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RESEARCH ARTICLE

Screening of phthalate esters in 47 branded perfumes

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Abstract In the last few years, the use of phthalates in perfumes has gained attention because these chemicals are sometimes added intentionally as a solvent and a fixative. Five phthalate esters, dimethyl phthalate (DMP), diethyl phthalate (DEP), dibutyl phthalate (DBP), benzyl butyl phthalate (BBP), and diethyl hexyl phthalate (DEHP), were measured in 47 branded perfumes using headspace solid phase microextraction (SPME) followed by gas chromatography–mass spectrometry (GC-MS). The results revealed considerable amounts of phthalate in all 47 brands with detection frequencies>limit of quantitation in the following order: DEP (47/47)>DMP (47/47)>BBP (47/47)>DEHP (46/47)>DBP (23/45). Of the 47 brands, 68.1, 72.3, 85.1, 36.2, and 6.7 % had DEP, DMP, BBP, DEHP, and DBP levels, respectively, above their reported threshold limits. Of these phthalates, DEP was found to have the highest mean value (1621.625 ppm) and a maximum of 23,649.247 ppm. The use of DEP in the perfume industry is not restricted because it does not pose any known health risks for humans. DMP had the second highest level detected in the perfumes, with a mean value of 30.202 ppm and a maximum of 405.235 ppm. Although DMP may have some uses in cosmetics, it is not as commonly used as DEP, and again, there are no restrictions on its use. The levels of BBP were also high, with a mean value of 8.446 ppm and a maximum of 186.770 ppm. Although the EU banned the use of BBP in cosmetics, 27 of the tested perfumes had BBP levels above the threshold limit of 0.1 ppm. The mean value of DEHP found in this study was 5.962 ppm, and a maximum was 147.536 ppm. In spite of its prohibition by the EU, 7/28 perfumes manufactured in European countries had DEHP levels above the threshold limit of 1 ppm. The DBP levels were generally low, with a mean value of 0.0305 ppm and a maximum value of 0.594 ppm. The EU banned the use of DBP in cosmetics; however, we found three brands that were above the threshold limit of 0.1 ppm, and all were manufactured in European countries. The results of this study are alarming and definitely need to be brought to the attention of the public and health regulators. Although some phthalate compounds are still used in cosmetics, many scientists and environmental activists have argued that phthalates are endocrine-disrupting chemicals that have not been yet proven to be safe for any use, including cosmetics. Phthalates may also have different degrees of estrogenic modes of action. Furthermore, we should not dismiss the widespread use of phthalates in everyday products and exposure to these chemicals from sources such as food, medications, and other personal care products.

Keywords Phthalates · Perfumes · GC-MS · SPME · Endocrine disruptors

Introduction

Phthalates are man-made chemicals that are widely distributed in the environment because of their use in many consumer products, such as building materials, household furnishings, clothing, cosmetics, pharmaceuticals, medical devices, dentures, children's toys, cosmetics, perfumes, food packaging, automobiles, lubricants, waxes, cleaning materials, and insecticides (Crinnion 2010). Phthalates are easily transported into the environment during their manufacture and disposal, and

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also, they leach from plastic materials because they are not covalently bound to the plastics (Huang et al. 2013).

The primary phthalates used in cosmetic products are dibutyl phthalate (DBP), used as a plasticizer in products such as nail polishes (to reduce cracking by making the polish less brittle); dimethyl phthalate (DMP), used in hair sprays (to avoid stiffness by allowing the spray to form a flexible film on the hair); and diethyl phthalate (DEP), used as a solvent and perfume fixative (http://www.fda.gov/cosmetics/productsingredients/ingredients/ucm128250.htm).

Koo and Lee (2004) were the first to report the levels of diethyl hexyl phthalate (DEHP), DEP, DBP, and butyl benzyl phthalate (BBP) in 102 branded personal products. Although the authors detected DBP in 19 of the 21 nail polishes and in 11 of the 42 perfumes and detected DEP in 24 of the 42 perfumes and 2 of the 8 deodorants, the estimated levels of daily exposure to phthalates in these products were relatively small. In 2006, Hubinger and Havery from the United States Food and Drug Administration (US FDA) analyzed 48 consumer cosmetic products and found these products to contain at least one phthalate ester; DEP was found most frequently and had a maximum concentration of 38,663 ppm. DBP was detected in fewer products but at levels of up to 59,815 ppm. A follow-up study was conducted by the US FDA in 2010 to determine if any of the products analyzed in the 2006 survey had been reformulated to reduce or eliminate phthalate esters. Hubinger (2010) reported that approximately 52 % (31/60) of the tested adult cosmetic products contained at least one phthalate ester. DBP was detected in 21 of these products in the range of 123 to 62,607 ppm, and DEP was found in 11 nail products in the range of 80 to 36,006 ppm. Additionally, DEP was found in 21 % of the tested baby-care products in the range of 10 to 274 ppm. Again, the US FDA stated that they will continue to monitor both adult and infant cosmetic products for the presence of phthalate esters and for any new materials that may have replaced them. Once the FDA determines that a health hazard exists, the agency will advise the public and industry, and it will take appropriate actions to protect public health (http://www.cfsan.fda.gov/~dms/cos-phth.html). In contrast, the European Commission-Scientific Committee on Consumer Products (SCCP) prohibited the manufacture and/or sale of cosmetics containing BBP, DEP, and DEHP in 2006 (http://ec.europa.eu/health/ph_risk/committees/04_sccp/docs/sccp_o_106.pdf).

Schettler (2006) revealed that although diet is considered to be the major source of phthalate exposure in the general population, one should not exclude other sources or pathways, and their relative contributions to the measured body burdens of phthalates are not well understood. Schutter suggested that phthalates may be present but unidentified in many consumer products, including cosmetics, personal care products, home furnishings, pharmaceuticals, nutritional supplements, and insecticides. In recent years, several scientists have studied the health risks of phthalates in personal care products widely used in daily life. However, searching PubMed with the words "Phthalates, Perfumes" revealed few articles confirming the presence of phthalates in perfumes and other personal care products (Shen et al. 2007; Sanchez-Prado et al. 2011; Dodson et al. 2012; Llompart et al. 2013; Guo and Kannan 2013; Perez-Fernandez et al. 2013).

Some phthalates were postulated to produce endocrine-disrupting effects in rodents, causing potential reproductive and developmental toxicity (Lyche et al. 2009). In recent years, DEHP has received more attention because it exerts more complex and broader disruptive effects on the endocrine system and metabolism than previously thought (Martinez-Arguelles et al. 2013). Although the majority of studies have been conducted in animals, Pak et al. (2011) presented a review article on a few human studies that demonstrate the endocrine-disrupting action of phthalates.

Witorsch and Thomas (2010) reviewed laboratory and epidemiological research into the endocrine-disruptive effects of components of personal care products, and concluded that although select constituents exhibit interactions with the endocrine system in the laboratory, the evidence linking personal care products to endocrine-disruptive effects in humans is for the most part lacking. Recent exposure-assessments revealed an association between urinary concentration of multiple phthalate metabolites and the use of women's personal care products, particularly perfumes and fragranced products (Buckley et al. 2012; Parlett et al. 2013).

Saudi Arabia is the Gulf's largest regional market for fragrances, accounting for $827.5 million last year, according to consumer research firm Euromonitor International. By 2014, it expects fragrance sales to have grown 14.4 % in Saudi Arabia (http://www.euromonitor.com/fragrances-in-saudi-arabia/report). Perfumes are widely used in Saudi Arabia and have equal popularity among women and men. The Saudi market overflows with various brands of perfumes imported from different countries with a wide price range that makes them affordable.

The objective of the present study was to conduct a national survey on the levels of phthalates in perfumes collected from the Saudi market to document the potential levels of exposure to phthalates related to the use of cosmetic and personal care products in Saudi Arabia. A total of five such phthalates, DMP, DEP, DBP, BBP, and DEHP, were measured in 47 branded perfumes using solid phase microextraction (SPME) and gas chromatography (GC) with mass spectrometry (MS).

Materials and methods

Chemicals, materials, and perfume samples

Organic HPLC-grade solvents, including methanol and acetone, were purchased from Fischer Scientific (Pittsburgh, PA, USA), but dichloromethane was supplied from Merck (Darmstadt, Germany). DMP, DEP, DBP, BBP, and DEHP were obtained as neat compounds with purities of 99.5 % from Chemservice (USA). Deuterated di-*n*-propylphthalate-3,4,5,6-d_4 (DPrP-d_4) was used as an internal standard (IS) and was obtained from Fluka Chemie GmbH (Steinheim, Germany). For SPME, 65 μm polydimethylsiloxane-divinylbenzene (PDMS/DVB) fibers was purchased from Bellefonte, PA, USA.

Forty-seven different brands of perfumes and eau de toilettes (for men and women) with a wide price range were purchased from local supermarkets in Riyadh City, Saudi Arabia. Based on the labels, these perfumes were imported from 12 countries, including France, Germany, Holland, Switzerland, the UK, Spain, USA, China, India, Twain, Turkey, United Arab Emirates, and Saudi Arabia. The samples were stored at room temperature until analysis. Table 1 lists the perfume brands studied. Each brand has a manufacturing lot number, which means that the complete history of the manufacturing process, control, packaging, and distribution of a batch can be determined. In this study, only one batch was tested for each of the 47 branded perfumes.

Analytical instrumentation

The gas chromatography–mass spectrometer (GC-MS) was composed of a 6890N gas chromatograph and a 5973 quadrupole mass-selective spectrometer (Agilent Technologies, Palo Alto, CA, USA). Data acquisition and data analysis were performed with Agilent Chemstation software (G1701 DJ version). The column was an Agilent J&W DB-5MS capillary column (cross-linked poly 5 % diphenyl, 95 % dimethylsiloxane), 30 m×0.25 mm (i.d.)×0.25 μm film thickness. An Agilent inlet liner (4 mm i.d.) packed with glass wool was used for the injector. The GC-MS was equipped with a CombiPAL autosampler that has a 32-sample tray, a cooler tray, a SPME fiber holder, a temperature controller, and a 20-ml-vial agitator. The PDMS/DVB fiber (65 μm) was selected on the recommendations of Carrillo et al. (2008) and Liu (2008). The fiber was conditioned for 1 h at 250 °C in accordance with the manufacturer's instructions. Each fiber was used for approximately 40 injections.

Instrument conditions

The GC oven temperature was programmed from 80 °C (held for 0.5 min) to 220 °C at 10 °C min^{-1} and was heated to 290 °C at 30 °C min^{-1} (held for 4 min) (total analysis time=20.83 min). The MS was auto-tuned with perfluorotributylamine (PFTBA, tuning standard). Electron ionization (EI) was performed at 70 eV. The ion source temperature was set to 250 °C, and the flow rate of the helium carrier gas (purity 99.999 %) was set to 1 ml/min. The temperature of the ion source was maintained at 250 °C. The splitless mode (held for 2 min) was used for the injections, the split flow was set to 50 ml/min, and the injector temperature was maintained at 300 °C. The MS system was set to selected ion monitoring (SIM) mode with a solvent delay of 8 min. The SIM mode was also used for quantitative determination. Three fragment ions were monitored for each compound. The fragments were selected after injecting standard solutions in full-scan mode and determining their retention times. The most characteristic ion in the spectrum was selected for quantification and the other two ions were selected for the purpose of confirmation, as displayed in Table 2. The areas of the peak were used for quantitation. The reported values of phthalates were presented either as parts per billion or parts per million.

Sample analysis

All perfume samples were clear liquids which required no pretreatment. Because of the wide range of phthalate concentrations in some branded perfumes, the samples were diluted 1:10 with deionized water. For each SPME analysis, 10 ml of the diluted perfume sample spiked with 6 μl of IS (2 ppb) was placed into a 20-ml glass vial (75.5 mm long and 22.5 mm diameter). The final concentration of IS in sample was 1.2 ppb. Then, the vial was tightly capped with a 1.5-mm PTFE/silicon septum. The samples were mixed well and then left to equilibrate for 10 min at 40 °C. The sample vial was then moved to the CombiPAL autosampler agitator. SPME was conducted at 90 °C for 13 min at an agitation rate of 500 rpm. The analytes were thermally desorbed from the SPME fiber into the GC-MS inlet at 270 °C for 5 min. The optimum extraction time for most of the phthalates was 30 min. The vial penetration depth was set to 25 mm, and the tip of the SPME fiber was 1.0 cm above the surface of the sample solution. Four replicates were measured for each brand of perfumes.

Standard solutions

The initial stock standard solutions were prepared by accurately weighing 25 mg of each phthalate and dissolving the sample in 25 ml of dichloromethane. An intermediate standard mixed solution of phthalates (DMP, DEP, DBP, BBP, and DEHP) containing 1.5 ppb of each compound was prepared in methanol. Both the stock and spiking standards were stored

Table 1 General information on the selected 47 branded perfumes

ID #	Brand	Manufacturer	Country of origin	LOT #[a]
1	Buzz Men 75 ml	Freedom Fragrances	India	97
2	Black Costume 100 ml	Amany Perfumes	France	907
3	Shine So Bright Pour Femme	S.P. Industries	–	–
4	International Perfumes	–	Saudi Arabia	–
5	Twilight Woods	Bath and Body Works	USA	2290 cea2
6	Hugo Boss Man	P and G	UK	1332
7	One million Paco Rabanne	Puig France	France	2801
8	Dior Home Sport	–	France	1Y03
9	Sweet Women Pink	Parfums Gims	France	–
10	Respect	–	India	172
11	Yes Boss	Saudi Perfume & Cosmetics Company Limited	Saudi Arabia	–
12	Rich Girl	–	United Arab Emirates	p 656
13	Zaru 777	Alzaru professional for cosmetics	India	–
14	Juliette	Grace Universal	India	932
15	Flower by Guli	–	China	–
16	Blue Charlie	–	China	–
17	Find Me	–	China	–
18	lilae	–	Holland	–
19	The Body Shop Japanese Cherry Blossom	–	UK	–
20	Raspberry Refreshing Body	Nectar beauty	UK	BN32
21	Ananya Eau De Toilette The Body Shop	The Body Shop Int'l PLC	UK	–
22	Amber Oud Body mist Brume Corporelle	The Body Shop Int'l PLC	UK	–
23	Bsaaem Al Qassem perfume 666	Bsaaem Al Qassem	Switzerland	–
24	Bsaaem Al Qassem	Bsaaem Al Qassem	Switzerland	–
25	Bob Esponja Eau De Toilette	Air-Val International	Spain	2035E045
26	Disney Eau De Toilette	Air-Val international	Spain	0304E2661100
27	Colibri	Dralle GmbH	Germany	–
28	114 ice Cool	Pamas Factory	Saudi Arabia	109/12
29	Farmasi baby cologne (soft)	Tanalize cosmetics	Turkey	01
30	Layl (Oud Mix)	Abdul Samad Al Qurashi	Saudi Arabia	001100
31	Rouge Rouge	Go Perfumes	United Arab Emirates	52,425
32	Only Millionaire	Premier cos industries LLC	United Arab Emirates	–
33	Danial Fresh	Premier cos Industries LLC	United Arab Emirates	–
34	Always Sport	Premier cos Industries LLC	United Arab Emirates	–
35	Dunhill Fresh (Smart Collection)	Smart Collection	France	2514/1175
36	Fendi (Smart Collection)	Smart Collection	France	2514/1294
37	Cartier (Declaration)	Cartier	France	2ABB
38	Dolce & Gabbana (The One)	Dolce & Gabbana	UK	1342
39	Burberry (London)	Burberry	France	044B10
40	Jadore	Dior	France	1S10
41	Lacoste (Green)	Lacoste	UK	1017
42	Chanel No5	Chanel	France	6804
43	Eaudemoiselle de Givenchy	Givenchy	France	P040235
44	Coco mademoiselle	Chanel	France	5001
45	Gucci Guilty	Gucci	France	1297
46	Manifesto	Yves Saint Laurent	France	62J917
47	Burberry (Body)	Burberry	France	03B47B231

[a] LOT # means any number written on the product from which the complete history of the manufacture, control, packaging, and distribution of a batch can be determined

Table 2 The list of tested phthalates including internal standard (IS), their retention times, quantification, and confirmation ions

Phthalate compound	Retention time (min)	Monitored ions (*m/z*)	
		Quantification	Confirmation
DEP	11.34	149	105, 177
DMP	9.79	163	77, 194
DBP	15.16	149	104, 223
BBP	17.34	149	123, 206
DEHP	18.11	149	113, 167
DPrP-d_4 (IS)	13.75	153	195, 100

in the dark at 4 °C until use. All standard solutions were prepared in glassware rinsed with methanol and dried.

Commercial perfumes are liquid samples, which largely consists of alcohol (i.e., ethanol). Matched calibration standards in the range of 0.75 to 24 ppb were first tested by diluting the intermediate standard mixed solution of phthalates with either pure ethanol or solutions with 50:50 and 25:75 ratios of ethanol/deionized water. However, the response was not stable, and to overcome this instability, calibration standards were prepared in deionized water. The concentration range of the phthalate compounds was between 0.75 and 24 ppb for DMP, DEP, DBP, BBP, and DEHP. The IS was added to give a final concentration of 1.2 ppb. A blank standard, which only contained deionized water and the IS, was also included. Figure 1 shows a chromatogram obtained for a 24-ppb standard mixture that includes all target compounds. The five phthalates and the IS were analyzed in less than 19 min.

Results and discussion

To verify that the developed SPME-GC-MS method was suitable for the quantitative determination of the selected phthalate compounds in the 47 selected perfumes, parameters such as linearity, accuracy, precision, and the limits of detection (LOD) and quantification (LOQ) were evaluated to ensure the quality of the method. The linearity was evaluated from the coefficient of determination (r^2) acquired by plotting the relative peak area (area for each phthalate compound divided by the IS peak area) as a function of the phthalate concentration in parts per billion. All of the calibration curves showed good linearity, with r^2 in the range of 0.9987–0.9997 (Table 3). The individual calibration curves are shown in Fig. 2. Ten independent samples of deionized water were fortified at the lowest acceptable concentration of 0.375 ppb for DEP, DMP, DBP, BBP, and DEHP to calculate LOD and LOQ (Table 3). The precision of the method was evaluated within the same day (within-run precision) and on different days (between-run precision) at three concentration levels (1.125, 2.5, and 4.5 ppb) for DEP, DMP, DBP, BBP, and DEHP. The results are expressed in terms of relative standard deviation (RSD) as shown in Table 4. The RSDs were lower than 15 % for all phthalates. The recoveries were satisfactory a minimum of 92.3 % and a maximum of 105.3 %. To check the stability of the method, we repeated the analysis of one of the tested perfumes (Twilight Woods Bath & Body collection) over a period of 10 days for only DMP, DEP, and BBP. The other phthalates (DBP and DEHP) were not found in this perfume, and we were unable to find other suitable commercial perfumes to check their accuracies because they are usually present in very low concentrations. The maximum RSD was 15 %.

Therefore, the SPME-GC-MS method exhibited good precision for quantification of the five selected phthalate compounds in the 47 different brands of perfume samples collected in this study. Results are given in Table 5. The averages of the tested phthalates were found to have the following order: DEP (1621.625 ppm)>DMP (30.202 ppm)>BBP (8.446 ppm)>DEHP (5.962 ppm)>DBP (0.0305 ppm). As shown in Table 6, DMP, DEP, and BBP were found in all brands, and all readings were above the LOQ of 0.00069, 0.00065, and 0.00061 ppm, respectively. DEHP was detected in 46 brands and all were above the LOQ of 0.00077 ppm. DBP was detected in 24 brands and all were above the LOQ of 0.0014 ppm.

Our results confirm the presence of phthalates in perfumes, whether they were added intentionally or through contamination during the manufacturing process. Among the six tested phthalate compounds, DEP was the most abundant compound with values between 0.232 and 23,649.25 ppm, and 32/47 samples (68.1 %) were above the reporting threshold limit of 1 ppm quoted by the Greenpeace investigation (Peters 2005). High DEP values in perfumes were also reported by other researchers: mean value=3044.236 ppm, N=42 (Koo and Lee 2004); median value=1187 ppm, N=36 (Peters 2005); mean value=15,235.909 ppm, N=11 (Hubinger 2010); median value=1679 ppm, N=30 (Koniecki et al. 2011); median value=4686 ppm, N=70 (Sanchez-Prado et al. 2011); and mean value=3420 ppm, N=12 (Guo and Kannan 2013). DEP is generally used as a solvent and a fixative in fragrances (FDA 2014) so the smell lasts longer. The Scientific Committee on Cosmetics and Non-Food Products (SCCNFP 2002) reviewed the toxicity of DEP in cosmetics on its 20th plenary meeting on 4 June 2002 and concluded that DEP showed low toxicity in testing for dermal irritation and sensitization in humans as well as in animals, and in photo-toxicity and photo sensitization in human volunteers, demonstrating its safety for use. They added that minimal or moderate effects were seen when undiluted doses were applied. At its 26th plenary meeting, 9 December 2003, the SCCNFP stated that the safety profile of DEP supports its use in cosmetics (SCCNFP 2003). In 2007, the SCCNFP again reiterated its

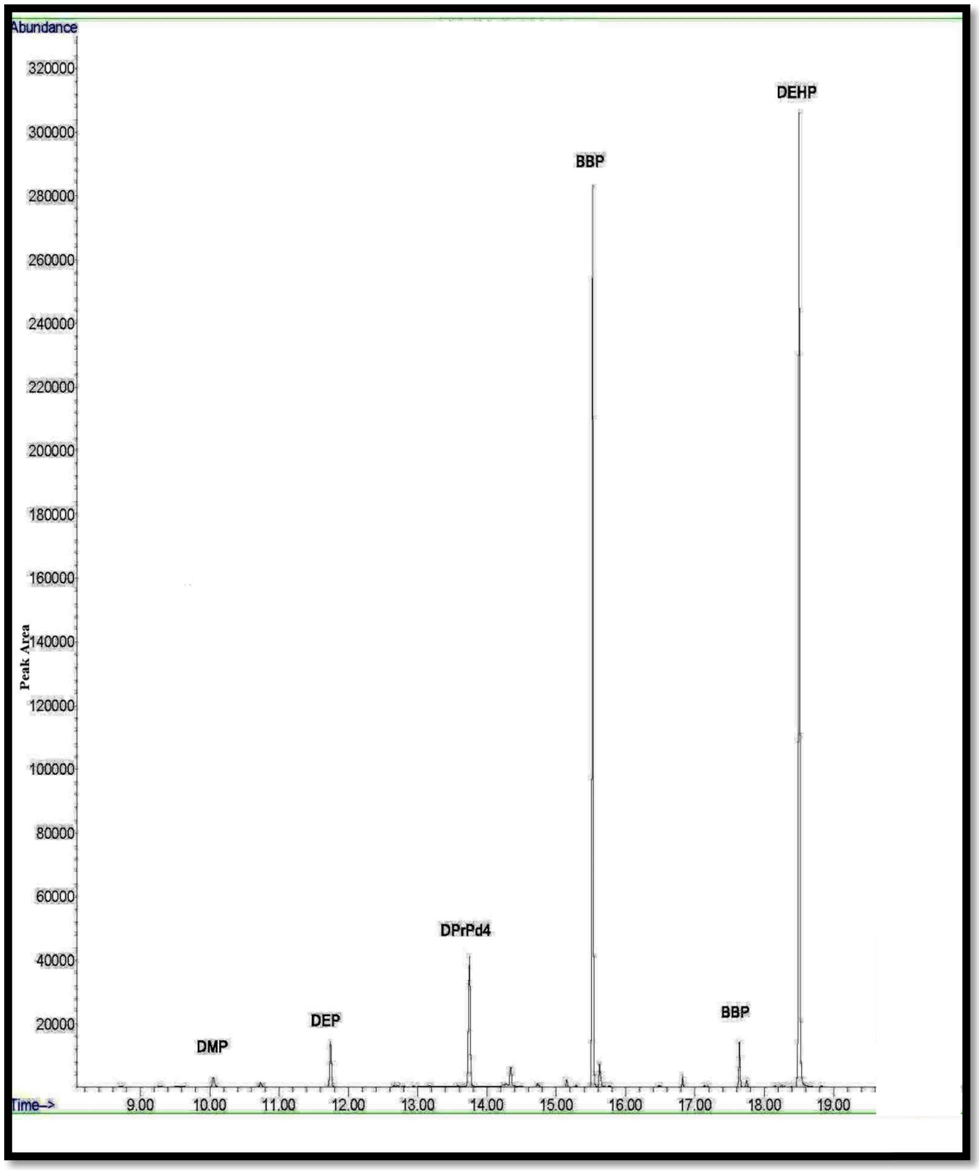

Fig. 1 Typical SPME-GC-MS chromatogram for the five studied phthalates as well as DPrPd4 (IS)

previous opinions (SCCNFP/411/01 and SCCNFP/0767/03) and stated there is still a very large margin of safety even when DEP is used as a fragrance solvent at concentrations of up to 50 % of the fragrance mix (SCCNFP 2007). In Australia, the use of DEP in cosmetics is only excluded in sunscreens or personal insect repellents for human use except in preparations containing 0.5 % or less (NICNAS 2011). The FDA also concluded that there is no compelling evidence that DEP use in cosmetics poses a safety risk (CIR 2005). Api (2001) reviewed the available data on the safety of using DEP in perfumes and found no toxicological endpoints of concern. Calafat and McKee (2006) concluded the following:

Table 3 Calibration curves, regression coefficients (r^2), limit of detection (LOD), and limit of quantitation (LOQ) of the six phthalate compounds

Compound name	Retention time (min)	Concentration range (ppb)	r^2±SD (*n*)	LOD (ppb)	LOQ (ppb)
DEP	10.42	0.75, 1.5, 3, 6, 12, 24	0.9997±0.00017 (12)	0.513	0.646
DMP	9.28	0.75, 1.5, 3, 6, 12, 24	0.9997±0.0003 (12)	0.514	0.693
DBP	12.43	0.75, 1.5, 3, 6, 12, 24	0.9996±0.0004 (14)	0.770	1.438
BBP	13.06	0.75, 1.5, 3, 6, 12, 24	0.9993±0.0008 (23)	0.455	0.607
DEHP	18.12	0.75, 1.5, 3, 6, 12, 24	0.9987±0.0014 (21)	0.629	0.766

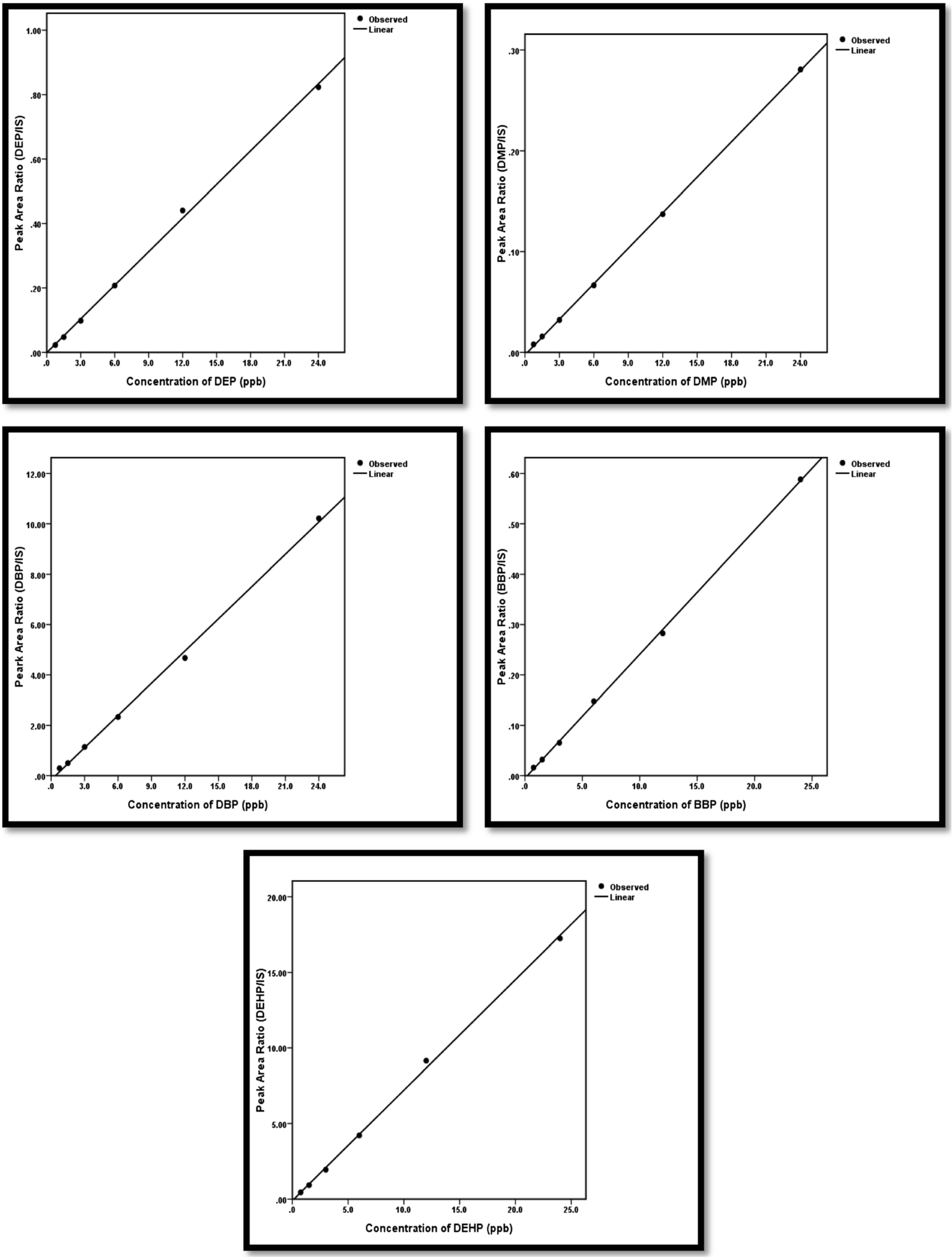

Fig. 2 Calibration curves for the five studied phthalates

Table 4 Precision and recovery of spiked with tested phthalates (ppb)

Phthalates	Concentration (ppb)	Within run	*n*	%RSD	Between run	*n*	RSD%
DEP	1.125	1.152±0.056	17	4.9 %	105.3±5.4	12	5.1 %
	2.5	2.201±0.127	17	5.8 %	97.7±3.5	12	3.6 %
	4.5	4.384±0.188	17	4.3 %	95.8±4.1	12	4.3 %
DMP	1.125	1.154±0.059	17	5.1 %	102.0±7.0	12	6.9 %
	2.5	2.251±0.082	17	3.6 %	97.7±4.5	12	4.6 %
	4.5	4.604±0.192	17	4.2 %	96.5±3.7	12	3.8 %
DBP	1.125	1.198±0.049	17	4.1 %	99.6±7.6	14	7.6 %
	2.5	2.311±0.219	17	9.5 %	92.3±9.1	12	9.9 %
	4.5	4.397±0.152	17	3.5 %	97.1±6.5	14	6.7 %
BBP	1.125	1.111±0.115	17	10.4 %	97.7±9.6	24	9.8 %
	2.5	2.087±0.116	17	5.6 %	99.9±11.1	24	11.1 %
	4.5	4.280±0.341	17	8.0 %	99.1±7.7	24	7.8 %
DEHP	1.125	1.107±0.090	17	8.1 %	100.1±8.0	20	8.0 %
	2.5	2.142±0.172	17	8.0 %	95.7±7.2	20	7.5 %
	4.5	4.124±0.273	17	6.6 %	95.6±9.8	20	10.3 %

(a) indirect methods can provide realistic estimates of exposure only if reasonable assumptions are used; (b) biomonitoring data can yield precise exposure estimates because they do not require overly conservative assumptions; and (c) it may identify situations in which not all potential sources of exposure were considered. A few recent studies reported the presence of urinary monoethyl phthalate (MEP), the metabolite of DEP, in boys (Lewis et al. 2013) and women (Just et al. 2010; Parlett et al. 2013) using personal products including perfumes. Although the existing data suggest that dermal exposure to DEP from personal care products is relatively low (Lalko et al. 2004; Koo and Lee 2004), one should not dismiss other routes of exposure from several sources that may be greater and require further investigation. For example, Pereira et al. (2007) reported that continuous exposure to low levels of DEP through food during gestation and lactation over three generations in male Wistar rats leads to an enhanced toxic effect in the latter generations. A recent study by Sun et al. (2013) showed that DEP affects sirtuins and methyltranferases during the apoptosis of pheochromocytoma cells.

The second highest detected phthalate compound in this study was DMP in the range of 0.150 to 405.235 ppm, and 34/47 perfume samples were above the reporting threshold limit of 0.1 ppm (Peters 2005). However, DMP does not seem to be used as commonly as DEP in cosmetics and our mean value (30.202 ppm) is much higher than that reported in similar studies. For example, Sanchez-Prado et al. (2011) reported a median value of 1.7 ppm for the 70 tested perfume samples. Peters (2005) detected DMP in only 1 of the 36 perfume products with a value of 2982 μg/g. Hubinger (2010) and Koniecki et al. (2011) did not find DMP in 11 and 30 perfume products, respectively. Again, the SCCP (2007) found that the margin of safety might be considered to be high if the highest concentration (2982 ppm or 0.3 %) found in only one perfume was used. Their calculation was based on the no observed adverse effect level (NOAEL) for maternal toxicity in rats (600 mg/kg bw/day, intraperitoneal, Peters and Cook 1973) and the dermal absorption of less than 5 %, as reported in the literature (Elsisi et al. 1989). They concluded that unintentional exposure from perfume and other cosmetics at the levels found in this study would have no measurable risk for the consumer. The Cosmetic Ingredient Review (CIR) Expert Panel confirmed the safe use of DMP in cosmetic products (CIR 2005). Similar observations were reported by the Australian government (NICNAS 2014). A study by Buckley et al. (2012) found that the use of three personal care products were associated with high urinary levels of monomethyl phthalate (MMP), the metabolite of DMP. Infant exposure to lotion, powder, and shampoo were significantly associated with increased urinary concentrations of MMP and MEP (Sathyanarayana et al. 2008).

The levels of DBP in this study were low (0.0305± 0.0934 ppm), in the range of 0 to 0.594 ppm, and only three samples were above the threshold reporting limit of 0.1 ppm (Peters 2005). Low DBP results were also reported by other investigators. Guo and Kannan (2013) reported a mean value of 0.21 ppm in 12 perfume samples, and Peters (2005) found DBP in 21/36 perfume samples with a median value of 0.2 ppm. Sanchez-Prado et al. (2011) reported a higher median value of 0.9 ppm for the 70 tested perfume products. SCCP (2007) suggested that DBP might have leached into products unintentionally through manufacturing or storage rather than through deliberate addition. In contrast, Hubinger (2010) tested 11 perfume samples and found no DBP. However, the mean value of DBP in 42 perfume samples found by Koo and Lee (2004) was very high (444.567 ppm). As per Directive 76/768/EEC, the EU banned the use of DBP in cosmetics, EC No. 201-557-4 (EC 2009). However, three brands of perfumes had DBP

Table 5 Concentration of five phthalate compounds (ppm) in 47 different brands of perfumes

Perfume ID	DEP					DMP				
	N	Mean	SD	Minimum	Maximum	*N*	Mean	SD	Minimum	Maximum
1	4	4432.377	499.359	3735.211	4922.052	4	40.351	7.388	30.203	47.900
2	7	3411.656	234.209	3152.726	3901.223	4	0.890	0.311	0.649	1.346
3	4	219.280	10.760	204.890	229.736	4	0.150	0.024	0.119	0.174
4	4	4.986	1.126	3.950	6.584	4	8.970	1.781	7.309	11.483
5	4	3.426	0.317	3.067	3.741	4	43.399	13.800	23.741	54.080
6	4	0.660	0.245	0.331	0.861	4	177.832	25.725	151.625	208.343
7	4	2332.890	49.816	2288.248	2398.680	4	7.560	0.668	6.886	8.386
8	4	11.833	1.243	10.563	13.132	4	98.314	4.128	94.132	102.535
9	4	2050.112	170.800	1816.160	2221.230	4	0.465	0.081	0.388	0.577
10	4	23,649.247	1395.491	22,094.606	25,270.370	4	0.767	0.048	0.702	0.813
11	4	10,237.435	317.024	9785.343	10,461.927	4	405.235	17.547	381.407	420.206
12	4	5.085	1.265	3.202	5.896	4	3.618	1.231	1.796	4.479
13	4	213.032	9.792	201.001	224.757	4	2.040	0.179	1.812	2.236
14	4	4264.194	177.885	4061.716	4478.202	4	3.504	0.256	3.182	3.766
15	4	414.911	3.981	409.817	419.170	4	2.278	0.261	1.940	2.576
16	4	7.675	1.591	6.221	9.263	4	10.045	2.175	7.587	12.319
17	4	11.052	0.919	9.834	12.065	4	2.760	0.560	2.208	3.511
18	4	3270.646	236.236	2951.685	3469.167	4	20.313	1.016	19.080	21.277
19	4	1.794	0.530	1.143	2.440	4	1.880	0.126	1.738	2.036
20	7	331.793	18.211	306.595	352.701	4	13.862	2.499	10.207	15.821
21	4	16.690	1.473	14.898	18.486	4	0.655	0.139	0.470	0.806
22	4	1.376	0.093	1.277	1.501	4	0.667	0.127	0.582	0.856
23	4	1690.718	87.114	1614.922	1785.359	4	5.882	1.826	3.238	7.321
24	4	375.518	49.625	319.621	432.693	4	0.183	0.011	0.168	0.190
25	4	1.522	0.423	0.968	1.990	4	0.342	0.072	0.273	0.438
26	4	3759.384	869.903	2809.387	4512.060	4	6.567	1.765	4.954	8.750
27	4	2757.107	253.828	2543.216	3073.581	4	1.951	0.165	1.743	2.111
28	4	190.753	6.566	182.783	198.239	4	10.158	0.170	9.948	10.326
29	4	42.617	3.335	38.468	46.565	4	4.414	0.799	3.672	5.548
30	4	45.242	5.165	41.402	52.667	4	24.739	4.117	20.757	30.474
31	4	522.833	82.725	412.048	602.900	4	71.345	18.723	52.043	90.908
32	4	233.534	6.709	228.502	243.125	4	0.960	0.031	0.915	0.981
33	4	0.403	0.121	0.227	0.493	4	28.054	0.844	27.015	29.081
34	4	1500.448	78.050	1430.259	1568.178	4	0.347	0.034	0.297	0.373
35	8	3682.309	459.643	2727.721	4327.841	8	18.514	4.162	12.819	25.889
36	7	1674.920	423.464	1248.730	2434.190	4	2.954	1.075	1.636	3.876
37	4	8.115	3.253	3.655	11.464	4	154.950	12.436	144.330	169.202
38	4	0.505	0.044	0.446	0.552	4	10.558	1.310	8.962	11.725
39	4	1.058	0.075	0.964	1.145	4	0.682	0.076	0.573	0.743
40	4	0.549	0.042	0.503	0.592	4	61.162	3.483	57.509	64.257
41	4	1125.997	88.643	1051.973	1233.990	4	0.740	0.057	0.668	0.798
42	4	57.422	5.175	52.465	62.846	4	31.304	2.808	27.733	33.813
43	4	0.758	0.086	0.665	0.871	4	42.524	2.108	39.922	44.899
44	4	0.840	0.164	0.657	1.002	4	6.860	0.896	5.534	7.471
45	4	0.232	0.010	0.220	0.245	4	3.539	0.493	2.823	3.885
46	4	4.677	0.151	4.534	4.885	4	58.354	2.991	56.230	62.771
47	4	3646.754	357.898	3115.127	3879.600	4	26.849	1.758	25.033	29.254
Total	201	1670.895	3687.873	0.220	25,270.370	192	29.958	66.388	0.119	420.206

Table 5 (continued)

Perfume ID	DBP					BBP				
	N	Mean	SD	Minimum	Maximum	*N*	Mean	SD	Minimum	Maximum
1	4	0.0089	0.0041	0.0035	0.0128	4	39.493	2.520	36.656	42.636
2	4	0.0092	0.0004	0.0088	0.0096	4	0.913	0.312	0.693	1.374
3	4	0.0195	0.0027	0.0163	0.0227	4	0.039	0.003	0.036	0.041
4	4	0	0	0	0	4	0.085	0.068	0.042	0.186
5	4	0.00095	0.0019	0	0.0038	4	0.074	0.022	0.042	0.095
6	4	0.1331	0.0705	0.0920	0.2384	4	2.105	1.159	0.369	2.725
7	4	0.00032	0.00064	0	0.0013	4	1.674	0.057	1.621	1.730
8	4	0	0	0	0	4	0.335	0.073	0.271	0.439
9	4	0.0223	0.0058	0.0186	0.0309	4	0.331	0.011	0.321	0.344
10	4	0.0006	0.0006	0	0.0009	4	186.770	16.242	164.298	201.724
11	4	0	0	0	0	4	0.339	0.019	0.324	0.367
12	4	0	0	0	0	4	0.340	0.019	0.325	0.367
13	4	0	0	0	0	4	0.521	0.066	0.472	0.615
14	4	0	0	0	0	4	0.674	0.164	0.447	0.836
15	4	0	0	0	0	4	0.010	0.001	0.008	0.012
16	4	0.0024	0.0018	0	0.0038	4	0.261	0.136	0.082	0.409
17	4	0.0044	0.0005	0.0038	0.0049	4	0.126	0.060	0.048	0.194
18	4	0	0	0	0	4	0.510	0.124	0.366	0.660
19	4	0	0	0	0	4	0.497	0.029	0.479	0.541
20	4	0	0	0	0	4	0.278	0.123	0.170	0.404
21	4	0	0	0	0	4	1.776	0.298	1.493	2.101
22	4	0.0463	0.0030	0.0433	0.0505	4	3.963	0.051	3.888	3.999
23	4	0.0042	0.0021	0.0014	0.0063	4	1.170	0.059	1.124	1.257
24	4	0	0	0	0	4	1.263	0.222	1.113	1.592
25	4	0.0253	0.0035	0.0225	0.0301	4	0.523	0.090	0.390	0.584
26	4	0.0187	0.0019	0.0161	0.0206	4	0.467	0.037	0.424	0.504
27	7	0.00013	0.00035	0	0.0009	4	0.433	0.039	0.409	0.492
28	4	0.0019	0.0038	0	0.0077	4	0.328	0.016	0.312	0.351
29	4	0	0	0	0	4	20.843	3.184	16.799	24.570
30	4	0.0045	0.0011	0.0029	0.0054	4	1.198	0.096	1.088	1.318
31	4	0.0160	0.0056	0.0121	0.0244	4	0.379	0.209	0.167	0.623
32	4	0	0	0	0	4	0.007	0.002	0.006	0.009
33	4	0.0029	0.0012	0.0018	0.0041	4	0.067	0.029	0.032	0.098
34	4	0.00014	0.00017	0	0.0003	4	3.131	0.505	2.401	3.553
35[a]						4	1.019	0.130	0.863	1.180
36[a]						4	0.918	0.174	0.723	1.112
37	4	0	0	0	0	4	1.615	0.170	1.454	1.851
38	4	0.0302	0.0066	0.0238	0.0390	4	0.583	0.065	0.498	0.655
39	4	0.0093	0.0063	0	0.0139	4	0.684	0.049	0.649	0.754
40	4	0.0959	0.0144	0.0861	0.1170	4	24.255	3.899	21.161	29.751
41	4	0.0344	0.0060	0.0303	0.0434	4	9.050	0.820	8.152	10.142
42	4	0.0029	0.0005	0.0022	0.0035	4	6.996	0.517	6.623	7.721
43	4	0.5936	0.0481	0.5386	0.6424	4	51.855	2.663	49.310	55.249
44	4	0.1749	0.0345	0.1421	0.2235	4	27.674	4.125	23.093	31.378
45	4	0.0955	0.0059	0.0866	0.0987	4	0.450	0.054	0.380	0.497
46	4	0.0181	0.0048	0.0142	0.0251	4	0.852	0.075	0.755	0.926
47	4	0	0	0	0	4	0.073	0.078	0.018	0.185
Total	183	0.0301	0.0927	0	0.6424	188	8.446	28.507	0.006	201.724
Perfume ID	DEHP									
	N	Mean	SD	Minimum	Maximum					
1	4	5.466	0.644	4.825	6.292					
2	4	0.035	0.006	0.030	0.042					
3	4	39.452	15.036	20.255	51.861					
4	4	0	0	0	0					
5	4	0.001	0.000	0.001	0.002					
6	8	0.049	0.051	0.001	0.099					
7	8	0.042	0.044	0.001	0.088					
8	8	0.051	0.054	0.001	0.109					
9	4	0.881	0.045	0.826	0.921					
10	4	5.034	0.341	4.624	5.375					
11	4	29.539	0.640	29.056	30.446					
12	4	0.485	0.066	0.399	0.558					

Table 5 (continued)

13	4	0.448	0.013	0.435	0.466
14	4	11.580	0.685	10.989	12.340
15	4	0.003	0.000	0.003	0.003
16	4	1.791	0.223	1.550	2.027
17	4	0.768	0.182	0.536	0.974
18	4	7.886	1.322	6.369	9.123
19	4	0.048	0.009	0.038	0.059
20	4	1.762	0.618	1.328	2.667
21	4	0.231	0.047	0.183	0.282
22	4	1.621	0.013	1.607	1.633
23	4	0.743	0.011	0.728	0.754
24	8	0.041	0.028	0.005	0.062
25	4	0.005	0.000	0.005	0.005
26	4	0.004	0.000	0.004	0.004
27	4	3.493	0.385	3.113	3.838
28	4	3.448	0.133	3.292	3.615
29	4	147.536	21.377	123.376	174.786
30	4	0.492	0.058	0.436	0.557
31	4	0.142	0.010	0.135	0.156
32	4	0.756	0.122	0.621	0.869
33	4	1.006	0.061	0.954	1.093
34	4	5.904	0.388	5.560	6.372
35	8	0.739	0.050	0.645	0.796
36	4	0.323	0.032	0.283	0.351
37	4	0.127	0.011	0.116	0.137
38	4	1.641	0.251	1.348	1.961
39	4	1.032	0.248	0.781	1.335
40	8	0.345	0.367	0.002	0.693
41	4	3.758	0.750	2.962	4.693
42	4	0.518	0.013	0.499	0.529
43	4	0.316	0.004	0.312	0.321
44	8	0.158	0.165	0.003	0.316
45	8	0.129	0.134	0.003	0.256
46	8	0.135	0.141	0.003	0.268
47	4	0.260	0.002	0.258	0.262
Total	224	5.032	20.591	0	174.786

[a] Not enough perfume sample to analyze DBP in samples ID 35 and 26

above the threshold limit of 0.1 ppm manufactured in European countries. In Australia, DBP was identified as being used in finished cosmetics and personal care products, such as nail polish and fragrance bases for personal care and cosmetic products. Currently in Australia, there are no restrictions on the use of DBP in consumer products such as cosmetics and personal care products. However, Australia's National Industrial Chemicals Notification and Assessment Scheme (NICNAS 2013) proposed banning the use of DBP in cosmetics because of its classification as a reproductive toxin with long-term effects. In USA, there is no restriction on the use of DBP in personal care products except in the state of California under Proposition 65 (http://www.oehha.ca.gov/prop65/prop65_list/files/p65single122614.pdf), which considers DBP to be a developmental toxin and requires label warnings when DBP is present above the designated amounts (http://www.leginfo.ca.gov/pub/05-06/bill/sen/sb_0451-0500/sb_484_bill_20051007_chaptered.pdf). A few bio-monitoring studies detected the metabolite of DBP, mono-isobutyl phthalate (MiBP), in the urine of women and children (Ye et al. 2009;

Table 6 The number of perfumes that had phthalates above their threshold limits, LOD, and LOQ

Phthalates	Threshold limit (1 ppm)	Brand >threshold limit	>LOD	>LOQ
DEP	1	32 (68.1 %)	47 (100 %)	47 (100 %)
DMP	0.1	34 (72.3 %)	47 (100 %)	47 (100 %)
DBP	0.1	3 (6.7 %)	23 (51.1 %)	23 (51.1 %)
BBP	0.1	40 (85.1 %)	47 (100 %)	47 (100 %)
DEHP	1	17 (36.2 %)	46 (97.9 %)	46 (97.9 %)

Romero-Franco et al. 2011; Lewis et al. 2013) associated with the use of personal care products.

In this study, the BBP levels in 47 perfume samples ranged between 0.0069 and 186.770 ppm, and 40 samples (85.1 %) were above the threshold reporting limit of 0.1 ppm (Peters 2005). Our mean value (8.446 ppm) was higher than the one reported by Koo and Lee (2004) of 1.64 ppm in 42 perfume samples. Peters (2005) found BBP in only 9/36 perfume samples in the range of 0.1 to 110 ppm. Hubinger (2010) and Sanchez-Prado et al. (2011) did not detect BBP in 11 and 70 tested perfume products, respectively. BBP is banned in cosmetics by the EU per Directive 76/768/EEC, EC No. 201-622-7 (EC 2009). However, this study revealed that 27/28 perfumes (96.4 %) manufactured in European countries had BBP above the threshold limit of 0.1 ppm. In contrast, the safety of BBP was assessed by the CIR Expert Panel on the basis of scientific data, and the CIR stated that BBP is safe for use as a cosmetic ingredient (http://cosmeticsinfo.org/ingredient/butyl-benzyl-phthalate). BBP is among the Current Priority Existing Chemicals and is still under assessment by the Australian government (http://www.nicnas.gov.au/communications/publications/chemical-gazette/Chemical-Gazette-August-2013/special-notices/list-of-priority-existing-chemicals-pecs), and its assessment for public health effects restricts its use in cosmetics and children's toys. TheCIR Expert Panel stated that although BBP is not used in cosmetic products, it is considered safe (Andersen 2011). The state of California has listed BBP under the Proposition 65 list of chemicals "known to cause development and cancer" (http://www.oehha.ca.gov/prop65/prop65_list/files/p65single122614.pdf) and any product that contains an unsafe chemical should bear a warning label (http://www.oehha.ca.gov/prop65/prop65_list/files/p65single122614.pdf). Human studies revealed that BBP metabolizes to mono-benzyl phthalate (MBzP) and is primarily excreted in the urine. A few studies showed an association between urinary MBzP and the use of personal care products in children and adults (Romero-Franco et al. 2011; Buckley et al. 2012; Lewis et al. 2013; Parlett et al. 2013).

The range of DEHP in the studied perfume samples was between 0 and 147.535 ppm, and 17/47 (36.2 %) were above the threshold reporting limit of 1 ppm (Peters 2005). Our mean value (8.456 ppm) is higher than those found in other studies: mean, 0.678 ppm (Koo and Lee 2004); range, 1–167 ppm (Peters 2005); median, 3.2 ppm (Sanchez-Prado et al. 2011) and mean, 2.71 ppm (Guo and Kannan 2013). DEHP was not found in the 11 perfume samples analyzed by Hubinger (2010). The use of DEHP in cosmetics was prohibited by some regularity government authorities because of its well-documented reproductive and developmental toxicity (Kavlock et al. 2006; Shelby 2006). For example, the use of DEHP in cosmetics is prohibited according to EU Directive 76/768/EEC, EC No. 204-211-0 (EC 2009) and the Australian government (NICNAS 2010). Nonetheless, our study found that seven perfumes manufactured in European countries had DEHP above the threshold limit of 1 ppm. In contrast, the US FDA has chosen not to take regulatory action against the use of DEHP in cosmetics, although the state of California listed DEHP as a developmental toxin and carcinogen under Proposition 65 in 2005 (http://www.oehha.ca.gov/prop65/prop65_list/files/p65single122614.pdf) and any product that contains this chemical at levels greater than the designated amount requires a label warning (http://www.leginfo.ca.gov/pub/05-06/bill/sen/sb_0451-0500/sb_484_bill_20051007_chaptered.pdf).

Some bio-monitoring studies related DEHP exposure to the use of personal care products and reported elevated levels of the DEHP metabolite, mono-2-ethylhexyl phthalate (MEHP), in the urine of women (Frederiksen et al. 2013; Cutanda et al. 2015).

Based on scientific evidence, the US National Toxicology Program concluded that BBP (NTP 2003a), DBP (NTP 2003b), and DEHP (Shelby 2006) were reproductive or developmental toxicants. No support has been yet found for DEP and DMP (NTP 1995; Field et al. 1993). As indicated earlier, phthalates have been identified to be endocrine-disrupting chemicals, but they may have different degrees of estrogenic modes of action. According to Heudorf et al. (2007), DEP's low molecular weight and volatile nature allows it to be absorbed dermally and by inhalation. In vitro and animal studies have reported the endocrine-disrupting activity of DEP and DMP. For example, a recent study by Kumar et al. (2014) suggested that DEP acts as an estrogenic compound and may induce reproductive abnormalities in the female reproductive system of rats by both genomic and non-genomic modes of action. Zhou et al. (2011) showed that acute exposure of abalone eggs or sperm to DMP adversely affects fertilization efficiency and subsequent embryogenesis. Sperm were more sensitive to DMP than eggs. Systematic absorption of DEP and DBP in men was reported by Janjua et al. (2007) after topical application. However, such absorption did not seem to have any short-term influence on the levels of reproductive and thyroid hormones in the young men examined.

Conclusions

The results of this study revealed considerable amounts of phthalates in 47 branded perfumes, and the detection frequencies (>LOQ) were in the following order: DEP (47/47)>DMP (47/47)>BBP (47/47)>DEHP (46/47)>DBP (23/45). Of the 47 brands, 68.1, 72.3, 85.1, 36.2, and 6.7 % had DEP, DMP, BBP, DEHP, and DBP, respectively, above their reported threshold limits. Of these phthalates, DEP was found to be present in the highest concentrations, up to 23,649.247 ppm. DEP is still used as a solvent and fixative in the perfumes industry because it does not pose any known health risks for humans. The second highest levels of phthalate detected in this study were for DMP at levels of up to 405.235 ppm, and this level was much higher than those reported in the aforementioned studies. Although DMP may have some uses in cosmetics, it is not used as commonly as DEP, and again, there are no restrictions on its use. Higher concentrations of BBP were also found in this study than in other studies, and the maximum concentration was 186.770 ppm. Although the EU banned its use in cosmetics, 27 of the tested perfumes had BBP levels above the threshold limit of 0.1 ppm. The levels of DEHP found in this study were higher (up to a maximum of 147.536 ppm) than those reported in other studies. Again, despite its prohibition by the EU, 7/28 perfumes manufactured in European countries had DEHP levels above the threshold limit of 1 ppm. The levels of DBP were generally low and the maximum value was 0.594 ppm. The EU banned the use of DBP in cosmetics; however, we found three brands that were above the threshold limit of 0.1 ppm, and all of these brands were manufactured in European countries. The results of this study are alarming and definitely need to be brought to the attention of the public and health regulators. Though some phthalate compounds are still used in cosmetics, many scientists and environmental activists have argued that they are endocrine-disrupting chemicals that have not yet been proven to be safe for any use, including cosmetics. Phthalates may also have different degrees of estrogenic modes of action. Furthermore, we should not dismiss the widespread use of phthalates in everyday products and exposure to these chemicals from sources such as food, medication, and other personal care products.

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Compliance with ethical standards The authors would like to confirm that (1) there is no potential conflict of interest and (2) the research project did not involve human participants and/or animals. The co-author has read and approved the paper and it has not been published previously nor is it being considered by any other peer-reviewed journal.

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