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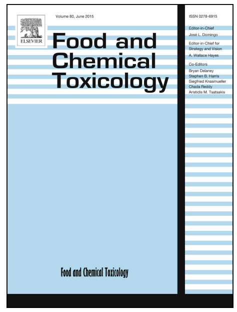

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PII: S0278-6915(19)30782-3

DOI: https://doi.org/10.1016/j.fct.2019.110992

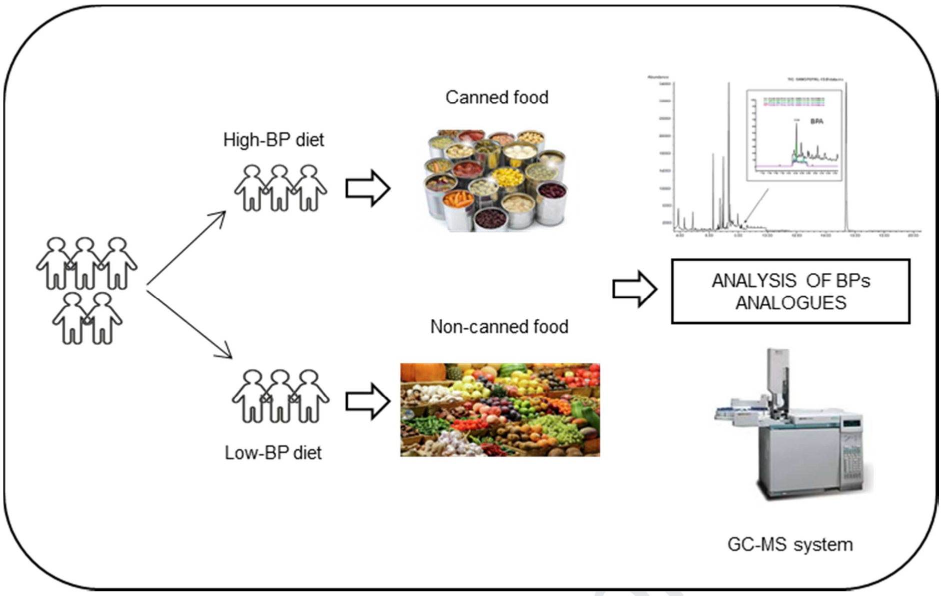
Reference: FCT 110992

To appear in: *Food and Chemical Toxicology*

Received Date: 24 October 2019

Revised Date: 13 November 2019

Accepted Date: 20 November 2019


Canned food
High-BP diet
ANALYSIS OF BPs ANALOGUES
Non-canned food
Low-BP diet
GC-MS system
BPA

Concentrations of nine bisphenol analogues in food purchased from Catalonia (Spain): Comparison of canned and non-canned foodstuffs

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ABSTRACT

The present study was aimed at assessing the exposure of an adult population to nine BPs analogues (BPA, BPS, BPF, BPB, BPAF, BPZ, BPE, BPAP and BPP) through a duplicate diet study. Up to 40 canned and non-canned food samples were purchased from Tarragona (Catalonia, Spain) and further analysed. Three of the nine BPs - BPA, BPB and BPE - were detected in the food samples. BPA was found in 93% and 36% of canned and non-canned samples, respectively, with a mean concentration of 22.49 and 4.73 µg/kg, respectively. Only one sample of canned asparagus (88.66 µg/kg) exceeded the new threshold set by the European Commission (50 µg/kg). BPB was found in canned and non-canned chicken and olive oil samples, with lower levels for canned chicken and non-canned olive oil. Finally, BPE was detected in non-canned mushrooms and nuts (2.40 and 12.35 µg/kg, respectively). Based on the current results, dietary intake for BPA was estimated to be 24.9 and 3.11 µg/day for canned and non-canned groups, respectively. The unexpected occurrence of BPs in non-canned products highlights the ubiquity of these compounds along the food production chain, beyond to the packaging.

Keywords: bisphenol A (BPA), bisphenol analogues, food, QuEChERS, dietary intake

Abbreviation list

BPA: Bisphenol A; BPS: Bisphenol S; BPF: Bisphenol F; BPB: Bisphenol B; BPAF: Bisphenol AF; BPZ: Bisphenol Z; BPE: Bisphenol E; BPAP: Bisphenol AP; BPP: Bisphenol P; BPs: Bisphenols; HPLC: High-Performance Liquid Chromatography; MeCN: Acetonitrile; DLLME: Dispersive Liquid-Liquid MicroExtraction; T4CE: Tetrachloroethylene; AA: Anhydride acetic; GC: Gas Chromatography; LOD: Limit of

Detection; LOQ: Limit of Quantification; EFSA: European Food Safety Authority; TDI: Tolerable Daily Intake

1. Introduction

Food products are sensitive to contamination at any stage of the production chain, from farm-to-fork (Mancini et al., 2016). Food contaminants can have a wide range of sources, including the environment, processing, and packaging, among others (Rather et al., 2017). Regarding food packaging, in recent years bisphenols (BPs) have received a great attention. BPs are organic compounds containing two phenol rings, which are connected by a different binding bridge, usually a methyl bridge (Bisphenol A, BPA), a methylene bridge (Bisphenol F, BPF), or a sulphur dioxide group (Bisphenol S, BPS), depending on the analogue (Kang et al., 2006; Usman and Ahmad, 2016). It has been widely reported that BPs can play an important role in diseases like diabetes and obesity (Mirmira and Evans-Molina, 2014), as well as to cause harmful developmental and reproduction effects (Rochester, 2013).

BPA is the most used BP analogue in the food industry, with a projected consumption of 10.6 million metric tons in 2022 (Lemhler et al., 2018). It is used as a monomer for the manufacture of polycarbonate plastics and can linings. With respect to its chemical structure, there is a similarity to that of 17β-estradiol, a natural occurring hormone. Thus, BPA can bind to endocrine receptors causing a dysfunctionality of the endocrine system (Matuszczak et al., 2019; Rochester, 2013; Usman and Ahmad, 2016).

In 2011, the regulation 2011/8/EU banned the use of BPA in baby bottles and set a specific migration limit of 0.6 mg/kg of food from varnishes or coatings applied to materials (European Commission, 2011). Recently, a new regulation (2018/213/EU) was adopted setting a more restrictive migration limit (0.05 mg/kg), while no migration of BPA, from varnishes or coatings applied to materials and articles specifically intended to infants and young children up to 3 years old, is permitted (European Commission, 2018).

As a consequence of these restrictions on BPA, manufacturing companies are gradually replacing BPA by other BP analogues. Nowadays, there are 24 analogues described in the literature (Pelch et al., 2017). Hence, exposure to BPs persists, occurring through different pathways, such as diet, inhalation and dermal contact. However, it has been reported that diet means up to the 99% of the exposure to BPA (Martínez et al., 2018). Therefore, an additional knowledge on the levels of BPs in foodstuffs, as well as risk assessment studies, are required to protect human health.

Even though BPs have gained attention in the last years, BPA is still the core research. Since their properties, structure and potential human health effects are very much alike, research on BP analogues – other than BPA – is needed. The present study was aimed at assessing the dietary exposure to nine bisphenol analogues (BPA, BPS, BPF, BPB, BPAF, BPZ, BPE, BPAP and BPP). The concentrations of these BPs analogues were determined in 40 canned and non-canned food samples consumed during a two days duplicate diet study. To the best of our knowledge, this is the very first study focused on assessing the dietary co-exposure to 9 BPs in Spain.

2. Materials and methods

2.1. Standards and chemicals

BPA (99% purity), BPB (98% purity), BPF (98% purity), BPE (98% purity), BPAF (98% purity), BPZ (99% purity) and BPAP (99% purity) were purchased from Sigma-Aldrich (West Chester, PA, USA). d16-bisphenol A ($BPAd_{16}$; 98 atom % D), used as internal standard (I.S.), was purchased from Cambridge Isotope Laboratories, Inc. (Tewksbury, MA, USA). Individual standard solutions and internal standards were prepared in methanol (HPLC grade from Sigma-Aldrich) at concentrations of 2000 µg/L. Acetonitrile (MeCN, gradient grade for HPLC), acetic anhydride (AA; >99% purity) and tetrachloroethylene (T4CE, >99% purity) were acquired from Sigma-Aldrich. Sodium chloride and potassium carbonate (both analytical grade) were obtained from PanReac Quimica (Barcelona, Spain) and magnesium sulfate was acquired from Sigma-Aldrich. Supel™ QuE Z-Sep$^+$ was purchased from Supelco (Bellefont, PA, USA).

2.2. Instrument

BPs analyses were performed in a gas chromatograph 6890 (Agilent, Little Falls, DE, USA) equipped with a Combi-PAL autosampler (CTC Analytics, Zwingen, Switzerland) and a mass selective detector (5975B, Agilent), with an electron ionization (EI) chamber. The separation was performed on a DB-5MS column (30 m × 0.25 mm I.D. × 0.25 µm film thickness; J&W Scientific, Folsom, CA, USA). Chromatographic and detection specifications have already been reported (González et al., 2019).

2.3. Quality Control/Quality Assurance

Procedural blanks were measured each batch of 10 samples. Blank samples were spiked with both recovery and internal standards to evaluate linearity, linear range, sensitivity, precision and accuracy, according to EU guidelines (European Commission, 2017). A multilevel matrix-matched calibration -with nine calibration levels- was generated by the least squares' linear regression model. The peak area ratios of target analyte, and internal standard versus the concentration of each target compound, were plotted. Detection limits were calculated using low level points to achieve signal-to-noise ratios of 3. The quantification limits were established as the lowest concentration assayed with acceptable accuracy and precision, corresponding to the lowest calibration level of the calibration curve.

2.4. Food sampling

A total of 40 food samples were purchased in a big grocery store in Tarragona (Catalonia, Spain). Foodstuffs were divided into 2 food baskets: 1) canned food, and 2) non-canned food (including fresh food, packed in glass containers, or other BP-free materials). Canned food included tuna, pâté, nuts, mushrooms, artichokes, asparagus, corn, olive oil, green beans, red beans, peach in syrup, fruit salad in syrup, mackerel and squid. Non-canned food included the same foodstuffs than the canned group, but in glass containers, excepting mackerel and chicken. In addition, canned group included yogurt in plastic, and pre-cooked quinoa and rice, while non-canned group included yogurt in glass, dry quinoa and rice, and fresh salmon – replacing canned mackerel – and chicken, packed in waxed paper. Both groups included fresh salad and banana, as well as toasts and cookies packed with plastic free of BPs.

2.5. Duplicate diet study

A duplicate diet study was performed to assess exposure to BPs of an adult. A cohort of 26 individuals was divided into two groups: 1) a potential high-BPA diet, consisting of the "canned food basket" above described, and 2) BPA-free diet, made of fresh food and food packed in glass containers and other BP-free materials, consisting of the "non-canned food basket" also above described. The cohort followed a two-days of balanced diet (Table 1), which was reviewed and approved by a nutritionist. Participants were able to drink as much water as they wished. However, the sources (tap, bottled, etc.) should be recorded. In parallel, each food item was homogenized using a domestic shredder and stored at -20ºC until further analysis. Only edible parts of each food item were used.

2.6. Food samples treatment

Sample preparation is described elsewhere (Cunha et al., 2012). Briefly, each food item was blended separately with a domestic shredder before weighting 10 g of sample and adding 100 µl of BPA_{d16} and 10 ml of deionised water. For the fatty samples, 5 ml of n-heptane was added, vigorously shaked and centrifuged at 1690 g for 2 minutes. The upper-layer was discarded. Then, 10 ml of MeCN were added and samples were vortexed and agitated for 10 minutes. Afterwards, 4 g of $MgSO_4$ and 1.2 g of NaCl were added and agitated for 15 minutes. Finally, samples were centrifuged at 1690 g for 5 minutes. An additional clean-up was needed for fatty food samples, consisting of the inclusion of 1.2 g $MgSO_4$ and 50 mg of Z-SEP in the clean-up step.

A DLLME (Dispersive Liquid-Liquid MicroExtraction) procedure was subsequently performed: 85 µl of T4CE and 100 µl of AA were added to 1 ml of the MeCN extract. Rapidly, the mixture was transferred to a 25-ml screw cap glass tube, with conical bottom containing 3 ml of deionised water and 300 µl of 5% K_2CO_3 solution to ensure a pH $\geq$ 10. Samples were gently shaked by hand and centrifuged at 1690 g for 4 minutes. Finally, 70 µl of the lower phase were transferred to a vial with a 100-µl insert and 1 µl was injected to the GC system.

2.7. Calculation of the dietary exposure

Food consumption data are shown in Table 1. The dietary intake of each BP analogue was calculated by multiplying its concentration in each food item by the quantity of consumed food. Total dietary exposure to BPs was obtained by summing the respective intakes of all food items. Exposure was also calculated according to the average body weight of the study participants (mean: 68 kg) in order to compare the estimated exposure to the threshold limit. For calculations, when the concentration of a BP analogue was under the respective limit of detection (LOD), it was assumed to be one-half of that limit (ND=1/2LOD).

2.8. Statistics

Data treatment was performed by means of the statistical package SPSS 20.0. A Kolmogorov-Smirnov test was used to compare the homogeneity of the variances. Subsequently, the significance of the data was computed by an ANOVA or the Mann-Whitney U-test. For calculations, non-detected values were excluded from data treatment, while non-quantified samples were assumed to have a concentration equal to one-half of the limit of quantification (NQ = 1/2 LOQ).

3. Results and discussion

3.1. Levels of BPs in food

The concentrations of BPs in the 40 canned and non-canned food samples are summarized in Table 2. BPA, BPB and BPE were the three analogues with levels above the LOD. BPA was identified in 58% of the food samples, presenting a mean concentration of 15.54 µg/kg. Regarding canned food, BPA was detected in 14 of 15 food items. Levels of BPA ranged from <0.17 for the olive oil – the only canned food item below its LOD – to 88.66 µg/kg for the asparagus (mean concentration of BPA = 22.49 µg/kg). In turn, BPA was found in the 36% of the non-canned food samples, with a mean concentration of 4.73 µg/kg. Toasts, quinoa, yogurt, salad, asparagus, fresh squid, banana, nuts, rice, artichokes, peach in syrup, cookies, green beans, salmon and olive oil were the food items with levels below the LOD. The highest concentration in non-canned food corresponded to mushrooms (9.56 µg/kg).

The levels of BPA in canned food were found to be higher than those observed in non-canned food. Pairs of foodstuffs with quantifiable concentrations of BPA were: pâté (13.39 vs 5.10 µg/kg), mushrooms (19.88 vs 9.56 µg/kg), chicken (20.91 vs 1.41 µg/kg), fruit salad in syrup (11.69 vs 3.85 µg/kg), corn (10.65 vs 4.21 µg/kg), tuna (32.22 vs 5.68 µg/kg) and red beans (26.16 vs 8.78 µg/kg). Also, pre-cooked quinoa and rice had detectable levels of BPA (2.93 and 1.04 µg/kg, respectively), while dry quinoa and rice were below the LOD.

The concentrations of BPA in canned food samples were compared with the new migration limit for BPA set recently by the European Commission in canned food (European Commission, 2018). Only canned asparagus was above 50 µg/kg (Fig. 1). Although asparagus exceeded the new migration limit, probably this does not mean a risk for human health since asparagus consumption by the Spanish adult population is estimated to be only 0.67 g/day, which would mean an exposure of 0.0008 µg/kg bw/day for the general population (0.02% of contribution to the established limit) (AECOSAN, 2016). Anyway, it should be explored if this occurs in all the commercial canned asparagus brands, or it is only related to the purchased brand in this study.

BPB was detected in four samples. Both pairs of canned and non-canned chicken and olive oil samples had BPB above their corresponding LOD. For chicken, the concentration of BPB in fresh samples was slightly higher than that found in the canned chicken (4.19 vs 3.86 µg/kg, respectively). In contrast, canned olive oil showed a higher concentration than non-canned olive oil (1.25 vs 0.85 µg/kg, respectively). Finally, BPE was found only in two food samples, both of them belonging to the non-canned group. Concentrations of BPE in mushrooms and nuts were 2.40 and 12.35 µg/kg, respectively.

As expected, canned food presented significantly higher levels of BPA than non-canned food ($p<0.01$), which is due to the fact that food is directly in contact with the can lining. Nonetheless, relevant concentrations of BPs were found in non-canned food. One explanation could be that packaging, other than cans, might also cause the migration of BPs into the food, even though these packaging are made to preserve a high-quality food (García Ibarra et al., 2019). BPs contamination in non-canned food could be the result of the migration from the coating of the caps of glass bottles, since a residual amount of BPs monomer could remain after the polymerization process (Noonan et al., 2011). Another hypothesis would be the potential contamination during the primary production of the products (Mercogliano and Santonicola, 2018; Santonicola et al., 2018). Finally, the ubiquity of plastics elsewhere could also be related to the unexpected presence of BPs in food.

The scientific literature assessing the levels of BPA in food is extensive, but each study comprises different food samples. Consequently, the comparison of non-canned food samples between studies conducted in different countries is not always easy. Table 3 summarizes concentrations of BPA in food of different countries. The levels of BPA show a huge variation between countries due to methodological differences. Anyhow, the levels of BPA found in the current study are in the lower part of the ranges for canned food and in the upper part of the ranges for non-canned food.

In China, BPA was detected in 36% of the canned and non-canned composites, a percentage lower than the 58% of the present survey. Concentrations ranged from 0.20 to 106 µg/kg, including canned and non-canned food (Cao et al., 2011). These results are in the same range to that of the current study. In Japan, BPA mean concentration in canned food was 3.4 µg/kg, being the highest level: 30 µg/kg, which are quite lower than the mean and the maximum level of BPA in our study: 22.49 and 88.66 µg/kg, respectively. This important difference is probably due to the decrease of the polycarbonate use in Japanese manufacturers since the late 1990s, when it was replaced by polyphenylsulfone and polyethersulfone, both materials BPA-free (Kawamura et al., 2014).

In Korea, BPA was found within the range from <1.41 to 278.5 µg/kg in canned food samples (Choi et al., 2018), while in Egypt, BPA levels ranged from 6.14 to 710.59 µg/kg in canned food, and from 5.75 to 236.76 µg/kg in food packaged in plastic (Osman et al., 2018). These results are certainly higher than those found in the present study. In the United States, BPA was found in 73% and in 7% of the canned and non-canned food samples, respectively. These percentages are lower than those found the present study (93% and 36%, respectively). BPA levels found in canned food ranged between 0.31 and 149 µg/kg, while in non-canned food varied between 0.28 and 0.41 µg/kg (Lorber et al., 2015). Thus, BPA concentrations in canned food are higher than those detected in the present survey. By contrast, BPA concentrations in non-canned food are lower than those found in the current study.

In Portugal, BPA levels were determined in canned samples of tuna and sardines, with levels ranging from <1 to 63 µg/kg, which is in accordance to those found in the present study (Cunha et al., 2017). Canned vegetables and canned fruit were also analyzed. Higher detection rates for BPA (87% versus 58%) and a range of concentrations, from 3.7 to 256.6 µg/kg, which is higher than in the present study (from <0.17 to 88.66 µg/kg) were reported (Cunha and Fernandes, 2013). In turn, Sakhi and co-workers (2014) analyzed the concentrations of BPA in 37 canned and non-canned foodstuffs in Norway. Composites for each food group comprised food samples with different packaging materials. Thus, comparison was made with joint results for canned and non-canned groups. Detectable levels for the food samples ranged from <0.020 to 8.7 µg/kg, being lower than the results of the present study (Sakhi et al., 2014). On the other hand, Tzatzarakis et al. (2016) analysed the content of BPA in the two phases of the canned product (liquid and solid). They found higher levels of BPA in the solid phase than in the liquid phase (2.70 vs. 33.4 µg/kg).

Beyond BPA, studies assessing the levels of BPs analogues are limited. Moreover, most of these studies only determined the concentrations of 2 or 3 analogues (especially, BPS, BPF and BPB). The occurrence of 8 BPs have been only determined in two studies. In USA, BPAF, BPP, BPS, BPAP, BPF, BPB and BPZ were found in analyzed food samples, with detection rates varying from 0 - 11% for BPZ, to 0 – 60% for BPF. Detection rates for BPB (0 – 13%) were in accordance with those found in this study (10%). On the other hand, BPB concentrations varied from <0.013 to 0.017 µg/kg, which are lower than the current results (<0.17 to 4.19 µg/kg) (Liao and Kannan, 2013). In Belgium, no bisphenol analogues were detected in any of the ready-to-eat meal samples analyzed, with the exception of BPS and BPF, which were only present in one sample (beef ravioli) (Regueiro and Wenzl, 2015). In Korea, BPS and BPF levels were determined in canned food samples. Like in the present study, BPS and BPF were not detected in any of the samples (Choi et al., 2018).

In parallel, BPB was found in canned seafood samples purchased in Portugal and Italy, both with lower detection rates than BPA (83% vs 12%, and 75% versus 12%, respectively) (Cunha et al., 2012; Fattore et al., 2015). These results agree with the percentages of BPB detection of the present survey (13%). Lower rates for BPB were found in Portugal, where BPB was only detected in 2 of 39 samples (Cunha and Fernandes, 2013).

In a recent review, Russo et al. (2019) reported BPs concentration in food from different countries and matrices. Regarding vegetables, asparagus was the food product that contained the highest level of BPA (959 µg/kg), being in accordance with the results here presented. Other types of food showed highly variable levels of BPA, being lower levels in beverages and higher in other foodstuffs (seafood, vegetables and meat). These data are in agreement with those provided by EFSA (2015), which highlighted the significant differences between canned and non-canned food, with meat, fish, grains, legumes, condiments, and snacks showing relatively higher levels (>30 µg/kg).

3.2. Estimated dietary intake of BPs through the diet

Total and daily intake through the diet of BPs analogues was assessed. Although in this study drinking water was not analyzed, exposure was calculated using concentrations of BPs taken from the literature (Zhang et al., 2018), being mean water consumption data from the ANIBES study (Nissensohn et al., 2016). BPA, BPAF, BPB, BPE, BPF and BPS exposure from drinking water was estimated to be 0.005, 0.001, 0.001, 0.0001, 0.0001 and 0.0003 µg/day, respectively.

Total BPA intake for the two-day diet for the canned group was estimated to be 24.9 µg, way above the estimated intake for the non-canned group: 3.12 µg. For BPB, a similar estimation was found for both groups: 0.46 and 0.45 µg, for canned and non-canned diet, respectively. Lastly, the estimated intakes of BPE were 0.28 and 1.16 µg, for the canned and non-canned groups, respectively.

Taking the days separately, canned group had a BPA intake of 15.7 µg/day for day one, and 9.26 µg/day for day two. On the other hand, non-canned group had an intake of

2.20 and 0.92 µg/day for the first and the second day, respectively. For BPB, canned group, had an intake of 0.31 and 0.15 µg/day for each day. Similarly, non-canned group had intakes of 0.31 and 0.14 µg/day, respectively. Finally, for the canned group BPE intake was 0.14 µg/day for both days, while for the non-canned group, the estimated intake was calculated to be 0.71 and 0.45 µg/day, for the first and second day, respectively (Table 4).

Based on the daily intake of BPs and the average body weight of the cohort (68 kg), two-day diet total BPA exposure was estimated to be 0.37 and 0.05 µg/kg bw for canned and non-canned diet, respectively. With respect to BPB, 0.007 µg/kg bw was the estimated exposure for both diet groups. Finally, BPE exposure was estimated to be 0.004 and 0.02 µg/kg bw, for canned and non-canned food, respectively.

Daily exposure was estimated as follows: on the first day for the canned diet, BPA, BPB and BPE exposures were 0.23, 0.004 and 0.002 µg/kg bw/day, respectively. On the second day, estimations were 0.14, 0.002 and 0.002 µg/kg bw/day for BPA, BPB and BPE, respectively. For the non-canned diet, exposures to BPA, BPB and BPE on the first day, were 0.03, 0.005 and 0.01 µg/kg bw/day, respectively, while in the second day, 0.01, 0.002 and 0.007 µg/kg bw/day were the exposures estimated for BPA, BPB and BPE, respectively.

Canned asparagus had BPA concentrations above the migration limit, being its contribution a 28% of the total exposure to BPA. However, high-BP diet group did not exceed the TDI of 4 µg/kg bw/day, which is established by the EFSA. Neither the BPA-free diet group exceeded the threshold limit (Fig. 2) (EFSA, 2015). The comparison between other analogues of BP and their TDI values was not possible, because international organizations have not set threshold limits yet.

Although the estimated dietary intake of BPA is below the TDI, other exposure pathways, such as dermal absorption or air inhalation, should not be disregarded. In addition, the presence of traces of other endocrine disruptors in food could increase the total exposure and cause adverse health effects, even at low-dose exposures (Tsatsakis et al., 2016).

4. Conclusions

BPA is the most widespread BP analogue in both canned and non-canned foodstuff purchased in Spain. Consequently, the Spanish population is mainly exposed to this BP analogue. BPB and BPE were also detected, but at a much lower rate than BPA. The other analogues here assessed (BPS, BPF, BPAF, BPZ, BPAP and BPP) were not detected in any food sample. Nevertheless, the assessment of the BPs levels in food – regardless the food packaging – is clearly needed in order to ensure that food products do not mean a risk for human health. The estimated dietary exposure to BPA showed that none of the groups (canned and non-canned) exceeded the TDI established by the EFSA, even though canned asparagus were above the new migration limit recently fixed by the European Commission.

Biomonitoring studies of BPs must be conducted in duplicate diet studies to explore their ADME -adsorption, distribution, metabolism and excretion- and to protect human health. These studies should not only be focused on BPA, but also on all BPs analogues. Moreover, as it has been proved that BPs analogues –other than BPA- are also used by the food industry, regulations on their occurrence in food, migration limits from food packaging materials, and TDIs are urgently required.

Acknowledgements

This study was financially supported by the Spanish Ministry of Economy and Competitiveness, through MODELBIS Project (AGL2016-78942-R). Sara C. Cunha and José O. Fernandes thanks to UID/QUI/50006/2019 with funding from FCT/MCTES. Sara C. Cunha also acknowledges FCT for the IF/01616/2015 contract.

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Table 1

Food consumption (g/day) for all analysed samples.

	Foodstuff	Food weight (g)	Homemade measures
DAY 1			
Breakfast	Pâté	37.5	½ can
	Toasts	40	4 slices
Snack	Nuts	25	1 handful
Lunch	Quinoa	125	1 cup
	Mushrooms	115	1 can
	Chicken	42	1 can
	Yoghurt	115	1 unit
Snack	Fruit salad in syrup	140	½ can
Dinner	Salad	150	½ bag
	Asparagus	80	3 units
	Corn	55	½ can
	Stuffed squid	72	1 can
	Toasts	40	4 slices
	Fruit	125	1 piece
DAY 2			
Breakfast	Tuna	52	1 can
	Toasts	40	
Snack	Nuts	25	1 handful
Lunch	Rice	125	1 cup
	Red beans	60	6 spoonful
	Artichokes	115	1 can

	Toasts	40	4 slices
	Peach in syrup	115	1 can
Snack	Yoghurt	115	1 unit
	Cookies	35	7 units
Dinner	Green beans	130	1 can
	Mackerel/salmon	85	1 can
	Toasts	40	4 slices
	Yoghurt	115	1 unit

Table 2

BPA, BPB and BPE concentrations (μg/kg) in canned and non-canned foods.

Food sample	Packaging	BPA	BPB	BPE
Pâté	Can	13.39	<0.33	<0.83
	Glass	5.10	<0.33	<0.83
Toasts	Plastic	<0.17	<0.17	<0.17
Quinoa	Plastic (pre-cooked)	2.93	<0.17	<0.17
	Plastic (dry)	<0.17	<0.17	<0.17
Mushrooms	Can	19.88	<0.17	<0.17
	Glass	9.56	<0.17	2.40
Chicken	Can	20.91	3.86	<0.83
	Fresh	1.41	4.19	<0.83
Yogurt	Plastic	<0.17	<0.17	<0.17
	Glass	<0.17	<0.17	<0.17
Fruit salad in syrup	Can	11.69	<0.17	<0.17
	Glass	3.85	<0.17	<0.17
Salad	Plastic	<0.17	<0.17	<0.17
Asparagus	Can	88.66	<0.17	<0.17
	Glass	<0.17	<0.17	<0.17
Corn	Can	10.65	<0.17	<0.17
	Glass	4.21	<0.17	<0.17
Squid	Can	30.85	<0.33	<0.83
	Fresh	<0.33	<0.33	<0.83
Banana	Fresh	<0.17	<0.17	<0.17
Tuna	Can	32.22	<0.33	<0.83
	Glass	5.68	<0.33	<0.83
Nuts	Can	3.45	<0.17	<0.17
	Plastic	<0.17	<0.17	12.35

Rice	Plastic (pre-cooked)	1.04	<0.17	<0.17
	Plastic (dry)	<0.17	<0.17	<0.17
Red beans	Can	26.16	<0.17	<0.17
	Glass	8.78	<0.17	<0.17
Artichokes	Can	6.31	<0.17	<0.17
	Glass	<0.17	<0.17	<0.17
Peach in syrup	Can	4.49	<0.17	<0.17
	Glass	<0.17	<0.17	<0.17
Cookies	Plastic	<0.17	<0.17	<0.17
Green beans	Can	13.02	<0.17	<0.17
	Glass	<0.17	<0.17	<0.17
Mackerel	Can	33.19	<0.33	<0.83
Salmon	Fresh	<0.33	<0.33	<0.83
Olive oil	Can	<0.17	1.25	<0.83
	Glass	<0.17	0.85	<0.83

Table 3

Concentrations of BPs in foodstuffs from different countries: a summary of scientific literature.

Country	BPA (μg/kg)	Type of food container	Type of food	Reference
China	0.20 – 106	Canned and non-canned	Dairy, meat, poultry, fish, soup, bread and cereal, vegetable, fruit, beverage, baby food, fast food, miscellaneous	Cao et al., 2011
Japan	3.4	Canned	Fish, meat, vegetable, fruit, other cooked food, coffee, tea, other beverages	Kawamura et al., 2014
Korea	<1.41 – 278.5	Canned	Meat, fish, corn and beans, fruit, sauces, vegetables, liquor, beverages and coffee	Choi et al., 2018
Egypt	6.14 – 710.59 5.75 – 236.76	Canned Non-canned	Meat, fish, vegetables, fruits, oil, milk and beverages	Osman et al., 2018
United States	0.31 - 149 0.28 – 0.41	Canned Non-canned	Fruit, vegetables, meat, fish and dairy	Lorber et al., 2015
Portugal	<1 - 62	Canned	Seafood	Cunha et al., 2017
Norway	0.11 – 5.8	Canned and non-canned	Grain and grain products, milk and dairy products, meat and meat products, fish	Sakhi et al., 2014

			and fish products, fats, fruits and vegetables, ready-to-eat, snacks, beverages, condiments, others	
Spain	<0.17 – 88.66	Canned	Meat, fish, vegetables, fruit, bread, dairy products and bakery	Present study
	<0.17 – 9.56	Non-canned		

Country	BPB (μg/kg)	Type of food container	Type of food	Reference
United states	<0.013 – 0.017	Canned and non-canned	Beverages, dairy products, fats and oils, fish and seafood, cereals and cereal products, meat and meat products, fruit, vegetables, others	Liao and Kannan., 2013
Portugal	<0.4 – 21.7	Canned	Seafood	Cunha et al., 2012
Italy	<0.9 – 145.9	Canned	Tuna	Fattore et al., 2015
Spain	<0.17 – 3.86	Canned	Meat, fish, vegetables, fruit, bread, dairy products and bakery	Present study
	<0.17 – 4.19	Non-canned		

Table 4

Estimated dietary intake of BPA, BPB and BPE for canned and non-canned diet.

Day of the diet	BPA (μg/day)		BPB (μg/day)		BPE (μg/day)	
	Canned	Non-canned	Canned	Non-canned	Canned	Non-canned
Day 1 (D1)	15.7	2.20	0.31	0.31	0.14	0.71
Day 2 (D2)	9.26	0.92	0.15	0.14	0.14	0.45
Mean ± SD	12.5 ± 4.6	1.56 ± 0.9	0.23 ± 0.11	0.22 ± 0.12	0.14 ± 0.002	0.58 ± 0.19

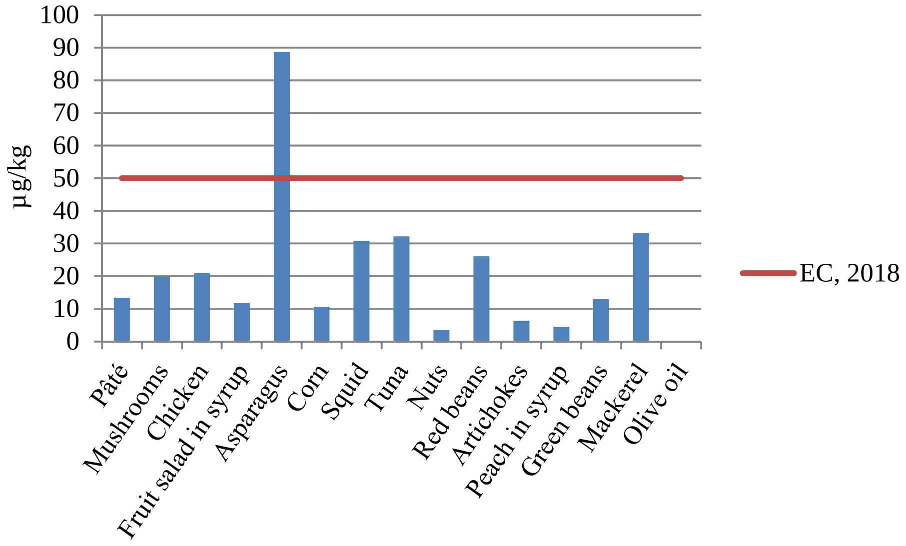

Fig. 1. Comparison between detected levels of BPA in canned samples and the new migration limit established by the European Commission in 2018.

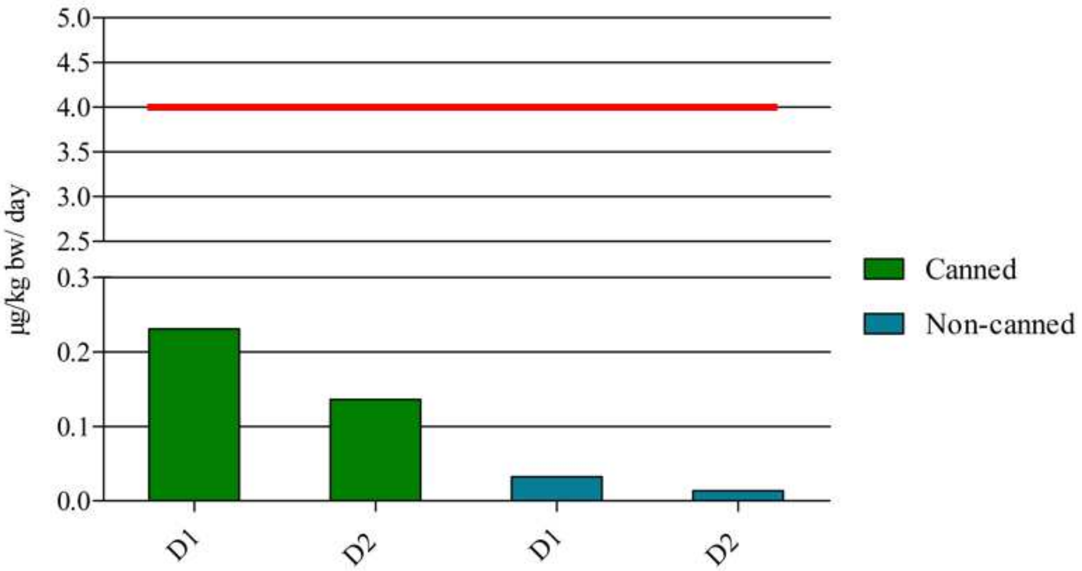

Fig. 2. Estimated dietary exposure of BPA for 2 different groups, and comparison with TDI (4 µg/kg bw/ day). D1: Day 1; D2: Day 2

Highlights

- Apart from BPA, other BP analogues may occur in canned and non-canned foodstuffs.
- BPA was the most detected analogue in food, regardless the kind of container.
- In a high-exposure scenario, the BPA dietary intake was estimated in 24.9 μg/day.
- BPA levels in canned asparagus exceeded the current threshold set by the EFSA.
- Beyond packaging, BPs may be ubiquitously found through the food production chain.

Declaration of interests

XX 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

No COIs.

Author contributions

Use this form to specify the contribution of each author of your manuscript. A distinction is made between five types of contributions: Conceived and designed the analysis; Collected the data; Contributed data or analysis tools; Performed the analysis; Wrote the paper.

For each author of your manuscript, please indicate the types of contributions the author has made. An author may have made more than one type of contribution. Optionally, for each contribution type, you may specify the contribution of an author in more detail by providing a one-sentence statement in which the contribution is summarized. In the case of an author who contributed to performing the analysis, the author's contribution for instance could be specified in more detail as 'Performed the computer simulations', 'Performed the statistical analysis', or 'Performed the text mining analysis'.

If an author has made a contribution that is not covered by the five pre-defined contribution types, then please choose 'Other contribution' and provide a one-sentence statement summarizing the author's contribution.

Manuscript title: Concentrations of nine bisphenols analogues in food purchased from Catalonia (Spain): Comparison of canned and non-canned foodstuffs

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