



Supramolecular solvent extraction and ambient mass spectrometry for the determination of organic contaminants in food packaging material

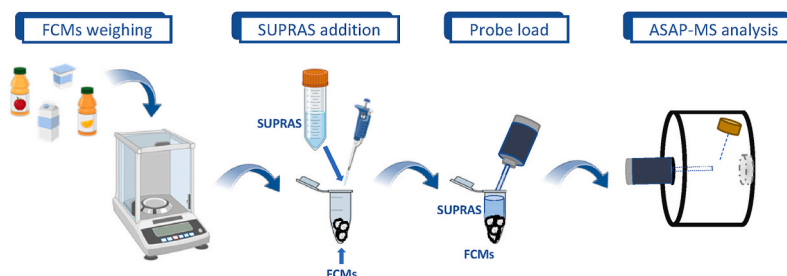
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HIGHLIGHTS

- SUPRASs and ambient mass spectrometry were combined for fast analysis.
- Quantification (bisphenols and aryl-OPFRs) and screening were performed in FCMs.
- Bisphenols (n.d.-292 µg/g) and aryl-OPFRs (n.d.-14.2 µg/g) were present in samples.
- Other 14 additives and unknown compounds were identified in FCMs too.

GRAPHICAL ABSTRACT



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ABSTRACT

A rapid method based on a fast sample treatment with supramolecular solvents (SUPRASs) and ambient mass spectrometry (AMS) analysis was developed for the screening and quantification of organic contaminants in food packaging materials (FCMs). The suitability of SUPRASs made up of medium chain alcohols in ethanol:water mixtures was investigated, given their low toxicity, proven capacity for multi-residue analysis (since they provide a wide variety of interactions and multiple binding sites) and restricted access properties for simultaneous sample extraction and clean-up. Two families of emerging organic pollutants, bisphenols and organophosphate flame retardants, were targeted as representative compounds. The methodology was applied to 40 FCMs. Target compounds were quantitated using ASAP (atmospheric solids analysis probe)-low resolution MS and a broad-spectrum screening of contaminants was performed through spectral library search using direct injection probe (DIP) and high resolution MS (HRMS). The results showed the ubiquity of bisphenols and of some flame retardants, as well as the presence of other additives and unknown compounds in about half of the analyzed samples, which highlight the complex composition of FCMs and the possible associated health risks.

1. Introduction

The chemical safety of food contact materials (FCMs) remains a priority for the European Food Safety Authority (EFSA) since there are

still significant gaps and regulatory challenges (Muncke et al., 2017, 2014; Simoneau et al., 2016). While around 8000 substances are regulated in FCMs, the so-called non-intentionally added substances (NIAS) are mostly unregulated. NIAS are impurities, by-products or degradation

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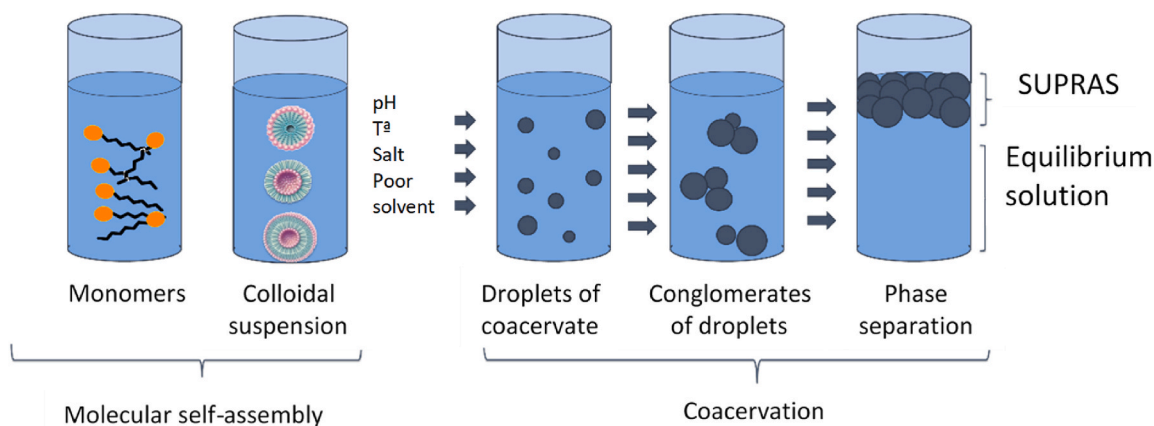


Fig. 1. SUPRAS formation by self-assembly and coacervation.

products, which are originated during the processing or the recycling of materials and that could constitute the majority of chemicals present in a product (Grob, 2014).

There is a growing concern about the presence of hazardous contaminants in FCMs. Recent studies have confirmed the presence of poly and per-fluorinated compounds, phthalates, bisphenol A and nonylphenol in pizza boxes (Rosenmai et al., 2017), contaminants related to printing inks in different food containers (Lago and Ackerman, 2016) and brominated flame retardants in thermal cup lids (Turner and Filella, 2017). In order to ensure safer FCMs, the complex chemical cocktail present in these materials needs to be elucidated. However, most of the current analytical methods are hampered by multiple, laborious and slow solvent extraction and clean-up steps that target certain groups of contaminants (Bignardi et al., 2014; Giannetti et al., 2017; Sanchis et al., 2017). To prevent these drawbacks, analysis should be matrix- and compound-independent, so that emerging and potentially toxic compounds are not overlooked. Methods need to be also rapid in order to provide consumers, the industry and institutions with fast answers to take immediate action.

In this study we combine a fast sample treatment step, which is based on supramolecular solvent extraction, with a fast analysis technique [atmospheric solids analysis probe and direct injection probe (ASAP-MS and DIP-MS)] coupled to with low and high resolution mass spectrometry to determine organic contaminants in FCMs. The first one was used to quantify the target compounds, while the last one was used to perform a broad-spectrum screening of contaminants through spectral library search. In ASAP-MS and DIP-MS, solid or liquid samples or extracts are loaded onto a disposable glass capillary and directly introduced onto an atmospheric chemical pressure ionization (APCI) source. Analytes are desorbed from the matrix by high temperature and ionized through the corona discharge reactions and enter the detector (McEwen et al., 2005). The only difference between the two AMS sources, which were those provided by each MS system manufacturer, was the position of probe inside the source with respect to the MS entrance. In ASAP-MS this position is opposite and in DIP-MS is orthogonal.

Supramolecular solvents (SUPRASs) are nanostructured liquids produced from amphiphilic compounds in aqueous or hydro-organic media through self-assembly and coacervation processes (Fig. 1). They are a great option to replace conventional organic solvents in analytical extractions due to their physico-chemical properties. These properties include: (a) mixed interaction mechanisms with organic compounds (e. g. polar, ionic, hydrogen, dispersion interactions, etc.), (b) presence of regions with a wide range of polarity in the supramolecular aggregates, (c) high number of available binding sites (high concentration of amphiphile in the range 0.1–1 mg μL^{-1}), (d) behavior as restricted access materials for polar macromolecular interferents and (e) low volatility and toxicity in comparison with conventional solvents.

(Ballesteros-Gómez and Rubio, 2012; Ballesteros-Gómez et al., 2010). SUPRASs have been used with excellent results in analytical extractions of a wide variety of organic compounds in liquid and solid biological, food and environmental samples (Ballesteros-Gómez and Rubio, 2012; Ballesteros-Gómez et al., 2010; Dueñas-Mas et al., 2019; Romera-García et al., 2019; Ruiz et al., 2007).

The application of SUPRASs to materials has been more limited. Recently, we developed a fast qualitative screening method for the analysis of BPA and analogs with SUPRASs loaded into ASAP probes, which were put in contact with thermal paper samples for few seconds before ASAP analysis by using low resolution MS/MS (Dueñas-Mas et al., 2022). In the present study, we apply the SUPRAS treatment in a separate step that is simple and fast, in order to make quantitative analysis easier. Two families of widely spread emerging organic compounds, i.e. bisphenols and analogs and aryl-organophosphate flame retardants (aryl-OPFRs), were investigated and quantitatively determined in FCMs. Among materials, plastics were selected as representative since they are one of the most frequently used FCMs (Simoneau et al., 2016). Furthermore, the SUPRAS-DIP technique was evaluated to carry out a broad-spectrum screening analysis using high resolution MS/MS and library search based on the wide variety of interactions supplied by SUPRASs.

2. Experimental section

2.1. Chemicals and reagents

Methanol (MeOH) and ethanol (EtOH) were supplied by Fisher Scientific (Madrid, Spain). Ultra-high-quality water was obtained from a Milli-Q water purification system (Millipore, Madrid, Spain). 1-Hexanol and 1-decanol were acquired from Sigma-Aldrich (Steinheim, Germany). The target aryl-OPFRs were bisphenol A bis(diphenyl phosphate) (BDP, CAS 5945-33-5), cresyl diphenyl phosphate (CDP, CAS 26444-49-5), 2-ethylhexyl diphenyl phosphate (EHDPP, CAS 1241-94-7), isodecyl diphenyl phosphate (IDPP, CAS 29761-21-5), resorcinol bis(diphenyl phosphate) (RDP, CAS 57583-54-7) and triphenyl phosphate (TPHP, CAS 115-86-6). All of them were obtained from AccuStandard (New Haven, CT) as 1 mL ampoules ($\sim 100 \mu\text{g mL}^{-1}$ of analyte certified concentration in toluene), except TPHP and the internal standard (IS) TPHP-d₁₅, which were acquired as solids from Sigma Aldrich (Zwijndrecht, the Netherlands). Bisphenols were 4,4'-(propane-2,2-diyl) diphenol (bisphenol A, BPA) and 4,4'-Sulfonyldiphenol (bisphenol S, BPS), obtained from Sigma-Aldrich (St. Louis, MO, USA), and 4-(4-phenylmethoxyphenyl)sulfonylphenol (BPS-MAE), 4-(4-propan-2-yloxyphenyl) sulfonylphenol (D-8) and 4-(4-hydroxy-3-prop-2-enylphenyl)sulfonyl-2-prop-2-enylphenol (TGSA), which were acquired from Toronto Research Chemicals (Toronto, Canada), together with the

Table 1

Slopes ($L \cdot mg^{-1}$) and determination coefficients (R^2) of calibration curves of target compounds made in SUPRAS and analyzed by ASAP-QqQ-MS/MS. Instrumental detection (LOD, $\mu g \cdot L^{-1}$) and quantification (LOQ, $\mu g \cdot L^{-1}$) limits are provided for SUPRAS of 1-decanol (optimal). Method LODs and LOQs ($\mu g \cdot g^{-1}$) are provided in brackets.

	Bisphenols		Aryl-OPFRs	
	SUPRAS _{C₆}	SUPRAS _{C₁₀}	SUPRAS _{C₆}	SUPRAS _{C₁₀}
TGSA	3.4 ± 0.1 $R^2 = 0.993$	7.5 ± 0.3 $R^2 = 0.992$ LOD: 0.7 (0.02) LOQ: 2 (0.06)	BDP	0.37 ± 0.02 $R^2 = 0.994$ 0.59 ± 0.03 $R^2 = 0.993$ LOD: 0.7 (0.01) LOQ: 2 (0.04)
D8	2.7 ± 0.12 $R^2 = 0.988$	7.4 ± 0.4 $R^2 = 0.992$ LOD: 1 (0.03) LOQ: 4 (0.1)	RDP	0.127 ± 0.003 $R^2 = 0.9992$ 0.279 ± 0.007 $R^2 = 0.997$ LOD: 3 (0.06) LOQ: 10 (0.2)
BPS-MAE	4.9 ± 0.2 $R^2 = 0.996$	11.6 ± 0.6 $R^2 = 0.990$ LOD: 0.3 (0.01) LOQ: 1 (0.03)	IDPP	2.2 ± 0.04 $R^2 = 0.9988$ $t = 0.16$ 2.16 ± 0.07 $R^2 = 0.998$ LOD: 1 (0.02) LOQ: 3 (0.06)
BPS	4.7 ± 0.2 $R^2 = 0.996$ $t = 0.31$	4.6 ± 0.1 $R^2 = 0.998$ LOD: 3 (0.1) LOQ: 10 (0.3)	EHDPP	2.51 ± 0.04 $R^2 = 0.9987$ $t = 1.04$ 2.40 ± 0.09 $R^2 = 0.993$ LOD: 3 (0.06) LOQ: 10 (0.2)
BPA	1.28 ± 0.03 $R^2 = 0.998$ $t = 0.6$	1.24 ± 0.05 $R^2 = 0.994$ LOD: 17 (0.4) LOQ: 50 (1.3)	CDP	0.42 ± 0.02 $R^2 = 0.9944$ $t = 1.26$ 0.46 ± 0.02 $R^2 = 0.995$ LOD: 3 (0.06) LOQ: 10 (0.2)
			TPHP	10.3 ± 0.3 $R^2 = 0.9956$ $t = 1.28$ 10.9 ± 0.4 $R^2 = 0.996$ LOD: 0.7 (0.01) LOQ: 2 (0.04)

*Calculated t values are shown when they were lower than tabulated t values (meaning no significant differences between slopes with SUPRAS made up of C₆ and C₁₀).

internal standards BPA-¹³C₁₂ y BPS-d₈. See Tables S1 and S2 in supporting information for more details about structures and physico-chemical properties of target compounds.

Spike solutions of ISs (one for aryl-OPFRs with TPHP-d₁₅, and one for bisphenols with a mix of BPA-¹³C₁₂ and BPS-d₈) were prepared in MeOH at concentrations of individual compounds of 5 mg L^{-1} , for both optimization and sample analysis. Stock and working solutions of bisphenols and aryl-OPFRs were prepared by dilution in MeOH. All solutions were stored at -20°C .

2.2. Apparatus

Instrumentation for SUPRAS preparation and extraction of FCMs were a vortex-shaker REAX Top (Heidolph, Schwabach, Germany) equipped with a head (ref. 549-01000-00) with 10 microtubes from Heidolph (Schwabach, Germany) and a $36 \times 2.2/1.5 \text{ mL}$ angle rotor (ref. 1162) MPW350R high speed centrifuge from MPW Med-Instruments (Warszaw, Poland).

2.3. SUPRAS preparation

On the basis of our previous study (Dueñas-Mas et al., 2022), SUPRASs were made up from solutions containing the amphiphile (either 1-hexanol or 1-decanol, 5% v/v), ethanol (10%, v/v) and water (85%, v/v). Mixtures were stirred for 5 min for extraction and centrifuged for 5 min at 2500 rpm to accelerate the phase separation. Approximately, a volume of $\sim 39 \mu\text{L}$ of SUPRAS/ml of initial synthesis solution were formed under these conditions. Once both phases were separated, the upper phase (SUPRAS) was transferred to a closed glass bottle and stored at 4°C until use (within 1 week).

2.4. Collection and analysis of FCMs

A total of 40 samples from different types of FCMs were acquired from local supermarkets (Córdoba, Spain). They were mainly plastic materials (see Table S3). FCMs were thoroughly rinsed with distilled water before analysis. Sample extraction was carried out in 2 mL

microtubes which contained 20 mg of samples cut in small pieces ($\sim 0.1 \times 0.1 \text{ cm}$) and 400 μL of SUPRAS (10 mg g^{-1} IS). They were vortex-shaken for 5 min and centrifuged for 5 min at 10,000 rpm. Then, the open end of a disposable glass probe was immersed in the SUPRAS extract and it was loaded with 1–2 μL of SUPRAS. The probe was immediately injected in the ASAP or DIP unit for MS analysis ($n = 5$). Samples were extracted in triplicate. Blanks of MeOH were injected between samples to ensure lack of cross-contamination.

Quantitative determination of bisphenols and aryl-OPFRs in FCMs was performed using an Agilent Technologies 6420 Triple Quadrupole mass spectrometer equipped with an atmospheric pressure chemical ionization source (APCI) modified with an ASAP unit (Ionsense Inc.), which operated in positive mode for the analysis of aryl-OPFRs and in negative mode for bisphenols. Optimal source parameters for ASAP were: gas temperature, 325°C ; gas flow, 4.0 L min^{-1} ; vaporization temperature, 400°C ; nebulizer gas pressure, 20 psi; capillary voltage, +4500 V (positive mode) and -1000 V (negative mode); corona voltage, 4 μA (positive mode) and 10 μA (negative mode). After the probe was inserted in the ASAP unit, the MS signal was recorded for 1 min. Probes were disposable glass melting point capillaries (0.8–1.1 i.d., 90 mm length) and were obtained from Pyrex (Thermo Fisher Scientific, USA). Qualitative analysis MassHunter workstation software from Agilent Technologies was used for data analysis. Characteristics MRM transitions were registered for each analyte (see Tables S4 and S5).

Broad spectrum screening with library search was carried out with a high resolution mass spectrometer (Bruker TimsTOF, Q-TOF) equipped with an APCI source with an unit for direct sample injection probe (DIP). Parameters of APCI source were: end plate offset, 500 V; capillary voltage, 2500 V; corona voltage, 3000 nA; nebulizer gas pressure, 2.5 bars; dry gas, 3 L min^{-1} ; dry temperature, 200°C ; vaporizer temperature, 350°C . Data acquisition was achieved in auto-MS/MS mode (abundant ions isolation and fragmentation) in order to perform a search on an open access spectral library (<https://massbank.eu/MassBank/>, [MassBank NIST.msp](https://massbank.nist.gov/)). The data acquisition programs were Data Analyst and Metaboscape (Bruker Daltonics). Identification was carried out on the basis of mass accuracy ($<10 \text{ ppm}$), isotopic pattern fit expressed as mSigma (<200) and MS/MS score (>500). The calculation of the

Table 2Levels of bisphenols and aryl-OPFRs found in food packaging samples ($\mu\text{g}\cdot\text{g}^{-1}$). Only positive samples are shown.

Sample	TGSA	D8	BPS-MAE	BPS	BPA	EHDPP	CDP
1	n.d.	0.28 ± 0.02	0.17 ± 0.01	1.6 ± 0.2	<LOQ	<LOQ	14.2 ± 1.6
3	n.d.	0.468 ± 0.006	0.057 ± 0.006	21.4 ± 1	n.d.	n.d.	n.d.
7	n.d.	n.d.	0.052 ± 0.00012	n.d.	n.d.	n.d.	n.d.
10	n.d.	0.28 ± 0.02	0.14 ± 0.02	10.4 ± 0.2	n.d.	n.d.	n.d.
11	n.d.	0.168 ± 0.002	0.054 ± 0.002	292 ± 28	<LOQ	n.d.	n.d.
15	n.d.	0.30 ± 0.06	0.0526 ± 0.0006	7 ± 1.4	2.2 ± 0.4	n.d.	n.d.
18	n.d.	0.5 ± 0.1	0.13 ± 0.02	16 ± 5	<LOQ	n.d.	n.d.
19	n.d.	0.316 ± 0.06	0.064 ± 0.008	106 ± 6	<LOQ	n.d.	n.d.
20	n.d.	n.d.	n.d.	n.d.	n.d.	<LOQ	4.6 ± 0.6
21	n.d.	0.38 ± 0.06	<LOQ	86 ± 14	n.d.	n.d.	n.d.
25	n.d.	n.d.	n.d.	n.d.	n.d.	0.20 ± 0.04	4.4 ± 1.2
26	n.d.	n.d.	n.d.	n.d.	n.d.	0.20 ± 0.02	n.d.
33	n.d.	0.32 ± 0.06	0.11 ± 0.02	4.0 ± 0.4	n.d.	n.d.	n.d.
36	n.d.	n.d.	<LOQ	<LOQ	n.d.	<LOQ	n.d.
37	1.8 ± 0.2	1.3 ± 0.3	0.294 ± 0.002	8.2 ± 0.8	<LOQ	<LOQ	0.28 ± 0.04
38	n.d.	2.44 ± 0.08	0.09 ± 0.02	16 ± 5	1.26 ± 0.06	<LOQ	1.2 ± 0.08
39	n.d.	0.22 ± 0.02	n.d.	0.5 ± 0.1	n.d.	<LOQ	n.d.
40	n.d.	0.556 ± 0.08	0.24 ± 0.01	122 ± 14	<LOQ	<LOQ	n.d.
DF (%) / 40 samples	2.5	32.5	35	35	20	22.5	12.5
Method LOD ($\mu\text{g}\cdot\text{g}^{-1}$)	0.02	0.03	0.01	0.1	0.4	0.06	0.06
Method LOQ ($\mu\text{g}\cdot\text{g}^{-1}$)	0.06	0.1	0.03	0.3	1.3	0.2	0.2

DF: detection frequency (%). Values > 10 $\mu\text{g}\cdot\text{g}^{-1}$ (0.001% p/p) are highlighted.

mSigma value is based on the relative mean square of the difference of an experimental mass spectrum from the theoretical isotopic pattern of a specific molecular formula. The instrument includes a maximum mSigma threshold value of 200 for molecular formula assignment. Therefore, the lower the mSigma value, the more precise the fit. The MS/MS score describes the difference between the measured and the theoretical fragmentation spectrum of the measured ion. Score-based equations typically include the m/z-intensity pairs of the search spectrum and library spectra as well as additional parameters such as weighing functions. MS/MS scores range from 0 to 999. A low score indicates that the compound is not found in the database, and scores of 999 would present a perfect hit. The instrument sets a minimum threshold value for MS/MS score of 500.

3. Results and discussion

3.1. Quantitation of bisphenols and aryl-OPFRs with SUPRAS-ASAP-QqQ-MS/MS

Calibration curves for bisphenols and aryl-OPFRs (0.01–1 $\text{mg}\cdot\text{L}^{-1}$, 0.5 $\text{mg}\cdot\text{L}^{-1}$ of IS) in SUPRAS of 1-hexanol and 1-decanol were analyzed by ASAP-QqQ-MS/MS. Determination coefficients were over 0.99. Differences between calibration slopes were compared by appropriate t-tests (Andrade et al., 2014). Results are shown in Table 1.

SUPRAS prepared with 1-decanol provided equal or better sensitivity than those with 1-hexanol and this was selected as optimal for further analysis. Slopes were 1–3.5 times higher for D8, TGSA, BPS-MAE, RDP and BDP with SUPRAS of 1-decanol in ASAP, this showing the influence of the amphiphile on the ionization process of some analytes due to the lack of previous LC separation. Instrumental limits of detection (LODs) and quantification (LOQs) were in the ranges 1–20 $\mu\text{g}\cdot\text{L}^{-1}$ and 2–50 $\mu\text{g}\cdot\text{L}^{-1}$ for bisphenols, respectively, and 1–3 $\mu\text{g}\cdot\text{L}^{-1}$ and 2–10 $\mu\text{g}\cdot\text{L}^{-1}$ for aryl-OPFRs, respectively, and they were around one order of magnitude higher than those obtained with LC-ESI-QqQ-MS/MS and LC-APCI-QqQ-MS/MS, respectively (LODs: 0.06–1.2 $\mu\text{g}\cdot\text{L}^{-1}$ and LOQs: 0.12–2.4 $\mu\text{g}\cdot\text{L}^{-1}$ for bisphenols (Dueñas-Mas et al., 2019) and LODs: 0.03–0.7 $\mu\text{g}\cdot\text{L}^{-1}$ and LOQs: 0.07–1.4 $\mu\text{g}\cdot\text{L}^{-1}$ for aryl-OPFRs (Dueñas-Mas et al., 2020)). The lower injection volume (1.1–2 μL in ASAP), different ionization source for bisphenols and the lack of LC separation leading to higher background noise are probable reasons.

Recoveries of internal standards in samples were acceptable and in

the ranges 108–120% for TPHP-d₁₅ (used for aryl-OPFRs), 75–120% for BPA-¹³C₁₂ (used for BPA) and 60–78% for BPS-d₈ (used for the rest of bisphenols). Method LODs and LOQs were estimated from instrumental values, considering an amount of sample of 0.02 g, 0.4 mL SUPRAS extract volume and the lowest IS recovery for each group of compounds. Taking into account this, the estimated method LODs (0.01–0.4 $\mu\text{g}\cdot\text{g}^{-1}$) and LOQs (0.04–1.3 $\mu\text{g}\cdot\text{g}^{-1}$) were low enough for the quantitative trace analysis of contaminants in materials (down to 0.001% considering the highest LOQ level).

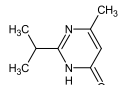
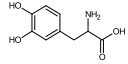
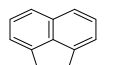
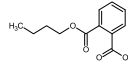
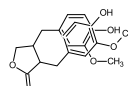
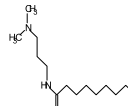
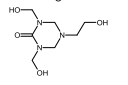
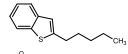
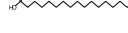
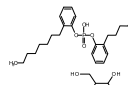
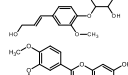
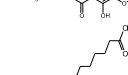
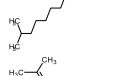
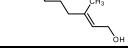
3.2. Analysis of bisphenols and aryl-OPFRs in FCMs with SUPRAS-ASAP-QqQ-MS/MS

Once SUPRAS of 1-decanol were selected as optimal, 40 samples from different FCMs (see Table S3) were analyzed and quantified following the specifications given in section 2.4. Target compounds were found in 18 samples (detection frequency, DF = 45%). Results are shown in Table 2. All positive samples were made up of plastic except sample 19 (paper tea bag), 33 (cardboard coffee cup) and 38 (aluminum lasagna pan). However, these materials, which are intended for warming up food or for containing hot food, have usually thermoplastic coatings, such as PVC, polypropylene or epoxy resins in contact with food. In fact, many food packages are not only formed by a single material, but they have several layers or sheets of different materials and mixtures. In Table S3, the nature of the main material of each FCM is given. For those items that were labelled by the manufacturer, the type of plastic is indicated too.

Results in Table 2 highlight the ubiquity of bisphenols in FCMs. BPA values (n.d.-2.2 $\mu\text{g}\cdot\text{g}^{-1}$, DF: 20%) were in a similar range or lower than those found in other studies (n.d.-3.09 $\mu\text{g}\cdot\text{g}^{-1}$ (Wang et al., 2019), n.d.-67.2 $\mu\text{g}\cdot\text{g}^{-1}$ (Chen et al., 2017) and n.d.-25.4 $\mu\text{g}\cdot\text{g}^{-1}$ (Pérez-Palacios et al., 2012)). The two quantifiable levels of BPA were found in a plastic package of bread (unknown composition) and in an aluminum pan. BPA is employed in the synthesis of epoxy resins or internal food can linings and in polycarbonate bottles (EFSA CEF Panel, 2015). It is also used as additive in other type of plastics, such as polysulphones, polyacrylates and PVC and it can be found in paintings, printing inks and thermal paper (Geens et al., 2012). As it was mentioned above, the presence of BPA in the aluminum pan was probably due to the fact that this item was protected with a thermoplastic coating.

BPS was the most frequently detected bisphenol (DF: 35%) and at

Table 3
Identified compounds by DIP-QTOF-MS/MS and spectral library search.

Formula	Error ppm	mSigma (isotopic pattern fit)	Main ion	Name	CAS	Application/use	Detection frequency	Structure
C ₈ H ₁₂ N ₂ O	9.5	198.2	[M+H] ⁺	2-Isopropyl-6-methyl-pyrimidin-4-ol	2814-20-2	Benzophenone derivatives synthesis intermediate, UV filter-type plastic additives	33%	
C ₉ H ₁₁ NO ₄	9.2	170.3	[M+H] ⁺	3,4-Dihydroxy-1-phenylalanine	59-92-7	Synthesis intermediate, bio-additive which confers cohesion and adhesion to plastics, rubber bands and adhesives	5%	
C ₁₂ H ₁₀	-2.9	20.6	[M+H] ⁺	Acenaphthene	83-32-9	Synthesis intermediate of dyes and plastic production	5%	
C ₁₉ H ₂₀ O ₄	3.6	5.5	[M + H-H ₂ O] ⁺ , [M+H] ⁺	Benzyl-butyl-phthalate	85-68-7	Plasticizer-type plastic additive (confers durability, flexibility and other beneficial properties for materials)	10%	
C ₂₀ H ₂₂ O ₆	4.2	13.4	[M+H] ⁺	Matairesinol	580-72-3	Plant lignan, high presence in oilseeds, whole grains, vegetables and fruits	10%	
C ₁₇ H ₃₆ N ₂ O	-6.1	9.3	[M+H] ⁺	N-[3-(Dimethylamino)propyl]dodecanamide	3179-80-4	Synthesis intermediate	33%	
C ₇ H ₁₃ N ₃ O ₄	4.1	6.5	[M - H] ⁻	Tetrahydro-5-(2-hydroxyethyl)-1,3-bis(hydroxymethyl)-1,3,5-triazin-2(1H)-one	1852-21-7	Plastic additives, UV filter	8%	
C ₁₃ H ₁₆ S	-2.3	50.1	[M - H] ⁻	2-Pentyl-1-benzothiophene	89,969-72-2	Unspecified	17%	
C ₂₂ H ₄₄ O ₂	8.1	18.9	[M - H] ⁻	Behenic Acid	112-85-6	Fatty acid, as plastic additives have emollient function, emulsifier or lubricant or release agent, among other	8%	
C ₂₈ H ₄₃ O ₄ P	5.6	10.6	[M - H] ⁻	Bis(2-octylphenyl) hydrogen phosphate	28,258-94-8	Unspecified	25%	
C ₁₆ H ₂₂ O ₈	-2.4	8.8	[M - H] ⁻	Coniferin	531-29-3	Glycoside, plant metabolite	8%	
C ₁₈ H ₁₆ O ₇	7.9	48.9	[M - H] ⁻	Eupatilin	22,368-21-4	Plant flavone (source from food)	8%	
C ₁₆ H ₃₂ O ₂	0.4	13.8	[M - H] ⁻	Isopalmitic Acid	32,844-67-0	Fatty acid, as plastic additives have emollient function, emulsifier or lubricant or release agent, among other	8%	
C ₁₀ H ₁₈ O	9.6	12.1	[M - H] ⁻	Nerol	106-25-2	Monoterpene, essential oils	33%	

higher concentrations (n.d.-292 $\mu\text{g g}^{-1}$). These results revealed the growing substitution of BPA by BPS, which has been proved by other authors (Chen et al., 2017; Vázquez-Loureiro et al., 2018). The greater concentration was found in a bottle cap made up of PET (polyethylene terephthalate). Although bisphenols are not traditionally associated to production of this type of plastic, a recent study has demonstrated their presence in recycled PET packages (Dreolin et al., 2019). Authors related the presence of bisphenols in PET with printing inks or other materials, or cross contamination during the processing. The presence of BPS in FCMs has been scarcely investigated and only two studies provided concentrations ranges of n.d.-7.5 $\mu\text{g g}^{-1}$ (Chen et al., 2017) and n.d.-12.17 $\mu\text{g g}^{-1}$ (Vázquez-Loureiro et al., 2018). It should also be noted that the presence of the other analyzed BPA replacements, have been only studied in thermal paper so far (Björnsdotter et al., 2017; Eckardt et al., 2017). D8 and BPS-MAE were detected with similar frequencies (DF: 32.5–35%) than BPS, although at lower concentration levels in the ranges of n.d.-2.44 $\mu\text{g g}^{-1}$ and n.d.-0.29 $\mu\text{g g}^{-1}$, respectively.

Aryl-OPFRs are plasticizers (among other functions). Their presence in food items have been reported in the last decade but scarcely in FCMs. To the best of knowledge, only a study of 2019 found 3 aryl-OPFRs, namely EHDPP (2-ethylhexyl diphenyl phosphate), TCPP [tris (2-chloropropyl) phosphate] and TPHP (triphenyl phosphate) in tetrabricks and juice containers, although they were not quantified. Among them, only EHDPP is a permitted substance to be used in FCMs (Sanchis et al., 2019). As it can be seen in Table 2, EHDPP was found in the range n.d.-0.2 $\mu\text{g g}^{-1}$ (DF: 22.5%) and CDP was also present in five samples with levels ranging n.d.-14 $\mu\text{g g}^{-1}$. EHDPP was quantified in two samples at the same concentration, which were a tube and its tube lid from the same package of apple cream, so that probably the same material was employed. The highest level of CDP was found in a yogurt cup, being the type of plastic of unknown composition.

3.3. Qualitative screening of other organic contaminants in FCMs with SUPRAS-DIP-QTOF-MS/MS and library search

The 18 positive samples were further analyzed with direct injection probe (DIP) coupled to high resolution mass spectrometry (QTOF). Data was acquired and treated as specified in section 2.4. Results of the tentatively identified compounds by library search are shown in Table 3. A Level 2 of identification (probable structure) was applied according to Schymanski et al., 2014). In our study, this involved matching spectrum data from a library to obtain an unambiguous spectrum-structure match. In total, 14 compounds were identified with detection frequencies in the range of 5 and 33%. Five natural compounds with vegetal origin were attributed to the contained food in the package (they were present due to migration from food or insufficient clean-up before analysis), seven compounds were plastic additives (UV filters to prevent package degradation, fatty acids and phthalates) or synthesis intermediates and for the other two ones the use could not be identified.

4. Conclusions

In this study, we evaluate the potential of using SUPRASs and ambient mass spectrometry for quantification and wide screening of organic contaminants in FCMs. The sample preparation consisted in rapid extraction step with SUPRAS of 1-decanol in ethanol:water mixtures (10:90, v/v) (1 min shaking with vortex, 0.4 mL SUPRAS per sample) and it was followed by analysis with ambient mass spectrometry. SUPRAS-ASAP-QqQ-MS/MS allowed the sensitive (LODs: 0.02–0.4 $\mu\text{g g}^{-1}$) and reproducible ($\leq 20\%$) quantification of bisphenols A and derivatives and organophosphate flame retardants with aryl substituents in FCMs, two families of emerging contaminants which were selected to carry out this study. SUPRAS-DIP-QTOF-MS/MS and spectral library search was evaluated to carry out a suspect screening to identify other types of additives in the samples and to investigate the potential of the technique to multi-residue analysis. Results showed that food contact materials are complex and that around the half of the analyzed samples contained bisphenols (n.d.-292 $\mu\text{g g}^{-1}$) or aryl-OPFRs (n.d.-14.2 $\mu\text{g g}^{-1}$) as well as other additives and unknown compounds, being FCMs a relevant human exposure route to contaminants.

Credit author

María Jesús Dueñas-Mas: Investigation, Writing-Original Draft; **Cristina de Dios-Pérez:** Investigation; **Ana Ballesteros-Gómez:** Conceptualization, Supervision, Writing-Review & Editing; Funding acquisition; **Soledad Rubio:** Conceptualization, Supervision, Writing-Review & Editing, Funding acquisition.

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.

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.chemosphere.2023.138359>.

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