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A sensitive determination method for trace bisphenol A in bottled water and wastewater samples: Binary solvent liquid phase microextraction-quadrupole isotope dilution-gas chromatography-mass spectrometry

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ABSTRACT

A sensitive, accurate and precise methodology was established for the preconcentration and determination of bisphenol A in bottled water and wastewater samples at trace levels. A binary solvent liquid phase microextraction (BSLPME) method was optimized to extract bisphenol A before determination by gas chromatography-mass spectrometry (GC-MS). The type of binary solvent/disperser solvent, vortex period and mode of adding extraction and disperser solvent mixture to aqueous solution were determined by univariate optimization. Three significant parameters including volume of binary solvent, volume of dispersive solvent and ratio of binary solvent were optimized using Box-Behnken Design. Low limit of detection (0.30 ng/g) and limit of quantitation (0.99 ng/g) values were recorded for the BSLPME-GC-MS method. Hence, 173 times enhancement in the detection limit of the GC-MS system was achieved by the developed microextraction method. Quadrupole isotope dilution (ID^4) strategy was used to augment the extraction method to achieve high accuracy and precision. When the developed BSLPME method was combined with the ID^4 strategy, bottled water and wastewater samples spiked at approximately 200 ng/g recorded excellent recovery results of 100.3 ± 0.4% and 100.0 ± 0.5%, respectively. Therefore, accurate and precise determination of bisphenol A at trace levels was achieved by a low cost, rapid and green analytical method.

1. Introduction

Plasticizers are organic compounds that are commonly used in the manufacturing of plastics and among them, Bisphenol A (BPA) is the most reputed, widely used and investigated plasticizer [1,2]. BPA is used in the production of leathers, textiles, wood, pharmaceuticals, pesticides, epoxy resins, polycarbonates [3–5] and several cosmetic products [6]. BPA is a hazardous chemical found in aquatic environments from ng/L to μg/L concentrations [7]. There are various sources of BPA contamination in environmental water bodies such as plastic degradation, landfill leachate, treatment plants [8], household products, industrial wastes [9] and unprocessed water [10]. Since BPA is one of the estrogenic compounds, it has the potential to cause hormonal imbalance, abnormal actions, human breast cancer and feminization in some animals [11]. Considering all these facts, it is crucial to detect BPA at trace levels with high precision and accuracy because of its extensive usage areas and negative impacts on living organisms. In the literature, chromatographic techniques with appropriate detectors have been preferred for the identification and quantification of BPA. Some examples are gas chromatography-mass spectrometry (GC-MS) [12,13] gas chromatography-tandem mass spectrometry (GC-MS/MS) [14], liquid chromatography mass spectrometry (LC-MS) [13], liquid chromatography tandem mass spectrometry (LC-MS/MS) [15,16], high performance liquid chromatography (HPLC) [17,18] and ultra-performance

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liquid chromatography with fluorescence detection (UPLC-FLD) [19].

Liquid phase microextraction (LPME) is a powerful and effective sample preparation method for both matrix separation and preconcentration of analytes prior to instrumental analysis [20]. There are several methods such as switchable solvent liquid phase microextraction (SSLPME) [21], hollow fiber-liquid phase microextraction based on deep eutectic solvent (DES-HF-LPME) [22], molecularly imprinted solid phase extraction (MISPE) [23] and magnetic solid phase extraction (MSPE) [24] for extraction and preconcentration of BPA. Among the LPME methods, dispersive liquid–liquid microextraction (DLLME) is a miniaturized liquid–liquid extraction process [25,26], which has been preferred for the determination of both organic and inorganic analytes [27]. This is due to its high output, quick procedure, cheapness and production of very low hazardous wastes, making it an environmentally friendly method [28]. Binary solvent liquid phase microextraction (BSLPME) is a modification of the DLLME method, and it is based on the combination of two or more extraction solvents. The combination of two or more solvents alters the polarity, density and extraction efficiency of the individual solvents, leading to an increase in overall extraction efficiency [29]. However, some measurement handicaps can arise during instrumental analysis like analyte loss and electrical fluctuations, and internal standards are generally used to mitigate these drawbacks [30].

Isotope dilution (ID) is a superlative external calibration strategy that yields exceptionally accurate and precise results relative to the other calibration strategies [31]. The principle of this technique is based on adding a certain amount of an isotopically enriched material to a sample and measuring the isotope ratios rather than the absolute analyte. Isotope ratios are not influenced by matrix effect, analyte losses, interferences or instrumental fluctuations [32]. There are several review articles that give detailed accounts of the different isotope dilution strategies that can be employed for both organic and inorganic analytes [33–36]. Among these isotope dilution strategies, quadrupole isotope dilution (ID^4) was developed to mitigate measurement errors and uncertainties without accounting for equation parameters such as isotopic composition of the sample (r_A), isotopic composition of the labelled analyte (r_B) and the enriched material's mass fraction (w_B) [37]. Coupled with GC-MS, the GC-ID^4-MS technique can be evaluated as a superior analytical measurement strategy for volatile compounds [38].

This study was aimed at combining GC-ID^4-MS strategy with BSLPME in order to maintain high precision and accuracy for the determination of BPA at trace levels. Box Behnken Design (BBD) was used to optimize variables of experimental parameters, and bottled water and wastewater were used as test samples for recovery experiments. This is the first study reported on the combination of ID^4 and GC-MS for the determination of an analyte at trace concentrations with very high accuracy and precision.

2. Materials and methods

2.1. Chemicals and reagents

High purity standard of bisphenol A (99.8%) and bisphenol A-*d16* (98.0%) were purchased from Dr. Ehrenstorfer, Germany. Chloroform (CHL), 1,2-dichloroethane (DCE), dichloromethane (DCM), carbon tetrachloride (CTC), ethanol (EtOH), isopropyl alcohol (IPA), acetonitrile (ACN) and acetone (ACT) were bought from Merck, Germany. Elga Flex 3 Water Purification system with 18.2 MΩ.cm resistivity was used to supply ultrapure water during all experiments.

2.2. Gas chromatographic and mass spectrometric conditions

All instrumental measurements were performed with a hyphenated system consisting of an HP 6890 series Agilent gas chromatograph and an HP 5973 series Agilent mass spectrometer. The analytical column used for BPA elution was (5%-phenyl)-methylpolysiloxane (HP5-MS column). For the sample introduction unit, the injection mode, inlet temperature and injection volume were fixed as splitless, 280 °C and 1.0 μL, respectively. Helium gas was used to purge the gaseous sample through the chromatographic system. The column temperature program utilized is summarized in Table 1. In the MS system, source temperature, quad temperature and transfer line temperature were 230, 150 and 280 °C, respectively. Qualifier/quantifier ions for bisphenol A and bisphenol A-*d16* were determined as 213/228 and 224/242, respectively [21].

Table 1
Temperature program for the GC-MS system [21].

Initial temperature, °C	Final Temperature, °C	Ramp, °C/min
120	220	60
220	300	30

2.3. Bottled water and wastewater samples

In this study, water samples were selected as representative samples to validate the developed quadrupole isotope dilution (ID^4) method for BPA. Different bottled water samples (exposed the sun light) were collected from Yıldız Technical University (Davutpaşa Campus) and mixed to have a sample pool. Wastewater samples were taken from a municipal wastewater treatment plant in İstanbul (Turkey). The samples were stored in polyethylene terephthalate bottles at 4.0 °C in a refrigerator.

Firstly, blank analyses were performed on the bottled water and wastewater samples using the GC-MS system after applying the BSLPME method. Detectable BPA concentrations were not found in both samples. Thus, two different BPA concentrations (approximately 50 and 200 μg/kg) were spiked to the bottled water and wastewater samples after two folds sample dilution with ultrapure water. The spiked sample solutions were treated with the BSLPME method and then sent to the GC-MS system.

2.4. Binary solvent liquid phase microextraction (BSLPME) protocol

A binary solvent mixture consisting of DCM (74.2 μL)/DCE (125.8 μL) and ACT (1.56 mL) as disperser solvent was injected into 8.0 g sample/standard solution, followed by 45 s vortex period to boost analyte transfer from the aqueous phase into the binary solvent mixture. Then, 2.0 min centrifugation at 3461 *g* was implemented to facilitate phase separation between the aqueous and extraction solvents. The settled phase at the bottom of the solution was withdrawn with an automatic pipette and injected into the GC-MS system.

2.5. Preparation of blends for BSLPME-ID^4-GC-MS methods

In this study, sample solution (X), standard solution (Y) and isotopically labelled material solution (Z) were prepared in ultrapure water by diluting stock solutions of bisphenol A and bisphenol A-*d16*. All blend preparations were gravimetrically performed on an OHAUS PA114C analytical balance. Theoretical blend compositions are summarized in Table S1 for the BSLPME-ID^4-GC-MS systems. Three calibration blends (YZ-1, YZ-2, YZ-3) and one sample blend (XZ) were used in this study. The exact matching method was applied to the system, and this was done to equalize the $r_{yz\text{-}2}$ and r_{XZ} values. Hence, isotopic measurements were not affected by the w_X value [39]. Total blend masses were fixed to 8.0 g because the BSLPME method was developed using 8.0 g initial sample amount. After the blend preparations given in Table S1 were performed, the developed BSLPME method was applied to all blends. Experimental sample/calibration blend preparations for bottled water and wastewater samples are given in Tables S2 and S3, respectively.

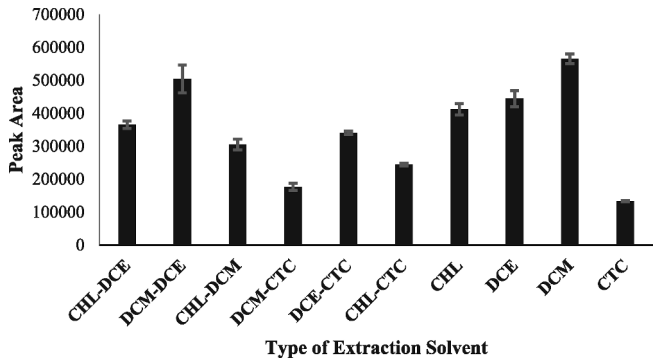

Fig. 1. Univariate optimization of extraction solvent type (50.0 μg/kg standard solution, 1.50 mL of disperser solvent (EtOH), 15 s of vortex and 300 μL of extraction solvent).

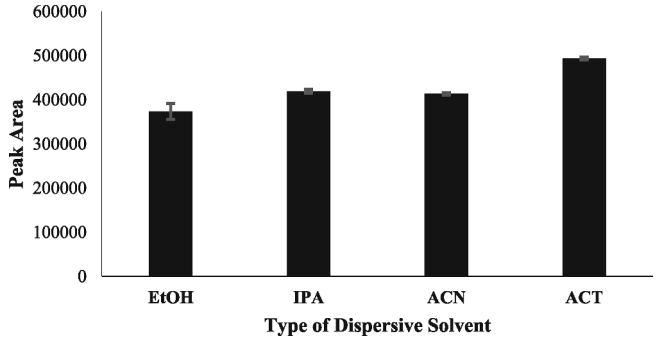

Fig. 2. Univariate optimization of dispersive solvent (50.0 μg/kg standard solution, 1.50 mL of dispersive solvent, 15 s of vortex and 300 μL of extraction solvent (1:1 ratio (v:v) of DCM-DCE mixture).

3. Results and discussion

3.1. Pre-experimental Design optimizations

Prior to the Box Behnken Design (BBD) experiments, univariate optimizations were performed to select optimum parameters of the BSLPME method. Firstly, the extraction efficiencies of CHL, DCE, DCM and CTC were evaluated as single (300 μL) and binary (300 μL, 1:1 v/v) extractants as shown in Fig. 1. The two highest signals were obtained for DCM solvent and DCM-DCE binary solvent, but the latter was selected because the settled phase of the former was very low and difficult to collect for instrumental measurement. Selection of a proper disperser solvent was done by testing EtOH, IPA, ACN and ACT. Similar peak area values were recorded for EtOH, IPA and ACN, but a slightly higher dispersion efficiency was recorded by ACT (Fig. 2). Therefore, ACT was used as the dispersive solvent for further experiments.

Mixing processes can affect the mass transfer of analytes between the organic and aqueous phases. Mixing by vortex was therefore investigated between 0 and 60 s periods. It is clear in Fig. S1 that 45 s yielded the highest peak area value, with a percent relative standard deviation value of 0.90%. The 60 s mixing period could have led to a reverse transfer of the analyte from the extraction phase into the aqueous solution. For these reasons, the optimum vortex period was selected as 45 s. The final univariate optimization parameter was the mode of adding the extraction and disperser solvent mixture into the aqueous sample. Two different addition modes (automatic pipette and injector) were tested to determine their effects of extraction output. The injector mode of addition gave results that were better (Fig. S2) than automatic pipette addition by approximately 27%. These results showed that the mode of addition significantly affects dispersion of the extraction and disperser solvent mixture.

3.2. Multivariate optimizations

In this section, Box-Behnken Design was employed to optimize the volume of extraction solvent (A), volume of disperser solvent (B) and binary solvent ratio (C). It is known that BBD depends on three levels at −1, 0 and + 1 combinations [40]. For this reason, the levels were set as 200, 300, 400 μL for parameter A, 1.50, 2.75, 3.0 mL for parameter B

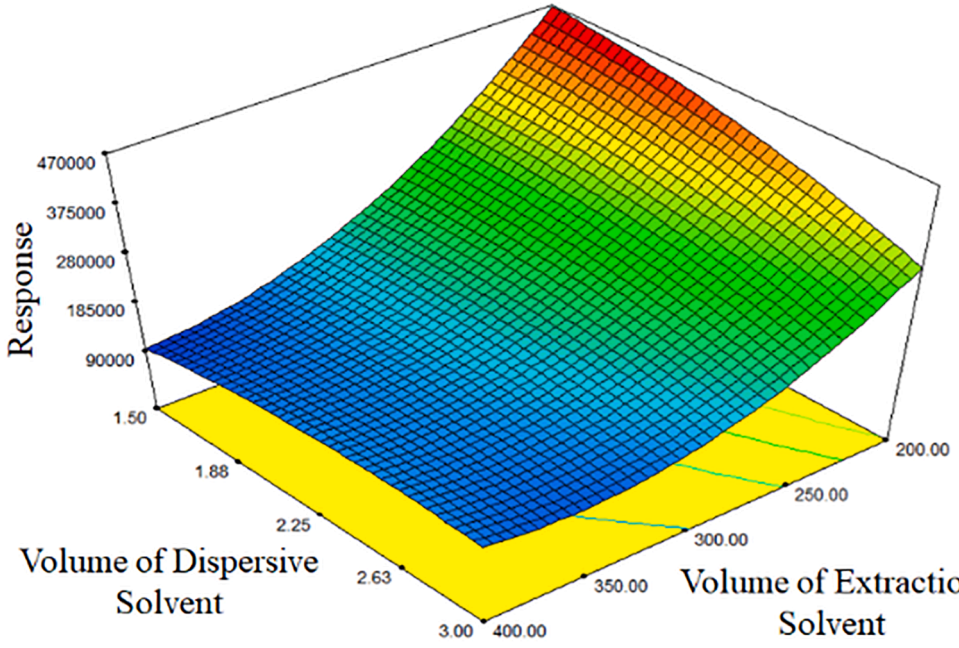

Fig. 3. 3D surface plot demonstrating significant interaction effects of the extraction solvent and the disperser solvent volumes (Binary solvent ratio was fixed at 1.0:1.7).

Table 2
Analytical figures of merit for the GC-MS and BSLPME-GC-MS systems and comparison to other methods in the literature.

System	LOD[a]	LOQ[b]	Dynamic Range	R^2	ECP[c]	Reference
GC-MS[d]	51.7	172.3	0.20–26.60 mg/kg	1.0000	y = 406687x – 1520.3	[21]
BSLPME-GC-MS[e]	0.3 μg/kg	1.0 μg/kg	1.1–1031 μg/kg	0.9999	y = 47237x + 42889	Present study
SPME-HPLC[f]	1.1 ng/mL	3.8 ng/mL	10–500 ng/mL	0.9991	–	[41]
DLLME-GC-IT/MS[g]	1.1 ng/mL	6.2 ng/mL	–	0.9843	y = 1.1453x-0.6973	[42]
DLLME-HPLC[h]	0.7 ng/mL	–	2–20 ng/mL	0.996	–	[43]

[a] LOD: Limit of detection.
[b] LOQ: Limit of quantification.
[c] ECP: Equation of calibration plot.
[d] GC-MS: Gas chromatography-mass spectrometry.
[e] BSLPME-GC-MS: Binary solvent liquid phase microextraction-gas chromatography-mass spectrometry.
[f] SPME-HPLC: Solid phase microextraction-high performance liquid chromatography.
[g] DLLME-GC-IT/MS: Dispersive liquid–liquid microextraction-gas chromatography-ion trap mass spectrometry.
[h] DLLME-HPLC: Dispersive liquid–liquid microextraction-high performance liquid chromatography.

and 1.0:2.0, 1.25:1.0, 2.0:1.0 (DCM:1,2-DCE) ratios for parameter C. The design consisted of 17 runs with five center points, and the mean value of quadruplicate extractions were considered as response value for each run. The quadratic expression for the BBD experiments was as follows:

$$Y = C_0 + C_1X_1 + C_2X_2 + C_3X_3 + C_{12}X_1X_2 + C_{13}X_1X_3 + C_{23}X_2X_3 + C_{11}X_1^2 + C_{22}X_2^2 + C_{33}X_3^2 \quad (1)$$

where Y is the response; C_0 is a constant term; C_1, C_2, and C_3 are linear terms; C_{12}, C_{13}, and C_{23} are interaction terms; C_{11}, C_{22}, and C_{33} are quadratic terms.

The *Design-Expert 7.0.0* Trial Software was used for the evaluation of experimental results. Analysis of variance (ANOVA) was applied to determine statistical significance of the independent parameters and their interactions. The empirical relationship between parameters and experimental values is shown in Equation (2).

$$R_1 = +176300 - 140900A - 27706.81B - 19340.13C + 45087.37AB + 84029.13A^2 - 24126.87B^2 \quad (2)$$

The regression model and ANOVA results of the experimental design are summarized in Table S4. The p-value indicates that the model is highly significant ($F_{model} = 141.33$, $p < 0.0001$). The goodness-of-fit statistics of the model were evaluated using R^2 and adjusted R^2. The respective R^2 and adjusted R^2 values of 0.9883 and 0.9814 indicate that the predicted model fitted well to the experimental data. This agreement can also be seen in the normal distribution plot given in Fig. S3. The p-values of A, B, C, AB, A^2 and B^2 were all statistically significant at 95% confidence level.

The three-dimensional (3D) graph of Fig. 3 shows the interaction effect of A and B parameters on the response at a fixed C parameter ratio of 1.0:1.7 (DCM:1,2-DCE). According to the ANOVA results, low volumes of the extraction solvent and dispersive solvent gave the highest responses, while high DCM:1,2-DCE ratios led to low responses. The optimum parameter values selected from the model predictor were 200.1 μL for parameter A, 1.56 mL for parameter B and 1.0:1.7 ratio for parameter C.

3.3. Equilibrium period

Equilibrium period is one of the most important parameters in isotope dilution analyses. Different analytes and their isotopic analogues require a certain period to mix homogeneously to allow them exhibit similar of physical and chemical characteristics during analysis. For example, 4-n-nonylphenol and 4-n-nonylphenol-*deutarated 8* had a stable isotopic ratio within two hours [37]. For this reasons, various equilibration periods between 0 and 120 min were applied to YZ-2 blends. According to isotopic measurements by the GC-MS system, the optimum period for stable isotopic ratios was obtained as 60 min [21]. After this optimization, sample and calibration blends were allowed to stand for 60 min in order to reach isotopic homogeneity.

3.4. Comparison of three different isotope dilution strategies for bottled samples

Standard addition triple isotope dilution (SA-ID^3), triple isotope dilution (ID^3) and quadrupole isotope dilution (ID^4) were compared with each other to determine the best isotope dilution strategy for bottled water samples. Here, the theoretical sample/calibration blends presented in Table S5 were prepared for SA-ID^3, ID^3 and ID^4 strategies. After the equilibrium period, all blends were directly sent to the GC-MS system. Experimental blend preparation and recovery results for SA-ID^3-GC-MS, ID^3-GC-MS and ID^4-GC-MS systems are given in Tables S6–S11. Recovery results were calculated as 100.8 ± 2.1%, 99.2 ± 1.9% and 100.5 ± 0.6% for SA-ID^3-GC-MS, ID^3-GC-MS and ID^4-GC-MS systems, respectively. These results showed that the ID^4 strategy was better than other strategies in terms of precision. Therefore, ID^4 strategy was combined with the BSLPME method to enhance accuracy and precision for determination of bisphenol A at trace levels in bottled water. In the next experiments, the selected isotope dilution method was also used for wastewater samples.

Table 3
Percent recovery results for the BSLPME-GC-MS system.

Sample	Theoretical Spiked Concentration, ng/g	Experimental Spiked Concentration, ng/g	Recovery %	±CV *
Bottled water	50.2	44.9	89.5	3.5
	221.8	262.2	118.2	2.4
Wastewater	51.6	49.8	96.5	4.1
	199.5	204.0	102.2	2.2

* Uncertainties (±): Coefficient of variance (CV) of quadruplicate measurements.

3.5. Analytical figure of merits

Bisphenol A standard solutions (prepared in EtOH) in the range of 0.10 and 100 mg/kg (ten different concentrations) were directly sent to the GC-MS to determine the system's performance. The parameters used for evaluation of the system were limit of detection (LOD), limit of quantification (LOQ), linear range, equation of calibration plot (ECP), coefficient of correlation (R^2) and percent relative standard deviation of the lowest concentration in the dynamic range (%RSD_{LC}) as summarized in Table 2.

Twelve different concentrations (between 1.0 and 5000 μg/kg) of the analyte standard solutions were prepared in 2.0% ethanol solution. These standard solutions were extracted with the optimum BSLPME protocol detailed in Section 2.4 and sent to the GC-MS system to evaluate analytical performance of the BSLPME-GC-MS system. LOD, LOQ, dynamic range, ECP, coefficient of correlation and %RSD_{LC} values of the BSLPME-GC-MS system are given in Table 2. Enhancement in detection power (comparison in LOD values of GC-MS and BSLPME-GC-MS systems) was calculated as 173 folds and calibration sensitivity (calibration plot slope of GC-MS divided by that of the BSLPME-GC-MS system) was determined as 116 folds.

The developed BSLPME-GC-MS method was compared to other studies in the literature. In a study performed by our research group, ID4 strategy was combined with switchable solvent liquid phase microextraction (SS-LPME) method to determine bisphenol A at trace levels in bottled water and wastewater samples [21]. Limit of detection obtained by the SS-LPME was relatively higher than the BSLPME method reported in this study. Offline solid phase microextraction-high performance liquid chromatography with florescence detection (SPME-HPLC), [41], dispersive liquid–liquid microextraction-gas chromatography-ion trap mass spectrometry (DLLME-GC-IT/MS) [42], dispersive liquid–liquid microextraction-high performance liquid chromatography with UV detection (DLLME-HPLC) [43] recorded higher LOD values than the BSLPME-GC-MS method developed in this study. It is also clear that the BSLPME-GC-MS method possesses a wider dynamic range with high correlation coefficient. Furthermore, the developed method is rapid, cheap and green method that does not involve time consuming laboratory procedures.

3.6. Recovery studies for BSLPME-GC-MS system

Spiking experiments were performed on bottled water and wastewater samples to determine applicability and accuracy of the BSLPME-GC-MS system for real samples. Preparation of bottled water and wastewater samples are detailed in Section 2.3. When the samples were analyzed by GC-MS system after applying the BSLPME protocol, there was no detectable bisphenol A in the samples. After the blank analysis, the samples were spiked with BPA at two different concentrations (50.0 and 200 μg/kg) and then sent to GC-MS system after preconcentrating with the BSLPME method. The percent recovery results presented in Table 3 were calculated using the external calibration method.

The recovery results given in Table 3 verified the applicability and accuracy of the BSLPME-GC-MS method. However, further improvements in terms of accuracy and precision of the developed BSLPME-GC-MS method were done by the combination of ID^4 and BSLPME methods.

3.7. Combination of ID^4 strategy and BSLPME-GC-MS system

The BSLPME method was developed to reach lower detection limits for BPA in bottled water and wastewater samples. Bisphenol A contamination can be determined using the eco-friendly and sensitive BSLPME method at trace levels, but accuracy and precision of the developed method (Table 3) were not very high. Therefore, the BSLPME method was combined with ID^4 strategy to determine the target analyte accurately and precisely at trace levels by the GC-MS system. The theoretical preparation of calibration/sample blends are detailed in Section 2.5. After the equilibrium period of isotopes (bisphenol A and bisphenol A-*d16*), the standard/sample blends were extracted/preconcentrated utilizing the optimized BSLPME method. With the combination of ID^4 and BSLPME methods prior to GC-MS determination, the theoretical and experimental spiked concentrations were very close to each other for both samples and precision was higher than the BSLPME-GC-MS method. Relative recovery results and coefficient of variations for the BSPLME-ID^4-GC-MS system are presented in Table 4. All calibration/sample blends were measured in quadruplicate by the GC-MS system and 81 blends combinations were evaluated to calculate recovery results with their coefficient of variance (Tables S12 and S13).

As seen in Table 4, high recovery results with very low standard deviation values were obtained by using the BSPLME-ID^4-GC-MS method. Some studies in the literature reported accuracy (%recovery) values lower or higher than 100%, and low precision (CV) values, which that could be due to matrix effects or random errors. The proposed BSLPME-ID^4-GC-MS method provided highly accurate and precise analytical results irrespective of matrix effects and instrumental errors. Moreover, bisphenol A can be accurately and precisely determined at ultra-trace levels with the developed method by employing more sensitive instruments such as gas chromatography-tandem mass spectrometry (GC-MS/MS) and gas chromatography-high resolution mass spectrometry (GC-HRMS).

4. Conclusion

The BSLPME method integrated with ID^4 strategy prior to GC-MS measurement was developed to enhance accuracy and precision for the determination of bisphenol A in bottled water and wastewater samples. Important parameters of BSLPME method were successfully optimized by employing univariate and multivariate optimization approaches. Type of binary extraction solvent, type of disperser solvent,

Table 4
Recovery results for BSPLME-ID^4-GC-MS system and comparison to other recovery results reported in the literature.

Sample	Theoretical Spiked Concentration, ng/g	Experimental Spiked Concentration, ng/g	Recovery%	±CV	Reference
Bottled water	192.6	192.1	100.3	0.4	This study
Wastewater	198.0	198.0	100.0	0.5	This study
River water	100 μg/L	–	97.28	2.31	[44]
Bottled water	0.30 μg/L	0.32 μg/L	106.7	3.20	[45]
Tap water	50 μg/L	60.0	120	14.3	[46]
Lake water	50 μg/L	47.5	95	7.8	
River water	50 μg/L	42.5	85	11.3	

vortex period and the mode of adding the mixture of extraction and disperser solvent to aqueous solution were optimized by a univariate approach. A multivariate approach based on Box-Behnken Design was used to optimize the volume of binary extraction solvent and disperser solvent, and ratio of binary solvent. Under the optimum conditions, system analytical performance of the BSLPME-GC-MS system were performed to determine LOD (0.3 μg/kg) and LOQ (1.0 μg/kg) values. Spiking experiments for the BSLPME-GC-MS system were carried out with bottle water and wastewater samples, and the recovery results were calculated in the range of 89–119% for both samples. The ID^4 strategy was combined with the BSLPME method to boost not only the accuracy of the method, but also precision. Recovery results for the BSLPME-ID^4-GC-MS system were recorded as 100.3 ± 0.4 and 100.0 ± 0.5% for bottled water and wastewater samples, respectively. Furthermore, the proposed method (BSLPME-ID^4-GC-MS) can be applied to other complex matrices to quantify bisphenol A with high accuracy and precision.

CRediT authorship contribution statement

Süleyman Bodur: Methodology, Validation, Writing - original draft. **Sezin Erarpat:** Methodology, Validation, Writing - original draft. **Gamze Dalgıç Bozyiğit:** Methodology, Validation, Writing - original draft. **Dotse Selali Chormey:** Methodology, Validation, Writing - original draft. **Ersoy Öz:** Methodology, Validation, Writing - original draft. **Nizamettin Özdoğan:** Methodology, Validation, Writing - original draft. **Sezgin Bakırdere:** Supervision, Project administration, Writing - review & editing.

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.

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Appendix A. Supplementary data

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References

[1] P.E. Rosenfeld, L.G.H. Feng, P.E. Rosenfeld, L.G.H. Feng, Emerging contaminants, risks hazard, Wastes (2011) 215–222, https://doi.org/10.1016/B978-1-4377-7842-7.00016-7.
[2] C. Florindo, N.V. Monteiro, B.D. Ribeiro, L.C. Branco, I.M. Marrucho, Hydrophobic deep eutectic solvents for purification of water contaminated with Bisphenol-A, J. Mol. Liq. 297 (2020), 111841, https://doi.org/10.1016/j.molliq.2019.111841.
[3] J.R. Koduru, L.P. Lingamdinne, J. Singh, K.-H. Choo, Effective removal of bisphenol A (BPA) from water using a goethite/activated carbon composite, Process Saf. Environ. Prot. 103 (2016) 87–96, https://doi.org/10.1016/J.PSEP.2016.06.038.
[4] R. Amini, J. Khandaghi, M.R.A. Mogaddam, Combination of Vortex-Assisted Liquid-Liquid Extraction and Air-Assisted Liquid-Liquid Microextraction for the Extraction of Bisphenol A and Bisphenol B in Canned Doogh Samples, Food Anal. Methods 11 (2018) 3267–3275, https://doi.org/10.1007/s12161-018-1260-8.
[5] T. Li, Y. Song, Z. Dong, Y. Shi, J. Fan, Hydrophobic deep eutectic solvents as extractants for the determination of bisphenols from food-contacted plastics by high performance liquid chromatography with fluorescence detection, J. Chromatogr. A 1621 (2020), 461087, https://doi.org/10.1016/j.chroma.2020.461087.
[6] A. Bhatnagar, I. Anastopoulos, Adsorptive removal of bisphenol A (BPA) from aqueous solution: A review, Chemosphere 168 (2017) 885–902, https://doi.org/10.1016/J.CHEMOSPHERE.2016.10.121.
[7] C. M'rabet, O. Kéfi-Daly Yahia, D. Couet, S.K.M. Gueroun, O. Pringault, Consequences of a contaminant mixture of bisphenol A (BPA) and di-(2-ethylhexyl) phthalate (DEHP), two plastic-derived chemicals, on the diversity of coastal phytoplankton, Mar. Pollut. Bull. 138 (2019) 385–396, https://doi.org/10.1016/J.MARPOLBUL.2018.11.035.
[8] Y. Zhou, J. He, J. Lu, Y. Liu, Y. Zhou, Enhanced removal of bisphenol A by cyclodextrin in photocatalytic systems: Degradation intermediates and toxicity evaluation, Chinese Chem. Lett. (2020), https://doi.org/10.1016/J.CCLET.2020.02.008.
[9] A. Cydzik-Kwiatkowska, K. Bernat, M. Zielińska, K. Bułkowska, I. Wojnowska-Baryła, Aerobic granular sludge for bisphenol A (BPA) removal from wastewater, Int. Biodeterior. Biodegrad. 122 (2017) 1–11, https://doi.org/10.1016/J.IBIOD.2017.04.008.
[10] I. Escalona, J. de Grooth, J. Font, K. Nijmeijer, Removal of BPA by enzyme polymerization using NF membranes, J. Membr. Sci. 468 (2014) 192–201, https://doi.org/10.1016/J.MEMSCI.2014.06.011.
[11] Y. Hu, Q. Zhu, X. Yan, C. Liao, G. Jiang, Occurrence, fate and risk assessment of BPA and its substituents in wastewater treatment plant: A review, Environ. Res. 178 (2019), 108732, https://doi.org/10.1016/J.ENVRES.2019.108732.
[12] L. Correia-Sá, S. Norberto, C. Delerue-Matos, C. Calhau, V.F. Domingues, Micro-QuEChERS extraction coupled to GC–MS for a fast determination of Bisphenol A in human urine, J. Chromatogr. B Anal. Technol. Biomed. Life Sci. 1072 (2018) 9–16, https://doi.org/10.1016/j.jchromb.2017.10.060.
[13] M. Deviot, I. Lachaise, C. Högg, J. Durner, F.-X. Reichl, J.-P. Attal, E. Dursun, Bisphenol A release from an orthodontic resin composite: A GC/MS and LC/MS study, Dent. Mater. 34 (2018) 341–354, https://doi.org/10.1016/J.DENTAL.2017.11.018.
[14] Z. Meng, D. Wang, S. Yan, R. Li, J. Yan, M. Teng, Z. Zhou, W. Zhu, Effects of perinatal exposure to BPA and its alternatives (BPS, BPF and BPAF) on hepatic lipid and glucose homeostasis in female mice adolescent offspring, Chemosphere 212 (2018) 297–306, https://doi.org/10.1016/J.CHEMOSPHERE.2018.08.076.
[15] N. Venisse, G. Cambien, J. Robin, S. Rouillon, C. Nadeau, T. Charles, S. Rabouan, V. Migeot, A. Dupuis, Development and validation of an LC–MS/MS method for the simultaneous determination of bisphenol A and its chlorinated derivatives in adipose tissue, Talanta 204 (2019) 145–152, https://doi.org/10.1016/J.TALANTA.2019.05.103.
[16] S.M. Zimmers, E.P. Browne, P.W. O'Keefe, D.L. Anderton, L. Kramer, D. A. Reckhow, K.F. Arcaro, Determination of free Bisphenol A (BPA) concentrations in breast milk of U.S. women using a sensitive LC/MS/MS method, Chemosphere 104 (2014) 237–243, https://doi.org/10.1016/J.CHEMOSPHERE.2013.12.085.
[17] Q. Wang, J. Bai, B. Ning, L. Fan, T. Sun, Y. Fang, J. Wu, S. Li, C. Duan, Y. Zhang, J. Liang, Z. Gao, Effects of bisphenol A and nanoscale and microscale polystyrene plastic exposure on particle uptake and toxicity in human Caco-2 cells, Chemosphere (2020), 126788, https://doi.org/10.1016/J.CHEMOSPHERE.2020.126788.
[18] Q. Xie, M. Xia, H. Lu, H. Shi, D. Sun, B. Hou, L. Jia, D. Li, Deep eutectic solvent-based liquid-liquid microextraction for the HPLC-DAD analysis of bisphenol A in edible oils, J. Mol. Liq. 306 (2020), 112881, https://doi.org/10.1016/j.molliq.2020.112881.
[19] P. Gallo, I. Di Marco Pisciottano, F. Esposito, E. Fasano, G. Scognamiglio, G. D. Mita, T. Cirillo, Determination of BPA, BPB, BPF, BADGE and BFDGE in canned energy drinks by molecularly imprinted polymer cleaning up and UPLC with fluorescence detection, Food Chem. 220 (2017) 406–412, https://doi.org/10.1016/J.FOODCHEM.2016.10.005.
[20] A. Najafi, M. Hashemi, Vortex-assisted supramolecular solvent microextraction based on solidification of floating drop for preconcentration and speciation of inorganic arsenic species in water samples by molybdenum blue method, Microchem. J. 150 (2019), 104102, https://doi.org/10.1016/J.MICROC.2019.104102.
[21] S. Bodur, S. Erarpat, D.S. Chormey, G. Dalgıç Bozyiğit, E. Öz, N. Özdoğan, S. Bakırdere, Assessment of different isotope dilution strategies and their combination with switchable solvent-based liquid phase microextraction prior to quantification of bisphenol A at trace levels *via* GC-MS, New J. Chem. (2020), https://doi.org/10.1039/d0nj02706e.
[22] M.R. Afshar Mogaddam, M.A. Farajzadeh, A. Mohebbi, M. Nemati, Hollow fiber–liquid phase microextraction method based on a new deep eutectic solvent for extraction and derivatization of some phenolic compounds in beverage samples packed in plastics, Talanta 216 (2020), https://doi.org/10.1016/j.talanta.2020.120986.
[23] N.C. Maragou, N.S. Thomaidis, G.A. Theodoridis, E.N. Lampi, M.A. Koupparis, Determination of bisphenol A in canned food by microwave assisted extraction, molecularly imprinted polymer-solid phase extraction and liquid chromatography-mass spectrometry, J. Chromatogr. B Anal. Technol. Biomed. Life Sci. 1137 (2020), https://doi.org/10.1016/j.jchromb.2019.121938.
[24] Q. Zhou, M. Lei, Y. Wu, X. Zhou, H. Wang, Y. Sun, X. Sheng, Y. Tong, Magnetic solid phase extraction of bisphenol A, phenol and hydroquinone from water samples by magnetic and thermo dual-responsive core-shell nanomaterial, Chemosphere 238 (2020), 124621, https://doi.org/10.1016/j.chemosphere.2019.124621.
[25] M.A. Farajzadeh, M. Abbaspour, M.R.A. Mogaddam, H. Ghorbanpour, Determination of some synthetic phenolic antioxidants and Bisphenol A in honey using dispersive liquid-liquid microextraction followed by gas chromatography-flame ionization detection, Food Anal. Methods 8 (2015) 2035–2043, https://doi.org/10.1007/s12161-015-0087-9.
[26] S.M. Sorouraddin, M.A. Farajzadeh, A. Hassanyani, M.R. Afshar Mogaddam, Combination of homogenous liquid-liquid extraction and dispersive liquid-liquid microextraction for extraction and preconcentration of amantadine from biological samples followed by its indirect determination by flame atomic absorption

spectrometry, RSC Adv. 6 (2016) 108603–108610, https://doi.org/10.1039/c6ra16572a.
[27] I. Rykowska, J. Ziemblińska, I. Nowak, Modern approaches in dispersive liquid-liquid microextraction (DLLME) based on ionic liquids: A review, J. Mol. Liq. 259 (2018) 319–339, https://doi.org/10.1016/j.molliq.2018.03.043.
[28] I. Machado, F. Tissot, Dispersive liquid-liquid microextraction as a preconcentration alternative to increase ETAAS sensitivity in the analysis of molybdenum in bovine meat and pasture samples, Talanta 212 (2020), 120783, https://doi.org/10.1016/J.TALANTA.2020.120783.
[29] M. Maham, R. Karami-Osboo, V. Kiarostami, S. Waqif-Husain, Novel binary solvents-dispersive liquid-liquid microextraction (BS-DLLME) method for determination of patulin in apple juice using high-performance liquid chromatography, Food Anal. Methods 6 (2013) 761–766, https://doi.org/10.1007/s12161-012-9483-6.
[30] R. Whelpton, Quality assurance | internal standards, in: Encycl. Anal. Sci.,, Elsevier, 2019, pp. 466–472, https://doi.org/10.1016/B978-0-12-409547-2.14399-9.
[31] B.P. Harp, P.F. Scholl, P.J. Gray, P. Delmonte, Quantitation of copper chlorophylls in green table olives by ultra-high-performance liquid chromatography with inductively coupled plasma isotope dilution mass spectrometry, J. Chromatogr. A (2020), 461008, https://doi.org/10.1016/J.CHROMA.2020.461008.
[32] L.N. Viana, T.D. Saint'Pierre, Direct determination of Cr and Ni in oil samples by isotope dilution and external standard calibration using inductively coupled plasma mass spectrometry, Microchem. J. 151 (2019), 104219, https://doi.org/10.1016/J.MICROC.2019.104219.
[33] S. Clémens, M. Monperrus, O.F.X. Donard, D. Amouroux, T. Guérin, Mercury speciation in seafood using isotope dilution analysis: A review, Talanta 89 (2012) 12–20, https://doi.org/10.1016/J.TALANTA.2011.12.064.
[34] J. Meija, Z. Mester, Paradigms in isotope dilution mass spectrometry for elemental speciation analysis, Anal. Chim. Acta 607 (2008) 115–125, https://doi.org/10.1016/j.aca.2007.11.050.
[35] D. Schaumlöffela, R. Łobińskia, b, Isotope dilution technique for quantitative analysis of endogenous trace element species in biological systems, Int. J. Mass Spectrom. 242 (2005) 217–223, https://doi.org/10.1016/J.IJMS.2004.11.020.
[36] H.D. Wizemann, Quantitative element analysis by isotope dilution in diode laser graphite furnace atomic absorption spectrometry, Spectrochim. Acta Part B At. Spectrosc. 63 (2008) 539–560, https://doi.org/10.1016/J.SAB.2008.03.003.
[37] S. Erarpat, S. Bodur, D.S. Chormey, S. Bakırdere, Switchable solvent liquid-phase microextraction-gas chromatography-quadrupole isotope dilution mass spectrometry for the determination of 4-n-nonylphenol in municipal wastewater, Microchem. J. 144 (2019) 1–5, https://doi.org/10.1016/j.microc.2018.08.049.
[38] P. Rodríguez-González, J.M. Marchante-Gayón, J.I. García Alonso, A. Sanz-Medel, Isotope dilution analysis for elemental speciation: a tutorial review, Spectrochim. Acta Part B At. Spectrosc. 60 (2005) 151–207, https://doi.org/10.1016/J.SAB.2005.01.005.
[39] E. Pagliano, Z. Mester, J. Meija, Reduction of measurement uncertainty by experimental design in high-order (Double, triple, and quadruple) isotope dilution mass spectrometry: Application to GC-MS measurement of bromide, Anal. Bioanal. Chem. 405 (2013) 2879–2887, https://doi.org/10.1007/s00216-013-6724-5.
[40] S.L.C. Ferreira, R.E. Bruns, H.S. Ferreira, G.D. Matos, J.M. David, G.C. Brandão, E. G.P. da Silva, L.A. Portugal, P.S. dos Reis, A.S. Souza, W.N.L. dos Santos, Box-Behnken design: An alternative for the optimization of analytical methods, Anal. Chim. Acta 597 (2007) 179–186, https://doi.org/10.1016/j.aca.2007.07.011.
[41] C. Nerín, M. Philo, J. Salafranca, L. Castle, Determination of bisphenol-type contaminants from food packaging materials in aqueous foods by solid-phase microextraction–high-performance liquid chromatography, J. Chromatogr. A 963 (2002) 375–380, https://doi.org/10.1016/S0021-9673(02)00554-X.
[42] I. Notardonato, C. Protano, M. Vitali, P. Avino, Phthalates and Bisphenol-A Determination and Release from Different Beverage Plastic Containers by Dispersive Liquid-Liquid Microextraction and GC-IT/MS Analysis, Food Anal. Methods 12 (2019) 2562–2571, https://doi.org/10.1007/s12161-019-01602-8.
[43] J. López-Darias, M. Germán-Hernández, V. Pino, A.M. Afonso, Dispersive liquid–liquid microextraction versus single-drop microextraction for the determination of several endocrine-disrupting phenols from seawaters, Talanta 80 (2010) 1611–1618, https://doi.org/10.1016/j.talanta.2009.09.057.
[44] D. Wang, Y. Liu, Z. Xu, D. Zhao, Y. Liu, Z. Liu, Multitemplate molecularly imprinted polymeric solid-phase microextraction fiber coupled with HPLC for endocrine disruptor analysis in water samples, Microchem. J. 155 (2020), 104802, https://doi.org/10.1016/j.microc.2020.104802.
[45] M. Kaykhaii, E. Yavari, G. Sargazi, A.K. Ebrahimi, Highly Sensitive Determination of Bisphenol A in Bottled Water Samples by HPLC after Its Extraction by a Novel Th-MOF Pipette-Tip Micro-SPE, J. Chromatogr. Sci. 58 (2020) 373–382, https://doi.org/10.1093/chromsci/bmz111.
[46] N.E.A.M. Subuhi, S.M. Saad, N.N.M. Zain, V. Lim, M. Miskam, S. Kamaruzaman, M. Raoov, N. Yahaya, An efficient biosorption-based dispersive liquid-liquid microextraction with extractant removal by magnetic nanoparticles for quantification of bisphenol A in water samples by gas chromatography-mass spectrometry detection, J. Sep. Sci. (2020), https://doi.org/10.1002/jssc.201901194.