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Evaluation of the Occurrence of Phthalates in Plastic Materials Used in Food Packaging

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Featured Application: Application of an inexpensive, easy, eco-friendly, and rapid analytical approach in the routine monitoring of phthalates in food packaging to guarantee food safety.

Abstract: Phthalates are multifunctional synthetic chemicals found in a wide array of consumer and industrial products, mainly used to improve the mechanical properties of plastics, giving them flexibility and softness. In the European Union, phthalates are prohibited at levels greater than 0.1% by weight in most food packaging. In the current study, headspace solid-phase microextraction (HS-SPME) combined with gas chromatography-mass spectrometry (GC-MS) was optimized, through the multivariate optimization process, and validated to evaluate the occurrence of four common phthalates, di-iso-butyl phthalate (DIBP), butyl-benzyl phthalate (BBP), di-n-octyl phthalate (DOP), and 2,2,4,4-tetrabromodiphenyl (BDE), in different food packaging. The best extraction efficiency was achieved using the polydimethylsiloxane/divinylbenzene (PDMS/DVB) fiber at 80 °C for 30 min. The validated method showed good linearity, precision (RSD < 13%), and recoveries (90.2 to 111%). The limit of detection (LOD) and of quantification (LOQ) ranged from 0.03 to 0.08 μg/L and from 0.10 to 0.24 μg/L, respectively. On average, the phthalates concentration varied largely among the assayed food packaging. DIBP was the most predominant phthalate in terms of occurrence (71.4% of analyzed simples) and concentration (from 3.61 to 10.7 μg/L). BBP was quantified in only one sample and BDE was detected in trace amounts (<LOQ) in only two samples.

Keywords: phthalates; food packaging; HS-SPME/GC-qMS optimization; validation

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1. Introduction

Phthalates are a chemical group of industrial compounds with a common chemical structure, dialkyl or alkyl/aryl esters of 1,2-benzenedicarboxylic acid, commonly used for a variety of purposes, including industrial plastics, personal care products, and pharmaceuticals. Humans are exposed to phthalates through different ways such as dermal contact, inhalation, and ingestion. However, due to the abundance of plastic in our society, the exposure to phthalates is ubiquitous, constituting a major problem both at the environmental and health levels. In Europe, eight million tons of plastics was used for food and drink packaging, being one area in which plastics make a major contribution.

Although its inherent and useful features including flexibility, impermeability, strength, stability, lightness, and ease of sterilization make plastic packaging an ideal material for all types of industry in both flexible and rigid formats, they also promote food safety and shelf life and facilitate the transport and use of products. This will significantly reduce food waste, energy consumption, and the resources used. They are constituted by a complex mixture of thousands of chemical compounds made essentially of polyvinyl chloride (PVC),

polyvinyl acetate (PVA), polyvinylidene chloride (PVDC), and different mixes to improve their plasticizer properties such as the incorporation of bisphenol A, used as a structural constituent, and phthalic acid-derived esters (phthalates) [1–3].

The occurrence of phthalates has been documented in different parts of the environment including surface water, sediments, soils, and the atmosphere, in addition to plastic materials used in food packaging [4,5], which are the most important human exposure pathway for phthalates, followed by inhalation of indoor air and ingestion of dust [6]. The European Union regulates the maximum content of these compounds in plastics that are in contact with all types of food (Commission Regulation (EU) No 10/2011 of 14 January 2011) and the management of packaging and packaging waste (Directive (EU) 2018/852 is the last amendment of Directive 94/62/EC).

The presence of phthalates in both the environment and food packages is an issue of special concern, not only from a health point of view, regarding their role as endocrine disrupting chemicals (EDCs) and their action on reducing testosterone production and changing thyroid function [7], but also due their ecological effects. Cardiovascular diseases, dysplasia, and reproductive system malformations are some of the other adverse effects associated with phthalates according to reports in several toxicity studies [8,9]. Moreover, prenatal exposure to some phthalates is linked to a male genital condition, which may increase the risk of testicular and prostate cancer, and lower fertility [10]. According to Hyland et al.'s studies [11], phthalates affect brain development and are associated with learning and behavior problems in children.

The determination of these compounds in different samples is challenging and demanded urgently for environmental and health risk assessment. The extraction procedure is the main key point of previous phthalates analyses. Extraction of phthalates in samples often employs microwave [12], Soxhlet [13], and ultrasonic techniques [14] prior to GC-MS analysis. The improvement of these procedures is followed by a pre-concentrating step, increasing phthalates detection. Usually, solid-phase extraction (SPE), solid-phase microextraction (SPME), and cloud point extraction (CPE) are the most applied to solve the matrix background [15,16], in combination with liquid chromatography (LC) and gas chromatography (GC) techniques hyphenated to conventional and mass spectrometry (MS) detectors [17], although other alternative procedures such as electronic sensors have also been used with this aim [18].

In this study, three phthalates (DIBP, BBP, DOP) and biphenyl ether (BDE) were simultaneously determined in different types of plastics used in the packaging of pasta, crackers, and frozen vegetables, by solid-phase microextraction in headspace mode (HS-SPME) followed by gas chromatography-mass spectrometry methodology. To achieve the maximum extraction efficiency, several SPME extraction parameters, namely, the fiber coating, extraction time, and temperature, were optimized using a multivariate design. Furthermore, the proposed method was validated according to IUPAC guidelines and applied to determine the levels of phthalates in several plastics used in food packaging.

2. Materials and Methods

2.1. Chemicals

All reagents were of analytical grade and used without any further purification. Di-iso-butyl phthalate (DIBP), butyl-benzyl phthalate (BBP), di-n-octyl phthalate (DOP), and 2,2,4,4-tetrabromodiphenyl ether (BDE) were purchased from Sigma-Aldrich Química S.A. (Spain). The digital stirring plate (Cimarec™) was supplied by Thermo Scientific (Waltham, MA, USA), while the SPME holder for manual sampling together with 50/30 µm divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS), 100 µm polydimethylsiloxane (PDMS), and 65 µm polydimethylsiloxane/divinylbenzene (PDMS/DVB) fibers, with 1 cm length, was purchased from Supelco (Bellefonte, PA, USA). Each fiber was daily conditioned according to the manufacturer's recommendations in order to avoid carryover between sets of analyses. In addition, sodium chloride (NaCl) was supplied by Panreac (Barcelona, Spain) and He (GC carrier gas) of purity 5.0 was supplied from Air Liquide,

Portugal. Ultrapure water (H_2O) was obtained from a Milli-Q Plus system (18 MΩ/cm, Millipore Bedford, MA, USA).

The sources of contamination can be present in any step of the analytical procedure, such as sampling, sample preparation, and chromatographic analysis, among others [19]. Prior to use, all glassware material was washed with ethanol followed by H_2O and heated at 300 °C for 2 h. Then, these materials were stored in desiccators containing aluminum oxide to avoid recontamination.

2.2. Sample Preparation

Different kinds of plastic packages were used (e.g., crackers, juice, milk, meat, legumes) in a total of 14 samples. Each plastic sample was cut into small pieces and ground with an T 25 digital ULTRA-TURRAX (IKA). An aliquot of 1.5 g of sample was added into beakers containing 6.0 mL of H_2O. Then, the samples were left under agitation (400 rpm, 60 min and 25 ± 1 °C) to extract the phthalates. The supernatant was collected, coded, and stored at −20 °C, in the dark, until HS-SPME extraction.

2.3. Standard Solutions

Ethanolic phthalates standard solutions (500 µg/L) were prepared, labeled, and stored at −20 °C. For validation purposes, six standard solutions containing the target analytes at different concentrations were prepared daily by dilution of the working solutions (10 mg/L) in H_2O.

2.4. HS-SPME Multivariate Optimization Process

Several factors influence the SPME efficiency, the most important being the fiber coating, extraction time, and temperature. A multivariate optimization process using a mixed standard solution containing phthalates at 60 µg/L was used to achieve the optimal extraction efficiency of HS-SPME. The study of the variables that were considered significant for the experiment was conducted using a 3^3 factorial design, namely, fiber coating (DVB/CAR/PDMS, PDMS, PDMS/DVB), extraction (15, 30, and 45 min), and extraction temperature (60, 70, and 80 °C). The optimal HS-SPME extraction conditions were used to analyze the samples. After sample preparation, an aliquot of 2 mL of sample and 0.2 g of NaCl was placed in an 8 mL vial. The vial was capped with a Teflon (PTFE) septum, and the fiber was introduced and exposed into the headspace for 30 min at 80 °C under constant agitation (400 rpm). Then, the fiber was removed from the vial and inserted into the GC injection port, where the extracted analytes were desorbed for 6 min at 250 °C. Each sample was analyzed in triplicate and blank chromatographic injections of the SPME device were performed before each set of analysis.

2.5. Gas Chromatography Quadrupole Mass Spectrometry (GC-qMS) Conditions

The SPME fiber with the target analytes was inserted into the injection port of an Agilent Technologies 6890N Network gas chromatograph system (Palo Alto, CA, USA) where the analytes were thermally desorbed. The gas chromatographer was equipped with a 60 m × 0.25 mm I.D. × 0.25 µm film thickness HP-5 (SGE, Dortmund, Germany) fused silica capillary column and interfaced with an Agilent 5975 quadrupole inert mass selective detector. The oven temperature program was set as follows: 120 °C (hold 3 min), increased until 190 °C at a rate of 10 °C/min (hold 4 min after reach 190 °C), further increased to 240 °C at a rate of 3 °C/min, maintained for 20 min. The total GC run time was 50.67 min. The column flow was constant at 1.0 mL/min using He of purity 5.0. The injection port was operated in the splitless mode and held at 250 °C. For the 5975 MS system, the operating temperatures of the transfer line, quadrupole, and ionization source were 270, 150, and 230 °C, respectively. Data acquisition was performed in the scan mode (30–300 m/z) with electron ionization at an energy of 70 eV and the ionization current of 10 µA. Phthalates identification was accomplished through manual interpretation through comparison of spectra and matching against the Agilent MS ChemStation Software, equipped with an

NIST05 mass spectral library with a similarity threshold higher than 90%, and by the standards. The analysis was performed in triplicate, and the results were expressed as mean ± standard deviation. In addition, to evaluate the occurrence of phthalates in the GC system, blank runs of the chromatograph and direct injections of ethanol were carried out. None of phthalate targets were detected.

2.6. Method Validation

The analytical performance was evaluated in terms of selectivity, linearity, sensitivity, precision (inter-/intra-day), and recovery (as a measure of trueness). The method selectivity was evaluated by the absence of interfering peaks at the retention time (RT) of the phthalates, through the direct injection of an aliquot of the blank extract, and the solvent was injected directly. Six-point calibration curves of investigated phthalates were built in the concentration range reported in Table 1, in triplicate, to evaluate the method linearity. The evaluation was performed based on the average GC peak areas, percentage of relative standard deviation (% RSD), regression coefficients (R^2), and linear ranges established for each target analyte analyzed. Sensitivity of the method was assessed through limit of detection (LOD, the lowest analyte concentration that produces a response detectable above the noise level of the system) and limit of quantification (LOQ, the lowest analyte concentration that can be accurately and precisely measured). The LOD and LOQ were determined using the residual standard deviation (Sy/x) of corresponding curves, LOD and LOQ being calculated by 3.3 Sy/x/b (b = slope) and 10 Sy/x /b, respectively, obtained in the calibration curve. Three different concentrations of target phthalates, added to the mixture of grounded packaging materials with water (1.5 g/6 mL of water), were used to evaluate the recovery of the proposed analytical method, within the linear range of the calibration curve. Seven replicates (n = 7) were carried out on the same day to determine intra-day precision (repeatability), whereas for the inter-day precision (reproducibility), five replicates (n = 5) were analyzed over six consecutive days (a total of n = 30). The recovery (accuracy) was determined as precision through the spiking of food packaging at three concentration levels. Both parameters were expressed as % RSD.

3. Results and Discussion

The phthalates chosen for the current study are the most relevant contaminants detected in environmental and food-related products [20].

3.1. Optimization of HS-SPME Procedure

To obtain the feasibility of the proposed analytical method, using the HS-SPME/GC-MS technique, a factorial design based on fiber coating, extraction time, and extraction temperature was optimized. The optimal conditions were chosen based on extraction efficiency measured by the GC-MS response (GC peak area) and reproducibility (the lowest % RSD). Figure 1 shows that the best extraction efficiency for DIBP, BBP, and DOP was achieved using the PDMS/DVB fiber at 80 °C, whereas for BDE, this was obtained using PDMS at 80 °C. Moreover, for DIBP, no significant difference was observed in terms of extraction efficiency between PDMS and the PDMS/DVB fiber at 80 °C. Therefore, the PDMS/DVB fiber was chosen for the HS-SPME extraction procedure since it provided a better extraction efficiency, with the exception of the BDE target, and better reproducibility than PDMS. Moreover, the PDMS/DVB fiber was reported to be the most suitable fiber for phthalates analysis in several environmental waters and food-related products [12,20].

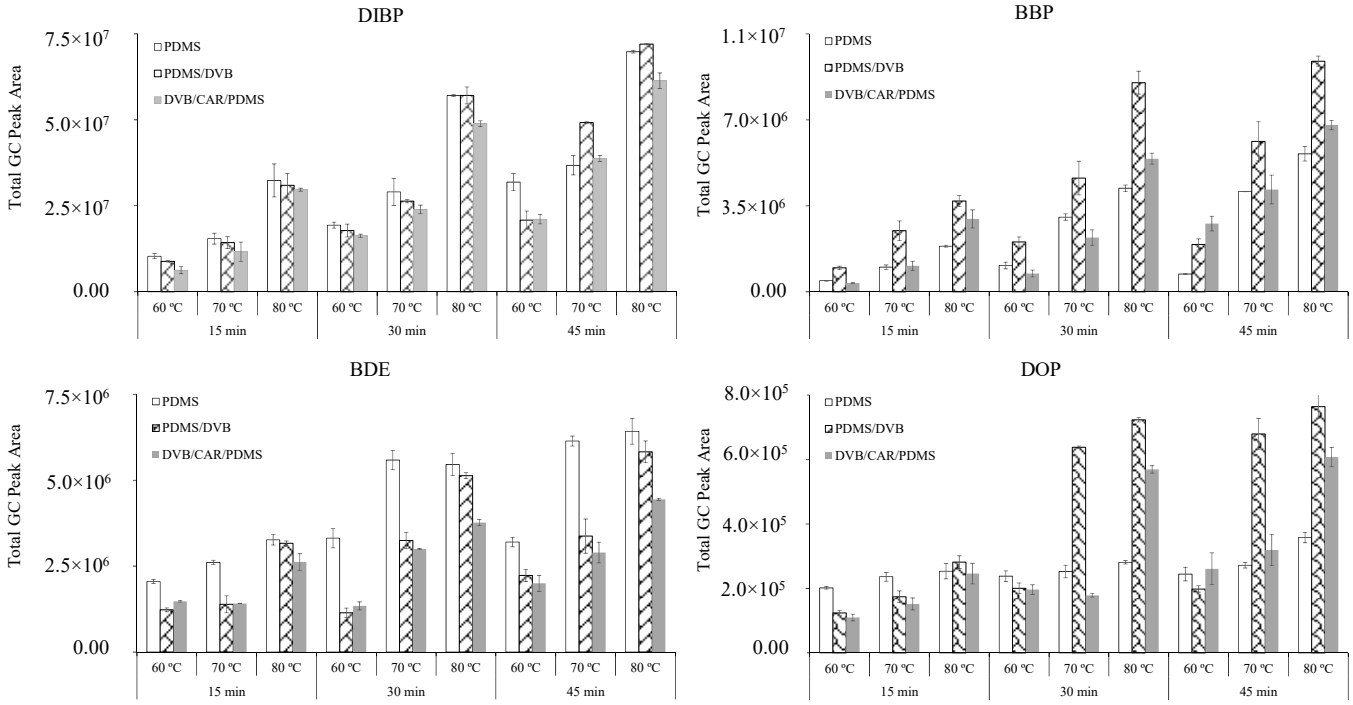

Figure 1. Multivariate analysis for HS-SPME optimization of phthalates target. Conditions: sample volume: 2 mL; concentration of phthalates: 60 µg/L; NaCl amount: 0.2 g; extraction time: 15, 30, and 45 min; extraction temperature: 60, 70, and 80 °C; desorption time and temperature: 6 min and 250 °C.

It is well known that SPME is an equilibrium-based extraction procedure and therefore a time-dependent process. Nonetheless, the extraction time can be shortened with the increase in the extraction temperature, since high temperatures improve the diffusion kinetics of the target analytes [21]. In the current study, temperatures higher than 80 °C were not considered to avoid the reduction in fiber sensitivity for phthalates due to overloading the fiber with H_2O molecules as well as to avoid possible degradations [20]. In addition, as microextraction is an endothermic process, high temperatures hamper the process. The extraction efficiency of HS-SPME increased for all phthalates with the increasing temperature. DOP is the only phthalate that does not show this remarkable increase, since a slight increase was observed between 70 and 80 °C; thus, 80 °C was selected as the extraction temperature. It has been reported that 80 °C is an optimal temperature to extract phthalates from environmental waters [22]. Regarding the extraction time, BBP, DOP, and BDE reached their equilibrium after 30 min, independently of the extraction temperature. For DIBP, the equilibrium was reached at 45 min. Thus, the optimal extraction conditions selected to determine phthalates in food packages were 30 min at 80 °C using a PDMS/DVB fiber coating.

3.2. Method Validation

The performance of the analytical method was assessed based on linearity, sensitivity, selectivity, precision (intra- and inter-days), and recovery (accuracy). The chromatogram profile of the optimized analytical method is depicted Figure 2, and phthalates (60 µg/L) were totally separated in less than 28 min.

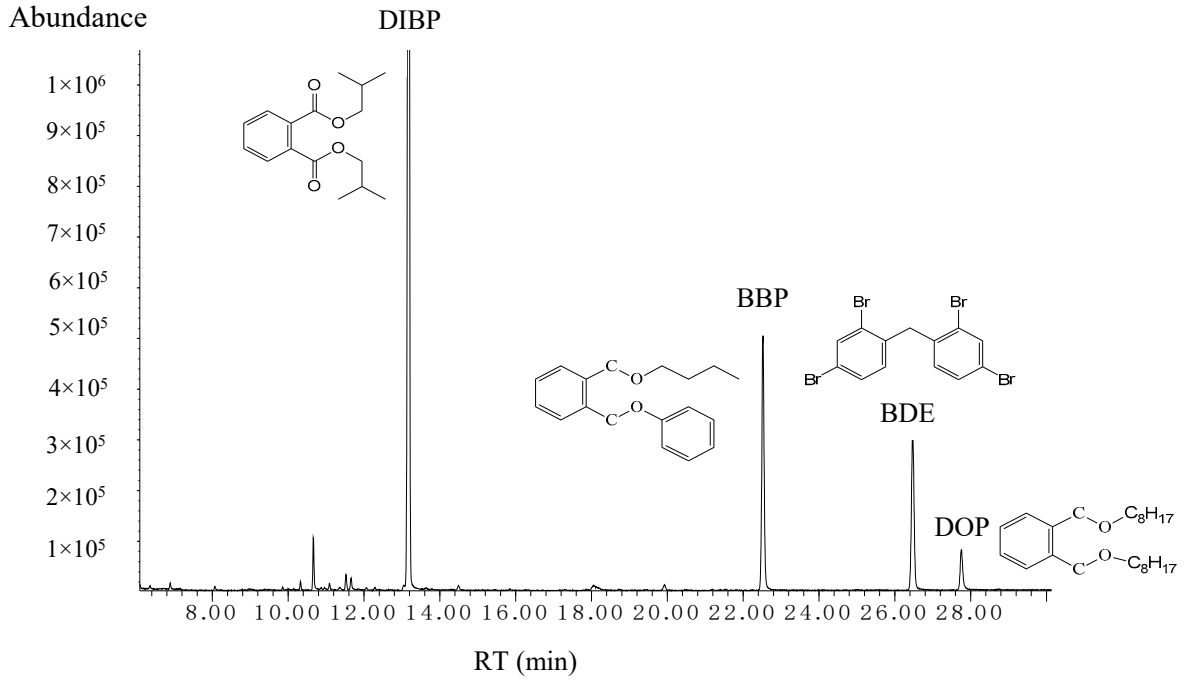

Figure 2. HS-SPME/GC-MS chromatograms of phthalates at 60 µg/L using PDMS/DVB fiber at 80 °C for 30 min.

Table 1 summarizes the phthalates involved in the current study, RT, linear range, R^2, LOD, and LOQ, whereas Table 2 reports the recovery and precision data.

Table 1. Figures of merit of the phthalates HS-SPME/GC-qMS methodology.

RT (min)	PAEs	Linear Range (µg/L)	Equation	R^2	LOD (µg/L)	LOQ (µg/L)
13.18	DIBP	0.5–60	$y = 817{,}649x + 10^6$	0.996	0.06	0.21
22.55	BBP	0.5–60	$y = 66{,}577x + 116{,}115$	0.999	0.03	0.10
26.49	BDE	1–60	$y = 124{,}317x + 755{,}468$	0.995	0.08	0.24
27.77	DOP	1–60	$y = 44{,}993x - 100{,}807$	0.999	0.07	0.23

To build the calibration curves for the phthalates, mixed working solutions were prepared in the concentration range 0.5 to 60 µg/L and plotted using their GC peak area. For all targets under study, a good linearity ($R^2 \geq 0.995$) with residuals not exceeding ±10% was achieved over the whole range of concentrations tested. The LODs ranged from 0.03 (BBP) to 0.08 (BDE) µg/L, while LOQs ranged from 0.10 (BBP) to 0.24 (BDE) µg/L. Regarding DIBP, the LOD and LOQ obtained were lower than the default maximum residue limit (MRL, 300 µg/L) established by many government agencies worldwide, including the European Environment Agency, the USEPA, and the Chinese Ministry of Health [23].

The precision of the method was assessed by intra- (repeatability) and inter-day (reproducibility) precisions. The intra-day precision varied from 0.65 to 7.93%, whereas the inter-day precision ranged from 1.65 to 12.68%. The recovery was performed by spiking the phthalates in the food package solution at three levels of concentration (low, medium, and high), which ranged from 90.2 to 111% (Table 2). The literature has reported that a quantitative method should be demonstrated as being able to provide mean recoveries within the range of 70–120% and precision with % RSD values lower than 20%. Similar precisions and recoveries for phthalates were obtained in different matrices using HS-SPME/GC-MS [20,24,25].

In addition, the LODs and LOQs obtained in this work (Table 1) are slightly betterthan those obtained by other authors employing HS-SPME/GC-MS to determine phthalates in plastic containers [24], milk [25], and beers [20].

Table 2. Recovery and precision of phthalates in food packaging, using sample 3, at three spiked levels *.

RT (min)	Compounds	Spiked Level (µg/L)	% REC ± SD	Intra-Day (%)	Inter-Day (%)
13.17	DIBP	0.5	90.20 ± 1.3	3.5	7.5
		30	91.60 ± 0.9	1.9	5.8
		60	104.9 ± 1.8	0.9	3.3
22.55	BBP	0.5	107.9 ± 2.0	5.9	8.5
		30	111.3 ± 1.9	1.3	6.7
		60	105.7 ± 3.2	0.9	1.7
26.49	BDE	1	98.30 ± 0.8	7.9	12.7
		30	91.30 ± 1.4	3.7	10.6
		60	94.00 ± 1.7	0.6	3.5
27.77	DOP	1	109.2 ± 4.3	1.5	8.2
		30	99.20 ± 1.6	1.4	3.1
		60	95.50 ± 0.8	0.7	2.2

RT—retention time; % REC—recovery percentage; SD—standard deviation; * validation obtained for sample 3.

However, a higher LOD (from 0.12 to 0.50 µg/L) was achieved previously to quantify six phthalates in environmental waters using liquid–liquid extraction (LLE) followed by GC-MS [26]. A summary of the different analytical methods, used for phthalates determination in plastic packaging, is presented in Table 3 [20,21,24,27–36].

Table 3. Comparison of the analytical performance of the developed method in this study with other studies reported in the literature.

Target Analytes	Samples	Extraction Procedure	Analytical Method	LOD (µg/L)	LOQ (µg/L)	Rec (%)	Ref.
6 PAEs	Milk products	LLE	LC-MS/MS	-	20–30 µg/kg	84–96	[30]
5 PAEs	Meats	LLE	LC-MS/MS	-	40 µg/kg	96–103	[31]
8 PAEs	Tea, juices	DES-VA-EDLLME	HPLC-DAD	5.1–17.8	17.2–59.4	84–120	[32]
6 PAEs, BPA	Waters	SB-DLLME	GC-MS	0.001–0.008	0.005–0.014	95–99	[33]
17 PAEs	Capsanthin	QuEChERS	GC-MS	0.2–0.5 µg/kg	0.6–1.5 µg/kg	83–118	[34]
20 PAEs	Breast milk	QuEChERS	GC-MS/MS	0.004–1.3 µg/kg	0.02–4.2 µg/kg	83–123	[35]
3 PAEs	Waters	MSPE	HPLC-VWD	0.025–0.16	0.082–0.54	93–102	[36]
15 PAEs	Beverages	MSPE	GC-MS/MS	0.005–2.748	0.018–9.151	79–122	[27]
6 PAEs, BPA	Honey	UVA-DLLME	GC-MS	3–13 µg/kg	7–22 µg/kg	71–100	[20]
6 PAEs, 1 Adipate	Beers	HS-SPME	GC-MS	0.006–0.590	0.020–1.959	74–101	[28]
11 PAEs	Vegetables	HS-SPME	GC-MS/MS	0.001–0.430	-	-	[21]
10 PAEs	Milk and rice	SPME	GC-MS	0.054–2.51 ng/L	0.18–8.37 ng/L	89–114	[24]
4 PAEs	Yogurts, waters	HFLMP-SPME	GC-FID	0.008–0.030	0.028–0.120	96–100	[29]
4 PAEs	Food packaging	HS-SPME	GC-MS	0.03–0.08	0.10–0.24	90–111	This study

BPA—bisphenol A; DES-VA-EDLLME—deep eutectic solvent-based dispersive liquid–liquid microextraction; GC-FID—gas chromatography-flame ionization detection; GC-MS—gas chromatography-mass spectrometry; GC-MS/MS—gas chromatography tandem mass spectrometry; HFLMP-SPME—hollow fiber liquid membrane-protected solid-phase microextraction; HPLC-DAD—high-performance liquid chromatography-diode-array detection; HPLC-VWD—high-performance liquid chromatography-variable wavelength detector; HS-SPME—headspace solid-phase microextraction; LC-MS/MS—liquid chromatography tandem mass spectrometry; LLE—liquid–liquid extraction; MSPE—magnetic solid-phase extraction; PAEs—phthalates; QuEChERS—quick, easy, cheap, effective, rugged, and safe; SB-DLLME—solvent-based dispersive liquid–liquid microextraction; SPME—solid-phase microextraction; UVA-DLLME—ultrasound vortex assisted dispersive liquid–liquid microextraction.

3.3. Quantification of Phthalates in Plastic-Based Food Packaging

The HS-SPME/GC-qMS method was applied to investigate the occurrence of phthalates in 14 types of plastic-based food packaging acquired in a local market. The RT and mass spectra comparison confirmed the occurrence of individual phthalates. Table 4 shows the phthalates concentration found in 14 plastic packages used in the food industry and determined by HS-SPME/GC-MS after method validation. DIBP was the most prominent phthalate found in all samples, with a frequency of occurrence (FO) of 100%, and its concentration ranged from 3.61 to 10.6 µg/L. DOP was the second most dominant phthalate detected in food packages (FO = 64%) at concentrations ranging from 1.03 to 2.83 µg/L. BDE was detected in two samples, but its concentration was lower than the LOQ. BBP was detected only in one sample, and its concentration did not exceed 1.42 µg/L. Therefore, the

results indicate that the proposed green extraction technique was effective and feasible for the determination of phthalates in plastic-based food packaging.

Table 4. Occurrence of phthalates in plastic-based food packages.

Samples	Phthalates Concentration (µg/L) ± SD			
	DIBP	BBP	BDE	DOP
Plastic 1	<LOD	-	-	-
Plastic 2	<LOD	-	-	-
Plastic 3	<LOD	-	-	-
Plastic 4	<LOD	1.4 ± 0.01	<LOD	2.8 ± 0.04
Plastic 5	4.8 ± 0.3	-	-	1.0 ± 0.01
Plastic 6	10.6 ± 0.2	-	-	2.2 ± 0.06
Plastic 7	9.0 ± 0.4	-	-	1.8 ± 0.07
Plastic 8	6.1 ± 0.3	-	-	1.1 ± 0.08
Plastic 9	8.2 ± 0.4	-	-	-
Plastic 10	4.7 ± 0.05	-	-	2.2 ± 0.02
Plastic 11	3.6 ± 0.7	-	-	1.9 ± 0.2
Plastic 12	10.7 ± 0.6	-	-	-
Plastic 13	6.8 ± 0.8	-	-	1.9 ± 0.4
Plastic 14	4.3 ± 0.2	-	<LOD	2.5 ± 0.2

SD: standard deviation; <LOD: lower than limit of detection; -: not detected.

Several studies (Table 5) revealed that phthalates and the ester derivative are passively ingested from the general environment, foods, drinks, breathing air, and dairy life products, causing various dysfunctions [3,20,30,31,34,37–46]. Exposures to DEHP, BBP, DBP, and DEP are associated with dermatitis, conjunctivitis, and allergic symptoms [47]. Other studies have found a relationship of asthma and worsening of pulmonary functions with these phthalates [48].

Table 5. Levels of different phthalates found in different types of samples reported in the literature.

Samples	Phthalates	Concentration Range	Ref.
Meats	DEHP (Pork and Chicken)	0.62, 0.8 mg/kg	[31]
	DEHP (Fruit jam, Salted meat); DnBP	170 µg/kg, 2380 µg/kg; 1580 µg/kg	[42]
Spices	DEHP; DiBP, DBP; BBzP	2598 µg/kg; >300 µg/kg	[3,49]
Tea	DMP, DEP, DIBP; DBP; DEHP	1.135–3.734 mg/kg	[43]
Wine	DMP, DEP/DBP/BBP	0.024–0.029 µg/mL	[44]
Waters	DEHP, DBP, DEP, BOP	0.76/0.96/1.06/0.77 µg/L	[46]
	DEHP, BBP, DBP, DEP, DMP (Bottled water)	3.42/2.89/13.99/5.35/1.15/2.07 µg/L	
Capsanthin	DBP, DEHP	0.872/0.992 µg/g	[34]
Beers	DMP, DEP, DBP, BBP, DEHP, DOP, DEHA	0.588, 0.175, 0.118, 0.079, 0.009, 0.006, 0.009 µg/L	[20]
Juice	DOP, DBP, DIBP, DEHP, BBP (Juice)	0.01–08 mg/dm^3	[37]
Beverages	DEHP, DEP	0.580 /0.070 µg/L	[38]
Honey/Royal Jelly	DIBP, BBP, BDE, DOP,	0.3/1.5; 0.8/3; 0.3/1.5; 1.2; 6 ng/g	[39]
Vegetables	DEHP, DnBP, DiBP, DEP, BBP	1881–4664/985/338/9/2 µg/kg	[40]
Powdered and Human/Raw Milk	Mono-BP, mono-BzP, DnBP, BzBP, DEHP	0.1–500 ng/mL 18/1.2/21 µg/kg	[3,41]
Yoghurt	DEHP, DBP, BBP	170/112/63 µg/kg	[30]
Plastic Containers	DIBP, BBP, BDE, DOP	4.39/1.42/<LOD/1.03 µg/L	This study

4. Conclusions

The detection of phthalates in plastics used in food packaging is of utmost importance in order to ensure the high quality and safety of packed food and food-derived products. In this context, a sensitive method based on the HS-SPME approach combined with GC-MS was developed using multivariate optimization. The optimal HS-SPME conditions were

achieved using the PDMS/DVB fiber at 80 °C for 30 min. The performance of the HS-SPME/GC-MS methodology was evaluated in terms of linearity, LODs, LOQs, precision, and recovery. A good linearity ($R^2 \geq 0.995$), intra-day/inter-day precision (RSD < 13%), and recovery (90.2 to 111%) were obtained for the quantification of phthalates. The LODs ranged from 0.03 to 0.08 µg/L, while the LOQs ranged from 0.10 to 0.24 µg/L. The method was applied to 14 foodstuff plastic packages, and DIBP was the most prominent phthalate found in all samples (FO of 100%), with a concentration ranging from 3.61 to 10.6 µg/L. The results obtained show the applicability and feasibility of HS-SPME/GC-MS for the quantification of phthalates in foodstuff plastic packages. In addition, this inexpensive, easy, eco-friendly, and rapid analytical approach can be used in routine monitoring studies, as well as for food safety analysis.

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