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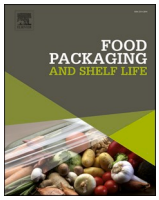

Investigation of migrants from can coatings: Occurrence in canned foodstuffs and exposure assessment

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ABSTRACT

In the present study migrants from can coatings, specifically epoxy and polyester resins, were determined in canned foods. Targeted and non-targeted approaches were applied to explore the migrating compounds. Bisphenol A (BPA), BADGE .2 H_2O, BADGE·H_2O.HCl and cyclodiBADGE from epoxy resins and three monomers i.e., terephthalic acid (TPA), phthalic acid (PA), isophthalic acid (IPA) and four tentatively identified oligomers from polyester resins were found in the foodstuffs. Using the consumption data from the Spanish consumption survey, dietary exposure to these chemicals was assessed. Mainly, our data suggested low exposure to the migrants evaluated, however, it is important to highlight that cyclic oligomers showed the highest mean exposure (0.00646–2.75 μg/kg bw/day) and these molecules belong to Cramer class III, which means that they may have significant toxicity.

1. Introduction

The food contact surface of metal cans is often covered with polymeric coatings that serve as a functional barriers between the food and the metallic can. Coatings based on different chemistries have been applied. Traditionally, BADGE epoxy resins have been extensively employed owing to their exceptional mechanical properties and chemical resistance (LaKind, 2013). Although they are still used there is a growing concern about the potentially adverse effects of BPA on consumers' health. In line with this, the recent EFSA draft opinion proposes lowering the TDI down to 0.04 ng/kg bw/day (EFSA, 2021). This situation has led to the development of new coatings. Polyester-based coatings appear as substitute to epoxy resins (Driffield et al. 2018).

Polymeric coatings are mixtures that contain a wide variety of compounds. Besides the intentionally added substances (e.g., additives, prepolymers, monomers and so on) they also contain substances formed during the processing of the polymeric materials, (e.g., reaction products, oligomers, and so on). All these substances may migrate into the food. Most of them are unknown and their toxicity has not been evaluated (Grob, Spinner, Brunner & Etter, 1999). In the case of oligomers, they could be considered substances inherent to polymers since they are always present (Hoppe, de Voogt, & Franz, 2016). Recently, the migration of oligomers from food contact materials has received increasing consideration in the EFSA risk assessments (EFSA, 2016, Tsochatzis, Lopes, Kappenstein, Tietz & Hoekstra, 2020).

To ensure the protection of human health, polymeric coatings as all types of food contact materials must comply with the requirements of Article 3 of the Regulation (EC) No. 1935/2004 (European Union, 2004). At present, there is no harmonized legislation for coatings in the European Union. There is a Resolution of the Council of Europe that includes a general guideline and a technical document with the list of substances to be used in the manufacture of coatings for food contact (CoE, 2009).

Migration data together with food consumption are key information for exposure and safety evaluations (Poças, & Hogg, 2007). Therefore, it is essential to analyse the packed foods to know whether unacceptable amounts of migrants are present in the food. At this point, it is important to mention that for many migrants (e.g., oligomers) there are no commercial standards available, which hamper the migration quantification. Therefore, alternative approaches should be explored, the custom synthesis of chemical migrants could be an option to overcome this inconvenience.

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On the other hand, migration data in food is also needed for a more realistic exposure estimation.

Very few migration data in food, particularly regarding polyester migrants, have been published (Driffield et al. 2018; Paseiro-Cerrato, DeJager, & Begley, 2019; Cariou et al. 2022), and there is even less data on exposure to migrants released from the coatings of metal cans.

This study aimed to determine starting substances and oligomers migrated from polymeric coatings, specifically epoxy and polyester resins, into canned foodstuffs. Samples were collected in order to cover different food types and to be representative samples of canned foods widely consumed in Europe. The polymeric coatings were identified by FTIR, and extracted to identify potential migrants, that would later be analysed in the packaged food. The analyses were achieved through non-targeted methods for unknown compounds (e.g., oligomers) and target methodologies for intentionally added substances (e.g., monomers). Finally, the exposure to chemicals migrated from polymeric coatings was estimated in the Spanish adult population, combining migration data with consumption data obtained from the national consumption survey.

2. Materials and methods

2.1. Samples

A total of twenty-two canned foodstuffs of several brands and covering different food types (e.g., fish, vegetables, legumes, etc.) were purchased in a local supermarket in Santiago de Compostela (Spain). Samples were selected among the canned foods most consumed by the European population according to the EFSA comprehensive European food consumption database (e.g., mackerel, tunas and similar, lentils etc.) (EFSA, 2022). Detailed information (e.g., fat content, pH) is listed in Table 1. The pH of the food samples was determined in a similar way to that described in a previous study (Lestido-Cardama et al., 2021). The values presented in Table 1 are the average of two measurements.

The polymeric food contact coatings were identified by FTIR, for that purpose small pieces of the different parts of the can (lid, body, base and seam) were cut and analysed. Results are displayed in Table 1.

2.2. Standards and reagents

Acetonitrile (ACN) HPLC and LC-MS grade, methanol (MeOH) HPLC and LC-MS grade, tetrahydrofuran (THF) HPLC grade, formic acid 98%– 100% LC-MS grade and trifluoroacetic acid (TFA) were from Merck (Darmstadt, Germany). Ultrapure water (type I) was obtained from an Autwomatic Plus purification system (Wasserlab, Navarra, Spain).

Commercially available QuEChERS kits containing 4 g magnesium sulphate, 1 g sodium chloride, 1 g sodium citrate dihydrate, 0.5 g sodium hydrogen citrate sesquihydrate were purchased from Agilent (Santa Clara CA, USA).

For the quantification of bisphenols and BADGEs, analytical standards used in this study were described elsewhere (Lestido-Cardama, Sendón, Bustos, Santillana, Paseiro-Losada & Rodríguez-Bernaldo de Quirós, 2019). Independent solutions of each bisphenol and BADGEs were prepared in ACN at a concentration of 1000 mg/L. A solution of 200 mg/L of cyclo-di-BADGE was prepared in a mixture of ACN:THF (30:20, v/v). An intermediate mix solution of all compounds at a concentration of 10 mg/L and calibration solutions were prepared in ACN by subsequent dilutions.

Analytical standards of polyvalent carboxylic acids, phthalic acid (PA)≥ 99.5%, isophthalic acid (IPA)≥ 97%, terephthalic acid (TPA)≥ 98%, and 3,4,5,6-d_4-phthalic acid (PAd4) were provided by Sigma-Aldrich (Schnelldorf, Germany). Single stock solutions of 50 mg/L for each compound were made in ACN, except for TPA which was prepared in MeOH. Working solutions of all compounds were prepared in ACN: H_2O (50:50, v/v) by subsequent dilutions from a single intermediate mix

Table 1
Samples description and FTIR identification of polymeric coatings.

Can Code	Food type	pH	Fat content (%)	Polymeric coating
AC	Light tuna in olive oil	6.0	14	Lid: acrylic base Body: acrylic base
BN	Tuna in olive oil	6.4	16	Lid: acrylic base Body: acrylic base
CH	Stuffed squid in sunflower oil	6.5	9.8	Lid: acrylic base Body: acrylic base
CTO	Mackerel fillets in tomato sauce	5.8	5.7 *	Lid: acrylic base Body: acrylic base
CAG	Mackerel fillets in sunflower oil	6.1	13 * *	Lid: acrylic base Body: acrylic base
CAO	Mackerel fillets in olive oil	6.1	12 * *	Lid: acrylic base Body: acrylic base
SCA	Sardines in olive oil	6.4	23 *	Lid: polyester Body: polyester
SCO	Sardines in olive oil	6.4	32.2 * ; 15.3 * *	Lid: acrylic base Body: acrylic base
LE	Riojan lentils	5.6	8.0	Lid: polyester Body: polyester Base: polyester Seam: PET
AL	Meatballs in sauce	5.4	6.0	Lid: polyester Body: epoxy Base: epoxy Seam: PET
RAV	Egg ravioli with meat and tomato sauce	4.6	2.5	Lid: polyester Body: epoxy Base: epoxy Seam: PET
PAT	Stewed potatoes with meat	5.3	1.5	Lid: polyester Body: polyester-polyurethane Base: polyester-polyurethane Seam: PET
LEV	Lentils with vegetables	5.2	2.7	Lid: polyester Body: polyester-polyurethane Base: polyester Seam: PET
PM	Bell peppers	3.7	< 0.5	Lid: polyester Body: epoxy Base: epoxy Seam: PET
GUIM	Green peas	5.9	< 0.5	Lid: polyester Body: epoxy Base: epoxy Seam: PET
TOE	Whole peeled tomato	4.1	0.1	Lid: acrylic base Body: acrylic base Base: epoxy Seam: PET
CHA	Sliced mushroom	5.1	0.1	Lid: acrylic base Body: epoxy Base: epoxy Seam: PET
TOT	100% Natural crushed tomato	4.1	0.1	Lid: acrylic base Body: acrylic base Base: epoxy Seam: PET
GUIB	Green peas	6.1	0.8 * *	Lid: acrylic base Body: polyester Base: polyester Seam: PET
TOR	Gherkin, carrot, pink onion and black olive	3.4	2.7	Lid: acrylic base Body: acrylic base Base: epoxy Seam: PET
JU	Broad green beans	5.0	0	Lid: polyester Body: acrylic base Base: epoxy Seam: polyester
ME	Pickled mussel	4.4	8.4 * *	Lid: epoxy Body: epoxy

*net weight, * *drained weight, PET polyethylene terephthalate.

solution of 10 mg/L and stored at 4ºC. Each working solution contained the corresponding amount of internal standard (IS) to yield a final concentration of 5 mg/L.

Bisphenol A ethoxylate dimethacrylate (bisEMA) was acquired from Sigma-Aldrich (Schnelldorf, Germany).

Bis(2-hydroxyethyl) terephthalate (BHET) used as a reference standard for the semi-quantification of some of the tentatively identified oligomers was purchased from Sigma-Aldrich (Schnelldorf, Germany). A solution of 1000 mg/L was made in ACN, and intermediate solutions were prepared by subsequent dilutions.

Oligoesters based on IPA and neopentylglycol (NPG), specifically 2NPG+ 2iPA(L), 2NPG+ 2iPA(C), 4NPG+ 4iPA(C) and d4–2NPG+ 2iPA (C) were used for identification and quantification purposes and as internal standard, respectively. Regarding d4- 2NPG+ 2iPA(C), the ammonium adduct (*m/z* 490.2) was selected for the quantification, the protonated molecular ion (*m/z* 473.2) was also observed.

Detailed information about the synthesis procedure is described elsewhere (Cariou et al. 2022). Single stock solutions of 200 mg/L were made in ACN and the working intermediate solutions were made by subsequent dilutions in ACN:H_2O (20:80, v/v) with the corresponding amount of IS to yield a final concentration of 1 mg/L.

2.3. Instrumentation and analytical conditions

2.3.1. FTIR

The polymeric coating of the internal side of the metallic cans (body, base, lid and seam) was identified using a FTIR spectrometer (FTIR 4700, Jasco, Tokyo, Japan) coupled to an ATR (attenuated total reflectance, ATR-PRO-ONE) acquiring in a range between 4000 and 650 cm^{-1}. Spectra Manager (version 2) software was used for the acquisition of the infrared spectra and KnowItAll 17.4.135. B software for the identification, comparing the sample spectra obtained with IR Spectral Libraries of Polymers & Related Compounds (Bio-Rad Laboratories, Inc. Philadelphia, PA, USA).

2.3.2. HPLC-FLD

The identification and quantification of bisphenols and BADGEs were performed with a HPLC-FLD method. A detailed description of the equipment used is presented in an earlier work (Lestido-Cardama et al. 2021). The chromatographic separation was performed on a reversed-phase column Phenosphere 80 A ODS (2) (150 mm × 4.6 mm internal diameter, 3 μm particle size) thermostated at 25 °C. Mobile phases were water (A) and ACN (B) using a gradient elution method in the following conditions: the mobile phase started with 80%A and 20%B for 2 min, reaching 50%B at minute 15 and, followed by another gradient up to 100%ACN at minute 40 and hold for 5 min. Finally, the initial conditions were resume at minute 50 with 5 min of post-time for cleaning and equilibration of the column. The injection volume was 10 μL, and the fluorescence detector was set at λex 225 nm and λem 305 nm. Moreover, LC-MS/MS was used for confirmation. The mass spectrometry conditions applied were reported in an earlier study (Lestido-Cardama et al. 2019).

2.3.3. LC-MS/MS

An LC-MS/MS method was used to quantify the carboxylic acids. A full description of the instrument used is provided elsewhere (Lestido--Cardama et al. 2021). The chromatographic separation was carried out on a reversed-phase column Gemini C18, 110 A, (150 ×3 mm with an internal diameter of 5 μm), also used in the previous work (Lestido--Cardama, et al. 2022). The mobile phases used were water (A) and ACN (B) both with 0.1%formic acid (v/v), using a flow rate of 0.3 mL/min and a gradient elution method. Briefly, the method started with 95%A and 5%B, increasing gradually the percentage of B until 10% at minute 5, then until 20%B at minute 10 and then until 30%B at minute 20. Finally, at minute 21 increased 100%ACN for 5 min and the gradient returned to initial composition for 5 min more. The column temperature and the injection volume were 35 °C and 10 μL, respectively.

Mass spectrometric conditions were optimized by direct infusion of a solution of 25 mg/L of each compound in negative ESI mode. A targeted method was carried out for the identification and quantification of three polyvalent carboxylic acid monomers: PA, IPA and TPA. MS data were acquired in selected reaction monitoring (SRM) mode. The *m/z* selected precursor ion was *m/z* 164.6 for PA, IPA and TPA; which was the most sensitive ion in the Q1 mass spectra. Two SRM transitions were monitored: *m/z* 164.6 > 121.1 transition used for quantification purposes for IPA and TPA and *m/z* 164.6 > 77.2 for quantification of PA with a collision energy of 16 and 19 V, respectively.

The internal standard (PAd4), previously infused in the conditions detailed above, the SRM transitions of *m/z* 169.2 > 81.2 (transition used for quantification purposes), and *m/z* 169.2 > 125.1 (transition used for identification purposes) were monitored with a collision gas energy of 19 and 14 V, respectively.

In addition, a non-targeted analysis was carried out with the aim to tentatively identify polyester oligomers following the methodology described earlier (Lestido-Cardama, et al. 2022). According to our previous results only positive electrospray ionization (ESI) mode was selected for the analysis; nitrogen was used as the nebulizer gas at a pressure of 35 psi and argon was used as auxiliary gas at a pressure of 10 psi. The spray voltage was maintained at − 3000 V. The MS data were acquired in full scan mode using two ranges (100–500 *m/z* and 500–1000 *m/z*) to increase the sensitivity. The temperatures of vaporizer and capillary were 340 and 350 °C, respectively.

For the semi-quantification of the tentatively identified oligomers, BHET was used as a proxy compound. A selected ion monitoring (SIM) method was applied, and *m/z* 255 > 193.1 transition was selected for quantification purposes.

With respect to the synthesised oligoesters, 2NPG+ 2iPA(L), 2NPG+ 2iPA(C) and 4NPG+ 4iPA(C) were injected under the same conditions, and d4–2NPG+ 2iPA(C) was used as internal standard.

2.3.4. LC-ESI-TOF

LC-ESI-TOF technique (timsTOF, mass spectrometer, Bruker, Massachusetts, USA) was used to confirm the identity of the oligomers extracted from the polyester coatings. The chromatographic and mass spectrometry conditions were the same as those used in LC-MS/MS analysis. MS data were acquired in a full scan mode in a range of 50–1000 *m/z*.

2.3.5. Sample treatment

2.3.5.1. Can coatings. The can coatings were extracted using ACN. Once the cans were empty and clean, they were extracted by filling with the solvent and stored at 40ºC for 24 h. Next, an aliquot of 5 mL was removed and concentrated to dryness with nitrogen, the residue was redissolved with 0.2 mL of ACN and with 0.2 mL of 20%ACN for epoxy and polyester resins analysis, respectively. Then, the resulting extracts were filtered through a PTFE membrane (0.22 μm pore size) before the chromatographic analysis.

2.3.5.2. Foods

2.3.5.2.1. Bisphenols and BADGEs. Bisphenols and BADGE derivatives were extracted from the canned food samples in accordance with the method proposed by Lestido-Cardama et al. (2021). The analysis was performed in duplicate. Samples containing both solid and liquid fractions were separated and treated independently. For the method validation, tuna in olive oil and the covering liquid of stuffed squid were used for recovery tests. Fortified samples were extracted as mentioned above.

2.3.5.2.2. Polyester monomers and oligomers. Polyester monomers were extracted using QuEChERS. The extraction was carried out on the basis of the procedure reported by Driffield et al. (2018). Briefly, to 10 g of sample previously homogenized was added 10 mL of ACN and the mixture was shaken in a laboratory shaker. Then, the QuEChERS salts were added and the mixture was hand-shaken for 1 min. Next, the extracts were centrifugated (Hettich Zentrifugen Universal 320 R) at 2000 rpm for 20 min and 5 mL of the supernatant was removed and placed in a vial. The extract was concentrated to dryness under nitrogen gas at a temperature of 35 °C. Finally, they were reconstituted with 0.5 mL of ACN and 0.5 mL of 0.1%formic acid in water, containing the internal standard (PAd4) at a final concentration of 5 mg/L, and filtered through a 0.22 μm PTFE filter. Recovery assays of polyester monomers were performed in spiked lentils samples.

To extract the polyester oligomers, 5 g of sample was weight in a tube of Teflon and 10 mL of ACN were added. The tube was capped and placed in an ultrasonic bath (Branson 5510 (Danbury, CT, USA)) for 2 h and then centrifuged at 2500 rpm for 5 min. Five mL of the supernatant was placed in a clean vial and concentrated to dryness under gentle nitrogen flow at 40 °C and reconstituted with 0.5 mL of 20%ACN:H_2O (v/v). The resulting extract was filtered through a 0.22 μm PTFE filter and transferred into a vial to be analysed.

2.3.6. Exposure assessment

The exposure was estimated by combining the migration data, namely the concentration of migrants released from the can coating in food, with consumption data obtained from the Spanish National Survey for adult population ENALIA-2.

It should be noted that for analytical results lower than the limit of quantification (LOQ) and limit of detection (LOD) values equal to LOQ/2 and LOD/2 respectively were considered according to the GEMS/Food–EURO recommendations (GEMS-Food Euro, 1995; Sirot, Hommet, Tard & Leblanc, 2012).

3. Results and discussion

3.1. Identification of polymeric food contact coatings

The inner coatings of metal cans were tentatively identified by FTIR. As can be inferred from Table 1 different coatings are currently being used. Several of the samples analysed incorporated coatings tentatively identified as epoxy-based resins. This type of coating is still used, it presents good mechanical properties, chemical resistance and in addition it is compatible with more food types than other coatings. However, owing to the concerns about the potential effects of bisphenol A on consumers' health, its use is being replaced by other alternative coatings.

Polyester-based resins are one of the newer coatings that are being used, nevertheless, they are not appropriate for very aggressive and acidic foods. Five of the samples analysed in this study had polyester-based coatings in the body of the can. The pH of the foods packed in these cans varied between 5.2 and 6.4. In 9 of the 11 samples containing foods with a pH value below 5.5, an epoxy coating was identified.

Other samples, specifically AC, BN, CH, CTO, CAG, CAO, SCO, TOT, TOR, JU and ME were tentatively identified as an acrylic base, obtaining good matches with the FTIR spectral libraries, but the analysis of the chemical migration profile after extraction revealed that the coating was clearly based on a BADGE resin. Since epoxy resins adhere well to the metal surfaces they are usually used as a base coat for acrylic coatings (LaKind, 2013), this fact could explain these results. In addition, it is also interesting to highlight that FTIR-ATR methods are used to analyse the sample surface within 1–2 μm in depth, which would support the identification of the superficial layer as acrylic base.

3.2. Food sample extraction procedure

3.2.1. Canned food

For bisphenols and BADGE derivatives, a solvent extraction-based method was carried out because of its simplicity and versatility to be applied to a wide variety of canned foods. The method consisted of three main steps homogenization, solvent extraction, and centrifugation as a clean-up process to remove solid particles. The mixture of n-heptane, for fat removal, and ACN90% proved to be an appropriate extraction solvent for epoxy migrants achieving recoveries > 63% (Goodson, Robin, Summerfield & Cooper, 2004, Lestido-Cardama et al. 2021).

Three different methods were assayed to extract carboxylic acids from the canned foods, specifically i) solvent extraction, ii) solid-phase extraction and iii) a QuEChERS method. The methods were evaluated based on the recoveries of the analytes. Thus, ACN was used as solvent since it has shown to be efficient in the extraction of migrants (Paseiro-Cerrato, DeJager & Begley, 2019; Driffield et al. 2018). A concentration step was necessary due to the low concentration of the monomers in food. Under these conditions fairly low recoveries (< 40%) were obtained. Further, solid-phase extraction using an SPE cartridge (Agilent Bond Elut C18, 500) and ACN containing 0.1%formic acid as extraction solvent was also tried, but lower recoveries (< 30%) were achieved.

The QuEChERS approach (Driffield et al. 2018) provided the best results in terms of recoveries (> 92%) and, in addition, it is considered a convenient alternative to traditional methods based on the principles of the green chemistry (Santana-Mayor, Socas-Rodríguez, Herrera-Herrera & Rodríguez-Delgado, 2019), therefore it was selected to perform the analyses.

Oligomers were extracted by a common solvent extraction method with ACN followed by centrifugation and concentration steps. Due to the low amounts of available analytical standards, the effectiveness of the clean-up procedure could not be evaluated. However, with this approach the matrix effects represent a significant limitation.

3.3. Chromatography, detection, and identification

Based on previous works and the data reported in the literature a generic gradient consisting of ACN and water was optimized for the analysis of epoxy migrants. Different elution programs and flow rates were tried. Moreover, four columns specifically, Kinetex C18 100 A (150 ×2.1 mm, 2.6 μm); Kinetex C18 100 A (150 ×2.1 mm, 5 μm); Kromaphase C18 100 (150 ×3 mm, 5 μm) and Phenosphere (ODS)2 80 A (150 ×4.6 mm, 3 μm) were tested. When using the Kinetex columns the separation of most compounds resulted in split peaks and a poor chromatographic resolution of BPA and BADGE·H_2O.HCl was observed with the Kromaphase C18 column.

The Phenosphere (ODS)2 stationary phase and the gradient started with 20% of ACN and increased to 100% in 40 min provided an appropriate separation for the analytes. Under the same chromatographic conditions LC-MS/MS was used as a confirmatory technique.

Since several coatings were tentatively identified as acrylic resins, the chromatographic method (HPLC-DAD) was applied to these samples to try to identify acrylic derivatives. Based on a study reported in the literature several wavelengths were selected (Paseiro-Cerrato, DeVries, & Begley, 2017). Three peaks with different UV spectra from phenolic compounds, namely at $t_R = 6.2$ (λ max. 226, 264, 362), $t_R = 16.6$ (λ max. 290) and $t_R = 23.2$ (λ max. 226, 268) were detected in both coatings and foods (BN, CTO, CAG, CAO, SCO and AC). The samples were also analysed by the LC-MS/MS method, but the identity of these 3 compounds could not be established., as no structural information was gained from the mass spectra obtained. A standard of bisphenol A ethoxylate dimetacrylate was injected under the same conditions but the retention time did not match the retention time of the unknown compounds, therefore they remained as unidentified migrants.

The separation of carboxylic acids was achieved using a Gemini (C18, 110 A, 150×3mm, 5 μm) column. Two different acids, specifically

0.1%(v/v) TFA and 0.1%formic acid, were tested to acidify the mobile phase. Both acids revealed a suitable separation of the monomers. However, although 0.1%TFA provided the best resolution, due to its dangerousness, 0.1%formic acid was chosen for subsequent analysis.

Full-scan analyses were performed over the range of 100–1000 *m/z* in positive mode for the detection of polyester oligomers and several peaks were detected. Masses were compared to an in-house oligomer database built with the common monomers used in the polyester coating formulations. The adducts of Na^+, K^+, NH_4^+, H^+ were considered. Only oligomers with a molecular weight up to 1000 *m/z* were considered since it is assumed that higher molecular weight compounds are non-absorbable in the gastrointestinal tract.

Three of the oligomers tentatively identified in the polyester coatings were also found in several food samples, specifically 2 TPA+BD/MBO+DEG(C) or 2 TPA+EG+ HMP(C), TPA+PG+EG(L) and 2 TPA+EG (L). In the case of 2TPA+BD/MBO+DEG (or 2TPA+HMP+EG)(C) the protonated molecular ion and the sodium adduct were observed at *m/z* 437.2 and *m/z* 459.2, respectively. The sodium adduct was chosen for quantitative analysis. For 2TPA+EG, the protonated molecule (*m/z* 359.1) and the ammonium adduct (*m/z* 376.1) were detected, this last one was used for quantification purposes. Whereas for TPA+PG+EG(L) only the sodium adduct (*m/z* 291.1) was detected. The selected adducts were those that provided the highest intensity. These results were also obtained by exact mass analysis using a LC-TOF-MS under the same chromatographic conditions. Thus, these three oligomers were detected at confidence level 4 according to the Schymanski scale (Schymanski et al. 2014).

As regards to the oligoesters synthesised, (2NPG+2iPA(L), 2NPG+ 2iPA(C), 4NPG+ 4iPA(C)) the protonated molecular ions (*m/z* 487.2; *m/z* 469.2) as well as the sodium, (*m/z* 509.2; *m/z* 491.2; *m/z* 959.3) ammonium (*m/z* 504.2; *m/z* 486.2; *m/z* 954.3) and potassium (*m/z* 525.2; *m/z* 507.1; *m/z* 975.3) adducts, respectively were observed. In the case of 4NPG+ 4IPA(C) the protonated molecule was not detected, which is in line with Cariou et al. (2022). 2NPG+ 2iPA(C) was identified and subsequently quantified in several food samples, precisely LEV, SCA_L, PAT_A and PAT_L, at concentrations between 0.27 and 0.91 μg/g.

3.4. In-house method validation

Both methods, HPLC-FLD for bisphenols and BADGE derivatives and LC-MS/MS for carboxylic acids were validated regarding linearity, sensitivity, repeatability, intermediate precision and recovery.

The quantification was performed by constructing calibration curves using six concentration levels for bisphenols, BADGE derivatives and carboxylic acids and four concentrations levels for BHET and 2NPG+ 2iPA(C), and they were adjusted to a linear equation. Each calibration-point is the average of two measurements. The linear equations of the calibration curves, and other linearity parameters are shown in Table 2. All compounds exhibited appropriate linearity over the range studied with r^2 values $\geq$ 0.9230.

The limits of detection (LOD) and quantification (LOQ) were estimated according to ACS guidelines (3:1 and 10:1 signal-to noise,

Table 2
Method validation (linearity, repeatability, recoveries and intermediate precision).

					Tuna (BN_A)						Stuffed squid's oil					
					Recovery (%)			Intermediate precision (R.S.D. %) (n = 6)			Recovery (%)			Intermediate precision (R.S.D. %) (n = 6)		
Compound	Range of linearity (mg/kg)	Equation	R^2	Repeatability (RSD%)	0.05	0.1	0.2	0.05	0.1	0.2	0.05	0.1	0.2	0.05	0.1	0.2
BADGE .2 H_2O	0.04–1	y = 1076.3x - 4.2117	0.9998	9	-	-	-	-	-	-	82	90	71	20	16	11
BPF	0.04–1.0	y = 508.26x + 0.6257	0.9999	13	-	-	-	-	-	-	75	76	70	9	11	7
BPE	0.04–1.0	y = 477.61x + 2.1945	0.9997	12	77	78	83	17	15	18	79	77	79	18	13	15
BPA	0.04–1.0	y = 621.58x + 0.833	0.9999	9	85	90	78	16	26	16	85	83	83	17	14	10
BADGE·H_2O. HCl	0.04–1.0	y = 1135.7x - 5.4496	0.9999	9	81	86	72	11	17	14	78	70	63	13	13	5
BADGE·H_2O	0.04–1.0	y = 1227.8x - 5.2233	0.9998	8	95	80	70	21	10	9	83	72	64	25	5	8
BPB	0.04–1.0	y = 819.51x - 1.4707	0.9998	10	95	87	72	22	24	5	80	76	67	19	6	13
BADGE.2HCl	0.04–1.0	y = 1165.7x + 1.123	0.9999	6	102	82	81	19	11	6	90	79	72	18	11	9
BADGE.HCl	0.04–1.0	y = 999.06x - 4.687	0.9999	9	90	69	75	10	13	7	71	71	71	16	12	9
BADGE	0.04–1.0	y = 1399.4x - 6.3097	0.9999	6	78	86	70	12	27	3	77	73	71	12	11	4
BPG	0.04–1.0	y = 935.23x - 3.6629	0.9997	10	78	71	74	10	5	5	78	71	75	20	4	14
CyclodiBADGE	0.04–2.0	y = 1152.3x + 5.3623	0.9997	7	101	72	76	25	4	9	-	-	-	-	-	-
					Lentils (LEV)											
					Recovery (%)						Intermediate Precision (R.S.D.%) (n = 6)					
					0.05		0.5		1.25		0.05		0.5		1.25	
TPA	0.01–1.0	y = 0.5385x + 0.0544	0.9958	2	137		107		99		15		22		16	
PA	0.01–1.1	y = 0.335x + 0.0125	0.9988	3	111		105		92		22		6		13	
IPA	0.01–1.2	y = 0.4429x + 0.0289	0.9978	5	129		106		97		12		18		12	
BHET	1–20	y = 27920x + 9449.8	0.9986													
2NPG-2IPA (C)	0.1–1	y = 3.8872x – 0.4601	0.9230													

respectively) (ACS, 1980). The LODs were 0.010 mg/kg for bisphenols and BADGE derivatives except for BPF and BPE for which a LOD of 0.020 mg/kg was achieved. LOQs of 0.025 mg/kg for bisphenols and BADGE derivatives and 0.040 mg/kg for BPE and BPF, respectively were obtained. The described methods have sufficient sensitivity to detect the compounds at a concentration below the specific migration limit (SML) namely, 0.05 mg/kg for BPA (Commission Regulation (EU) No 10/2011) (European Union, 2011) and 9 mg/kg for the sum of BADGE and their hydrolysed derivatives and 1 mg/kg for the sum of their hydrochloric derivatives (Regulation (EC) No. 1895/2005)(European Union, 2005). LODs and LOQs of 0.004 and 0.01 mg/kg, respectively, were reached for the carboxylic acids, which was lower than those reported by Brenz, Linke, & Simat, 2017 using HPLC-DAD.

In addition, the LOD; LOQ for BHET and 2NPG+ 2iPA(C) were determined obtaining values of 0.1; 0.2 and 0.05; 0.1 mg/kg, respectively.

Repeatabilities determined analysing seven replicates of the standards at one concentration level, 0.1 mg/kg for bisphenols and BADGE derivatives and 0.02 mg/kg for carboxylic acids and expressed as RSD (RSD% (n = 7)) were ≤ 13% and ≤ 5% respectively.

Intermediate precision and recoveries were evaluated by the addition of known amounts of the target compounds to food at three concentrations levels, specifically 0.05, 0.1 and 0.2 mg/kg for bisphenols and BADGE derivatives and 0.05, 0.5 and 1.25 mg/kg for PA, TPA and IPA, and in three separate days by duplicate (n = 6 replicates). Since these compounds usually migrate in a greater extent to fatty foods (Cabado et al. 2008; Lestido-Cardama et al. 2021), tuna and the covering liquid of squid (sunflower oil) were selected as representative of oily solid food and covering liquid to conduct the recovery assays.

For bisphenols and BADGE derivatives, recoveries ranged from 63% to 102%. The recoveries of BADGE .2 H_2O and BFE in tuna and cyclodiBADGE in stuffed squid's oil are not reported due to matrix interferences hampering good estimation. This behaviour has also been previously reported for BADGE in fat samples (Rauter, Dickinger, Zihlarz & Lintschinger, 1999).

Carboxylic acid recoveries varied between 92% and 137%. The worst recovery value (137%) was obtained for TPA at a concentration of 0.05 mg/kg. In connection with these results, Paseiro-Cerrato, DeJager, & Begley (2019), investigated the migration of these monomers in canned foods and obtained poor recoveries for TA in most of the samples analysed. The poor recovery measured for TPA at a spiked concentration of 0.05 mg/kg suggests that the extraction procedures should be optimized and improved to analyse the monomer in the different food items. In the present study a generic procedure was applied to determine the monomers in foods as a practical and compromise analytical solution for the different food matrices. However, despite this poor recovery value according to European Commission (EC) guidelines (European Commission Directorate General for Health and Food Safety, 2017), considering the method performance acceptability criteria, acceptable mean recovery value within the 70–120% range were obtained for the other monomers.

The precision values expressed as RSD% ranged between 3% and 27%. All values were < 25% except for BPA (26%) and BADGE (27%) in a tuna sample spiked at a concentration of 0.1 mg/kg. For BPA, the results were comparable to those reported by Tzatzarakis et al. (2017) from 7.9% to 17.5% in soft drinks, liquid and solid phase of canned food. RSD% values obtained for carboxylic acids were ≤ 22%.

3.5. Concentration of migrants in canned foodstuffs

3.5.1. Bisphenols and BADGE derivatives

The HPLC-FLD method was used to analyse bisphenols and BADGEs in canned foods. The concentrations obtained are presented in Table 3. Three BADGE derivatives (BADGE .2 H_2O, BADGE·H_2O.HCl and cyclodiBADGE) and BPA were detected above the LOD in more than 50% of the samples. Generally, the foods with the highest concentrations of BADGE derivatives, particularly cyclodiBADGE, and BPA were those with the highest fat content (e.g., BN_A (16% fat); CAO_A (12% fat)). Conversely, lower concentrations were found in low-fat foods (e.g., TOE_A (0.1% fat); CHA_L (0.1% fat)). These results are in agreement with those reported by Cabado et al. (2008) who found that the migration of BADGE and BFDGE occurs to a large extent in high-fat foods. Considering food categories seafood products presented the highest concentrations of the target analytes and vegetables the lowest. This trend was also observed in a previous work (Lestido-Cardama et al. 2021). Of all monitored migrants, the highest concentration found was 4.01 μg/g of cyclodiBADGE in a sample of mackerel fillets in sunflower oil. This result is comparable to that obtained in a previous work in which a concentration of 3.59 μg/g was found in a sample of mussels (Lestido-Cardama et al. 2021). It is worth mentioning that in many samples higher concentrations were detected in the covering liquids than in the solid foods. Biedermann, Zurfluh, Grob, Vedani, and Brüschweiler (2013) reported lower values of cyclodiBADGE, specifically over the range of < 0.025–1.98 μg/g in canned fish. The acceptable migration level of 0.05 μg/g stated by the BfR in its opinion (BfR Opinion 022/2016) was exceeded in most of the samples analysed in this study.

Regarding BADGE .2 H_2O and BADGE·H_2O.HCl, the found concentrations ranged from < LOD to 0.65 μg/g and from < LOD to 0.09 μg/g, respectively. All samples were below the restriction levels (Regulation

Table 3
Concentrations of bisphenol A and BADGE derivatives in canned foodstuffs.

Sample	Compound concentration (μg/g)			
	BADGE .2 H_2O	BPA	BADGE·H_2O.HCl	CyclodiBADGE
BN_A	0.65	0.05	0.04	0.41
BN_L	0.16	0.02	<LOD	0.49
CH_A	0.11	0.04	<LOD	0.30
CH_L	<LOD	<LOD	<LOD	2.78
CTO_A	0.51	0.06	0.07	0.55
CTO_L	0.11	<LOD	<LOD	1.22
CAG_A	0.43	0.08	0.09	0.71
CAG_L	0.03	0.04	<LOD	4.01
CAO_A	0.51	0.09	0.11	0.49
CAO_L	0.31	0.03	<LOD	3.63
SCO_A	0.52	0.04	0.06	0.44
SCO_L	0.26	<LOD	<LOD	2.44
ME_A	0.09	<LOD	<LOD	0.11
ME_L	<LOD	<LOD	<LOD	0.72
AC_A	0.64	0.07	0.06	1.19
AC_L	0.09	<LOD	<LOD	0.99
AL_A	0.11	<LOD	<LOD	0.07
RAV_A	0.11	<LOD	<LOD	<LOD
RAV_L	0.07	<LOD	<LOD	0.69
PM_A	0.09	0.08	<LOD	0.03
PM_L	0.06	<LOD	<LOQ	<LOD
GUIM_A	0.37	0.13	0.05	0.09
GUIM_L	0.06	<LOD	<LOD	<LOD
TOE_A	0.08	<LOD	<LOQ	0.02
TOE_L	0.07	<LOD	<LOD	0.02
CHA_A	0.31	0.09	0.07	0.05
CHA_L	0.06	<LOD	<LOD	<LOD
TOT	<LOD	<LOD	<LOD	<LOD
TOR_A	0.05	<LOD	<LOD	0.03
TOR_L	0.05	<LOD	<LOD	<LOD
JU_A	0.13	0.04	0.05	0.07
JU_L	<LOD	<LOD	<LOD	<LOD
GUIB_A	<LOD	<LOD	<LOD	<LOD
GUIB_L	<LOD	<LOD	<LOD	<LOD

LOD BADGE.2H2O; BPA; BADGE. H2O.HCl; CyclodBADGE: 0.010 mg/kg.
LOQ BADGE .2 H_2O; BPA; BADGE·H_2O.HCl; CyclodBADGE: 0.025 mg/kg.
(Median: BADGE .2 H_2O: 0.11; BPA:0.055; BADGE·H_2O.HCl:0.06; CyclodiBADGE:0.49).
(Max.value: BADGE .2 H_2O: 0.65; BPA:0.13; BADGE·H_2O.HCl:0.11; CyclodiBADGE:4.01).
_A refers to solid fraction.
_L refers to liquid fraction.

(EC)No 1895/2005)(European Union, 2005). In comparison, our results are analogous to those reported by Míguez, Herrero, Quintás, Rodríguez, Gigosos, and Mariz (2012) in fish products and lower than those found by Alabi, Caballero-Casero, & Rubio, (2014) in canned vegetable products, fish and other seafood.

For BPA the concentrations obtained were in the range of <LOD–0.09 μg/g. These results were similar to those found by Munguía-López, M., Gerardo-Lugo, Peralta, Bolumen, & Soto-Valdez (2005) in tuna fish and lower than those reported by Sajiki, Miyamoto, Fukata, Mori, Yonekubo, and Hayakawa (2007) in canned food sold in Japanese markets. Seven of the analysed samples (CTO_A, CAG_A, CAO_A, AC_A, PM_A, GUIM_A, CHA_A) exceeded the SML of 0.05 mg/kg (Regulation [EU] No. 2018/213)(European Union, 2018), and in three of them BPA migrated in a quantity more than twice the SML. Following the new TDI established in the EFSA draft re-evaluation of BPA, it is probably expected that the current SML could be revised, and it could be lowered. Considering the results obtained in this study if the specific migration limit is lowered, the samples with BPA concentrations closer to the current SML (e.g., CH_A, CAG_L, SCO_A, JU_A) would be the ones most likely to be affected.

Lastly, it is worth mentioning that differences in the concentration of BADGE .2 H_2O and cyclodiBADGE were observed depending on the composition of the covering liquid in the mackerel fillets samples (CTO, CAG, CAO). Thus, the highest concentrations were found in the oily media, olive oil in the case of BADGE .2 H_2O and sunflower and olive oil for cyclodiBADGE, and on contrary the lowest concentrations were found in the covering sauce of tomato. This observation is in accordance with that reported by Cabado et al. (2008), who studied the influence of the covering sauce on the migration BADGE and BFDGE and found highest concentrations in the foods with the highest levels of fat.

3.5.2. Monomers and polyester oligomers

An overview of the concentrations of the monomers detected in the samples analysed is presented in Table 4. The concentrations of the individual monomers ranged from <LOD to 0.047 μg/g for TPA, from <LOD to 0.022 μg/g for PA and from <LOD to 0.013 μg/g for IPA. TPA was detected in almost all samples analysed, in contrast, IPA was detected in only six samples (GUIB, AL, GUIM_L, RAV_L, PAT, PAT_L). The TPA concentrations are consistent with those reported by Paseiro-Cerrato et al. (2019), however, the concentrations of IPA found in this study are lower than those described by the mentioned authors.

The detected concentrations of the monomers were in all samples much lower than the specific migration limits (SML) (IPA 5 mg/kg; TPA 7,5 mg/kg) (Commission Regulation (EU) No 10/2011)(European Union, 2011). Among the samples analysed it was not possible to establish a clear tendency between the concentration of the monomers and the food composition (i.e., fat content).

Four oligomers previously identified in the polymeric coatings (i.e., 2 TPA+BD/MBO+DEG(C) or 2 TPA+EG+HMP(C); TPA+PG+EG(L); 2TPA+EG(L) and 2NPG+ 2iPA(C) were detected in several food samples. Due to the lack of analytical standards no confirmation of identity was performed for the first three oligomers. BHET was used as a proxy for the semi-quantification of oligomers. Nonetheless, for 2NPG+ 2iPA (C) the confirmation of the identity was carried out by using the synthesised standard. The estimated concentrations of the oligomers are given in Table 4. 2 TPA+BD/MBO+DEG(C) was detected at concentrations ranging from <LOD to 1.37 μg/g, being a sample of green peas the one that presented the highest concentration. 2NPG+ 2iPA(C) was detected in several samples at concentrations varying between <LOD and 0.91 μg/g, whilst TPA+PG+EG and 2TPA+EG were only detected in one sample; the quantification of this last oligomer was not possible due to the matrix effect leading to signal enhancement. Comparing our

Table 4
Concentration of polyester monomers and estimated concentration of oligomers in canned foodstuffs.

Compound concentration (μg/g)							
Sample	TPA	PA	IPA	2TPA+EG (L) (NH_4^+)	2TPA+BD/MBO+DEG (C)/2TPA+EG+HMP (C) (Na+)	TPA+PG+EG (L) (Na+)	2NPG+ 2IPA (C) (NH_4^+)
LEV	0.018	<LOQ	<LOD	<LOD	1.12	<LOD	0.37
LE	0.047	<LOD	<LOD	<LOD	0.48	0.24	<LOD
GUIB_A	0.025	<LOQ	<LOQ	*	1.37	<LOD	<LOD
GUIB_L	0.03	<LOQ	<LOD	<LOD	<LOD	<LOD	<LOD
SCA_A	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
SCA_L	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.45
AL	<LOQ	<LOD	<LOQ	<LOD	<LOD	<LOD	<LOD
PM_A	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PM_L	<LOQ	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
GUIM_A	<LOQ	<LOQ	<LOD	<LOD	<LOD	<LOD	<LOD
GUIM_L	<LOQ	<LOQ	<LOQ	<LOD	<LOD	<LOD	<LOD
CHA_A	<LOQ	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
CHA_L	<LOQ	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
TOT	<LOD	0.022	<LOD	<LOD	<LOD	<LOD	<LOD
TOR_A	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
TOR_L	<LOD	0.006	<LOD	<LOD	<LOD	<LOD	<LOD
RAV_A	<LOQ	<LOQ	<LOD	<LOD	<LOD	<LOD	<LOD
RAV_L	0.01	0.009	<LOQ	<LOD	<LOD	<LOD	<LOD
TOE_A	<LOD	<LOQ	<LOD	<LOD	<LOD	<LOD	<LOD
TOE_L	<LOQ	0.009	<LOD	<LOD	<LOD	<LOD	<LOD
PAT_A	0.016	<LOD	0.013	<LOD	<LOD	<LOD	0.91
PAT_L	0.02	<LOD	0.013	<LOD	<LOD	<LOD	0.27
JU_A	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
JU_L	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

BD: butanediol (1,3 and 1,4); DEG: diethylene glycol; EG: ethylene glicol; HMP: 1,1,1-Tris(hydroxymethyl)propane; MBO:2-methyl-1,3-propanediol; PG: propylene glycol (1,2 and 1,3).
(L):linear; (C): cyclic
LOD TPA, PA, IPA: 0.004 mg/kg; LOD BHET: 0.1 mg/kg LOD 2NPG+ 2IPA (C): 0.05 mg/kg.
LOQ TPA, PA, IPA: 0.01 mg/kg; LOQ BHET: 0.2 mg/kg LOQ 2NPG+ 2IPA (C): 0.1 mg/kg.
(*) Not quantified.
(Median: TPA:0.02; PA:0.009; IPA:0.013; 2TPA+BD (C):1.12; TPA+PG+EG(L): 0.24; 2NPG+ 2IPA(C): 0.41).
(Max. value: TPA:0.047; PA:0.022; IPA:0.013; 2TPA+BD (C):1.37; TPA+PG+EG(L): 0.24; 2NPG+ 2IPA(C): 0.91).
_A refers to solid fraction; _L refers to liquid fraction.

results with other studies recently published on the occurrence of polyester oligomers in canned foodstuffs (Paseiro-Cerrato et al. 2019; Cariou et al. 2022), the estimated concentrations obtained in this work were slightly higher. These differences could be due to the different types of coatings, even also to the different types of canned foods.

3.6. Dietary exposure assessment

The dietary exposure data (mean and 95th percentile) to chemicals (i.e., bisphenols, BADGE derivatives and polyester monomers and oligomers) transferred from food contact coatings of metal cans are summarized in Tables 5 and 6. To estimate the exposure, both the liquid and solid fractions were considered as a whole sample.

Regarding epoxy migrants, estimated mean dietary exposure ranged from 0.000646 to 0.670 μg/kg bw/day for BADGE .2 H_2O and between 0.000646 and 0.235; 0.000646–0.104 and 0.000646–0.671 μg/kg bw/day for BPA, BADGE·H_2O.HCl and cyclodiBADGE, respectively.

CTO, CAO, CAG and AC were identified to be the major contributors to the adult BPA and BADGE derivatives exposure within the seafood products category and GUIM and JU within the vegetable category.

In general, the exposure levels to BADGE derivatives obtained in this study were low, in all cases below the TDI of 0.15 mg/kg bw/day for BADGE and its hydrolysis products (EFSA, 2004, EFSA, 2015). In the case of BPA, the calculated dietary intakes were in all cases below the temporary tolerable daily intake (t-TDI) of 4 μg/kg bw/day, but however were higher than the recent TDI proposed in the EFSA draft opinion. Thus, by comparing the new TDI with the dietary exposure estimation to BPA, the consumers with both average and high exposure to BPA in the population group studied exceeded the new TDI. These results confirm the exposure data reported in the literature (Zhou et al. 2019; Liao and Kannan, 2013). The lower TDI recommended by EFSA can also affect the industrial practices, in the sense that they should carry out a stricter control of the materials they use to ensure that they comply with the limits.

Concerning the polyester monomers, very limited information on exposure to these chemicals has been reported in the literature; the results obtained in this study varied between 0.000517 and 0.0851 μg/kg bw/day. LEV and GUIB turned out to be the main contributors. Our data were slightly lower than the dietary exposure levels (0.01–0.13 μg/kg bw/day) of TPA migrated from PET reported by Shin, Kim, Kim, Kim, Song & Oh, 2021, and well below the reference dose (RfD) of 1.0 mg/kg bw/day (Shin et al. 2021).

The dietary exposure to oligomers has been scarcely studied, recently. Tsochatzis et al. (2020) investigated the exposure to PET oligomers migrated from teabags. The authors concluded that the threshold of 90 μg/day/person was not exceeded with a single consumption. As regards our study, the estimated exposure varied between 0.00646 and 2.75 μg/kg bw/day. Lentils (LEV) and the green peas (GUIB) appeared to be major contributors to dietary exposure. The highest values corresponded to the cyclic oligomers, which is particularly interesting for several reasons. On the one hand, these molecules belong to Cramer class III (high toxicity), especially those formed from aromatic dicarboxylic acids TPA or IPA (Eckardt, Hetzel, Brenz & Simat, 2020) and, on the other hand, usually the oligomers together with impurities and reaction products are the greatest migrating substances (Grob, 2014). Regarding the threshold of toxicological concern (TTC) approach it is interesting to note that Cramer rules are used as a screening tool to estimate the toxicity of a given compound when toxicological data do not exist or are very limited. The exposure assessment used should overestimate dietary exposure of high consumers using conservative assumptions in particular in what concerns to food consumption and chemical concentrations (EFSA and WHO, 2016). Molecules belonging to Cramer class III include structural features that permit no strong initial impression of safety or may even suggest significant toxicity, the threshold of toxicological concern (TTC) established for these molecules is 90 μg/person/day. Structures indicative of potential high toxicity include aliphatic secondary amino, cyano, halogeno-compounds, etc. many of them are Class III because they undergo metabolic bioactivation to potentially toxic chemical entities. Additionally, neurotoxins, teratogens or endocrine disrupting chemicals should be considered as separate classes (Patlewicz, Wambaugh, Felter, Simon & Becker, 2018; Kroes et al. 2004). Although high exposure to class III molecules could represent health concerns, however, these results need to be considered carefully, since any exposure assessment is confronted with a number of uncertainties related to the concentration of chemicals in food and the food consumption surveys (Kroes et al. 2002).

Table 5
Dietary exposure mean and (P95) to bisphenol A and BADGE derivatives in the Spanish adult population (μg/kg bw per day).

Sample	BADGE .2 H_2O	BPA	BADGE·H_2O.HCl	CyclodiBADGE
BN	0.333 (0.676)	0.0256 (0.0520)	0.0205 (0.0416)	0.210 (0.426)
CH	0.151(n.a.)	0.0547 (n.a.)	0.00342 (n.a.)	0.4105 (n.a.)
CTO	0.482 (1.16)	0.0567 (0.136)	0.0662 (0.159)	0.520 (1.25)
CAG	0.407 (0.977)	0.0756 (0.182)	0.0851 (0.205)	0.671 (1.61)
CAO	0.482 (1.16)	0.0851 (0.205)	0.104 (0.250)	0.463 (1.11)
SCO	0.492 (1.18)	0.0378 (0.0909)	0.0567 (0.136)	0.416 (1.00)
ME	0.0395 (n.a.)	0.00110 (n.a.)	0.00110 (n.a.)	0.0482 (n.a.)
AC	0.328 (0.666)	0.0359 (0.0728)	0.0308 (0.0624)	0.610 (1.24)
RAV	0.0804 (0.177)	0.00183 (0.00402)	0.00183 (0.00402)	0.00183 (0.00402)
GUIM	0.670 (n.a.)	0.235 (n.a.)	0.0906 (n.a.)	0.163 (n.a.)
TOE	0.0207 (0.0986)	0.000646 (0.00308)	0.00162 (0.00770)	0.00517 (0.0246)
TOT	0.000646 (0.00308)	0.000646 (0.00308)	0.000646 (0.00308)	0.000646 (0.00308)
TOR	0.0898 (0.238)	0.00449 (0.0119)	0.00449 (0.0119)	0.0539 (0.143)
JU	0.233 (0.619)	0.0718 (0.190)	0.0898 (0.238)	0.126 (0.333)
GUIB	0.00453 (n.a.)	0.00453 (n.a.)	0.00453 (n.a.)	0.00453 (n.a.)

n.a.: not available

4. Conclusions

Targeted and non-targeted methodologies were applied to determine migrants transferred from polymeric coatings, specifically epoxy and polyester, into canned foodstuffs.

Sample extraction procedures were optimized for the different analytes. Overall satisfactory results were obtained. However, in some matrices (e.g., stuffed squid's oil) and for certain analytes, the method should be improved to achieve optimal performances. As regards the concentration of the migrants in foods and despite the limited number of samples tested, it is interesting to remark that even though of the potential adverse effects of BPA, the concentrations detected exceeded the regulatory limit in several samples, and cyclodiBADGE exceeded the acceptable migration level of 0.05 μg/g stated by the BfR in most of samples analysed. The estimated concentrations of the other analytes were lower than the existing SMLs. Oligomer concentrations ranged from not detected to 1.37 μg/g, mainly, our results suggested a low dietary exposure. Nevertheless, the highest values corresponded to oligomers, which is of particular concern since some of them belong to Cramer Class III. These results cannot be compared with other studies because to the knowledge of the authors no exposure data to these migrants have been previously published. A total diet study with a larger panel of oligomers, and further toxicological studies would be recommended to refine this rough estimation.

Table 6
Dietary exposure mean and (P95) to polyester monomers and oligomers in the Spanish adult population (μg/kg bw per day).

Sample	TPA	PA	IPA	2TPA+EG (L)	2TPA+BD/MBO+DEG (C)	TPA+PG+EG (L)	2NPG+ 2IPA (C)
LEV	0.0326 (n.a.)	0.00906 (n.a.)	0.00362 (n.a.)	0.0905 (n.a.)	2.03 (n.a.)	0.0905 (n.a.)	0.670 (n.a.)
LE	0.0851 (n.a.)	0.00362 (n.a.)	0.00362 (n.a.)	0.0905 (n.a.)	0.870 (n.a.)	0.435 (n.a.)	0.0453 (n.a.)
GUIB	0.0453 (n.a.)	0.00906 (n.a.)	0.00906 (n.a.)	*	2.75 (n.a.)	0.0905 (n.a.)	0.0453 (n.a.)
SCA	0.00189 (0.00455)	0.00189 (0.00455)	0.00189 (0.00455)	0.0472 (0.113)	0.0472 (0.113)	0.0472 (0.113)	0.425 (1.02)
GUIM	0.00906 (n.a.)	0.00906 (n.a.)	0.00362 (n.a.)	0.0905 (n.a.)	0.0905 (n.a.)	0.0905 (n.a.)	0.0453 (n.a.)
TOT	0.000517 (0.00246)	0.00568 (0.02710)	0.000517 (0.00246)	0.0129 (0.0615)	0.0129 (0.0615)	0.0129 (0.0615)	0.00646 (0.0308)
TOR	0.00359 (0.00952)	0.00359 (0.00952)	0.00359 (0.00952)	0.0897 (0.238)	0.0897 (0.238)	0.0897 (0.238)	0.0449 (0.119)
RAV	0.0036 (0.00804)	0.0036 (0.00804)	0.00146 (0.00322)	0.0365 (0.0803)	0.0365 (0.0803)	0.0365 (0.0803)	0.0183 (0.0402)
TOE	0.000517 (0.00246)	0.00192 (0.00616)	0.000517 (0.00246)	0.0129 (0.0615)	0.0129 (0.0615)	0.0129 (0.0615)	0.00646 (0.0308)
JU	0.00359 (0.00952)	0.00359 (0.00952)	0.00359 (0.00952)	0.0897 (0.238)	0.0897 (0.238)	0.0897 (0.238)	0.0449 (0.119)

n.a.: not available

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CRediT authorship contribution statement

P. Vázquez Loureiro: Investigation, Formal analysis, Validation, Writing – original draft. **A. Lestido-Cardama:** Investigation, Formal analysis, Validation, Writing – review & editing. **R. Sendón:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration. **J. Bustos:** Conceptualization, Methodology, Writing – review & editing. **R. Cariou:** Writing – review & editing. **P. Paseiro:** Conceptualization, Methodology, Writing – review & editing, Supervision. **A. Rodríguez-Bernaldo de Quirós:** Conceptualization, Methodology, Writing – original draft, Supervision, Project administration, 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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References

Alabi, A., Caballero-Casero, N., & Rubio, S. (2014). Quick and simple sample treatment for multiresidue analysis of bisphenols, bisphenol diglycidyl ethers and their derivatives in canned food prior to liquid chromatography and fluorescence detection. *Journal of Chromatography A, 1336*, 23–33. https://doi.org/10.1016/j.chroma.2014.02.008

American Chemical Society (ACS). (1980). Subcommittee of environmental analytical chemistry. *Analytical Chemistry, 52*, 2242–2280. https://pubs.acs.org/doi/pdf/10.1021/ac50064a004.

BfR Opinion 022/2016. (2016). *Epoxide resin coatings of cans: Substance transfer to oil-containing foods possible*. Germany: German Federal Institute for Risk Assessment.

Biedermann, S., Zurfluh, M., Grob, K., Vedani, A., & Brüschweiler, B. J. (2013). Migration of cyclo-diBA from coatings into canned food: Method of analysis, concentration determined in a survey and in silico hazard profiling. *Food and Chemical Toxicology, 58*, 107–115. https://doi.org/10.1016/j.fct.2013.04.004

Brenz, F., Linke, S., & Simat, T. (2017). Qualitative and quantitative analysis of monomers in polyesters for food contact materials. *Food Additives & Contaminants: Part A, 34*(*2*), 307–319. https://doi.org/10.1080/19440049.2016.1265672

Cabado, A. G., Aldea, S., Porro, C., Ojea, G., Lago, J., Sobrado, C., & Vieites, J. M. (2008). Migration of BADGE (bisphenol A diglycidyl-ether) and BFDGE (bisphenol F diglycidyl-ether) in canned seafood. *Food and Chemical Toxicology, 46*, 1674–1680. https://doi.org/10.1016/j.fct.2008.01.006

Cariou, R., Rivière, M., Hutinet, S., Tebbaa, A., Dubreuil, D., Mathé-Allainmat, M., … Dervilly, G. (2022). Thorough investigation of non-volatile substances extractible from inner coatings of metallic cans and their occurrence in the canned vegetables. *Journal of Hazardous Materials, 435*, Article 129026. https://doi.org/10.1016/j.jhazmat.2022.129026

CoE (2009). Policy Statement concerning coatings intended to come into contact with foodstuffs. Version 3, 12–02-2009.

Driffield, M., Garcia-Lopez, M., Christy, J., Lloyd, A. S., Tarbin, J. A., Hough, P., … Oldring, P. K. T. (2018). The determination of monomers and oligomers from polyester-based can coatings into foodstuffs over extended storage periods. *Food Additives & Contaminants: Part A, 35*(*6*), 1200–1213. https://doi.org/10.1080/19440049.2018.1440643

Eckardt, M., Hetzel, L., Brenz, F., & Simat, T. J. (2020). Release and migration of cyclic polyester oligomers from bisphenol A non-intent polyester–phenol-coatings into food simulants and infant food – A comprehensive study. *Food Additives & Contaminants: Part A, 37*(*4*), 681–703. https://doi.org/10.1080/19440049.2019.1616831

EFSA. (2004). Opinion of the scientific panel AFC related to bisphenol A diglycidyl ether (BADGE). *The EFSA Journal, 86*, 1–40.

EFSA. (2015). Scientific opinion on the risks to public health related to the presence of bisphenol A (BPA) in foodstuffs. *EFSA Journal, 13*(*1*), 3978.

EFSA. (2016). Recent developments in the risk assessment of chemicals in food and their potential impact on the safety assessment of substances used in food contact materials. *EFSA Journal, 14*(*1*), 4357.

EFSA and WHO (European Food Safety Authority and World Health Organization). (2016). *Review of the Threshold of Toxicological Concern (TTC) approach and development of new TTC decision tree* (p. 50). EFSA Supporting Publications. EN-1006.

EFSA (2021). Bisphenol A: EFSA draft opinion proposes lowering the tolerable daily intake. https://www.efsa.europa.eu/en/news/bisphenol-efsa-draft-opinion-proposes-lowering-tolerable-daily-intake (Accessed 10 January 2023).

EFSA (2022). The EFSA Comprehensive European Food Consumption Database. https://www.efsa.europa.eu/en/data-report/food-consumption-data (Accessed 14 December 2022).

European Commission Directorate General for Health and Food Safety. SANTE/ 11813/2017. (2017) Analytical Quality Control and Method Validation Procedures for Pesticide Residues Analysis in Food and Feed.

European Union. (2004). Regulation (EC) 1935/2004. *Official Journal of the European Union, L338*, 4–17.

European Union. (2005). Regulation (EC) 1895/2005. *Official Journal of the European Union, L302*, 28–32.

European Union. (2011). Regulation (EU) 10/2011. In *Official Journal of the European Union, L12* pp. 1–89).

European Union. (2018). Regulation (EU) 2018/213. In *Official Journal of the European Union, L41* pp. 6–12).

GEMS-Food Euro. Second workshop on reliable evaluation of low-level contamination of food. In Proceedings of the Workshop in the Frame of GEMS-Food Euro, Kulmbach, Germany, 26–27 May 1995. EUR/HFA Target 22.

Goodson, A., Robin, H., Summerfield, W., & Cooper, I. (2004). Migration of bisphenol A from can coatings—effects of damage, storage conditions and heating. *Food Additives and Contaminants, 21*(*10*), 1015–1026. https://doi.org/10.1080/02652030400011387

Grob, K., Spinner, C., Brunner, M., & Etter, R. (1999). The migration from the internal coatings of food cans; summary of the findings and call for more effective regulation of polymers in contact with foods: A review. *Food Additives and Contaminants, 16*(*12*), 579–590. https://doi.org/10.1080/026520399283722

Grob, K. (2014). Work plans to get out of the deadlock for the safety assurance of migration from food contact materials? A proposal. *Food Control, 46*, 312–318. https://doi.org/10.1016/j.foodcont.2014.05.044

Hoppe, M., de Voogt, P., & Franz, R. (2016). Identification and quantification of oligomers as potential migrants in plastics food contact materials with a focus in polycondensates – A review. *Trends in Food Science & Technology, 50*, 118–130. https://doi.org/10.1016/j.tifs.2016.01.018

Kroes, R., Müller, D., Lambe, J., Löwik, M. R. H., Van Klaveren, J., Kleiner, J., … Visconti, A. (2002). Assessment of intake from the diet. *Food and Chemical Toxicology, 40*, 327–385.

Kroes, R., Renwick, A. G., Cheeseman, M., Kleiner, J., Mangelsdorf, I., Piersma, A., … Würtzen, G. (2004). European branch of the international life sciences institute, structure-based thresholds of toxicological concern (TTC): guidance for application to substances present at low levels in the diet. *Food and Chemical Toxicology, 42*, 65–83. https://doi.org/10.1016/j.fct.2003.08.006

LaKind, J. S. (2013). Can coatings for foods and beverages: Issues and options. *International Journal of Technology, Policy and Management, 13*(*1*), 80–95.

Lestido-Cardama, A., Sendón, R., Bustos, J., Santillana, M. I., Paseiro-Losada, P., & Rodríguez-Bernaldo de Quirós, A. (2019). GC-MS Screening for the identification of potential migrants present in polymeric coatings of food cans. *Polymers, 11*(*12*), 2086. https://doi.org/10.3390/polym11122086

Lestido-Cardama, A., Sendón, R., Bustos, J., Santillana, M. I., Paseiro-Losada, P., & Rodríguez-Bernaldo de Quirós, A. (2021). Multi-analyte method for the quantification of bisphenol related compounds in canned food samples and exposure assessment of the Spanish adult population. *Food Packaging & Shelf Life, 28*, Article 100671. https://doi.org/10.1016/j.fpsl.2021.100671

Lestido-Cardama, A., Vázquez-Loureiro, P., Sendón, R., Bustos, J., Santillana, M. I., Paseiro Losada, P., & Rodríguez Bernaldo de Quirós, A. (2022). Characterization of polyester coatings intended for food contact by different analytical techniques and migration testing by LC-MS^n. *Polymers, 14*(*3*), 487. https://doi.org/10.3390/polym14030487

Liao, C., & Kannan, K. (2013). Concentrations and profiles of bisphenol A and other bisphenol analogues in foodstuffs from the United States and their implications for human exposure. *Journal of Agri- cultural and Food Chemistry, 61*(*19*), 4655–4662. https://doi.org/10.1021/jf400445n

Míguez, J., Herrero, C., Quintás, I., Rodríguez, C., Gigosos, P. G., & Mariz, O. C. (2012). A LC-MS/MS method for the deter- mination of BADGE-related and BFDGE-related compounds in canned fish food samples based on the formation of [M + NH4]+ aducts. *Food Chemistry, 135*, 1310–1315. https://doi.org/10.1016/j.foodchem.2012.05.099

Munguía-López, E. M., Gerardo-Lugo, S., Peralta, E., Bolumen, S., & Soto-Valdez, H. (2005). Migration of bisphenol A (BPA) from can coatings into a fatty-food simulant and tuna fish. *Food Additives and Contaminants, 22*(*9*), 892–898. https://doi.org/10.1080/02652030500163674

Paseiro-Cerrato, R., DeVries, J., & Begley, T. H. (2017). Evaluation of Short-term and long-term migration testing from can coatings into food simulants: Epoxy and acrylic−phenolic coatings. *Journal of Agricultural and Food Chemistry, 65*, 2594–2602. https://doi.org/10.1021/acs.jafc.7b00081

Paseiro-Cerrato, R., DeJager, L., & Begley, T. H. (2019). Determining the migration of nadic acid, terephthalic acid, isophthalic acid and two oligomers from polyester food cans into food in the US market. *Food Control, 101*, 69–76. https://doi.org/10.1016/j.foodcont.2019.02.033

Poças, M. F., & Hogg, T. (2007). Exposure assessment of chemicals from packaging materials in foods: A review. *Trends in Food Science & Technology, 18*, 219–230. https://doi.org/10.1016/j.tifs.2006.12.008

Patlewicz, G., Wambaugh, J. F., Felter, S. P., Simon, T. W., & Becker, R. A. (2018). Utilizing threshold of toxicological concern (TTC) with high throughput T exposure predictions (HTE) as a risk-based prioritization approach for thousands of chemicals. *Computational Toxicology, 7*, 58–67. https://doi.org/10.1016/j.comtox.2018.07.002

Rauter, W., Dickinger, G., Zihlarz, R., & Lintschinger, J. (1999). Determination of Bisphenol A diglycidyl ether (BADGE) and its hydrolysis products in canned oily foods from the Austrian market. *Zeitschrift für Lebensmittel Untersuchung und Forschung, 208*, 208–211.

Sajiki, J., Miyamoto, F., Fukata, H., Mori, C., Yonekubo, J., & Hayakawa, K. (2007). Bisphenol A (BPA) and its source in foods in Japanese markets. *Food Additives and Contaminants, 24*(*1*), 103–112. https://doi.org/10.1080/02652030600936383

Santana-Mayor, A., Socas-Rodríguez, B., Herrera-Herrera, A. V., & Rodríguez-Delgado, M. A. (2019). Current trends in QuEChERS method. A versatile procedure for food, environmental and biological analysis. *Trends in Analytical Chemistry, 116*, 214–235. https://doi.org/10.1016/j.trac.2019.04.018

Schymanski, E. L., Jeon, J., Gulde, R., Fenner, K., Ruff, M., Singer, H. P., & Hollender, J. (2014). Identifying small molecules via high resolution mass spectrometry: Communicating confidence (dx.doi.org/) *Environmental Science & Technology, 48*, 2097–2098. https://doi.org/10.1021/es5002105.

Shin, C., Kim, D. G., Kim, J. H., Kim, J. H., Song, M. K., & Oh, K. S. (2021). Migration of substances from food contact plastic materials into foodstuff and their implications for human exposure. *Food and Chemical Toxicology, 154*, Article 112373. https://doi.org/10.1016/j.fct.2021.112373

Sirot, V., Hommet, F., Tard, A., & Leblanc, J. C. (2012). Dietary acrylamide exposure of the French population: Results of the second French Total Diet Study. *Food and Chemical Toxicology, 50*(3–4), 889–894. https://doi.org/10.1016/j.fct.2011.12.033

Tsochatzis, E. D., Lopes, J. A., Kappenstein, O., Tietz, T., & Hoekstra, E. J. (2020). Quantification of PET cyclic and linear oligomers in teabags by a validated LC-MS method – In silico toxicity assessment and consumer's exposure. *Food Chemistry, 317*, Article 126427. https://doi.org/10.1016/j.foodchem.2020.126427

Tzatzarakis, M. N., Karzi, V., Vakonaki, E., Goumenou, M., Kavvalakis, M., Stivaktakis, P., … Tsatsakis, A. M. (2017). Bisphenol A in soft drinks and canned foods and data evaluation. *Food Additives & Contaminants: Part B, 10*(*2*), 85–90. https://doi.org/10.1080/19393210.2016.1266522

Zhou, J., Chen, X. H., Pan, S. D., Wang, J. L., Zheng, Y. B., Xu, J. J., … Jin, M. C. (2019). Contamination status of bisphenol A and its analogues (bisphenol S, F and B) in foodstuffs and the implications for dietary exposure on adult residents in Zhejiang Province. *Food Chemistry, 294*, 160–170. https://doi.org/10.1016/j.foodchem.2019.05.022