HHS Public Access
Author manuscript
Environ Int. Author manuscript; available in PMC 2023 January 01.

Published in final edited form as:
Environ Int. 2022 January ; 158: 106967. doi:10.1016/j.envint.2021.106967.

Widespread occurrence of phthalate and non-phthalate plasticizers in single-use facemasks collected in the United States

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Abstract

Single-use or disposable facemasks have been widely used by the public for personal protection against the spread of COVID-19. The majority of disposable facemasks are made of synthetic polymers such as polypropylene, polyethylene terephthalate (as polyester), and polystyrene, and could therefore be a source of human exposure to plasticizers that are incorporated into these polymers during production. Little is known, however, about the occurrence of plasticizers in facemasks. In this study, we determined the concentrations of nine phthalate diesters and six non-phthalate plasticizers in 66 facemasks purchased in the United States. Among phthalate diesters, dibutyl phthalate, di(2-ethylhexyl)phthalate, di-*iso*-butyl phthalate, and butyl benzyl phthalate were found in all facemask samples, at median concentrations of 486, 397, 254, and 92 ng/g, respectively. Among non-phthalate plasticizers, dibutyl sebacate (median: 3390 ng/g) and di(2-ethylhexyl)adipate (352 ng/g) were found at notable concentrations. Inhalation exposure to select phthalate and non-phthalate plasticizers from the use of facemasks was estimated to range from 0.1 to 3.1 and 3.5 to 151 ng/kg-bw/d, respectively. To our knowledge, this is the first study to report the occurrence of phthalate and non-phthalate plasticizers in facemasks collected from the United States.

Graphical Abstract

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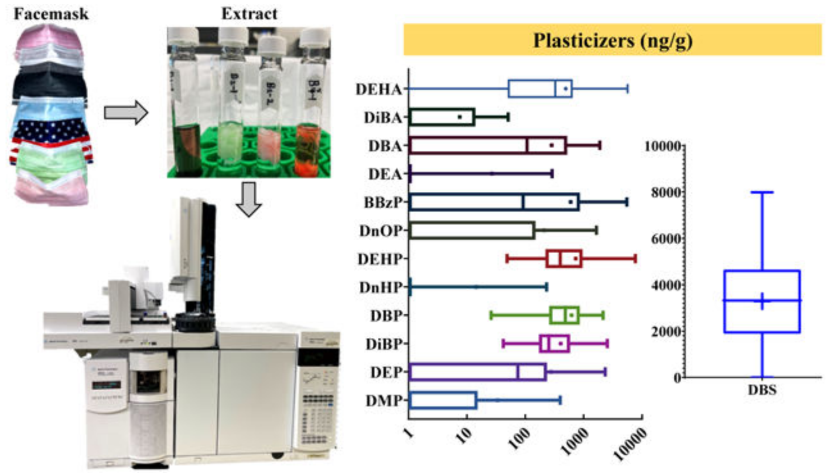
CRediT authorship contribution statement
Krishnamoorthi Vimalkumar: Data curation, Formal analysis, Writing - original draft. Hongkai Zhu: Formal analysis, Writing - review & editing. Kurunthachalam Kannan: Conceptualization, Funding acquisition, Supervision, Writing - review & editing

CRediT authorship contribution statement
Krishnamoorthi Vimalkumar: Methodology, Formal analysis, Data curation, Writing original draft
Hongkai Zhu: Methodology; Review of the Draft Manuscript
Kurunthachalam Kannan: Conceptualization, Funding acquisition, Supervision, Manuscript review.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



Keywords

Phthalates; Adipate; Facemask; Covid; Exposure assessment

1. Introduction

During the COVID-19 pandemic, the facemask has become an indispensable accessory worn by the public to reduce the spread of the virus. As the virus was known to spread through respiratory droplets of affected individuals, facemasks provided a barrier preventing these from reaching other people. National and international health organizations recommended the wearing of facemasks during the pandemic. This has resulted in an increased demand and production of facemasks since 2020 (Adyel, 2020), with an estimated over 129 billion facemasks consumed monthly worldwide in 2020 (Prata et al., 2020). Single-use facemasks generally comprise three layers: an inner layer (soft fibers), a middle layer (melt-blown filter), and an outer layer (water-resistant non-woven fibers). The majority are made from synthetic fabrics such as polypropylene (PP), polyurethane (PU), polyacrylonitrile (PA), polystyrene (PS), and polyethylene terephthalate or polyester (PE) (Hennebery, 2020; Prata et al., 2020). The occurrence of thousands of microplastics ≥1 μm in size and billions of nanoplastics <1 μm in size (per mask) has been reported in facemasks (Ma et al., 2021). Moreover, numerous additives, including plasticizers, are incorporated into synthetic polymers during production (Wiesinger et al., 2021). Facemasks are in direct contact with the respiratory system, and therefore humans may inhale volatile plasticizers from the use of these products. One study reported the occurrence of 13 phthalate diesters in facemasks using in situ desorption ionization mass spectrometry (Min et al., 2021), but that study focused primarily on the analytical approach, with little emphasis on exposure levels. Liu and Mabury (2021) reported the occurrence of synthetic antioxidants in facemasks at concentrations in the range of 20 –575 μg/g (median: 175 μg/g).

Besides phthalates, adipates, tributyl phosphate (TBP) and dibutyl sebacate (DBS), are used as plasticizers in synthetic polymers (EU, 2008; LCSP, 2011). Adipates (especially, di(2-ethylhexyl)adipate; DEHA) and DBS are used in soft plastics, especially food wraps and films. The occurrence of adipate esters at concentrations of a few thousand micrograms per gram in plastic food packaging materials (Balafas and shaw 1999), 0.51–880 μg/g in indoor dust (Subedi et al., 2017), and 34 ng/m^3 in indoor air (Fromme et al., 2016) has been reported. Studies have reported low toxicity of DBS in laboratory animals, with a no observed adverse effect level (NOAEL) of >1000 mg/kg for various toxic endpoints (CPSC, 2019). In contrast, DEHA-induced developmental toxicity has been observed in rats, and a NOAEL of 200 mg/kg has been proposed for this compound (Dalgaard et al., 2003).

In this study, we investigated the occurrence of nine phthalate diesters, four adipates, TBP, and DBS in 66 single-use facemasks marketed in the United States. The objectives of this study were to determine the occurrence, concentrations, and profiles of these plasticizer compounds and to estimate inhalation exposure doses to plasticizers from the use of disposable facemasks.

2. Materials and Methods

2.1. Standards and Reagents

Nine phthalate diester standards (purity ≥99%)), namely dimethyl phthalate (DMP), diethyl phthalate (DEP), dibutyl phthalate (DBP), di-*iso*-butyl phthalate (DiBP), butyl benzyl phthalate (BBzP), dicyclohexyl phthalate (DCHP), di-*n*-hexyl phthalate (DnHP), di(2-ethylhexyl)phthalate (DEHP), and di-*n*-octyl phthalate (DnOP), were purchased from AccuStandard Inc. (New Haven, CT, USA) and/or from C/D/N Isotopes (Pointe-Claire, Quebec, Canada). Four adipate ester standards (≥98%), namely diethyl adipate (DEA), dibutyl adipate (DBA), di-*iso*-butyl adipate (DiBA), and di(2-ethylhexyl) adipate (DEHA), as well as TBP and DBS, were purchased from Sigma Aldrich (St. Louis, MO, USA). Nine deuterated standards, d_4-DMP, d_4-DEP, d_4-DBP, d_4-DiBP, d_4-BBzP, d_4-DCHP, d_4-DnHP, d_4-DEHP, and d_4-DnOP were purchased from Sigma Aldrich (St. Louis, MO, USA). Hexane and dichloromethane (DCM) were of HPLC grade and purchased from J.T. Baker (Center Valley, PA, USA).

2.2. Sample Collection and Extraction

In total, 66 facemask samples representing 16 major brands were purchased from online retailers (such as Amazon.com) during March–April 2021. Some facemask samples were also purchased from local stores in New York City in March 2021. Facemask samples were grouped based on country of origin as being from China (CH; $n = 29$), the United States (USA; $n = 16$), Canada (CA; $n = 12$), or other countries (OC; $n = 9$). The majority of the facemasks were of dimensions 17.5 cm × 9.5 cm (pleated), and all brands were three-ply, non-surgical grade, and for use by adults except for one brand that was specifically marketed for children of ages 4–12 years (size: 14 cm × 7.5 cm). The cost of each facemask varied from US \$0.5 to US \$3. The labels on the boxes indicated that most brands were made of non-woven PP, PE, PET, and cotton, while some brands were labeled as containing a polyester/nylon spandex blend, especially in ear loops. Some brands did not list the polymer type used.

For analysis, each facemask (with all three layers) was cut into 1 cm^2 at the midsection, and 0.1 g of these were weighed into a 15-mL glass tube for each sample. Five milliliters of a hexane/DCM mixture (1:3 v/v) were added to the glass tube, followed by deuterated internal standards (50 ng each). The samples were ultrasonicated at 40 kHz for 30 min (Branson 3510 R-DTH, Branson Ultrasonics Corporation, Danbury, CT, USA) and then shaken in an orbital shaker at 250 strokes per minute for 40 min (Eberbach Corp., Ann Arbor, MI, USA). Samples were then centrifuged at 5000 rpm for 15 min (Eppendorf 5804, Hamburg, Germany). The solvent layer was transferred into another glass tube and the extraction was repeated. Ten milliliters of the extract were concentrated to 1 mL under a gentle nitrogen stream, and 250 μL of the extract was transferred into a gas chromatographic glass vial insert.

Contents of phthalates, adipates, DBS, and TBP were determined using an Agilent Technologies 7890A gas chromatograph (GC) coupled with an Agilent Technologies 5975C mass spectrometer (MS). An HP-5 fused-silica capillary column (Agilent; 30 m × 0.250 mm × 0.25 μm) was used for chromatographic separation of target chemicals. Further details of the instrument parameters are provided in Table S1 (Supporting Information).

2.3. Exposure Assessment

To assess inhalation exposure to plasticizers released from facemasks, three samples each from three randomly selected brands (total $n = 9$) were cut into equal halves; one half was analyzed without further treatment, and the other half was kept at 30 °C for 24 h (for degassing) in an oven (with a vent) and then analyzed (Supporting Information, Figure S1). A temperature of 30 °C was used for the degassing experiment to represent the temperature of inhaled/exhaled air. The difference in the concentrations measured in masks before and after degassing at 30 °C for 24 h represented the amount of plasticizers volatilized at that temperature, and we used that value to estimate inhalation exposure. For inhalation exposure assessment, we assumed that each mask was worn for 24-h.

The loss of analytes in the 24-h period was considered as the amount that would be inhaled by a person wearing the mask, and inhalation exposure was calculated by using the formula below:

$$\mathrm{IE} = \frac{[(C(\mathrm{BU}) - C(\mathrm{AU})) \times m]}{(\mathrm{BW} \times T)}$$

where IE is the inhalation exposure (in nanograms per kilogram body weight per day, ng/kg-bw/d); C(BU) is the concentration in facemask before degassing (ng/g); C(AU) is the concentration in facemask after degassing at 30 °C for 24 h (ng/g); m is the mass of masks in direct contact with human mouth and nose; BW is body weight (with mean body weights taken as 32 kg for 10-year-old children, 60 kg for 16-year-old teenagers, and 80 kg for adults of >21 years, from the U.S. EPA’s exposure factor handbook, (USEPA 2012)); and T is exposure duration (1 day).

2.4. Quality Assurance and Quality Control (QA/QC)

For each batch of 15 samples, two procedural blanks and two matrix spikes were analyzed. An 8-point calibration curve at concentrations ranging from 2 to 200 ng/ml for phthalates and a 7-point calibration curve (also 2–200 ng/ml) for adipates, DBS, and TBP with a correlation coefficient of >0.99 for each compound were used in the quantification. The mean recoveries of phthalates, adipates, DBS, and TBP spiked into facemask samples (at 100 ng/g; $n = 5$) were 91 ± 14%, 121 ± 23%, 78 ± 4.0%, and 114 ± 15%, respectively. For calculating the recoveries of adipates and DBS, corresponding internal standards of phthalates were used. Reported concentrations were corrected for the recoveries of internal standards. Limit of quantification (LOQ) values for phthalates, adipates, DBS, and TBP were in the range of 2–10 ng/g. Further details of recoveries, limit of detection (LOD), LOQ, and relative standard deviation (RSD) of replicate analysis of samples are provided in the supporting information (Tables S2 and S3), along with GC-MS chromatograms of standards and samples (Figures S2 and S3). Trace levels of DEP (0.29 ng/mL), DiBP (0.59 ng/mL), DBP (0.56 ng/mL), and DEHP (0.77 ng/mL) were found in procedural blanks, and the concentrations measured in samples were subtracted from the blank values. The sum concentrations of nine phthalate diesters and four adipates are presented as Σ_9 phthalates and Σ_4 adipates, respectively. The reported concentrations represent averages for all three layers of each mask.

2.5. Data Analysis

Data were acquired and quantified using GraphPad Prism version 8 and Microsoft Excel 2016. Concentrations below the LOD were assigned as zero and those below the LOQ were assigned a value of LOQ divided by the square root of 2, for statistical analysis. Differences in the concentrations of plasticizers in facemasks from various countries were examined by a non-parametric Kruskal-Wallis *H* test. Spearman's correlation analysis and principal component analysis (PCA) were performed for the concentrations of individual plasticizers measured in masks. The statistical significance was set at $p < 0.05$. All statistical analyses were performed using SPSS software (version 26.0, SPSS Inc).

3. Results and Discussion

3.1. Concentrations and Profiles of Phthalates, Adipates, DBS, and TBP

Among nine phthalate diesters measured, we found DiBP, DBP, and DEHP in all facemask samples at mean (± SD) concentrations of 405 ± 399, 620 ± 497, and 732 ± 1060 ng/g, respectively (Table 1). BBzP was found in 67% of the samples analyzed, at a mean concentration of 598 ± 1050 ng/g. DMP, DEP, DnHP, and DnOP were found at detection frequencies (DFs) of between 21% and 61% and mean concentrations of 34, 276, 14, and 210 ng/g, respectively. DCHP was not found in any samples. The major source of phthalates in facemasks was synthetic fabrics such as PE and PP. DBP and DiBP are used in the production of PP and PE (Bach et al., 2012). DEHP is a widely used plasticizer in polyvinyl chloride (PVC) and other plastics, and leaching of DEHP from polyethylene terephthalate (PET) bottles has been reported (Keresztes et al., 2013; Li et al., 2016). The presence of DEP, DBP, and DEHP in feminine hygiene products, including sanitary napkins, at concentrations of 205–11,200 ng/g has also been reported (Gao and Kannan 2020).

Phthalate concentrations measured in facemasks were lower than those found in sanitary napkins. Xie et al. (2022) reported the occurrence of phthalates in facemasks from China at concentrations in the range of 115–37,700 ng/g (median: 1950 ng/g), similar to those found in our study. Furthermore, DEHP, DBP, and DiBP were the major phthalates found in Chinese facemasks, as has been found in our study (Xie et al., 2022).

We also analyzed Σ_4 adipates, DBS, and TBP in facemask samples. We did not detect TBP in any samples. The overall mean (± SD) concentrations of DEA, DBA, DiBA, and DEHA were 26 ± 72, 288 ± 379, 8.0 ± 11, and 526 ± 800 ng/g, respectively, and their DFs were 14%, 65%, 42%, and 83%, respectively. Among all plasticizer chemicals analyzed, DBS was found at the highest mean concentration, 3350 ± 2130 ng/g. This is the first study to report adipates and DBS in facemasks. Due to increasing concern over endocrine-disrupting properties of phthalates, substitute plasticizers such as DBS are becoming more widely used in consumer products. DBS is a substitute for DBP, whereas DEHA is a substitute for DEHP (CPSC, 2019; USEPA, 2018). DBS is permitted as a plasticizer in food contact and pharmaceutical applications, and is listed on the U.S. EPA's Safer Choice program's "safer chemical"; U.S. production and usage of this plasticizer were between 250 and 500 tons per year in 2015 (USEPA, 2018).

The concentration ranges of each plasticizers measured in facemasks were grouped based on the country of origin (Table 2 and Table S4) into those from Canada ($n = 12$), the USA ($n = 16$), China ($n = 29$), and other countries ($n = 9$) (Figure 1). The overall mean concentrations of all three types of plasticizers (sum of phthalates, adipates, and DBS) in facemasks from China, the USA, Canada and other countries were 8180, 6660, 6150, and 4860 ng/g, respectively, but none of these differences in overall plasticizer concentration by country of origin was statistically significant. Nevertheless, there were some significant variations in the profiles of plasticizers found in facemasks between countries. Median concentrations of phthalate diesters in masks made in China (3470 ng/g) and Canada (3370 ng/g) were approximately twofold higher than those in masks made in other countries, including the USA (1830 ng/g; $p < 0.05$). Elevated concentrations of non-phthalate plasticizers were found in masks made in China (median: 4260 ng/g) and the USA (4050 ng/g) relative to those from other countries, including Canada (1860 ng/g; $p < 0.05$).

3.2. Correlation among Plasticizers

We performed Spearman rank correlation analysis to examine the relationship among plasticizers in facemasks (Table 3). Statistically significant correlations existed among individual phthalate or non-phthalate plasticizers. For instance, the concentrations of DBP, DiBP, and BBzP were significantly correlated (Spearman's $r = 0.253$–0.599, $p < 0.05$). Many commercial phthalate technical mixtures contain chemicals with different chain lengths, and the correlation among DBP, DiBP, and BBzP may imply similar origin. Among non-phthalate plasticizers, DiBA, DEHA, and DBS were significantly correlated with each other (Spearman's $r = 0.674$–0.748, $p < 0.01$). These results indicate that several plasticizers are used in combination. DiBP and DBP are considered specialty plasticizers, and are volatile, for use in PVC. They are often combined with other phthalates for use in products. A negative but weak correlation was found between some phthalate (DEP vs DEHP) and non-phthalate plasticizers (e.g., DBS vs DBP; DBS vs BBzP; DBS vs DiBP; DBP vs DiBA). This suggests that phthalates are being replaced with adipate and DBS plasticizers in consumer products (Ventrice et al., 2013).

To further investigate patterns of plasticizers in facemasks, we performed PCA on the concentrations of eight plasticizers with a DF of >50%. The first three principal components (PC1–PC3) with an eigenvalue >1 were extracted. PC1 explained 29.6% of the total variance, whereas PC2 and PC3 accounted for 21.1% and 17.5% of the total variance, respectively. BBzP clustered with three lower-molecular-weight phthalates (i.e., DEP, DiBP, and DBP), whereas DEHP clustered with three non-phthalate plasticizers (i.e., DBA, DEHA, and DBS) (Figure 2). Higher-molecular-weight phthalates (e.g., DEHP) have different usage patterns, and co-clustering of DEHP with adipates and DBS may indicate replacement of the former with the latter as plasticizers (Wang et al., 2019).

3.3. Inhalation Exposure

The concentrations of phthalates, adipates, and DBS decreased significantly following degassing of facemasks at 30 °C for 24 h. The mean reduction in total phthalate concentrations in the three brands of facemasks ranged from 6% (DBP) to 53% (BBzP); BBzP showed highest reduction among the five phthalates measured. The concentrations of adipates and DBS decreased by 23%–68% and 24%–63%, respectively (Table S5).

Mean inhalation exposures to phthalate and non-phthalate plasticizers from the use of facemasks were 0.11–3.1 ng/kg-bw/d and 3.5–151 ng/kg-bw/d, respectively (Table 4). The exposure doses of phthalates from the use of facemasks were two to three orders of magnitude lower than those reported from dietary sources (Wang et al., 2019). The inhalation exposure to non-phthalate plasticizers (maximum, 151 ng/kg-bw/d) was higher than that to phthalates (maximum, 3.1 ng/kg-bw/d), which could be explained by higher concentrations and greater degassing in facemasks. A dietary intake dose of 550 ng/kg-bw/d for DEHA was reported from Germany (Fromme et al., 2013), and inhalation exposure from facemasks was two orders of magnitude lower. A study from China that estimated daily intake of 11 phthalates from dermal exposure to facemasks reported values in the range of 3.71–639 ng/kg-bw/d (Xie et al., 2022), which were higher than those found in our study. However, that study addressed dermal exposure values and different body weights and exposure scenarios, whereas our study focused on inhalation exposures.

Little is known about the toxicity of non-phthalate plasticizers. A tolerable daily intake (TDI) of 0.3 mg/kg/d was established for DEHA by the Scientific Committee on Food in 2000 (Fromme et al., 2013). The inhalation exposures calculated for DEHA were three to five orders of magnitude lower than the TDI. Reference doses are available for phthalates (DEP 800, DBP 100, BBzP 200, and DEHP 20 μg/kg/d), and our inhalation exposure doses of select phthalates were three to five orders of magnitude lower than these values (USEPA, 2007a; USEPA, 2007b; USEPA, 2007c; USEPA, 2007d).

4. Conclusions

This is the first study to determine non-phthalate plasticizers in facemasks. DEHP, DBP, BBzP, and DEHA were found at mean concentrations >500 ng/g in facemasks, whereas DBS was the most predominant plasticizer, with a mean overall concentration of >3200 ng/g. Inhalation exposure from wearing facemasks were in the ranges of 0.11–3.1 ng/kg-bw/d for phthalates and 3.5–151 ng/kg-bw/d for non-phthalate plasticizers, which were several orders of magnitude lower than those reported for dietary exposures. Thus, our results suggest that facemasks are not a significant source of human exposure to phthalates, but exposure to non-phthalate plasticizers from facemasks is “notable”.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Research reported here was supported, in part, by the U.S. National Institute of Environmental Health Sciences (NIEHS) under award number U2CES026542. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIEHS.

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Highlights

- Nine phthalate and six non-phthalate plasticizers were measured in single use facemasks
- Plasticizers were found at hundreds to thousands of nanograms per gram mask
- Dibutyl sebacate was the major plasticizer found in facemasks
- Inhalation exposure to non-phthalate plasticizers from plasticizers is notable

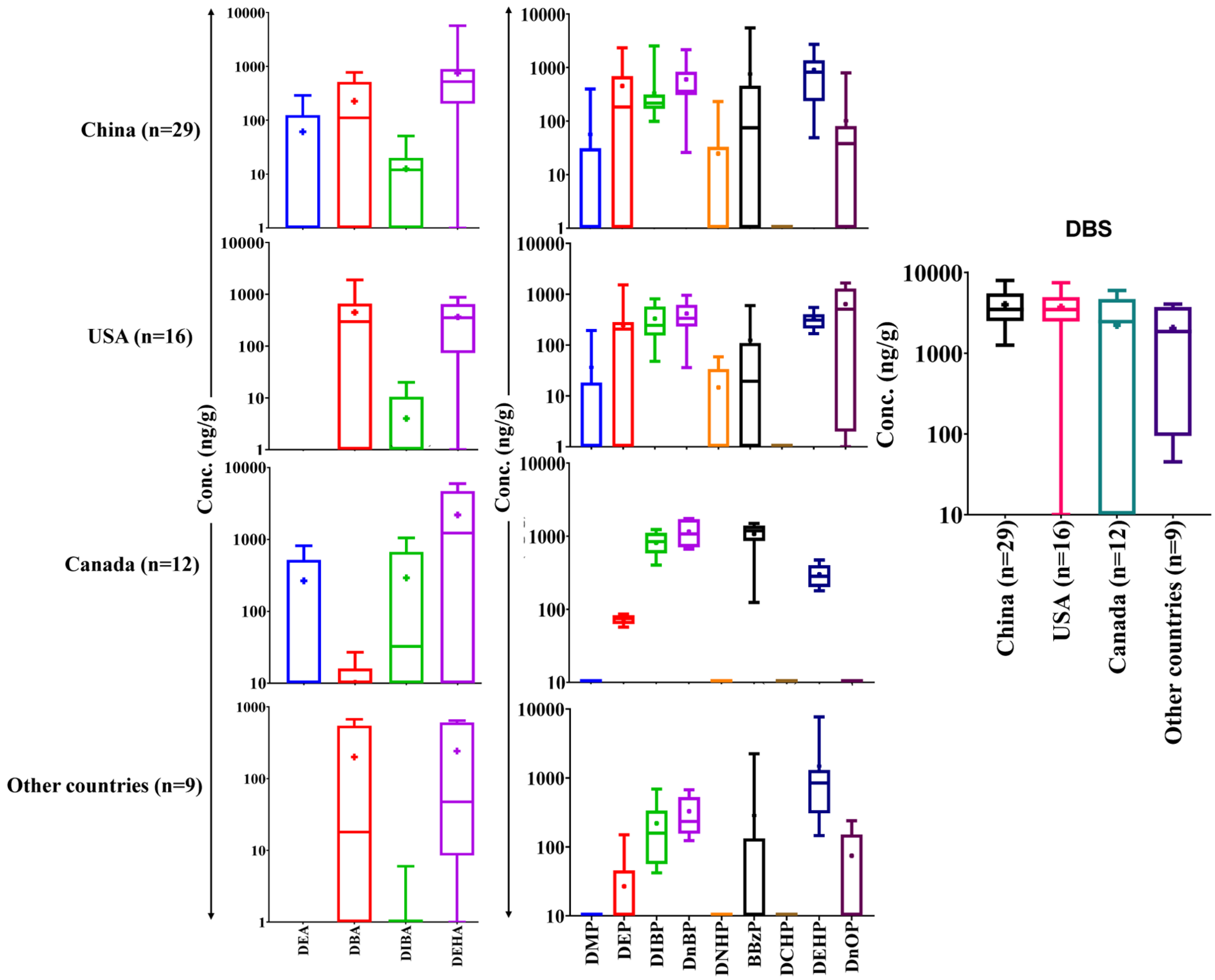

Figure 1.

Concentrations of adipates, phthalates diesters and dibutyl sebacate in facemasks stratified based on the country of origin: China, the USA, Canada and other countries.

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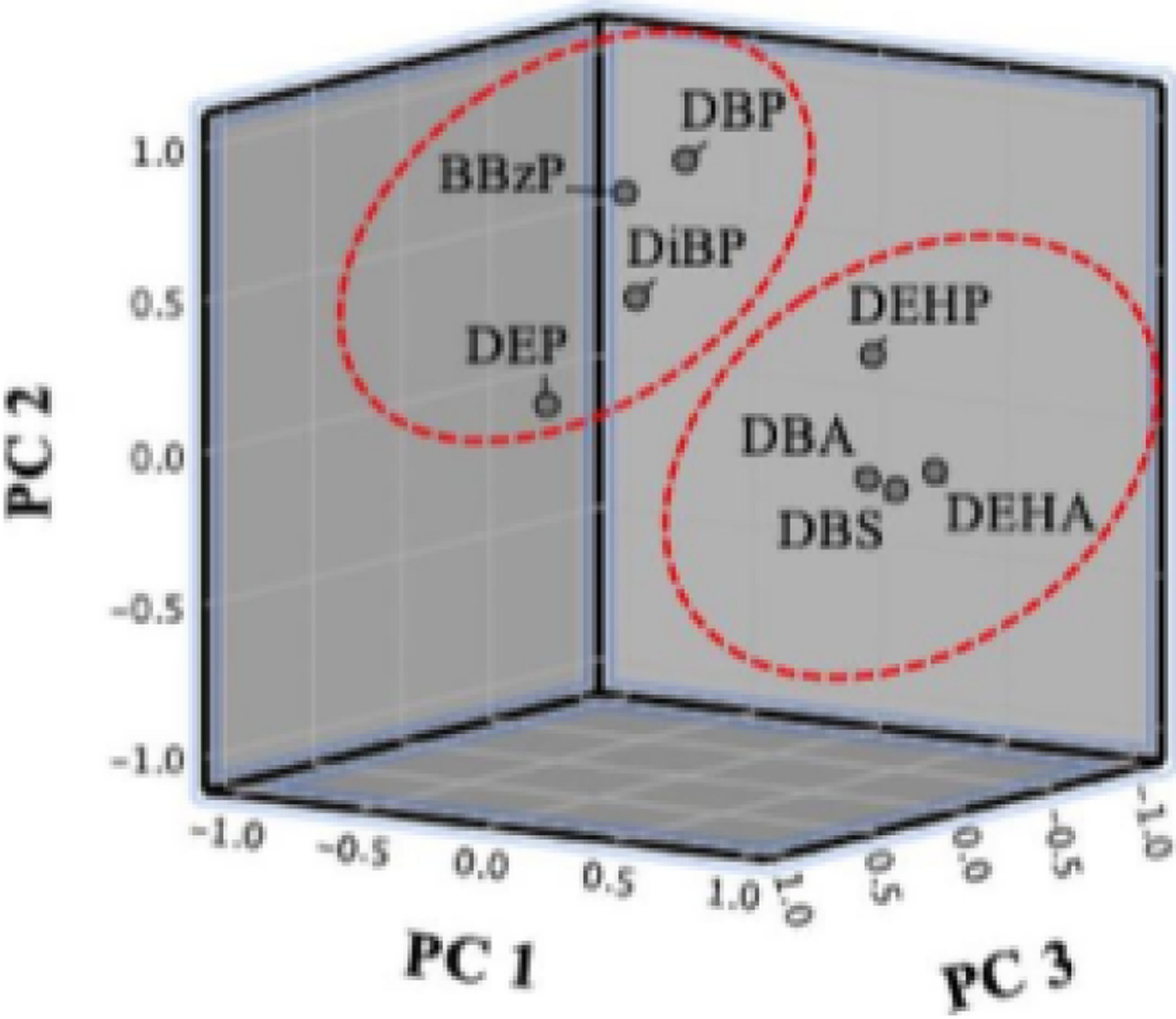

Figure 2.

Principal component analysis (PCA) of concentrations of plasticizers detected in >50% samples of facemasks.

Table 1.

Mean, range (minimum and maximum), median (ng/g), and detection frequency (%) of phthalates, adipates, dibutyl sebacate, and tributyl phosphate in facemasks collected in the USA (n=66).

Target chemicals (ng/g)	Acronym	Minimum	Maximum	Mean	SD	Median	Detection frequency %
Phthalates							
Dimethyl phthalate	DMP	3	398	34	84	<LOD	26
Diethyl phthalate	DEP	32	2340	276	520	75	61
Di-*iso*-butyl phthalate	DiBP	42	2530	405	399	254	100
Dibutyl phthalate	DBP	26	2010	620	497	486	100
Di-*n*-hexyl phthalate	DnHP	25	232	14	41	<LOD	21
Dicyclohexyl phthalate	DcHP	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Di(2-ethylhexyl) phthalate	DEHP	49	7670	732	1060	397	100
Di-*n*-octyl phthalate	DnOP	8	1660	210	426	<LOD	47
Butyl benzyl phthalate	BBzP	13	5500	598	1050	92	67
Σ_9 phthalates				2890	4080	1300	
Adipates							
Diethyl adipate	DEA	100	288	26	72	<LOD	14
Dibutyl adipate	DBA	6	1890	288	379	113	65
Di-*iso*-butyl adipate	DiBA	6	51	8	11	<LOD	42
Di(2-ethylhexyl) adipate	DEHA	28	5660	526	800	352	83
Σ_4 adipates				848	1260	465	
Tributyl phosphate	TBP	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dibutyl sebacate	DBS	45	7980	3350	2130	3390	92

ND, not detected;SD, standard deviation; <LOD, below the limit of detection.

Table 2.

Concentration ranges and median (ng/g) of phthalate diesters and non-phthalate plasticizers stratified based on country of origin and fabric types of facemasks

		Phthalaites								Adipates				
Country of origin	Content[a]	DMP	DEP	DiBP	DBP	DnHP	DEHP	DnOP	BBzP	DEA	DBA	DiBA	DEHA	DBS
Canada (*n* = 12)	Melt-blown PP	<LOD	57–86 (75)	403–1230 (844)	668–1750 (1080)	<LOD	179–472 (283)	<LOD	124–1500 (1190)	<LOD	<LOD–820 (383)	<LOD–27 (16)	<LOD–1050 (529)	<LOD–5980 (3490)
USA (*n* = 16)	PP, nylon, PE, PET, Spandex	<LOD–194 (91)	<LOD–1530 (282)	48–810 (245)	36–956 (337)	25–59 (39)	168–549 (310)	<LOD–1660 (976)	<LOD–−600 (109)	<LOD	<LOD–1892 (297)	<LOD–20 (14)	<LOD–873 (395)	<LOD–7870 (3480)
China (*n* = 29)	Fabric cotton, PP	<LOD–398 (99)	<LOD–2340 (309)	99–2530 (217)	26–2160 (358)	<LOD–232 (53)	49–2720 (821)	<LOD–795 (78)	<LOD–5500 (351)	<LOD–288 (191)	<LOD–769 (520)	<LOD–51 (17)	<LOD–5660 (620)	1260–7980 (4680)
Other countries (*n* = 9)	Cotton with PP fiber	<LOD	<LOD–150 (59)	42–691 (158)	123–674 (234)	<LOD	146–7670 (846)	<LOD–239 (151)	<LOD–2240 (132)	<LOD	<LOD–670 (538)	<LOD–6	<LOD–−642 (57)	45–4060 (1860)

ND, not detected; <LOD, less than limit of detection; PP, polypropylene; PE, polyethylene; PET, polyethylene terephthalate. Values are listed as range (median).

[a]Common material types. DCHP and TBP were not detected in any sample.

Table 3.

Spearman correlation coefficient (*r*) of concentrations of phthalates, adipates, and DBS in facemasks

		Phthalates					Adipates		
	Chemicals	**DEP**	**DiBP**	**DBP**	**DEHP**	**BBzP**	**DiBA**	**DEHA**	**DBS**
Phthalates	DEP	1							
	DiBP	0.253 *	1						
	DBP	0.120	0.483 **	1					
	DEHP	−0.335 **	0.011	0.132	1				
	BBzP	0.037	0.172	0.599 **	−0.039	1			
Adipates	DiBA	0.027	0.096	−0.135	0.038	−0.172	1		
	DEHA	0.002	−0.047	−0.125	0.165	−0.093	0.676 **	1	
	DBS	0.172	−0.017	−0.068	0	−0.148	0.674 **	0.748 **	1

* $p < 0.05$;

** $p < 0.01$.

Only plasticizers with detection frequency >50% were included in this analysis.

Table 4.

Mean inhalation exposure (IE, ng kg-bw/d) to phthalates and non-phthalates plasticizers through the use of facemasks by various age groups

IE (ng/kg-bw/d)									
	Phthalate diesters					**Non-phthalate plasticizers**			
	DEP	**DiBP**	**DBP**	**BBzP**	**DEHP**	**DEA**	**DiBA**	**DEHA**	**DBS**
Children	0.26	0.66	0.72	3.1	0.40	28	24	8.7	151
Teenagers	0.14	0.35	0.38	1.6	0.21	15	13	4.6	81
Adults	0.11	0.26	0.29	1.2	0.16	11	10	3.5	60