Food Chemistry 327 (2020) 126882

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Short communication

Trace analysis of bisphenol A and its analogues in eggs by ultra-performance liquid chromatography-tandem mass spectrometry

Zhiming Xiao, Ruiguo Wang, Decheng Suo, Tong Li, Xiaoou Su*

Institute of Quality Standard and Testing Technology for Agro-Products, Chinese Academy of Agricultural Sciences, Beijing 100081, China

ARTICLE INFO

Keywords:
Bisphenol A
Analogues
Eggs
Ultra-performance liquid chromatography
Mass spectrometry

ABSTRACT

Presence of bisphenol A (BPA) and its analogues in various environmental matrices have been well studied by now, but there is still an insufficient data on the occurrence of BPA analogues in animal-derived foodstuffs. Hence, this work describes a quick, sensitive and reliable analytical method for the simultaneous determination of eight BPA analogues in eggs, applying a solid-phase extraction procedure with PRiME HLB cartridges that combines isolation of the analytes from matrix and the sample clean-up on a single column. The limits of detection (LODs) and quantification (LOQs) for BPA analogues were in the ranges of 0.02–0.05 μg kg^{-1} and 0.1–0.2 μg kg^{-1}, respectively. Average recoveries were ranged between 82.7% and 105.2%. Quantitative analysis was performed on 24 real samples, the results indicate that low levels of BPA, BPB and BPS were detected, and interestingly, over ten folds higher BPP contamination levels compared to BPA were found in two egg samples.

1. Introduction

In recent decades, the rapid progress of human civilization and urbanization has led to increased levels of chemical pollution. These man-made chemicals used for industrial, agricultural and/or domestic purposes can be released into the environment, enter the food chain, and produce a number of disorders in animals, and possibly in human (Rochester & Bolden, 2015). Among tens of thousands of these chemicals, bisphenol A (BPA) has attracted increased attentions owing to its widespread utilization and environmental ubiquity. BPA is one of the most important monomers used worldwide in the manufacture of polycarbonates, epoxy resins, phenol resins, polyesters, and also in flame retardants and polyester resin intermediates. Nowadays, the annual production of BPA reaches over 7.7 million tons, estimated by Industry Experts (2016), and its demand is predicted to increase over the next few years.

Exposure to BPA in humans has been implicated in the development of chronic disease, including diabetes, asthma, and cancer, and in causing decreased fecundity in wildlife via disrupted spermatogenesis and ovulation (Kinch, Ibhazehiebo, Jeong, Habibi, & Kurrasch, 2015; Tucker, Bouknight, Brar, Kissling, & Fenton, 2018). With increasing concerns regarding the risks of BPA, the US Food and Drug Administration (FDA) and European Food Safety Authority (EFSA) have restricted its use in plastic infant feeding bottles, and recommended no exposure to BPA of infants, young children, pregnant and breast feeding women who were identified as the most susceptible populations (US FDA, 2010; Commission Directive, 2011/8/EU). The amount of BPA legally permitted to migrate from packaging into food, known as the specific migration limit, was set at 0.6 mg/kg by EU commission (Commission Regulation EU 10/2011). Furthermore, in 2015, EFSA has published a re-evaluation of BPA which reduced the “tolerable daily intake” (TDI) of BPA from 50 μg per kilogram of body weight per day (μg/kg of bw/day) to only 4 μg/kg of bw/day (EFSA, 2015).

Facing growing restrictions worldwide on the use of BPA in food contact materials, the plastic and canning industry are seeking alternative chemicals that can replace BPA. In the past 30 years, over 20 BPA analogues have been produced to fulfill different requirements by industry, among which bisphenol B (BPB), bisphenol S (BPS), bisphenol F (BPF), bisphenol AF (BPAF), bisphenol P (BPP), bisphenol AP (BPAP) and bisphenol BP (BPBP) are, apparently, the most important (Xiong et al., 2018). These alternatives mainly belong to the same class of *p,p'*-bisphenols and have physical and chemical properties similar to BPA, while the safety of these analogues is still debated and their effects on human health and potential role as endocrine disruptors have not been fully demonstrated. Recent studies have revealed that BPS and BPF can induce toxic and reproductive neuroendocrine effects similar to those of BPA (Ahsan, Ullah, Ullah, & Jahan, 2018; Qiu et al., 2019; Kudłak, Wieczerzak, & Namieśnik, 2019), and some analogues (e.g., BPB and

* Corresponding author.
E-mail address: suxiaoou@caas.cn (X. Su).

https://doi.org/10.1016/j.foodchem.2020.126882
Received 28 December 2019; Received in revised form 5 April 2020; Accepted 19 April 2020
Available online 20 April 2020

BPAF) are even more toxic than BPA (Russo et al., 2018). These BPA alternative chemicals are, therefore, described as "regrettable substitutions", and their industrial applications are suggested to be reconsidered in the future (Sosvorova et al., 2017).

Since international production and application of BPA analogues have not been regulated, their levels in the environment and therefore human exposure to these chemicals are steadily increasing. Human exposure to BPA substitutes through different ways, generally include dietary (as a most probable) and non-dietary (e.g., inhalation, dermal) routes (Owczarek et al., 2018). BPS and BPF have been detected in surface water, sediment and sewage effluent, generally at concentrations lower than BPA, but in the same order of magnitude (Ismail, Wee, & Aris, 2017; Wu et al., 2018). BPA, BPAF, BPAP, BPB, BPF, BPP, BPS, BPZ have also been detected in foodstuffs (e.g., canned foods, meat and meat products, cereals, milk, vegetables, and dairy products) (Liao & Kannan, 2013; Russo, Barbato, Mita, & Grumetto, 2019; Cunha & Fernandes, 2013). Although the environmental abundance of bisphenols undoubtedly indicates that humans are constantly exposed to these chemicals, the data concerning the presence of BPA analogues in foodstuffs is still very scarce. It is, therefore, of great importance to develop ultrasensitive and reliable analytical methods to quantify and assess the risks of such chemicals exposure from the food origins.

For screening purpose, several analytical methods have been developed for the determination of BPA and/or its analogues in various matrices such as milk (Xiong et al., 2018), human plasma (Sosvorova et al., 2017; Owczarek et al., 2018), canned vegetables and fruits (Cunha & Fernandes, 2013), human urine (Silveira, Rocha, Rodrigues, & Jr, 2020), tap water (Goeury, Duy, Munoz, Prévost, & Sauvé, 2019; Chang, Shen, Shao, & Wu, 2018), canned energy drinks (Gallo et al., 2017), muscle and liver (Deceuninck et al., 2019), hotpot seasoning (Dong, Zeng, & Bai, 2018), bottled carbonated beverages (Mandrah, Satyanarayana, & Roy, 2017), and edible oils (Xian et al., 2017). To the best of our knowledge, no methods have been published for simultaneous determination of BPA and its analogues in egg samples. Furthermore, most of the published papers present procedures for a limited number of bisphenols. Consequently, there is a lack of multi-residue methods for the analysis of BPA and its analogues in eggs. Hence, the objective of this study was to develop a sensitive and reliable analytical method for routine analysis of BPA and its analogues in eggs. The proposed method was validated and applied to determine the presence of bisphenols in real eggs collected from the supermarkets and local farms in Beijing, China.

2. Experimental

2.1. Materials and reagents

Detailed information including CAS number, chemical structure and IUPAC name of BPA and its analogues evaluated in this work are illustrated in Table S1. Analytical standards of BPA, BPB, BPS, BPF, BPAF, BPP and BPBP were purchased from Sigma-Aldrich (St. Louis, USA, purity ≥99%), while BPAP (≥99%) was provided by Toronto Research Chemicals Inc. (TRC, Canada). Methanol, acetonitrile and formic acid of HPLC grade were obtained from Fisher Scientific Inc. (Pittsburgh, PA, USA). Analytical grade ammonium hydroxide, ammonium acetate, acetic acid and anhydrous magnesium sulfate ($MgSO_4$) were purchased from Beijing Chemical Co. (Beijing, China). Ultrapure water was prepared by the Milli-Q Synthesis system (Millipore, Bedford, USA). Oasis PRiME HLB (200 mg, 6 mL) cartridges were supplied by Waters (Milford, MA, USA). Syringe filters (0.22 μm) were purchased from Pall Co. (Ann Arbor, MI, USA).

Individual stock solutions (100 μg mL^{-1}) of all BPA and its analogues were prepared by dissolving accurately weighed amounts of the analytical standards in methanol. Mixed working standard solution was prepared by diluting the stock solutions with methanol. Because of the fact that detection of EDCs in biological samples often encounter contamination problem during the sampling, handling and storage processes, as described previously in the literature for BPA (Vitku et al., 2015). Therefore, in order to avoid bisphenols contamination, all glassware used in this study were pre-washed with ultrapure water and methanol, and all plastics were made of high quality polypropylene and also pre-washed as described above.

2.2. Sample preparation

A homogenized sample (2.0 g) was weighed into a 50 mL polypropylene centrifuge tube. Ten milliliter (10 mL) of acetonitrile (containing 0.1% formic acid) was added and vortex-mixed for 1 min, and then ultrasonicated for 15 min. Add 1 g anhydrous $MgSO_4$, and the mixture was immediately shaken for 5 min, followed by centrifugation at 10,000 rpm for 5 min at 4 °C. The supernatant was collected and then placed into a −20 °C refrigerator for 2 h. After centrifugation at 10,000 rpm for 5 min, the supernatant was collected and evaporated to dryness with nitrogen at 50 °C. The residue was re-dissolved in 5 mL of methanol-water (10:90, v/v).

The extract solution was directly loaded on the Oasis PRiME HLB cartridge and passed through under gravity. The target analytes were eluted from the cartridge using 3 mL methanol-water (90:10, v/v). The elute was evaporated to less than 0.3 mL with nitrogen at 50 °C, and then reconstituted to 1 mL by methanol-water (50:50, v/v). The final solution was filtered through 0.22 μm syringe filter into an autosampler vial. To evaluate the matrix effects, the matrix-matched calibration standards were prepared by adding seven different levels of working standard solutions to the blank egg sample extracts to yield 0.05, 0.1, 0.25, 0.5, 2.5, 5, and 25 μg kg^{-1}.

2.3. Instrumental conditions

Chromatographic analysis was performed on an Acquity UPLC system (Waters, Milford, MA, USA) and separation was achieved using an Acquity BEH C_{18} column (100 mm × 2.1 mm, 1.7 μm). The column temperature was maintained at 35 °C. The injection volume was 10 μL. The mobile phase was constituted by solvent A (methanol) and solvent B (0.1% ammonium hydroxide). The flow rate was 0.3 mL min^{-1} with a linear gradient program conducted as follows: 0–2 min, 20–100% A; 2–4 min, 100% A; 4.1 min, return to 20% A; 4.1–6 min, equilibration of the UPLC system.

Mass spectrometry analysis was carried out on a Xevo TQ-S triple quadrupole tandem mass spectrometer (Waters, Manchester, UK) with an electrospray ionization (ESI) source operated in negative mode. Typical source conditions for maximum intensity of precursor ions were as follows: capillary voltage, 3.0 kV; source temperature, 150 °C; desolvation temperature, 500 °C; cone gas (N_2) flow rate, 150 L h^{-1}; desolvation gas (N_2) flow rate, 800 L h^{-1}. The MS/MS detection was obtained using multiple reaction monitoring (MRM) mode. Data acquisition and processing were performed using MassLynx 4.1 software with QuanLynx program. Optimized MS/MS transitions as well as specific cone voltages and collision energies are summarized in Table S2.

2.4. Data analysis

Statistical analysis was conducted with Origin 9.0 (OriginLab Co., Northampton, MA). Differences between groups were tested by one-way ANOVA with the Tukey test, and p less than 0.05 was considered to be significantly different.

3. Results and discussion

3.1. UPLC-MS/MS conditions

Various types of LC columns such as reverse phase C_{18} (Xiong et al.,

2018; Sosvorova et al., 2017; Owczarek et al., 2018; Dong et al., 2018), Aquity HSS T3 (Chang et al., 2018), and Ascentis RP-Amide (Gallo et al., 2017) have been used for the separation of BPA and/or its analogues in biological samples. In this study, an Acquity BEH C_{18} column (100 mm × 2.1 mm, 1.7 μm) was selected for the separation of the eight bisphenols, as it provided the best resolution between the target analytes (Dong et al., 2018). In preliminary experiments, different mobile phases consisting of acetonitrile, methanol and water with formic acid, acetic acid, ammonium formate or ammonium acetate at different concentrations were studied. It was found that peak broadening, peak shape deterioration along with much smaller response were observed for all of the eight analytes with acetonitrile as organic solvent. This phenomenon has been observed for several BPA analogues determined in ESI negative mode (Owczarek et al., 2018; Dong et al., 2018). On the other hand, previous reports (Xian et al., 2017) demonstrated that the addition of ammonium hydroxide provided higher responses and ionization efficiencies, and therefore 0.1% ammonia in water (B) and methanol (A) were selected as the mobile phase. Under current optimized chromatographic conditions, each LC run was completed in 6 min, which is more suitable for high-throughput routine analysis.

Selection and tuning of MRM transitions were performed by direct infusion of standard solution (100 μg L^{-1}) of each analyte using Water's Intellistart System and then checked manually. As described in Table S1, the chemical structures of all the BPA analogues contain phenolic hydroxyl groups, while BPS and BPAF also contain halogen atoms, both of which show high electronegativities, therefore better sensitivity can be obtained in negative ionization mode (ESI-). For each compound, two different mass transitions were monitored for confirmatory analysis, among which the most abundant product ion was used for quantification. The MS/MS transitions for quantification and confirmation, as well as the optimized parameters for BPA analogues are summarized in Table S2.

3.2. Sample preparation

Sample preparation is a critical part of multi-residue method to simultaneously extract all the analytes of widely different physicochemical properties from matrix, effectively remove matrix interference, and improve method sensitivity and robustness. Previous reports demonstrated that the addition of formic acid in acetonitrile was important for the extraction of these weakly acid bisphenols (Xiong et al., 2018), which indeed improve the extraction efficiency in this work. Therefore, acetonitrile (containing 0.1% formic acid) was selected as the extraction solvent for further study. Next, dying the extract with anhydrous $MgSO_4$ enhanced the method sensitivity due to precipitation of water soluble interferences which could cause signal suppression. Furthermore, the salting-out effect could also help to improve the transport of compounds from aqueous solvent into the organic phase (Owczarek et al., 2018). Then, the extracts were stored in the refrigerator at −20 °C to eliminate lipids. This freezing step has proven to be worthwhile for these high phospholipids egg samples, since the following sample preparation became more reproducible and less matrix interference occurred. However, the freezing step can only remove part of the interference. SPE cartridge was applied to purify the samples and minimize matrix effects.

Three different kinds of SPE cartridges including C_{18}, HLB and ENVI-Carb were evaluated and the effects on recoveries were compared. As shown in Fig. 1, C18 and ENVI-Carb were not suitable for extraction of the strong polar compounds (BPS and BPF), with average recoveries lower than 60%. Oasis HLB cartridge provided good extraction efficiencies (recoveries 87.4–99.6%) for all of the eight analytes due to its hydrophilic lipophilic balanced property, which could retain both weak and strong polarity compounds. The recommended HLB method suggested using 5% methanol as the washing solvent followed by 100% methanol for elution, but this non-selective

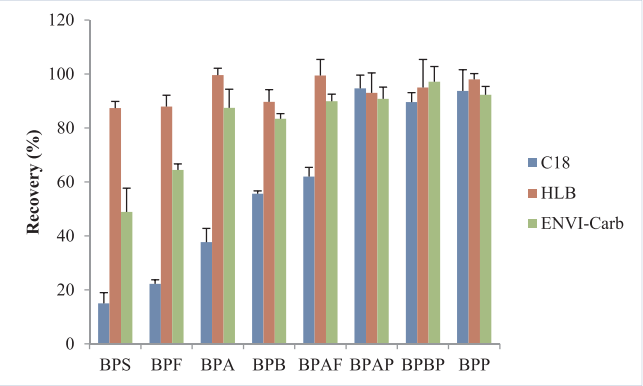

Fig. 1. Effects of different SPE cartridges on the recoveries of the eight BPA and its analogues evaluated (n = 3).

recommendation can not sufficiently remove interferences from complex matrices such as eggs. Further optimization of SPE procedure was carried out by washing the HLB cartridge successively with 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% methanol. All the washing solutions were collected separately and analyzed to obtain the elution curve of each compound. According to the elution curves (Fig. S1), we adjusted the SPE procedure of washing and eluting step to that described in Section 2.2. As it can be seen in Fig. 2, significant signal increasing was observed using the optimized method which should be attributed to the reduction of ion suppression effect. During the method development, a new type of SPE cartridge, Oasis PRiME HLB, was recommended by Waters. According to the manufacturer's manual, PRiME HLB cartridge can totally replace HLB, but does not require activation/equilibration and washing steps, and has better clean-up effects, especially for high phospholipids samples such as eggs. In our trials, as compared to HLB, PRiME HLB was less laborious and slightly improved the recoveries of the target compounds.

3.3. Method validation

To evaluate the performance of the proposed method, it was validated according to US FDA criteria in terms of selectivity, linearity, accuracy, precision, limit of detection (LOD), and limit of quantification (LOQ) (US FDA, 2001; Xiao, Yang, Li, Fan, & Ding, 2013). Fifteen blank egg samples from different origins were analyzed to verify the selectivity of the proposed method. Specificity was found to be satisfactory, with no chromatographic interference above S/N of 3 being observed around the retention time of the target compounds. Typical MRM chromatograms of the fortified samples are shown in Fig. 3.

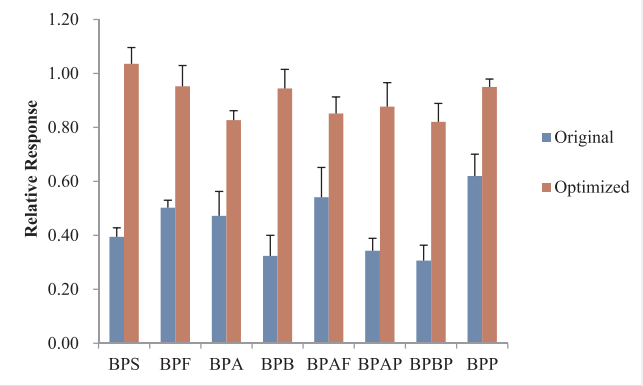

Fig. 2. Comparison of relative response (response matrix/response solvent) of the analytes in eggs between original and optimized clean-up procedures (n = 3).

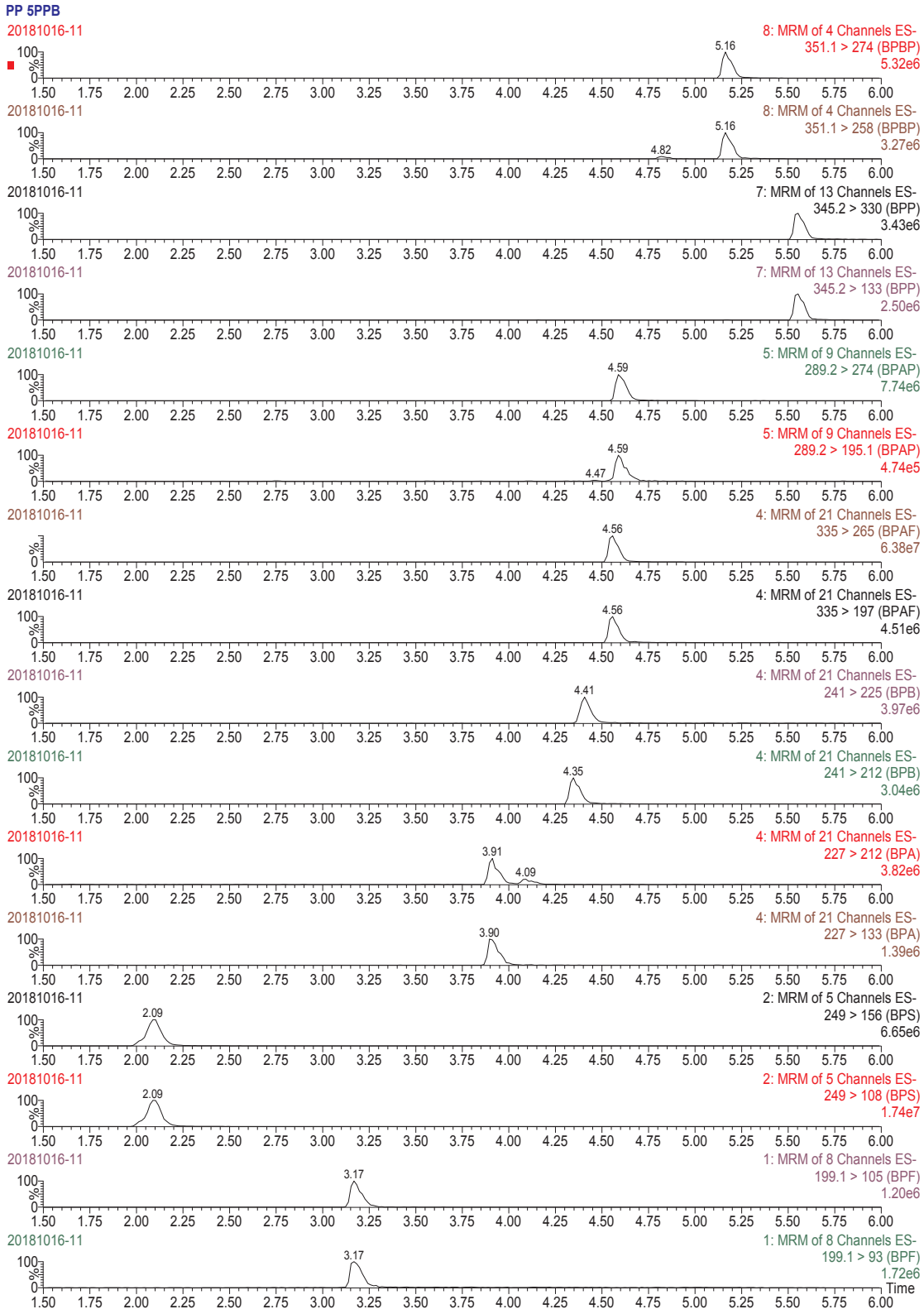

Fig. 3. Typical UPLC-MS/MS chromatograms of the fortified egg sample (0.5 μg kg^{-1}).

Linear regression results of standard solution and matrix-matched calibration curves are summarized in Table S3. Good linearity was obtained throughout all the tested concentrations for each analyte with the corresponding correlation coefficients (R^2) higher than 0.9962. To investigate the matrix effects, the response of standard solution calibration curves were compared to matrix-matched calibration curves using two-tailed paired *t*-test with a probability of 95%. The $|t|$ values imply that the data of these two series are not significantly different (Table S3). Furthermore, signal suppression or enhancement effects can be ignored in the ranges of 0.8–1.2 (response matrix/response solvent), and values outside this range indicates strong matrix effects (Zhang et al., 2017). As shown in Fig. 2, matrix effects for each compound were

Table 1
Intra- and inter-day repeatability and corrected recovery of the proposed method.

Analytes	Fortified levels (μg kg^{-1})	Intra-day (n = 6)		Inter-day (n = 18)	
		Mean (%)	RSD (%)	Mean (%)	RSD (%)
BPA	0.2	89.2	2.52	88.1	5.33
	0.4	87.3	3.16	91.4	6.75
	2.0	94.6	2.47	90.7	5.64
	20.0	88.4	1.50	85.6	2.66
BPB	0.2	96.6	2.68	87.1	4.52
	0.4	97.3	5.40	89.8	8.60
	2.0	91.9	5.81	90.0	9.42
	20.0	89.0	2.18	87.2	3.72
BPS	0.1	86.6	6.85	93.2	10.1
	0.2	82.7	2.26	104.3	8.86
	1.0	97.5	3.57	101.2	7.92
	10.0	90.3	3.52	92.5	6.91
BPF	0.2	89.6	3.24	94.6	4.38
	0.4	94.3	2.43	92.7	11.5
	2.0	87.7	2.98	97.6	9.71
	20.0	86.1	4.90	87.4	9.12
BPAF	0.1	88.2	3.80	93.0	8.73
	0.2	86.9	3.66	89.4	11.0
	1.0	93.1	2.32	89.0	10.5
	10.0	92.8	4.34	94.7	7.60
BPP	0.2	97.3	4.37	99.4	6.29
	0.4	86.6	5.84	102.0	7.89
	2.0	92.3	6.33	93.2	6.56
	20.0	89.6	2.35	88.7	7.11
BPAP	0.2	98.1	4.74	99.1	10.7
	0.4	96.4	7.02	92.1	8.93
	2.0	86.8	4.11	88.8	10.6
	20.0	85.5	3.45	87.4	6.97
BPBP	0.2	88.0	5.04	105.2	10.3
	0.4	89.3	1.96	95.6	6.70
	2.0	88.5	3.37	94.2	9.21
	20.0	92.6	1.62	91.4	8.65

in the ranges of 0.83–1.04, which can be ignored.

The accuracy and precision of the method were assessed using the blank eggs fortified with four different levels. The spiked samples were analyzed and the corrected recoveries were calculated by comparing the measured concentrations (calculated by matrix-matched calibration curves) to the spiked concentrations. Good corrected recoveries were obtained for each of the eight BPA analogues at all fortification levels as shown in Table 1. The average recoveries ranged between 82.7% and 105.2% with intra-day RSD values ≤7.02%. However, for the inter-day repeatability, it was slightly higher (≤11.5%) but, in any case it was lower than 20%, which was acceptable. The LODs and LOQs of the proposed methods are also summarized in Table S3. The achieved LOQs were approximately 3000–6000 fold lower than the specific migration limit (0.6 mg/kg) established by EU Commission (Regulation EU 10/2011), demonstrating the good sensitivity of this method, which was adequate for routine analysis of the eight BPA analogues in eggs.

3.4. Analysis of contamination of BPA and its analogues in eggs

The proposed method was applied to analysis of the target bisphenols in 24 egg samples collected from the supermarkets and local farms between September 2018 and January 2019 in Beijing, China. One sample contained a batch of six eggs, and the eggs were homogenized and stored at −20 °C before analysis. All of the real egg samples were analyzed in triplicate. The results are described in Table 2, and the detailed detection values are also illustrated in Table S4. Typical UPLC-MS/MS chromatograms of measurable BPA analogues in eggs are shown in Fig. S2. BPA was the most abundant contaminant, presented in 9 egg samples (37.5%) at concentration levels ranging from 0.28 to 1.05 μg kg^{-1}, with median value at 0.67 μg kg^{-1}. BPB was detected in one sample (4.2%), while BPS was identified in 5 samples (20.8%), at concentration levels similar to BPA, between 0.51 and 0.89 μg kg^{-1}. Interestingly, BPP was detected in two samples (8.3%), with contamination levels over ten-times higher than BPA, up to 13.7 and 15.3 μg kg^{-1}, respectively. To the extent of our literature search, no studies have been reported dealing with estimation of BPP in foodstuffs. These extremely high levels may be caused by ingestion of dietary feed supplements containing BPP as coating materials, therefore further studies are needed to examine the sources, transport, effects, environmental and biological consequences of BPP usage.

Generally, of the alternative bisphenols BPB, BPS and BPP were detected, which indicated an increasing usage of these substitutes as a consequence of the restrictions of BPA. Recent studies revealed that BPB, BPS and BPF have been found in surface water, wastewater and sewage sludge (Ismail et al., 2017; Wu et al., 2018), which also reflected their widespread occurrence in the environment. More information on the comparison of the results obtained in this work to other published studies were illustrated in Table S5. Since very limited data on BPA analogues in animal foods, the comparison has been extended to other bisphenols and biological matrices. Generally, except for BPP, most of the detection rates and concentration levels of BPA analogues described in the published literatures are found to be similar

Table 2
Confirmatory and quantitative analysis of incurred egg samples.

Samples	Analytes detected	Product ions (*m/z*)	Incurred samples		Matrix-matched standard		Levels* (μg kg^{-1})
			t_R (min)	Ion ratio	t_R (min)	Ion ratio	
#3	BPA	212.0/133.0	3.93	2.90	3.91	2.75	0.80 ± 0.09
#4	BPA	212.0/133.0	3.96	2.92	3.91	2.75	0.98 ± 0.11
	BPB	225.0/212.0	4.41	1.46	4.41	1.31	0.56 ± 0.07
	BPS	156.0/108.0	2.07	2.97	2.09	2.62	0.68 ± 0.06
	BPP	330.0/133.0	5.61	1.25	5.56	1.37	13.7 ± 1.2
#10	BPA	212.0/133.0	3.90	2.86	3.91	2.75	1.05 ± 0.10
	BPS	156.0/108.0	2.07	2.77	2.09	2.62	0.89 ± 0.07
	BPP	330.0/133.0	5.59	1.29	5.56	1.37	15.3 ± 1.4
#11	BPA	212.0/133.0	3.91	2.89	3.91	2.75	0.59 ± 0.06
	BPS	156.0/108.0	2.08	2.78	2.09	2.62	0.76 ± 0.05
#15	BPA	212.0/133.0	3.91	2.79	3.91	2.75	0.36 ± 0.05
#17	BPA	212.0/133.0	3.90	2.90	3.91	2.75	0.67 ± 0.07
	BPS	156.0/108.0	2.09	2.68	2.09	2.62	0.86 ± 0.11
#18	BPA	212.0/133.0	3.91	2.77	3.91	2.75	0.91 ± 0.13
	BPS	156.0/108.0	2.09	2.79	2.09	2.62	0.51 ± 0.06
#20	BPA	212.0/133.0	3.77	2.88	3.91	2.75	0.45 ± 0.06
#24	BPA	212.0/133.0	3.86	2.81	3.91	2.75	0.28 ± 0.05

*n = 3.

to the results presented.

4. Conclusions

In this work the development of a sensitive and robust UPLC-MS/MS method for the simultaneously determination of a broad spectrum of BPA and its analogues was described. To the best of authors' knowledge, this study is the first attempt to simultaneously determine the selected eight BPA analogues in eggs. Good validation parameters such as linearity, accuracy, precision, LODs and LOQs were obtained in this work, indicating the suitability of the proposed analytical method for routine monitoring of bisphenols contamination in foods. The developed method was successfully applied for the analysis of real egg samples. Results indicate that the problem of BPA analogues contamination in foods is still underestimated, and may lead to some adverse health effects.

CRediT authorship contribution statement

Zhiming Xiao: Conceptualization, Writing - original draft, Writing - review & editing. **Ruiguo Wang:** Investigation. **Decheng Suo:** Methodology. **Tong Li:** Validation. **Xiaoou Su:** Project administration.

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.

Acknowledgements

This study was financially supported by the National Key Research and Development Program of China (No. 2017YFC1600303) and the National Natural Science Foundation of China (No. 31502116).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2020.126882.

References

Ahsan, N., Ullah, H., Ullah, W., & Jahan, S. (2018). Comparative effects of bisphenol S and bisphenol A on the development of female reproductive system in rats: A neonatal exposure study. *Chemosphere, 197*, 336–343.

Chang, H., Shen, X., Shao, B., & Wu, F. (2018). Sensitive analysis of steroid estrogens and bisphenol A in small volumes of water using isotope-dilution ultra-performance liquid chromatography-tandem mass spectrometry. *Environmental Pollution, 235*, 881–888.

Commission Directive 2011/8/EU of 28 January 2011 amending Directive 2002/72/EC as regards the restriction of use of Bisphenol A in plastic infant feeding bottles.

Commission Regulation EU 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food.

Cunha, S. C., & Fernandes, J. O. (2013). Assessment of bisphenol A and bisphenol B in canned vegetables and fruits by gas chromatography-mass spectrometry after QuEChERS and dispersive liquid-liquid microextraction. *Food Control, 33*, 549–555.

Deceuninck, Y., Bichon, E., Gény, T., Veyrand, B., Grandin, F., Viguié, C., et al. (2019). Quantitative method for conjugated metabolites of bisphenol A and bisphenol S determination in food of animal origin by ultra high performance liquid chromatography-tandem mass spectrometry. *Journal of Chromatography A, 1601*, 232–242.

Dong, H., Zeng, X., & Bai, W. (2018). Solid phase extraction with high polarity Carb/PSA as composite fillers prior to UPLC-MS/MS to determine six bisphenols and alkylphenols in trace level hotpot seasoning. *Food Chemistry, 258*, 206–213.

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

Gallo, P., Pisciottano, I. D. M., Esposito, F., Fasano, E., Scognamiglio, G., Mita, G. D., & Cirillo, T. (2017). Determination of BPA, BPB, BPF, BADGE and BFDGE in canned energy drinks by molecularly imprinted polymer cleaning up and UPLC with fluorescence detection. *Food Chemistry, 220*, 406–412.

Goeury, K., Duy, S. V., Munoz, G., Prévost, M., & Sauvé, S. (2019). Analysis of Environmental Protection Agency priority endocrine disruptor hormones and bisphenol A in tap, surface and wastewater by online concentration liquid chromatography tandem mass spectrometry. *Journal of Chromatography A, 1591*, 87–98.

Industry Experts, (2016). Bisphenol A – A Global Market Overview.

Ismail, N. A. H., Wee, S. Y., & Aris, A. Z. (2017). Multi-class of endocrine disrupting compounds in aquaculture ecosystems and health impacts in exposed biota. *Chemosphere, 188*, 375–388.

Kinch, C. D., Ibhazehiebo, K., Jeong, J. H., Habibi, H. R., & Kurrasch, D. M. (2015). Low-dose exposure to bisphenol A and replacement bisphenol S induces precocious hypothalamic neurogenesis in embryonic zebrafish. *PNAS, 112*, 1475–1480.

Kudłak, B., Wieczerzak, M., & Namieśnik, J. (2019). Bisphenols (A, S, and F) affect the basic hormonal activity determined for pharmaceuticals-Study of Saccharomyces cerevisiae. *Environmental Pollution, 246*, 914–920.

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 Agricultural and Food Chemistry, 61*, 4655–4662.

Mandrah, K., Satyanarayana, G. N. V., & Roy, S. K. (2017). A dispersive liquid-liquid microextraction based on solidification of floating organic droplet followed by injector port silylation coupled with gas chromatography–tandem mass spectrometry for the determination of nine bisphenols in bottled carbonated beverages. *Journal of Chromatography A, 1528*, 10–17.

Owczarek, K., Kubica, P., Kudłak, B., Rutkowska, A., Konieczna, A., Rachoń, D., et al. (2018). Determination of trace levels of eleven bisphenol A analogues in human blood serum by high performance liquid chromatography–tandem mass spectrometry. *Science of the Total Environment, 628–629*, 1362–1368.

Qiu, W., Fang, M., Liu, J., Fu, C., Zheng, C., Chen, B., & Wang, K. J. (2019). In vivo actions of bisphenol F on the reproductive neuroendocrine system after long-term exposure in zebrafish. *Science of the Total Environment, 665*, 995–1002.

Rochester, J. R., & Bolden, A. L. (2015). Bisphenol S and F: A systematic review and comparison of the hormonal activity of bisphenol A substitutes. *Environmental Health Perspectives, 123*, 643–650.

Russo, G., Barbato, F., Mita, D. G., & Grumetto, L. (2019). Occurrence of bisphenol A and its analogues in some foodstuff marketed in Europe. *Food and Chemical Toxicology, 131*, 110575.

Russo, G., Capuozzo, A., Barbato, F., Irace, C., Santamaria, R., & Grumetto, L. (2018). Cytotoxicity of seven bisphenol analogues compared to bisphenol A and relationships with membrane affinity data. *Chemosphere, 201*, 432–440.

Silveira, R. S., Rocha, B. A., Rodrigues, J. L., & Jr, F. B. (2020). Rapid, sensitive and simultaneous determination of 16 endocrine-disrupting chemicals (parabens, benzophenones, bisphenols, and triclocarban) in human urine based on microextraction by packed sorbent combined with liquid chromatography tandem mass spectrometry (MEPS-LC-MS/MS). *Chemosphere, 240*, 124951.

Sosvorova, L. K., Chlupacova, T., Vitku, J., Vlk, M., Heracek, J., Starka, L., et al. (2017). Determination of selected bisphenols, parabens and estrogens in human plasma using LC-MS/MS. *Talanta, 174*, 21–28.

Tucker, D. K., Bouknight, S. H., Brar, S. S., Kissling, G. E., & Fenton, S. E. (2018). Evaluation of prenatal exposure to pisphenol analogues on development and long-term health of the mammary gland in female mice. *Environmental Health Perspectives, 126* 087003-1–17.

US Food and Drug Administration, (2001). Guidance for industry: Bioanalytical method validation.

U.S. Food and Drug Administration – US FDA. (2010). Update on bisphenol A for use in food contact applications.

Vitku, J., Chlupacova, T., Sosvorova, L., Hampl, R., Hill, M., Heracek, J., et al. (2015). Development and validation of LC-MS/MS method for quantification of bisphenol A and estrogens in human plasma and seminal fluid. *Talanta, 140*, 62–67.

Wu, L. H., Zhang, X. M., Wang, F., Gao, C. J., Chen, D., Palumbo, J. R., ... Zeng, E. Y. (2018). Occurrence o