

## Electronic Supplementary Material

# Analytical methodology for unveiling human exposure to (micro)plastic additives

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## Supporting Tables

**Table S1.** List of plastic additives and plastic constituents, including conventional and alternative plasticizers, flame-retardants antioxidants and bisphenol compounds, along with their main phase-I metabolites included in this review (\* refers to metabolites not discussed in this review).

Phthalate Esters (PAEs)					
Parent		Primary Phase I metabolite		Secondary Phase I metabolite	
DMP	dimethyl phthalate	MMP	monomethyl phthalate	n.r. <sup>a</sup>	
DEP	diethyl phthalate	MEP	monoethyl phthalate	n.r. <sup>a</sup>	
DPrP	dipropyl phthalate	MnPrP	mono-n-propyl phthalate	MCCPP (cx-MPrP)	mono(3-carboxypropyl) phthalate
DiPrP	di-isopropyl phthalate	MiPP	mono-isopropyl phthalate	n.r. <sup>a</sup>	
DAP	diallyl phthalate	MAP*	monoallyl phthalate*	n.r. <sup>a</sup>	
DMEP	di(2-methoxyethyl) phthalate	MMEP*	monomethoxyethyl phthalate*	MAA*	methoxyacetic acid
DEEP	di(ethoxyethyl) phthalate	MEEP*	monoethoxyethyl phthalate*	n.r. <sup>a</sup>	
DnBP	di-n-butyl phthalate	MnBP	mono-n-butyl phthalate	3OH-MnBP	mono(3-hydroxybutyl) phthalate
				MCCPP	mono (3-carboxypropyl) phthalate
DiBP	di-isobutyl phthalate	MiBP	mono-isobutyl phthalate	2OH-MiBP	mono(2-hydroxy-isobutyl) phthalate
DnPeP	dipentyl phthalate	MnPeP (MPP)	mono-n-pentyl phthalate	cx-MPeP	mono(5-carboxypentyl) phthalate
				OH-MPeP	mono(4-hydroxypentyl) phthalate
DiPeP	di-isopentyl phthalate	MiPeP	mono-isopentyl phthalate	4OH-MiPeP	mono(4-hydroxy-isopentyl) phthalate
DBEP	di(2-butoxyethyl) phthalate	n.r. <sup>a</sup>		n.r. <sup>a</sup>	
BBzP	butyl benzyl phthalate	MBzP	monobenzyl phthalate	n.r. <sup>a</sup>	
DnHP	di-n-hexyl phthalate	MHxP	monohexyl phthalate	5OH-MHxP	mono(5-hydroxyhexyl) phthalate
DMPP	di(4-methyl-2-pentyl) phthalate	n.r. <sup>a</sup>		n.r. <sup>a</sup>	
DCHP	dicyclohexyl phthalate	MCHP	monocyclohexyl phthalate	n.r. <sup>a</sup>	
DEHP	di(2-ethylhexyl) phthalate	MEHP	mono(2-ethylhexyl) phthalate	cx-MEPP	mono(2-ethyl-5-carboxypentyl) phthalate
				MEHHP	mono(2-ethyl-5-hydroxyhexyl) phthalate
				MEOHP	mono(2-ethyl-5-oxohexyl) phthalate
				cx-MMHP	mono[(2-carboxymethyl)hexyl] phthalate
DPrHP	di(2-propylheptyl) phthalate	cx-MPHxP	mono(2-propyl-6-carboxyhexyl) phthalate	n.r. <sup>a</sup>	
DHPP	di-n-heptyl phthalate	MnHP	mono-n-heptyl phthalate	6OH-MnHP	mono(6-hydroxyheptyl) phthalate
DnOP	di-n-octyl phthalate	MnOP	mono-n-octyl phthalate	cx-MiOP	mono(carboxy-iso-octyl) phthalate
				MCCPP	mono(3-carboxypropyl) phthalate
DnNP	di-nonyl phthalate	MnNP	Mono-n-nonylphthalate	n.r. <sup>a</sup>	
DiNP	di-isononyl phthalate	MiNP	mono-isononyl phthalate	cx-MiNP	mono(carboxy-isononyl) phthalate
				OH-MiNP	mono(hydroxy-isononyl) phthalate
				oxo-MiNP	mono(oxo-isononyl) phthalate
nPiPP	n-pentyl-isopentyl phthalate	n.r. <sup>a</sup>		n.r. <sup>a</sup>	
DiDP	di-isodecyl phthalate	MiDP (MPHP)	mono-isodecyl phthalate	cx-MiDP	mono(carboxy-isodecyl) phthalate
				OH-MiDP	mono(hydroxy-isodecyl) phthalate
				oxo-MiDP	mono(oxo-isodecyl) phthalate

<sup>a</sup> Not reported.

**Table S1 (cont).** List of plastic additives and plastic constituents, including conventional and alternative plasticizers, flame-retardants antioxidants and bisphenol compounds, along with their main phase-I metabolites included in this review (\* refers to metabolites not discussed in this review).

Alternative plasticizers (APs)					
Parent		Primary Phase I metabolite		Secondary Phase I metabolite	
DMTP	dimethyl terephthalate	MMTP	monomethyl terephthalate	n.r. <sup>a</sup>	
DETP	diethyl terephthalate	METP	monoethyl terephthalate	n.r. <sup>a</sup>	
DTBTP	di-tert-butyl terephthalate	MTBTP	mono-tert-butyl terephthalate	n.r. <sup>a</sup>	
BBzTP	butyl benzyl terephthalate	MBzTP	monobenzyl terephthalate	n.r. <sup>a</sup>	
DEHTP	di(ethylhexyl) terephthalate	TPA	terephthalic acid	n.r. <sup>a</sup>	
		MEHTP	mono(2-ethylhexyl) terephthalate	2cx-MMHTP	mono-(2-carboxyl-methyl-hexyl) benzene-1,4-dicarboxylate
				5cx-MEPTP	mono(2-ethyl-5-carboxypentyl) terephthalate
				MEHHTP	mono(2-ethyl-5-hydroxyhexyl) terephthalate
MEOHTP	mono(2-ethyl-5-oxo-hexyl) terephthalate				
DINCH	di(isononyl)cyclohexane-1,2-dicarboxylate	MCOCH	cyclohexane-1,2-dicarboxylic acid monocarboxyisooctyl ester	n.r. <sup>a</sup>	
		MINCH	mono-isononyl-cyclohexane-1,2-dicarboxylate	cx-MINCH	Mono-(7-carboxy-4-methyl-octyl) cyclohexane-1,2-dicarboxylate
				OH-MINCH	Mono-(4-methyl-7-hydroxy-octyl) cyclohexane-1,2-dicarboxylate
oxo-MINCH	Mono-(4-methyl-7-oxo-octyl) cyclohexane-1,2-dicarboxylate				
DEHA	di(2-ethylhexyl) adipate	MEPA	mono(2-ethylhexyl) adipate	5cx-MEPA	mono(5-carboxy-2-ethylpentyl) adipate
		MEHA	mono(2-ethylhexyl) adipate	5OH-MEHA	mono(2-ethyl-5-hydroxyhexyl) adipate
				5oxo-MEHA	mono(2-ethyl-5-oxohexyl) adipate
TOTM (TEHTM)	tri(2-ethylhexyl) trimellitate	1-MEHTM	1-mono-(2-ethylhexyl) trimellitate	5cx-1-MEPTM	1-mono(2-ethyl-5-carboxypentyl) trimellitate
				5OH-1-MEHTM	1-mono(2-ethyl-5-hydroxyhexyl) trimellitate
				5oxo-1-MEHTM	1-mono(2-ethyl-5-oxohexyl) trimellitate
		2-MEHTM	2-mono-(2-ethylhexyl) trimellitate	5cx-2-MEPTM	2-mono(2-ethyl-5-carboxypentyl) trimellitate
				5OH-2-MEHTM	2-mono(2-ethyl-5-hydroxyhexyl) trimellitate
				5oxo-2-MEHTM	2-mono(2-ethyl-5-oxohexyl) trimellitate
4-MEHTM	4-mono-(2-ethylhexyl) trimellitate	n.r. <sup>a</sup>			
DiPGDB	dipropylene glycol dibenzoate	DiPGDB-M194	3-(3-hydroxypropoxy)propyl benzoate	n.r. <sup>a</sup>	
ATBC	Acetyl tributyl citrate	ADBC*	acetyl dibutyl citrate*	AMBC*	acetyl monobutyl citrate*
				DBC*	dibutyl citrate*

<sup>a</sup> Not reported.

**Table S1 (cont).** List of plastic additives and plastic constituents, including conventional and alternative plasticizers, flame-retardants antioxidants and bisphenol compounds, along with their main phase-I metabolites included in this review (\* refers to metabolites not discussed in this review).

<b>Organophosphate Flame Retardants (OPFRs)</b>					
<b>Parent</b>		<b>Primary Phase I metabolite</b>		<b>Secondary Phase I metabolite</b>	
TMP	trimethyl phosphate	DMP	dimethyl phosphate	n.r. <sup>a</sup>	
TEP	triethyl phosphate	DEP	diethyl phosphate	n.r. <sup>a</sup>	
TPrP	tripropyl phosphate	DPrP	dipropyl phosphate	n.r. <sup>a</sup>	
TnBP	tri-n-butyl phosphate	DBP	di-n-butyl phosphate	n.r. <sup>a</sup>	
		3OH-TNBP	di-n-butyl-3-hydroxybutyl phosphate	n.r. <sup>a</sup>	
TiBP	tri-iso-butyl phosphate	DIBP	diisobutyl phosphate	n.r. <sup>a</sup>	
TBzP	tribenzyl phosphate	DBzP	dibenzyl phosphate	n.r. <sup>a</sup>	
TCP	tricresyl phosphate	DoCP	di-o-cresyl phosphate	n.r. <sup>a</sup>	
		BMPP	di(2-methylhexyl) phosphate	n.r. <sup>a</sup>	
		DpCP	di-p-cresyl phosphate	n.r. <sup>a</sup>	
TPHP	triphenyl phosphate	MPHP	Monophenyl phosphate	n.r. <sup>a</sup>	
		DPHP	diphenyl phosphate	3OH-DPHP	3-hydroxyphenyl phenyl phosphate
				4OH-DPHP	4-hydroxyphenyl phenyl phosphate
		3OH-TPHP	3-hydroxyphenyl diphenyl phosphate	n.r. <sup>a</sup>	
4OH-TPHP	4-hydroxyphenyl diphenyl phosphate	n.r. <sup>a</sup>			
TPPO	triphenylphosphine oxide	n.r. <sup>a</sup>		n.r. <sup>a</sup>	
TMPP	trimethylpropane phosphite	n.r. <sup>a</sup>		n.r. <sup>a</sup>	
TEHP	tri(2-ethylhexyl) phosphate	BEHP	di(2-ethylhexyl) phosphate	n.r. <sup>a</sup>	
TBOEP	tri(2-butoxyethyl) phosphate	BBOEP	di(2-butoxyethyl) phosphate	n.r. <sup>a</sup>	
		BBOEHEP	di(2-butoxyethyl) 2-hydroxyethyl phosphate	n.r. <sup>a</sup>	
		3OH-TBOEP	di(2-butoxyethyl) 3-hydroxy-2-butoxyethyl phosphate	n.r. <sup>a</sup>	
TIPPP	tri(isopropylphenyl) phosphate	IPPPP	isopropylphenyl phenyl phosphate	n.r. <sup>a</sup>	
EHDHP	2-ethylhexyldiphenyl phosphate	EHPHP	2-ethylhexyl phenyl phosphate	n.r. <sup>a</sup>	
		5OH-EHDHP	2-ethyl-5-hydroxyhexyl diphenyl phosphate	n.r. <sup>a</sup>	
TCIEP	tri(2-chloroethyl) phosphate	BCIEP	di(2-chloroethyl) phosphate	n.r. <sup>a</sup>	
TCIPP	tri(1-chloro-2-propyl) phosphate	BCIPP	di(1-chloro-2-propyl) phosphate	n.r. <sup>a</sup>	
TDCIPP	tri(1,3-dichloro-2-propyl) phosphate	BDCIPP	di(1,3-dichloro-2-propyl) phosphate	n.r. <sup>a</sup>	
TCIPP	tri(2-chloroisopropyl) phosphate	BCIPP	di(2-chloropropyl) hydrogen phosphate	n.r. <sup>a</sup>	
		BCIPHIPP	di(1-chloro-2-propyl) 1-hydroxy-2-propyl phosphate	n.r. <sup>a</sup>	
TBP	tri(2,3-dibromopropyl) phosphate	BDBPP	di(2,3-dibromopropyl) phosphate	n.r. <sup>a</sup>	
TBB	2-ethylhexyl-2,3,4,5-tetrabromobenzoate	TBBA	2,3,4,5-tetrabromobenzoic acid	n.r. <sup>a</sup>	
BDMEPPP	bis(tert-butylphenyl) phenylphosphate	tBPPP	tert-butylphenyl phenyl phosphate	n.r. <sup>a</sup>	
<b>Other Flame Retardants (FRs)</b>					
		n.r. <sup>a</sup>		n.r. <sup>a</sup>	
TBBPA	tetrabromobisphenol	2,4-DBP	2,4-dibromophenol	n.r. <sup>a</sup>	
HBCD	hexabromocyclodecane	OH-HBCD*	monohydroxy-hexabromocyclodecane*	n.r. <sup>a</sup>	

<sup>a</sup> Not reported.

**Table S1 (cont).** List of plastic additives and plastic constituents, including conventional and alternative plasticizers, flame-retardants antioxidants and bisphenol compounds, along with their main phase-I metabolites included in this review (\* refers to metabolites not discussed in this review).

<b>Synthetic antioxidants compounds (SAs)</b>			
<b>Parent</b>		<b>Primary Phase I metabolite</b>	
BHT	2,6-di-tert-butyl-4-methylphenol	BHT-OH	2,6-di-tert-butyl-4-(hydroxymethyl)phenol
		BHT-CHO	3,5-di-tert-butyl-4-hydroxybenzaldehyde
		BHT-COOH	3,5-di-tert-butyl-4-hydroxybenzoic acid
		BHT-Q	2,6-di-tert-butylcyclohexa-2,5-diene-1,4-dione
		BHT-quinol	3,5-di-tert-butyl-4-hydroxy-4-hydroxy-4-methyl-2,5-cyclohexadione
2-BHA <sup>a</sup>	2-tert-butyl-4-hydroxyanisole	2-BHA <sup>a</sup>	2-tert-butyl-4-hydroxyanisole
3-BHA <sup>a</sup>	3-tert-butyl-4-hydroxyanisole	3-BHA <sup>a</sup>	3-tert-butyl-4-hydroxyanisole
6PDD	N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine	6PDD-Q	6PDD-Quinone
<b>Bisphenols</b>			
BPA	Bisphenol A	n.r. <sup>b</sup>	
BPC	Bisphenol C	n.r. <sup>b</sup>	
BPF	Bisphenol F	n.r. <sup>b</sup>	
BPG	Bisphenol G	n.r. <sup>b</sup>	
BPS	Bisphenol S	n.r. <sup>b</sup>	
BPAF	Bisphenol AF	n.r. <sup>b</sup>	

<sup>a</sup> Isomers.

<sup>b</sup> Not reported.

**Table S2.** Human oral bioaccessibility data of plastic additives using different *in-vitro* physiologically based extraction tests. (See Table S1 for the full names of the compounds).

Oral bioaccessibility												
References	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
PBET methods	Fasted (mod. Ruby, 1996) <sup>b</sup>	Fasted (mod. Ruby, 1996) <sup>b</sup>	Fasted (CE-mod. Ruby, 1996) <sup>b</sup>	Fasted (Ruby, 1996) <sup>b</sup>	Fasted (Ruby, 1996) <sup>b</sup>	Fasted (Ruby, 1996) <sup>b</sup>	Fasted (UBM)	Fasted (UBM)	Fed (RIVM method)	Fasted (UBM) and fed (RIVM) methods	Fasted (UBM) and fed (RIVM) methods	Fasted (UBM) and fed (FOREhST) methods
Plastic additives	% Bioaccessibility											
<b>DMP</b>	32	17-27		73-94		60-80	70-72			81-87	55-83	
<b>DEP</b>	25	17-27				50-75	56-74			84-87	40-68	
<b>DnBP</b>	15			1-5		45-50	18-27	80-100			12-32	
<b>BzBP</b>	13	2-13		2-10		40-55	12-16	60-80			5-28	
<b>DEHP</b>	10	2-13		1-5		20-40	<LOQ <sup>a</sup>	30-40			5-32	
<b>DnOP</b>	14	2-13				30-50	<LOQ <sup>a</sup>	20-30			6-25	
<b>DiNP</b>		2-13				30-50					2-22	
<b>BPA</b>							30-43		80-99	48-51	37-67	
<b>TCEP</b>				53-57	50-80							71-98
<b>TCIPP</b>			53-94	50-57	41-82							16-52
<b>TDCIPP</b>			48-99	15-27	9-57							<LOQ <sup>a</sup>
<b>TPP</b>				7-8	5-24							
<b>TPhP</b>			61-95									

<sup>a</sup> Limit of quantification.

<sup>b</sup> Ruby, M. V., Davis, A., Schoof, R., Eberle, S., and Sellstone, C. M. 1996. Estimation of lead and arsenic bioavailability using a physiologically based extraction test. *Environ. Sci. Technol.* 30:422–430.

**Table S3.** Overview of the main metabolites of plastic-related chemicals and their respective 24-hour excretion rates.

Parent	Metabolite	Average percentage of excretion (24 h) <sup>a,b</sup>	References
Dimethyl phthalate (DMP)	Monomethyl phthalate (MMP)	69	[13] <sup>a</sup>
Diethyl phthalate (DEP)	Monoethyl phthalate (MEP)	69	
Di- <i>isobutyl</i> phthalate (DiBP)	Mono- <i>isobutyl</i> phthalate (MiBP)	71	
Di- <i>n-butyl</i> phthalate (DnBP)	Mono- <i>n-butyl</i> phthalate (MnBP)	63	
Butyl benzyl phthalate (BBzP)	Monobenzyl phthalate (MBzP)	73	
Di(2-ethylhexyl) phthalate (DEHP)	Mono(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP)	16	
	Mono(2-ethyl-oxohexyl) phthalate (MEOHP)	11	
	Mono(2-ethyl-5-carboxypentyl) phthalate (cx-MEPTP)	14	
Di- <i>isononyl</i> phthalate (DiNP)	Mono(hydroxy- <i>isononyl</i> ) phthalate (MHINP)	20.2	[14]
	Mono(oxo- <i>isononyl</i> ) phthalate (oxo-MiNP)	10.6	
	Mono(carboxy- <i>isononyl</i> ) phthalate (cx-MiNP)	10.7	
Di- <i>isodecyl</i> phthalate (DiDP)	Mono(carboxy- <i>isodecyl</i> ) phthalate (cx-MiDP)	10.7	
Di(2-ethylhexyl) terephthalate (DEHTP)	Mono(2-ethyl-5-hydroxyhexyl) terephthalate (MEHHTP)	1.8	[15]
	Mono(2-ethyl-5-oxohexyl) terephthalate (MEOHTP)	1.0	
	Mono(2-ethyl-5-carboxypentyl) terephthalate (cx-MEPTP)	13	
Di( <i>isononyl</i> )cyclohexane-1,2-dicarboxylate (DINCH)	Mono- <i>isononyl</i> -cyclohexane-1,2-dicarboxylate (MINCH)	0.65	[15]
	Mono-(7-carboxy-4-methyl-octyl) cyclohexane-1,2-dicarboxylate (cx-MINCH)	1.67	
	Mono-(4-methyl-7-hydroxy-octyl) cyclohexane-1,2-dicarboxylate (OH-MINCH)	9.55	
	Mono-(4-methyl-7-oxo-octyl) cyclohexane-1,2-dicarboxylate (oxo-MINCH)	1.85	
Bisphenol A (BPA)	Bisphenol A Monosulfate (BPA-S)	3 / 12	[16,17]
	Bisphenol A $\beta$ -D-Glucuronide (BPA-G)	87 / 64	
Bisphenol S (BPS)	Bisphenol S $\beta$ -D-Glucuronide (BPS-G)	54	[18]
Tri(2-butoxyethyl) phosphate (TBOEP)	Di(2-butoxyethyl) phosphate (BBOEP)	0.75	[18]
	Di(2-butoxyethyl) 3-hydroxy-2-butoxyethyl phosphate (OH-TBOEP)	0.02	
	Di(2-butoxyethyl) 2-hydroxyethyl phosphate (BBOEHEP)	5.77	

<sup>a</sup> Obtained from curated metastudies, whenever possible.

<sup>b</sup> Average corresponding to the sum of the excretion of the phase I metabolite and its phase II conjugate after being enzymatically deconjugated, except for BPA and BPS, which correspond to phase-II metabolites.

**Table S4.** Concentration levels of plasticizers, bisphenols, flame retardants and antioxidants in human biomonitoring approaches as applied to urine, breast milk and plasma (2019-2023). (See Table S1 for the full names of compounds, the “m” refers to “metabolite of”)

Compound Family	N° compounds	Region/ Country	Matrix	N° Samples	Studied population	Concentration range per family (ng/mL)	Analyte found at highest concentration	Ref.
<i>Plasticizers</i>								
PAEs, mPAEs, APs and mAPs	50	Guangzhou, China	Breast milk	64	Breast-feeding women	PAEs: 2.12-34.1 (range)	DEHP	[19]
						mPAEs: 4.41-138 (range)	MnBP	
						APs 0.252-16.1 (range)	DEHTP	
						mAPs: 0.02-5.52 (range)	MEHTP	
mPAEs and mAPs	40	Copenhagen, Denmark	Urine	300	Young Danish men (18-30 years, 2009-2017)	mPAEs: <LOD-6255 (max) or <LOD-85 (median) or <LOD-233 (75% P.) or <LOD-1565 (95% P.) (osmolality adjusted)	MEP	[20]
						mAPs: 0.8-908 (max) or <LOD-3.79 (median) or <LOD-9.53 (75% P.) or <LOD-42.5 (95% P.) (osmolality adjusted)	5cx-MEPTP and OH-MINCH	
mPAEs and mAPs	17	Copenhagen, Denmark	Urine	349	Danish newborns and their parents (Infants, n = 144; mothers n = 127; fathers n = 118)	Infants: mPAEs: <LOD-381; mAPs: <LOD-583 (ranges, osmolality adjusted)	MEP and $\sum$ mDINCH (molar sum of OH-MiNCH and cx-MiNCH expressed as DINCH)	[21]
						Mothers: mPAEs: <LOD-1022; mAPs: <LOD-440 (ranges, osmolality adjusted)	$\sum$ mDiNP (molar sum of MiNP, OH-MiNP, oxo-MiNP and cx-MiOP expressed as DiNP) and $\sum$ mDEHTP (molar sum of MEHHTP, MEOHTP, 5cx-MEPTP and 2cx-MMHTP expressed as DEHTP)	
						Fathers: mPAEs: <LOD-1162(Range); mAPs: 0.19-334 (ranges, osmolality adjusted)		
mPAEs	11	Norway	Urine	254	General population (2016-2017)	n.r. <sup>a</sup>	Dibutyl phthalate metabolites (mDBPs)	[22]
mAPs (mDINCH)	3	Germany	Urine	300	Young adults (2000-2017)	<0.05-72.4 (range, creatinine adjusted, ng/mL)	OH-MINCH	[23]
mPAEs	6	Crete, Greece	Urine	100	Pregnant women (22-44 years)	4.9-2256.6 (range, unadjusted)	MiBP	[24]
mPAEs and mAPs (mDINCH)	23	Korea and Thailand	Urine	183	Pregnant women (<14 weeks of gestation)	Korea: mPAEs (2.0-18.3); mDINCH (0.3-0.6) (GM <sup>b</sup> for mPAEs and 75% P. for mDINCH, SG adjusted <sup>c</sup> )	cx-MEPP, MEP and OH-MINCH	[25]
						Thailand: mPAEs (1.2-33); mDINCH (0.5) (GM for mPAEs and 75% P. for mDINCH, SG adjusted <sup>c</sup> )		
mPAEs	19	Riyadh, Saudi Arabia	Urine	109	Children (3-9 years)	0.8-277.5 (GM <sup>b</sup> , unadjusted)	MEP	[26]

<sup>a</sup> Not reported; <sup>b</sup> Geometric mean; <sup>c</sup> Specific gravity adjusted.

**Table S4 (cont.).** Concentration levels of plasticizers, bisphenols, flame retardants and antioxidants in human biomonitoring approaches as applied to urine, breast milk and plasma (2019-2023). (See Table S1 for the full names of compounds, the “m” refers to “metabolite of”)

Compound Family	N° compounds	Region/Country	Matrix	N° Samples	Studied population	Concentration range per family (ng/mL)	Analyte found at highest concentration	References
<i>Plasticizers</i>								
mPAEs and mAPs	32	Indonesia, Saudi Arabia and Thailand	Urine	302	Children (3-11 years)	Indonesia: mPAEs (<LOQ-77.8); mAPs (<LOQ-3.6) (GM <sup>b</sup> , unadjusted) Saudi Arabia: mPAEs (1.2-270.5); mAPs (<LOQ-139.6) (GM <sup>b</sup> , unadjusted) Thailand: mPAEs (<LOQ-43.6); mAPs (<LOQ-8) (GM <sup>b</sup> , unadjusted)	5cx-MEPP and 5cx-MEPTP MEP and 5cx-MEPTP MnBP and 5cx-MEPTP	[27]
mPAEs	11	Senzhen, China	Urine	309	Waste incineration plant workers (cases, n = 104) and general population 8 km away from the incinerator plant (controls, n = 205)	Cases: 217-3480 (range, unadjusted) Controls: n.d.-1850 (range, unadjusted)	MEP and MnBP MnBP	[28]
mPAEs	18	Kyoto, Japan	Urine	132	General population (1993-2016)	<LOD-2508 (range, creatinine adjusted, µg/g)	MEP	[29]
mPAEs	16	Aichi Region, Japan	Urine	1023	Toddlers (1.5-year-old)	41-34696 nmol/L (range) or 496 nmol/L (GM <sup>b</sup> ) (unadjusted)	cx-MEPP	[30]
mPAEs and mAPs	19	Illinois, USA	Urine	482	Pregnant women (18-40 years, 2013-2018)	mPAEs: 0.7-25 (median) or 0.4-12.6 (25% P.) or 1.5-46.5 (75% P.) (unadjusted) mAPs: 9.2-69.2 (median) or 4.0-24.7 (25% P.) or 20.7-146 (75% P.) (unadjusted)	MEP cx-MEPTP	[31]
mPAEs and mAPs (mDINCH)	10	Liege, Belgium	Urine	251	General population (2015 and 2018)	mPAEs: <LOQ-21.25 (median) or 1.10-62.85 (75% P.) or 2.4-689.67 (95% P.) (unadjusted) mAPs: <LOQ (median) or <LOQ-4.76 (75% P.) or 9.13-35.99 (95% P.) (unadjusted)	MEP OH-MINCH	[32]
mPAEs	16	Jalisco, Mexico	Urine	90	Pregnant women (< 20 weeks of gestation)	<LOD- 1830 (range, unadjusted) or 0.3 - 55.8 (GM <sup>b</sup> , unadjusted) or 2.1 - 48.6 (median, unadjusted) or 1.7-55.8 (GM <sup>b</sup> , creatinine adjusted, µg/g)	MEP	[33]
mPAEs	21	Germany	Urine	2256	Children and teenagers (2014-2017)	0.6 - 27.0 (range) or 0.6 - 26.1 (GM <sup>b</sup> ) (Unadjusted)	MiBP	[34]

<sup>b</sup> Geometric mean; <sup>c</sup> Specific gravity adjusted.

**Table S4 (cont.).** Concentration levels of plasticizers, bisphenols, flame retardants and antioxidants in human biomonitoring approaches as applied to urine, breast milk and plasma (2019-2023). (See Table S1 for the full names of compounds, the “m” refers to “metabolite of”)

Compound Family		N° compounds	Region/Country	Matrix	N° Samples	Studied population	Concentration range per family (ng/mL)	Analyte found at highest concentration	References
<i>Plasticizers</i>									
mPAEs and mAPs (mDINCH)	and	15	Sweden	Urine	206	Preschool children	mPAEs: <LOD-1700 (range) or 1.5-69 (median) or 0.85-56 (GM <sup>b</sup> ) (SG adjusted <sup>c</sup> ) mAPs: 0.24-130 (range) or 1.7 (median) or 2.0 (GM <sup>b</sup> ) (SG adjusted <sup>c</sup> )	MEP oxo-MINCH	[35]
mPAEs and mAPs (mDINCH)	and	17	South Moravian region, Czech Republic	Urine	600	Teenagers (12-17 years, n = 300) and young adults (18-37 years, n = 300)	Teenagers: mPAEs (0.03-704, range) or (0.14-45.5, median) or (0.15-42.2, GM <sup>b</sup> ); mAPs (0.10-494, range) or (0.76-1.71, median) or (0.80-1.76, GM <sup>b</sup> ) (SG adjusted <sup>c</sup> ) Young adults: mPAEs (0.02-1649, range) or (0.10-60.6, median) or (0.18-64.0, GM <sup>b</sup> ); mAPs (0.25-952, range) or (0.25-1.34, median) or (0.74-1.67, GM <sup>b</sup> ) (SG adjusted <sup>c</sup> )	MEP and OH-MINCH OH-MiNP and OH-MINCH	[36]
mPAEs and mAPs (mDINCH)	and	22	Prague, Czech Republic	Urine	630	Mothers (n = 315) and newborns (n = 315) (2016-2017)	Mothers: mPAEs (<LOQ-1602, range) or (<LOQ-22.9, median); mAPs: (<LOQ-142.48, range) or (<LOQ-0.08, median) (unadjusted) Newborns: mPAEs (<LOQ-550, range) or (<LOQ-21.55, median); mAPs: (<LOQ-33.41, range) or (<LOQ-0.08, median) (unadjusted)	MEP and OH-MINCH MnBP and OH-MINCH	[37]
mPAEs and mAPs	and	26	Puerto Rico and USA	Urine	171	Pregnant women (ca. 29.5 years, 2017-2022)	mPAEs: <LOD-24 (GM <sup>b</sup> ) or <LOD-10 (25% P.) or <LOD-58 (75% P.) (creatinine adjusted, ng/mL) mAPs: <LOD-0.28 (GM <sup>b</sup> ) or <LOD-0.056 (25% P.) or <LOD-0.9 (75% P.) (creatinine adjusted, ng/mL)	MEP OH-MINCH	[38]

<sup>b</sup> Geometric mean; <sup>c</sup> Specific gravity adjusted.

**Table S4 (cont.).** Concentration levels of plasticizers, bisphenols, flame retardants and antioxidants in human biomonitoring approaches as applied to urine, breast milk and plasma (2019-2023). (See Table S1 for the full names of compounds, the “m” refers to “metabolite of”)

Compound Family	N° compounds	Region/Country	Matrix	N° Samples	Studied population	Concentration range per family (ng/mL)	Analyte found at highest concentration	References
<i>Plasticizers</i>								
mPAEs and mAPs (mDINCH)	15	Oslo and Akershus regions, Norway	Urine	144	Employees from governmental institutes and authorities, and universities (44 males between 25–72 years and 100 females between 24–72 years)	mPAEs: <LOD-1588 (range) or 0.36-12.41 (GM <sup>b</sup> ) (SG adjusted <sup>c</sup> ) mAPs: <LOD-18.55 (range) or 0.49-0.52 (GM <sup>b</sup> ) (SG adjusted <sup>c</sup> )	MEP and OH-MINCH	[39]
PAEs and mPAEs	4	Austria	Plasma	21	Premature infants (gestational age <28 weeks, birth weight <1 kg)	PAEs: <0.66-100 (range) mPAEs 0.062-75 (range)	DnBP MEHP	[40]
mPAEs	4	Austria	Breast milk	86	Breast-feeding women (<211 days post-partum)	<0.16-6.4 (range)	MnBP	[40]
mAPs (mTOTM)	6	Germany	Urine	431	Population-representative German Environmental Survey on Children and Adolescents (3-17 years, 2014–2017)	<LOQ-3.99 (range, unadjusted)	2-MEHTM	[41]

<sup>b</sup> Geometric mean; <sup>c</sup> Specific gravity adjusted.

**Table S4 (cont.).** Concentration levels of plasticizers, bisphenols, flame retardants and antioxidants in human biomonitoring approaches as applied to urine, breast milk and plasma (2019-2023). (See Table S1 for the full names of compounds, the “m” refers to “metabolite of”)

Compound Family	N° compounds	Region/Country	Matrix	N° Samples	Studied population	Concentration range per family (ng/mL)	Analyte found at highest concentration	References
<i>Bisphenols</i>								
BPA and replacements	7	Copenhagen, Denmark	Urine	300	Young Danish men (18-30 years, 2009-2017)	0.06-371 (max) or <LOD-2.27 (median) or <LOD-3.78 (75% P.) or <LOD-24.2 (95% P.) (osmolality adjusted)	BPC and BPG	[20]
BPA and replacements	7	Senzhen, China	Urine	309	Waste incineration plant workers (cases, n = 104) and general population 8 km away from the incinerator plant (controls, n = 205)	Cases: 0.86-75.7 (range, unadjusted) Controls: <LOD-45.3 (range, unadjusted)	BPA	[28]
BPA and replacements	5	Liege, Belgium	Urine	251	General population (2015 and 2018)	<LOQ-0.82 (median) or <LOQ-1.58 (75% P.) or <LOQ-7.96 (95% P.) (unadjusted)	BPA	[32]
BPA and replacements	6	Puerto Rico and USA	Urine	171	Pregnant women (2017-2022, ca. 29.5 years)	0.05-0.2 (GM <sup>b</sup> ) or <LOD-0.088 (25% P.) or 0.49-1.1 (75% P.) (creatinine adjusted, ng/mL)	BPA	[38]
BPA and replacements	3	Oslo and Akershus regions, Norway	Urine	144	Employees from governmental institutes and authorities, and universities (44 males between 25–72 years and 100 females between 24–72 years)	<LOD-12.74 (range) or 0.10-1.40 (GM <sup>b</sup> ) (SG adjusted <sup>c</sup> )	BPS and BPA	[39]
BPA and replacements	3	Austria	Plasma	21	Premature infants (gestational age <28 weeks, birth weight <1 kg)	<0.33-15 (range)	BPA	[40]
BPA and replacements	3	Austria	Breast milk	86	Breast-feeding women (<211 days post-partum)	<0.0078-0.051 (range)	BPS	[40]
BPA and replacements	8	Chengdu, Nantong & Shehong, China	Urine	300	General population (males, n = 167 and women, n = 133)	Chengdu: <LOQ-46.6 (range, unadjusted) Nantong: <LOQ-38.1 (range, unadjusted) Shehong: <LOQ-49.6 (range, unadjusted)	BPA	[42]

<sup>b</sup> Geometric mean; <sup>c</sup> Specific gravity adjusted.

**Table S4 (cont.).** Concentration levels of plasticizers, bisphenols, flame retardants and antioxidants in human biomonitoring approaches as applied to urine, breast milk and plasma (2019-2023). (See Table S1 for the full names of compounds, the “m” refers to “metabolite of”)

Compound Family	N° compounds	Region/Country	Matrix	N° Samples	Studied population	Concentration range per family (ng/mL)	Analyte found at highest concentration	References
<i>Flame retardants</i>								
mOPFRs	13	Flanders, Belgium	Urine	582	Adolescents (14-15 years)	0.01-12.9 (95% P., SG adjusted <sup>c</sup> )	EHPHP	[43]
mOPFRs	8	Boston, USA	Urine	900	Pregnant women (16-weeks of gestation)	0.04-3.46 (95% P., SG adjusted <sup>c</sup> )	BDCIPP and DPHP	[44]
mOPFRs	9	Durham, USA	Urine	163	6-week-old (n = 100) and 12-month-old infants (n = 63)	0.97-276 (95% P., SG adjusted <sup>c</sup> )	BCIPP	[45]
mOPFRs	5	Puerto Rico	Urine	141	Pregnant women (n = 48, 3 visits)	0.26-1.51 (GM <sup>b</sup> , unadjusted) or 0.26-1.85 (GM <sup>b</sup> , SG adjusted <sup>c</sup> )	BDCIPP	[46]
mOPFRs	14	China	Urine	46	General population	0.02-8.91 (range unadjusted) or 0.04-12.8 (range, creatinine adjusted, µg/g)	BCIPHIPP and 4OH-DPHP	[47]
mOPFRs	16	Wuhan, China	Urine	339	Newborns with <2.5 kg (cases, n = 113) and between 2.5-4.0 kg (controls, n = 226)	Cases: 7.04-9.95 nmol/L (GM <sup>b</sup> , SG adjusted <sup>c</sup> ) Controls: 6.47-8.21 nmol/L (GM <sup>b</sup> , SG adjusted <sup>c</sup> )	DoCP and DpCP	[48]
mOPFRs	4	Cincinnati, USA	Urine	357	Pregnant women (2003-2006)	0.25-2.3 (range, creatinine adjusted, µg/g)	DPHP	[49]
mOPFRs	8	Senzhen, China	Urine	170	Incinerator male workers (cases, n = 73) and general population 8 km away from the incinerator plant (controls, n = 97)	Cases: 0-11.1 (range) or 0.04-0.53 (median) (unadjusted) Controls: 0.01-19.2 (range) or 0.03-0.42 (median) (unadjusted)	BCIPP DPHP	[50]
mOPFRs	11	Albany, USA	Urine	213	General population (21-45 years, 2018)	<LOD-13.5 (range, SG adjusted <sup>c</sup> ) or 13.4-1060 (GM <sup>b</sup> , SG adjusted <sup>c</sup> ) or <LOD-3.99 (range, creatinine adjusted, µg/g) or 0.00053-0.404 (GM <sup>b</sup> , creatinine adjusted, µg/g)	DPHP	[51]
mOPFRs	14	USA	Breast milk	100	Breast-feeding women (2009-2012; 19-40 years)	0.67-7.38 (range)	TBOEP	[52]
mOPFRs	7	Puerto Rico and USA	Urine	171	Pregnant women (ca. 29.5 years, 2017-2022)	<LOD-0.66 (GM <sup>b</sup> ) or <LOD-0.34 (25% P.) or <LOD-1.4 (75% P.) (creatinine adjusted, ng/mL)	DPHP	[38]

<sup>b</sup> Geometric mean; <sup>c</sup> Specific gravity adjusted.

**Table S4 (cont.).** Concentration levels of plasticizers, bisphenols, flame retardants and antioxidants in human biomonitoring approaches as applied to urine, breast milk and plasma (2019-2023). (See Table S1 for the full names of compounds, the “m” refers to “metabolite of”)

Compound Family	N° compounds	Region/Country	Matrix	N° Samples	Studied population	Concentration range per family (ng/mL)	Analyte found at highest concentration	References
<i>Flame retardants</i>								
HBCDD and TBBPA	2	Beijing, China	Breast milk	111	Breast-feeding women (n = 37, 2014, <3 months after gestation)	<LOD-42 (range, ng/g lw)	TBBPA	[53]
TBBPA	1	Reus, Spain	Breast milk	60	Breast-feeding women (<12 months after gestation)	11-286 (range, lipid adjusted, ng/g)	TBBPA	[54]
TBBPA, TCBPA and TBBPS	2	Chengdu, Nantong and Shehong, China	Urine	300	General population (males, n = 167 and women, n = 133)	Chengdu: <LOQ-34.4 (range, unadjusted) Nantong: <LOQ-40.2 (range, unadjusted) Shehong: <LOQ-7.26 (range, unadjusted)	TBBPA and TBBPS	[42]
<i>Antioxidants</i>								
mSPAs	6	China, India, Japan, Saudi Arabia and USA	Urine	145	General population (2-87 years)	<LOQ-46.4 (range, unadjusted)	BHT-COOH	[55]
mSPAs	2	South China, China	Urine	150	General adults (n = 50; 20-54 years old), children (n = 50; 1-13 years old) and pregnant women (n = 50; 20-41 years old)	<LOQ-8.58 (range, unadjusted) or <LOQ-9.17 (range, creatinine adjusted, µg/g)	6PPD and 6PDD-Q	[56]
mSPAs	1	Halle/Saale, Germany	Urine	329	Male (n= 165) and female (n= 164) (20–29 years; 2000-2018)	<LOQ-18.1 (range, unadjusted) or 3.28 (90% P., unadjusted) or 3.91 (90% P., creatinine adjusted, µg/g)	BHT-COOH	[57]
mSPAs	1	Germany	Urine	2091	Population-representative German Environmental Survey on Children and Adolescents (3-17 years, 2014–2017)	<LOQ-248 (range, unadjusted) or <LOQ-269 (range, creatinine adjusted, µg/g)	BHT-COOH	[41]

**Table S5.** Survey of Correction Factors (CFs) and estimated exposure of several plastic-related chemicals by WBE. (See Table S1 for the full names of compounds).

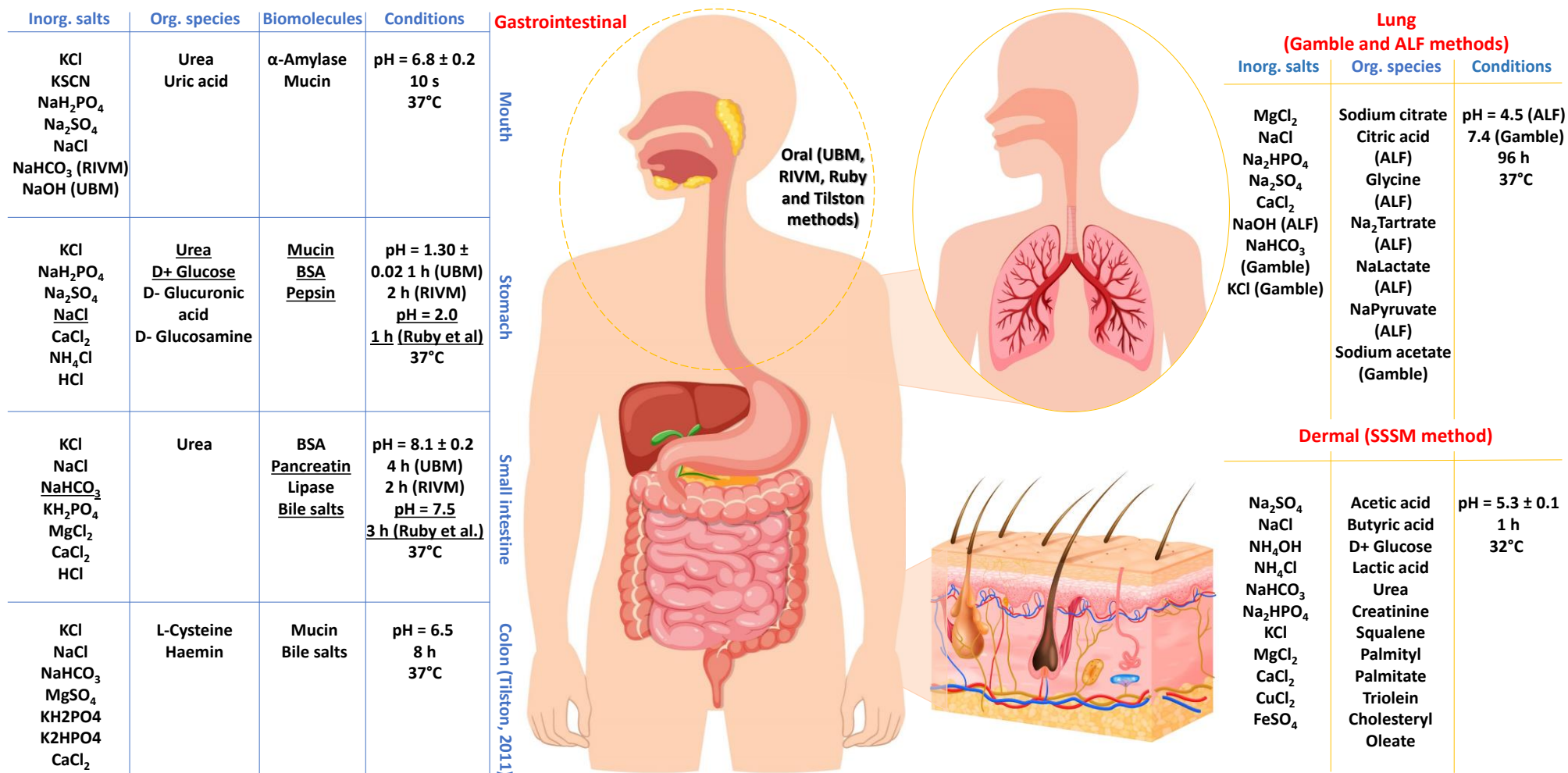
Class	Compound	Biomarker	CF	Estimated exposure ( $\mu\text{g inh}^{-1} \text{day}^{-1}$ )	Location	References
Phthalate esters	DMP	MMP	1.55	141 $\pm$ 87	27 cities, China	[58]
	DEP	MEP	1.65	230 $\pm$ 147		
	DiBP	MiBP	1.76	306 $\pm$ 236		
	DnBP	MnBP	1.8	1413 $\pm$ 649		
	DEHP	MEHHP	8.4	94 $\pm$ 54		
Phthalate esters	DEP	MEP	1.65	1347 $\pm$ 490	13 cities, Spain	[59]
	DiBP	MiBP	1.76	158 $\pm$ 74		
	DnBP	MnBP	1.8	112 $\pm$ 56		
	DEHP	MEOHP	11.8	38 $\pm$ 36 – 44 $\pm$ 33		
		MEHHP	8.4	26 $\pm$ 27 – 33 $\pm$ 26		
Phthalate esters	DMP	MMP	1.55	185 $\pm$ 14	1 city, Spain	[60]
	DEP	MEP	1.65	1880 $\pm$ 47		
	DiBP	MiBP	1.76	147 $\pm$ 7		
	DnBP	MnBP	1.8	205 $\pm$ 12		
	DEHP	MEOHP	11.8	64 $\pm$ 2		
		MEHHP	8.4	71 $\pm$ 6		
		cx-MEPP	9.01	68 $\pm$ 3		
	BBzP	MBzP	1.68	11 $\pm$ 1		
	DEHTP	MEHHTP	73.7	458 $\pm$ 17		
		MEOHTP	134	639 $\pm$ 45		
5cx-MEPTP		9.74	476 $\pm$ 12			
Phthalate esters	DEP	MEP	1.65	178 $\pm$ 86 - 603 $\pm$ 78	2 cities Belgium, 1 city Spain, 1 city Croatia	[61]
	DiBP	MiBP	1.76	66 $\pm$ 34 - 154 $\pm$ 31		
	DnBP	MnBP	1.8	43 $\pm$ 24 - 180 $\pm$ 41		
	DEHP	MEHHP	8.4	N.D. - 28 $\pm$ 8		
	DEHTP	5cx-MEPTP	9.74	13 $\pm$ 6 - 188 $\pm$ 27		

**Table S5. (cont.).** Survey of Correction Factors (CFs) and estimated exposure of several plastic-related chemicals by WBE. (See Table S1 for the full names of compounds).

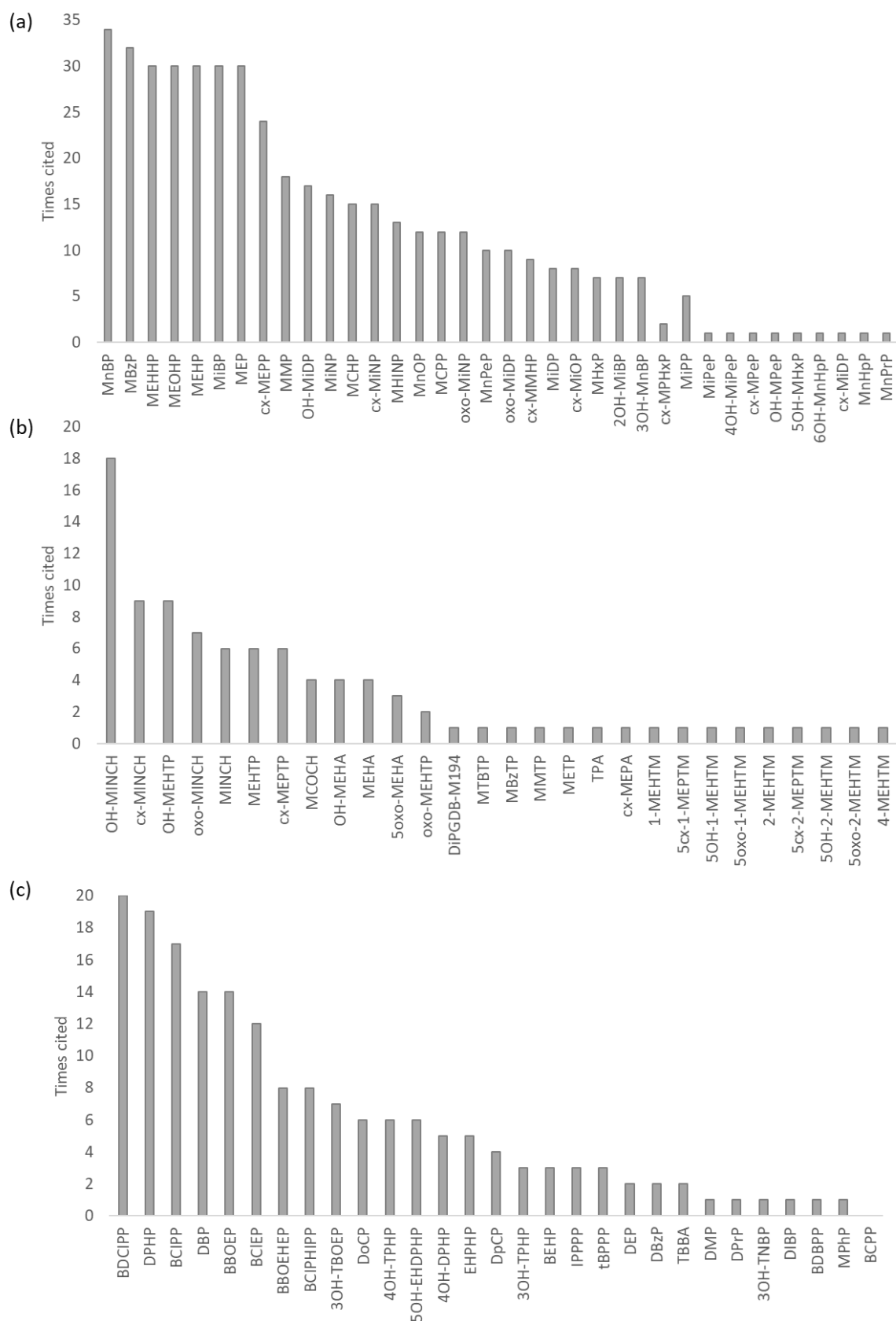
Class	Compound	Biomarker	CF	Estimated exposure ( $\mu\text{g inh}^{-1} \text{day}^{-1}$ )	Location	Ref.	
Bisphenols	BPA	BPA-S	24.7	$43 \pm 9 - 407 \pm 183$	2 cities Belgium, 1 city Spain, 1 city Croatia	[61]	
Bisphenols	BPA	BPA-S	0.45	4 – 6	1 city, USA	[62]	
	BPS	Free BPS	(1)	$91 \pm 59$			
Bisphenols	BPA	BPA-S	0.45	$0.97 \pm 0.1 - 157 \pm 16$ (4)	5 WWTP, UK	[63]	
			0.16	$0.35 \pm 0.03 - 46.2 \pm 5.6$ (4)			
Flame retardants	TBOEP	BBOEHEP	13.9	$395 \pm 60 - 1783 \pm 830$	2 cities Belgium, 1 city Spain, 1 city Croatia	[61]	
Flame retardants	TBOEP	BBOEP OH-TBOEP BBOEHEP	(1)	(3)	5 cities, Europe	[64]	
	TPHP	DPHP (2) OH-DPHP	(1)	(3)			
	TDCIPP	BDCIPP	(1)	(3)			
	EHDPHP	DPHP (2) OH-EHDPHP EHPHP	(1)	(3)			
	TCIPP	BCIPP BCIPHIPP	(1)	(3)			
	TCIEP	Free TCIEP	(1)	(3)			
Flame retardants	TCIPP	BCIPP		45-47	1 city, Spain	[65]	
Flame retardants	TCIPP	BCIPHIPP		1.8-3.3	4 cities, Belgium	[66]	
	TCEP	Free TCIEP		18-108			
	EHDPHP		DPHP (2)				18-175
			EHPHP				38-393
			5OH-EHDPHP				0.6-2.7
	TBOEP		BBOEHEP				6.9-35
3OH-TBOEP				12-61			
TPHP		DPHP (2)		18-175			

(1) No correction factor was applied. (2) biomarker of exposure for more than 1 parent compound (3) Data reported in figures (4) Loads reported as  $\mu\text{g day}^{-1} \text{kg}^{-1}$ .

## Supporting Figures



**Figure S1.** Overview of physiologically-based extraction tests for the investigation of the gastrointestinal, dermal and lung bioaccessibility of plastic-related chemicals. In oral bioaccessibility, underlined chemicals and experimental conditions are those recommended by Ruby et al. (2002). The remaining conditions are both applied to UBM (Unified Bioaccessibility Method) and RIVM (Dutch Institute for Public Health and the Environment Method). ALF: Artificial Lysosomal Fluid, SSSM: Synthetic Sweat and Sebum Mixture.



**Figure S2.** Top phase I metabolites monitored in human biomonitoring papers (2019-2023) included in this review and given as the number of times they have been analyzed in biological samples: a) primary and secondary phthalate ester metabolites, b) primary and secondary phase-I metabolites of alternative plasticizers, and c) primary phase-I metabolites of organophosphate flame-retardants. (See Table S1 for the full names of compounds as well as the information related to the parent compound).

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