0.128	0.023	0.116	0.001	1									
BMPP	-0.005	-0.07	-0.057	-0.096	0.223	1								
DEEP	-0.016	0.474**	0.268*	0.04	0.268*	-0.041	1							
DPP	0.037	0.317**	0.054	0.058	-0.083	-0.085	0.247*	1						
BzBP	0.225	0.408**	0.286*	0.166	0.144	-0.053	0.347**	0.111	1					
DBEP	-0.168	-0.22	-0.387**	-0.005	-0.21	-0.111	-0.126	0.039	-0.073	1				
DCHP	0.029	-0.213	-0.315**	0.224	-0.081	0.021	-0.195	-0.055	-0.165	0.361**	1			
DEHP	-0.233*	-0.222	-0.049	0.137	-0.246*	-0.02	-0.166	-0.285*	-0.180	0.150	0.225	1		
DiDP	0.097	0.031	-0.214	-0.084	0.100	0.178	0.135	-0.182	0.229	0.168	0.158	0.071	1	
DnOP	0.305**	0.085	0.111	0.515**	0.234*	0.195	0.068	0.114	-0.019	0.095	0.448**	0.197	0.153	1
DNP	-0.210	-0.195	-0.253*	-0.100	-0.231	-0.173	-0.240*	-0.287*	-0.12	0.523**	0.042	0.318**	0.288*	-0.072

94 * $p<0.05$; ** $p<0.01$

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96 **Table S4. Input Parameters and Values Used to Estimate Daily Exposure (ng/kg-bw/day) and Health Risk from Phthalates in Sanitary**
 97 **Napkins.**

Parameters	Definition	Units	Values	References
C_i	Concentration of individual phthalate	mg/kg		this study
T	Weight of sanitary napkin	g	11	this study
N	Used numbers/d		5	Ishii et al (2014)
D	The number of days per month that women use sanitary napkins	d	7	Ishii et al (2014)
Y	Used years	years	40	Ishii et al (2014)
BW	Average woman's body weight	kg	57.3	Chai et al (2017)
L	Life years	years	80.4	Chai et al (2017)
A	Absorption rate of phthalate	%	15	Chai et al (2017)
RfD	Reference dose	$\mu\text{g/kg-bw/day}$	DMP, 100	USEPA (2019)
			DEP, 800	USEPA (1987a)
			DnBP, 100	USEPA (1987b)
			BzBP, 200	USEPA (1989)
			DEHP, 20	USEPA (1987c)
			DnOP, 40	USEPA (2018)
CFS	Cancer slope factor	$(\text{mg/kg-bw/day})^{-1}$	BBP (0.0019)	Ji et al (2014)
			DEHP (0.014)	

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Table S5. Estimated Daily Exposure Dose (ng/kg-bw/day) of Phthalates in Sanitary Napkins from Different Countries

		DMP	DEP	DiBP	DnBP	DMEP	DPP	DEEP	BzBP	DCHP	BMPP	DBEP	DEHP	DnOP	DNP	DiDP	15 phthalates
Japan	Geomean	2.52	1.26	7.26	13.9	0.025	0.025	0.021	0.129	0.203	1.56	1.34	26.7	0.101	0.71	0.189	68.9
	P ₅₀	2.79	1.24	10.1	13.1	0.025	0.004	0.006	0.202	0.465	2.08	2.98	24.9	0.170	2.89	0.241	60.9
	P ₉₀	3.20	2.29	49.9	19.5	0.025	0.283	1.77	3.63	1.77	6.32	9.51	106	0.44	18.0	1.20	169
South Korea	Geomean	2.04	1.18	9.72	11.14	0.031	0.121	0.047	0.134	0.016	1.38	0.559	18.2	0.038	1.30	0.203	53.5
	P ₅₀	2.08	1.28	7.27	8.10	0.025	0.244	0.046	0.465	0.016	1.29	0.997	17.2	0.030	2.41	0.277	44.0
	P ₉₀	2.48	1.65	52.7	41.8	0.246	4.73	1.26	1.75	0.016	3.10	2.78	31.3	0.184	6.42	1.04	128
USA	Geomean	1.74	1.98	11.6	6.92	0.097	0.221	0.805	0.479	0.016	2.97	0.141	12.7	0.030	0.106	0.143	52.2
	P ₅₀	2.08	2.10	12.8	7.85	0.025	0.704	0.582	1.14	0.016	3.32	0.170	13.7	0.030	0.036	0.197	48.8
	P ₉₀	3.06	3.46	24.0	12.7	1.54	1.86	3.53	6.08	0.016	41.0	12.9	26.3	0.030	1.13	1.70	82.7
UK	Geomean	3.47	1.67	17.4	12.8	0.068	0.072	0.392	0.812	0.016	0.977	0.106	10.1	0.039	0.066	0.184	51.4
	P ₅₀	3.52	1.65	16.8	12.2	0.025	0.264	0.423	1.07	0.016	0.859	0.149	9.75	0.030	0.036	0.380	50.8
	P ₉₀	4.06	2.86	21.4	18.9	2.70	1.20	1.17	3.20	0.016	3.88	2.36	13.1	0.130	1.71	1.92	63.7
Australia	Geomean	2.96	1.55	20.4	12.6	0.025	0.035	0.278	0.447	0.020	1.40	0.235	17.2	0.034	0.504	0.130	68.6
	P ₅₀	2.93	1.23	17.1	10.5	0.025	0.004	0.489	0.669	0.016	1.45	0.404	14.2	0.030	1.50	0.104	66.5
	P ₉₀	3.81	7.09	101	29.9	0.025	1.56	1.81	3.15	0.218	8.30	3.10	39.9	0.127	3.78	2.46	153
Germany	Geomean	3.80	2.35	23.7	16.1	0.113	0.589	0.121	0.952	0.017	2.20	0.129	12.0	0.192	0.152	0.172	69.9
	P ₅₀	3.96	2.60	23.8	15.2	0.025	0.594	0.398	1.83	0.016	1.74	0.362	11.1	0.201	0.039	0.068	76.4
	P ₉₀	4.75	4.09	38.4	25.4	3.02	7.15	1.53	3.47	0.038	15.6	0.821	21.9	1.92	3.74	2.72	98.0
Six countries	Geomean	2.65	1.62	13.8	11.9	0.049	0.100	0.148	0.376	0.025	1.64	0.264	15.3	0.056	0.281	0.168	60.2
	P ₅₀	2.87	1.48	15.1	11.9	0.030	0.255	0.375	0.890	0.020	1.62	0.485	13.7	0.030	0.205	0.245	53.4
	P ₉₀	4.04	2.91	33.0	20.8	1.41	1.91	1.57	2.91	0.41	6.37	3.71	28.7	0.227	4.03	1.82	94.0

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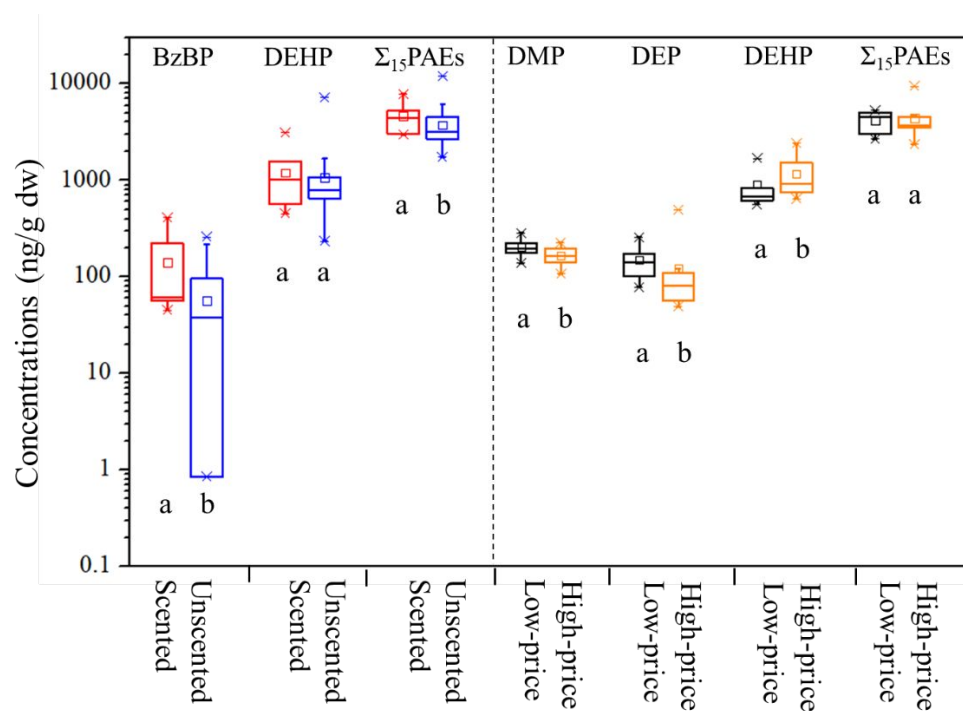
104 **Table S6. Carcinogenic and Non-carcinogenic Risks from Women's Exposure to Individual Phthalates in Sanitary Napkins from Six**
105 **Countries**

		Non-carcinogenic risks							Carcinogenic risks		
		DMP	DEP	DnOP	DnBP	BzBP	DEHP	Total risks ^a	BzBP	DEHP	Total risks ^b
Japan	Geomean	2.52E-05	1.58E-06	2.52E-06	1.39E-04	6.43E-07	1.33E-03	1.53E-03	2.45E-10	3.74E-07	3.75E-07
	P ₅₀	2.76E-05	1.41E-06	3.26E-06	1.34E-04	1.12E-06	1.20E-03	1.37E-03	4.27E-10	3.38E-07	3.38E-07
	P ₉₀	3.18E-05	2.82E-06	1.03E-05	1.94E-04	1.65E-05	4.97E-03	5.15E-03	6.27E-09	1.39E-06	1.39E-06
South Korea	Geomean	2.04E-05	1.48E-06	9.59E-07	1.11E-04	6.69E-07	9.11E-04	1.07E-03	2.54E-10	2.55E-07	2.56E-07
	P ₅₀	2.08E-05	1.60E-06	7.46E-07	8.10E-05	2.33E-06	8.59E-04	9.82E-04	8.83E-10	2.41E-07	2.42E-07
	P ₉₀	2.48E-05	2.06E-06	4.61E-06	4.18E-04	8.75E-06	1.57E-03	1.78E-03	3.32E-09	4.38E-07	4.39E-07
USA	Geomean	1.74E-05	2.47E-06	7.46E-07	6.92E-05	2.39E-06	6.37E-04	7.41E-04	9.09E-10	1.78E-07	1.81E-07
	P ₅₀	2.08E-05	2.63E-06	7.46E-07	7.85E-05	5.69E-06	6.88E-04	7.77E-04	2.17E-09	1.93E-07	1.93E-07
	P ₉₀	3.06E-05	4.33E-06	7.46E-07	1.27E-04	3.04E-05	1.32E-03	1.47E-03	1.15E-08	3.69E-07	3.76E-07
UK	Geomean	3.47E-05	2.09E-06	4.34E-04	1.28E-04	4.06E-06	5.06E-04	9.09E-04	1.54E-09	1.42E-07	1.63E-07
	P ₅₀	3.52E-05	2.07E-06	4.21E-04	1.23E-04	5.36E-06	4.88E-04	1.06E-03	2.04E-09	1.37E-07	1.38E-07
	P ₉₀	4.06E-05	3.57E-06	5.35E-04	1.89E-04	1.60E-05	6.53E-04	1.33E-03	6.08E-09	1.83E-07	6.39E-07
Australia	Geomean	2.96E-05	1.94E-06	5.10E-04	1.26E-04	2.23E-06	8.61E-04	1.17E-03	8.48E-10	2.41E-07	2.43E-07
	P ₅₀	2.93E-05	1.54E-06	4.28E-04	1.05E-04	3.35E-06	7.08E-04	1.41E-03	1.27E-09	1.99E-07	2.01E-07
	P ₉₀	3.81E-05	8.86E-06	2.53E-03	2.99E-04	1.58E-05	2.00E-03	3.24E-03	5.99E-09	5.59E-07	5.60E-07
Germany	Geomean	3.80E-05	2.94E-06	5.93E-04	1.61E-04	4.76E-06	6.02E-04	1.42E-03	1.81E-09	1.69E-07	1.72E-07
	P ₅₀	3.97E-05	3.25E-06	5.95E-04	1.52E-04	9.13E-06	5.56E-04	1.36E-03	3.47E-09	1.56E-07	1.57E-07
	P ₉₀	4.75E-05	5.12E-06	9.62E-04	2.54E-04	1.74E-05	1.10E-03	2.21E-03	6.59E-09	3.07E-07	3.10E-07
Six countries	Geomean	2.65E-05	2.02E-06	2.49E-05	1.19E-04	1.88E-06	7.67E-04	1.11E-03	7.15E-10	2.15E-07	2.22E-07
	P ₅₀	2.87E-05	1.85E-06	1.26E-04	1.19E-04	4.45E-06	6.87E-04	1.12E-03	1.69E-09	1.92E-07	1.94E-07
	P ₉₀	4.04E-05	3.63E-06	6.56E-04	2.08E-04	1.46E-05	1.43E-03	2.01E-03	5.54E-09	4.02E-07	4.50E-07

106 ^a Total risks, summed risks of summed risks of DMP, DEP, DnBP, DnOP, BzBP and DEHP. ^b Total risks, summed risks of DEHP and BzBP.

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110 **Figure S1.** Comparison of concentrations of phthalates between types of sanitary
 111 napkins collected from six countries. The horizontal lines represent the 10th, 50th, and
 112 90th percentiles, and the boxes represent the 25th and 75th percentiles. Outliers are
 113 shown as individual asterisks. Letters indicate significant differences between different
 114 products, and the significance defined at the $p < 0.05$ level.

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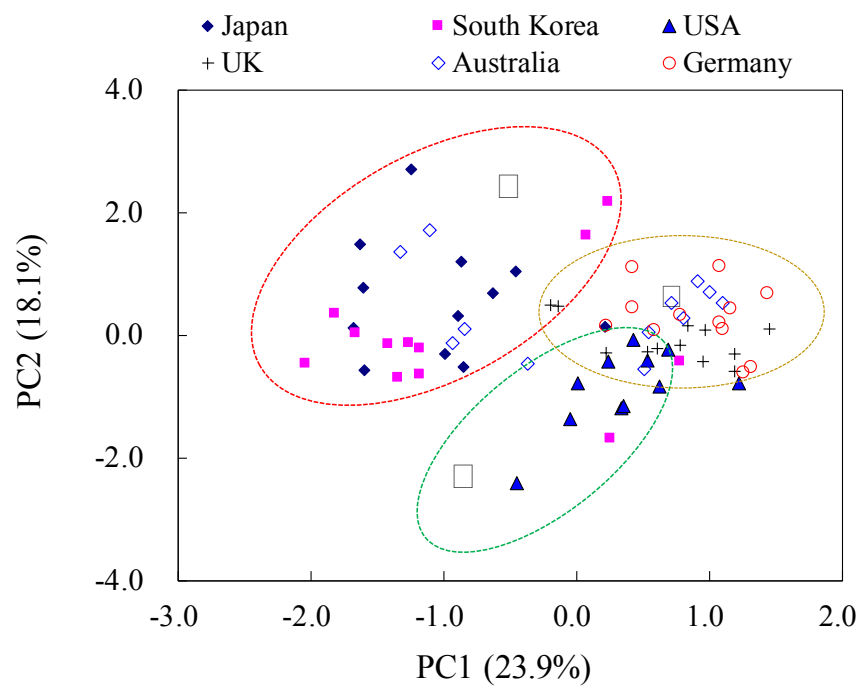
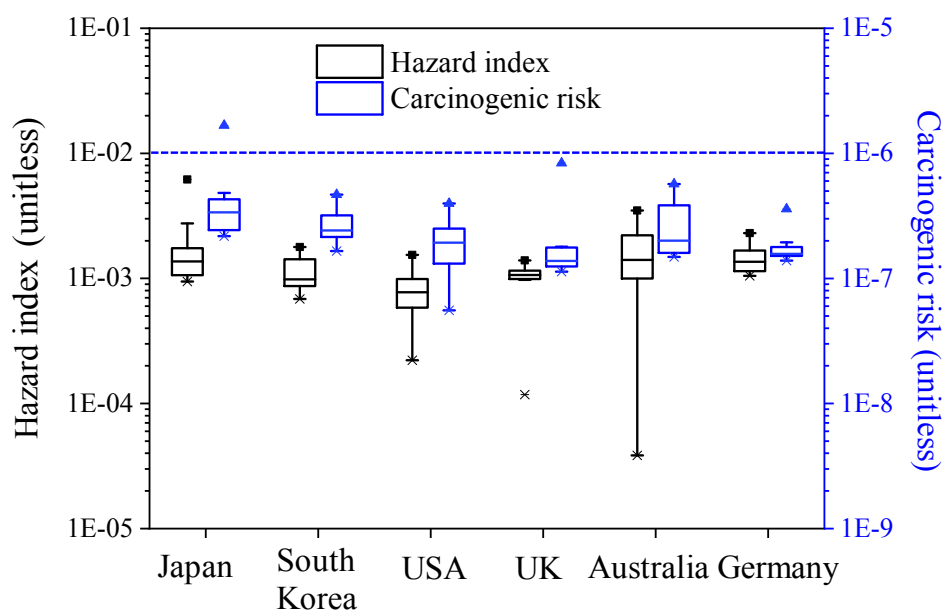


Figure S2. Plot of PC1 versus PC2 from the principal components analyses of the sanitary napkin samples collected from six countries.

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123 **Figure S3.** The hazard index (sum of hazard quotients of DMP, DEP, DnBP, DnOP,
 124 BzBP and DEHP) and total carcinogenic risk (sum of carcinogenic risks of BzBP and
 125 DEHP) in the sanitary napkins collected from six countries. The horizontal lines
 126 represent the 10th, 50th, and 90th percentiles, and the boxes represent the 25th and 75th
 127 percentiles. The acceptable limit was set at 10^{-6} .

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