



35 between 0.01 ng mL<sup>-1</sup> and 0.03 ng mL<sup>-1</sup>. The relative standard deviations were better  
36 than 5.3% and 9.2% for intra-day and inter-day study, respectively. The relative  
37 recoveries ranged between 90.5-105.2% (intra-day) and 93.0-105.0% (inter-day),  
38 demonstrating good method trueness. Finally, the proposed protocol was implemented  
39 for the monitoring of OCPs in tap, river, pond, and lake water. The developed method  
40 presents better analytical features than existing methods.

41

42 **Keywords:** Organochlorine pesticides; capsule phase microextraction; water; sample  
43 preparation, GC-MS, monolithic sorbents

44

45

## 46 1. Introduction

47 Pesticides are used in agriculture to repel, prevent, mitigate, or destroy pests [1].  
48 They are classified into different types including insecticides, herbicides, nematicides,  
49 rodenticides, fungicides, molluscicides and plant growth regulators [2]. Pesticide  
50 residues may constitute a significant source of contamination for the environment since  
51 they can be present in air, water and soil [3]. Nowadays, water resources pollution  
52 because of the uncontrolled use of pesticides represents a significant environmental and  
53 health threat. In order to be able to design and implement strategy plans for  
54 environmental and human health protection, the estimation of the type and amount of  
55 pesticide residues in water resources is crucial [4].

56 Organochlorine pesticides (OCPs) are a class of pesticides used for controlling  
57 vector-borne diseases (e.g., typhus and malaria) and to destroy pests due to their low  
58 cost and high efficiency [5,6]. These compounds were the first major pesticide class  
59 that was produced on large scale since the rapid growth of the pesticide industry in the  
60 late 1940's [7]. Because of their chemical stability, their high persistence in the natural  
61 environment and their low biodegradability, OCPs are ubiquitous among  
62 environmental, food and biological samples [3,8]. These compounds are responsible for  
63 a wide variety of adverse effects including damages to the human nervous system,  
64 cancer predisposition, reproductive disorders, and disruption of the cellular immune  
65 system. As a result, their use has been banned by the United Nations Environment  
66 Program, while they have been also listed as persistent organic pollutants by the  
67 Stockholm Convention [3,9]. Moreover, OCPs have been reported to be toxic by both  
68 the World Health Organization (WHO) and the Environmental Protection Agency



69 (EPA) [8]. The toxicity of these pollutants is clearly related to their chemical structure  
70 [5]. Although the use of OCPs has been banned in most industrialized advanced  
71 countries and their production has been terminated, their lasting and adverse influence  
72 on aquatic biota, human health and wildlife still causes concerns regarding the  
73 monitoring of the levels of these compounds in environmental samples [10].

74 The main difficulties of the determination of these analytes in real-world  
75 samples are related to their low concentrations, the sample complexity, and the potential  
76 presence of a wide range of interfering compounds. Therefore, an extraction and  
77 enrichment step is typically required prior to the determination of the OCPs using an  
78 instrumental analytical technique [11,12]. Conventional approaches for the extraction  
79 of OCPs include liquid-liquid extraction (LLE) and solid-phase extraction (SPE) that  
80 show high consumption of hazardous organic solvents, increased number of complex  
81 steps and high waste generation [13].

82 After the introduction of Green Analytical Chemistry (GAC) [14] that aims to  
83 provide the principles for developing of more sustainable and environmentally friendly  
84 methodologies, SPE and LLE tend to be progressively replaced by microextraction  
85 approaches. Thus, several novel methodologies including solid phase microextraction  
86 [15], dispersive solid-phase extraction (d-SPE) [16], magnetic solid-phase extraction  
87 (MSPE) [10], fabric phase sorptive extraction (FPSE) [17], stir bar sorptive extraction  
88 (SBSE) [18], dispersive liquid-liquid extraction [19] and hollow fiber-liquid phase  
89 microextraction [20] have been proposed for the accurate and sensitive monitoring of  
90 OCPs in a wide range of samples. An interesting technique that was recently proposed  
91 for the monitoring of pesticides in environmental water samples is capsule phase  
92 microextraction (CPME) [21].

93 In CPME, the analytes are extracted by appropriately designed devices that are  
94 made of two permeable microporous polypropylene tubes welded together to form a  
95 single, bipartite microextraction capsule. One polypropylene capillary tube contains a  
96 sol-gel hybrid organic-inorganic sorbent, while the other capillary tube contains a  
97 cylindrical magnet that provides to the device the ability to spin when a magnetic field  
98 is implemented [22]. The integration of sample stirring can efficiently simplify the  
99 extraction procedure to a large extent, while it prevents potential loss of analytes due to  
100 their retention on external devices and it results in increased extraction yield [23].  
101 Moreover, the polypropylene membranes exhibit inherent porosity and thus the  
102 capsules can be directly employed for the analysis of sample matrices containing



103 insoluble matrix interferants, debris and particulates, without any requirement of  
104 sample pretreatment (i.e., filtration) [21]. CPME is based on equilibrium extraction and  
105 due to the integration of the stirring mechanism, rapid extraction kinetics can be  
106 obtained [24]. An important characteristic of CPME is the utilization of sol-gel  
107 technology to prepare hybrid organic–inorganic porous products of various shapes,  
108 sizes, and formats. Sol-gel sorbents exhibit good chemical and thermal stability,  
109 selectivity, tunable porosity and high purity resulting in the fabrication of powerful  
110 microextraction devices [25].

111 In this work, we aimed to develop a simple and rapid method for the  
112 determination of ten OCPs in water samples by CPME combined with gas  
113 chromatography-mass spectrometry (GC-MS). Various monolithic sol-gel coated  
114 microextraction capsules were evaluated for their performance. Subsequently, the  
115 CPME procedure was optimized to ensure that the highest possible extraction efficiency  
116 is obtained. After method optimization, the CPME GC-MS protocol was validated. As  
117 a final step, the validated methodology was applied for the monitoring of OCPs in  
118 different environmental water samples.

119

## 120 2. Experimental

### 121 2.1. Reagents and chemicals

122 Acetonitrile and methanol of LC-MS grade were obtained from Honeywell  
123 (Charlotte, North Carolina, USA). HPLC grade acetone (ACE) and reagent grade NaCl  
124 were obtained from Merck (Darmstadt, Germany).  $\alpha$ -HCH (99.9%),  $\beta$ -HCH (98.4%),  
125  $\gamma$ -HCH (99.7%), alachlor (99.3%), aldrin (98.5%), p,p'-DDE (99.8%), o,p'-DDD  
126 (99.9%), p,p'-DDD (99.9%) and methoxychlor (98.7%) were obtained from Supelco  
127 (Bellefonte, PA, USA). o,p'-DDE (99.39%) was obtained from Dr. Ehrenstorfer GmbH  
128 (Augsburg, Germany). The structures of the target analytes are summarized in Figure  
129 S1. Stock solutions ( $c=1000\text{ mg L}^{-1}$ ) for all analytes were prepared in methanol. Multi-  
130 analyte working solutions were prepared daily with appropriate dilution in methanol.

131 Capsule phase microextraction devices were built using Membrana Accurel®  
132 porous capillary membranes, which were purchased from 3M Inc. (St. Paul, MN, USA).  
133 Cylindrical magnetic rods (1/4" x 1/16") were purchased from K&J Magnetics Inc.  
134 (Pipersville, PA, USA). Sol-gel synthesis materials, namely methyl trimethoxysilane  
135 (MTMS), tetramethyl orthosilicate (TMOS), poly(tetrahydrofuran) (PTHF), and  
136 polyethylene glycol 300 (PEG 300), were obtained from Sigma-Aldrich (St. Louis, MO,

137 USA). Poly(dimethylsiloxane) (PDMS), octadecyltrimethoxysilane (C<sub>18</sub>),  
138 poly(dimethyldiphenylsiloxane) (PDMDPS) were obtained from Gelest Inc.  
139 (Morrisville, PA, USA). Ammonium hydroxide, methylene chloride, isopropanol, and  
140 hydrochloric acid were purchased from Fisher Scientific (Milwaukee, WI, USA).

141 Environmental water samples (*i.e.*, lake, river, pond and tap water) were  
142 collected in Vienna, Austria. Amber-glass vials with no headspace were used for sample  
143 collection and storage. All samples were stored at 4°C, while no sample pretreatment  
144 was required prior to the CPME GC-MS procedure.

145

## 146 **2.2. Instrumentation**

147 A Shimadzu GC-2010 instrument coupled to a QP2010 Plus mass spectrometer  
148 (Shimadzu, Kyoto, Japan) was used for the quantification of the OCPs. Separation was  
149 achieved using Helium (99.999%) as mobile phase that was delivered at a flow rate of  
150 1.00 mL min<sup>-1</sup>. Constant linear velocity was employed as flow control mode. An Rtx-  
151 5MS (30 m × 0.25 mm, 0.25 μm) column (Restek Corporation, Bellefonte, PA, USA)  
152 was used under the following oven temperature program: 100 °C initial temperature  
153 (hold time: 2.5 min), increased to 200 °C (rate: 15 °C min<sup>-1</sup>), then increased to 250 °C  
154 (rate: 5 °C min<sup>-1</sup>) and finally increased to 300°C (rate: 6 °C min<sup>-1</sup>). The run time and  
155 the solvent delay were 27.5 min and 7.0 min, respectively. The injector temperature,  
156 the ion source temperature and the interface temperature were 280°C, 220°C and 250  
157 °C, respectively. The injection volume was 2 μL and high-pressure injection (450 kPa)  
158 took place. Finally, the OCPs were quantified at the selected ion monitoring (SIM)  
159 mode. For each analyte, one target ion was used as quantifier, while two reference ions  
160 were used as qualifiers. Table S1 shows the recorded *m/z* ratios for each analyte, as well  
161 as their respective retention times.

162 The CPME procedure was carried out using a magnetic stirrer (Heidolph  
163 Instruments GmbH & CO, Schwabach, Germany).

164

165

## 166 **2.3. Preparation of sol-gel monolithic sorbent encapsulated CPME devices**

167 CPME devices with built-in magnet and encapsulated sol-gel PDMS, sol-gel  
168 C18, sol-gel PEG 300, sol-gel PTHF and sol-gel PDMDPS monolithic sorbent beds  
169 were prepared using a simple protocol which is illustrated in Figure 1.





170

171 **Figure 1.** Preparation of the sol-gel monolithic sorbent encapsulated CPME  
 172 devices

173 Environmental samples can be collected in large volumes and the target analytes  
 174 are often at very low concentration levels. As such, a higher sorbent loading is needed  
 175 to accomplish higher method sensitivity. Thus, CPME media of 3 cm length were used.  
 176 The synthetical route for the fabrication of the microextraction capsules is described in  
 177 Supplementary Material.

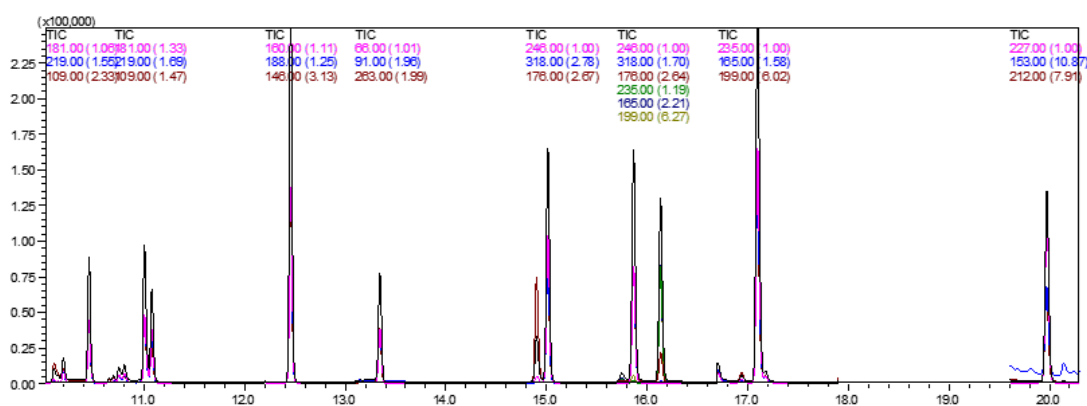
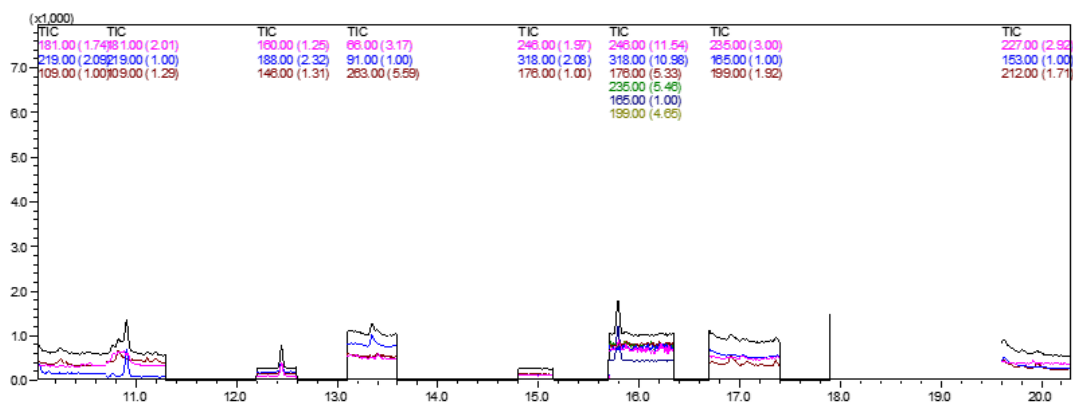
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#### 179 **2.4 CPME procedure**

180 Initially, the CPME capsules were immersed into a vial containing 2 mL of  
 181 MeOH mixture for 5 min to remove impurities that remained from the material  
 182 preparation. Accordingly, the capsules were rinsed with water.

183 Following the activation step, the pre-treated CPME capsules were immersed  
 184 into 20 mL of sample solution containing 5% *w/v* NaCl and adsorption was carried out  
 185 within 50 min under stirring at 800 rpm. Following this step, the supernatant was  
 186 discarded, and the capsule was rinsed with water and dried using lint free tissue. The  
 187 adsorbed OCPs were eluted by placing the CPME media into Eppendorf tubes  
 188 containing 250  $\mu$ L acetone. Finally, the capsules were recovered, and eluent filtration  
 189 was performed using 0.22  $\mu$ m polytetrafluoroethylene (Frisenette ApS, Knebel,  
 190 Denmark). Then, 2  $\mu$ L was analyzed by GC-MS system. Figure 2 shows a  
 191 representative chromatogram of a blank river water sample (a) and a spiked river water  
 192 sample (b) subjected to the herein described protocol.

193 The monolithic sol-gel PEG 300 CPME device used was immersed in the initial  
 194 mixture of ACN: MeOH (50:50 *v/v*) for 5 min. The utilization of the initial solvent  
 195 mixture meets the requirements of GAC regarding material recycling and reusing [26].  
 196 Following this procedure, no carry-over effects were observed. After washing, the clean  
 197 capsules were left to dry at ambient temperature, and they were stored in airtight sealed  
 198 vials.



199

200 **Figure 2.** Chromatogram of (a) a blank river water sample and (b) a spiked river  
 201 water sample ( $c=20 \text{ ng mL}^{-1}$ ) after their sample preparation using the monolithic sol-  
 202 gel PEG 300 CPME device

203

### 2043. 3. Results and discussion

#### 205 3.1 Characterization of the CPME media

206 The characterization of the CPME media by scanning electron microscopy and  
 207 Fourier transform infrared spectroscopy has been previously conducted [27], with the  
 208 aim of investigating the functional makeup of the sol-gel sorbents and the surface  
 209 morphology of the sol-gel sorbent.

210

#### 211 3.2 Optimization of CPME method

##### 212 3.2.1 Selection of sol-gel coated microextraction capsule

213 Initially, five monolithic sol-gel coated capsules were evaluated to assess the  
 214 performance of different sorbents and to select the material with the highest affinity  
 215 towards the target analytes. The examined sorbents were sol-gel PDMS, sol-gel  $C_{18}$ ,

216 sol-gel PEG 300, sol-gel PTHF and sol-gel PDMDPS. As shown, in Figure S2, sol-gel  
217 PEG 300 showed the best extraction performance towards the majority of the examined  
218 analytes. Higher extraction efficiency was observed for aldrin, o,p'-DDE and p,p'-  
219 DDE, only in the case of sol-gel PDMS. However, this sorbent exhibited significantly  
220 lower extraction efficiency for  $\alpha$ -HCH,  $\beta$ -HCH and  $\gamma$ -HCH and thus, further  
221 experiments were conducted using sol-gel PEG 300 as a compromise for all the  
222 analytes.

223

### 224 3.2.2 Optimization of the adsorption step

225 To ensure high extraction efficiency of the OCPs from the water samples, the  
226 experimental parameters that influence the performance of the adsorption step (*i.e.*, the  
227 stirring rate, the sample volume, the extraction time, and the salt content) were  
228 examined under a univariate approach. A spiked water sample solution ( $c=10 \text{ ng mL}^{-1}$ )  
229 was used in the optimization study. Table S2 summarizes the experimental conditions  
230 before and after the optimization study.

231 The effect of stirring rate was primarily investigated because it affects the  
232 analyte diffusion. For this purpose, four different stirring rates (*i.e.*, 0, 400, 800, and  
233 1000 rpm) were studied. According to the mass transfer theory, sample agitation is  
234 important to assist the movement of the analytes to the sol-gel sorbent surface with a  
235 reduction in the thickness of the boundary layer in order to shorten the thermodynamic  
236 equilibrium time [17]. As shown in Figure S3, sample stirring is critical for the  
237 adsorption of the OCPs. Under no stirring (*i.e.*, 0 rpm) negligible adsorption was  
238 achieved. The performance of the CPME method increased at 800 rpm for most analytes  
239 and it remained constant up to 1000 rpm. Thus, a stirring rate of 800 rpm was chosen.

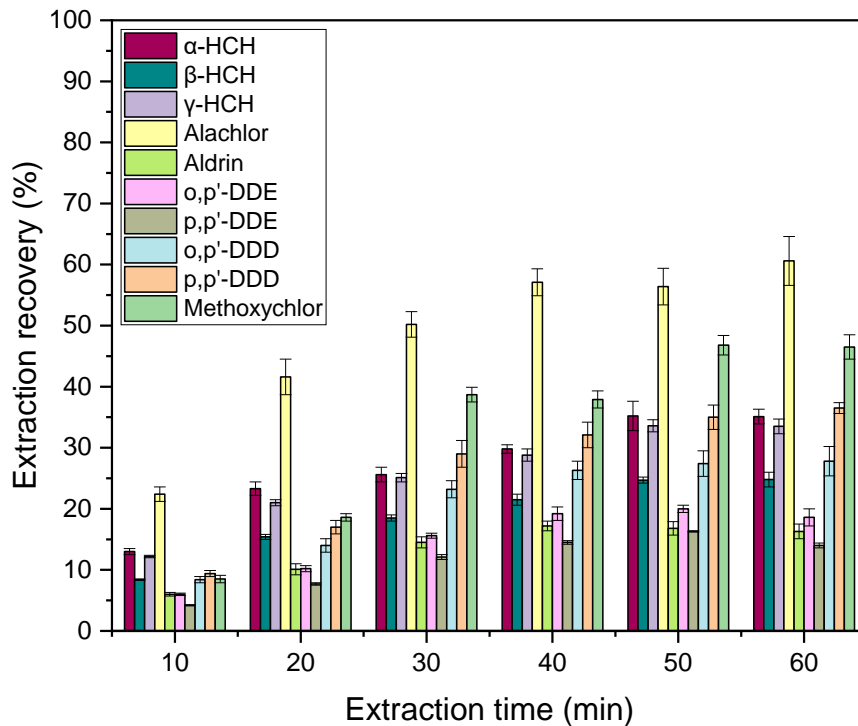
240 Accordingly, the sample amount was studied using three different volumes, *i.e.*,  
241 10 mL, 20 mL and 50 mL (Figure S4). A reduction of the extraction recovery was  
242 observed by increasing the sample volume from 10 mL to 50 mL. However, the  
243 utilization of 10 mL of sample results in lower preconcentration factors (PF) and thus  
244 in reduced method sensitivity. Therefore, an amount of 20 mL was used in the CPME  
245 method as a compromise between the extraction efficiency and the overall method  
246 sensitivity.

247 The extraction time is an significant factor in equilibrium-based techniques [28].  
248 The extraction time was studied from 10 to 60 min (Figure 3). Equilibrium was  
249 achieved at 40 min for aldrin, alachlor, o,p'-DDE, p,p'-DDE, o,p'-DDD and p,p'-DDD





250 while 50 min were required for  $\alpha$ -HCH,  $\beta$ -HCH,  $\gamma$ -HCH and methoxychlor. Thus, an  
251 extraction time of 50 min was chosen taking into consideration all the analytes.



252

253 **Figure 3.** Evaluation of the effect of extraction times. Sample volume: 20 mL, salt  
254 content: 0% *w/v* NaCl, eluent: acetonitrile, stirring rate: 800 rpm, volume of eluent: 500  
255  $\mu$ L, desorption time: 5 min.

256

257 As a final step, the effect of salt addition was studied by adding variable  
258 concentrations of NaCl (*i.e.*, 0-20% *w/v*). An increase in the extraction recovery was  
259 observed for  $\alpha$ -HCH,  $\beta$ -HCH,  $\gamma$ -HCH by enhancing the NaCl content up to 5% *w/v*  
260 (Figure S5). This phenomenon can be attributed to the salting-out effect, based on  
261 which, the addition of salt results in a reduction of the analyte solubility in the sample  
262 solution, favoring its interaction with the sorptive phase. However, a further increase  
263 from 5% *w/v* to 20% *w/v* had a negative impact on the extraction performance for o,p'-  
264 DDD, p,p'-DDD and methoxychlor, probably due to the reduced mass transfer of the  
265 OCPs which can be attributed to the enhancement of sample density [21]. Thus, a NaCl  
266 content of 5% *w/v* was chosen for further experiments.

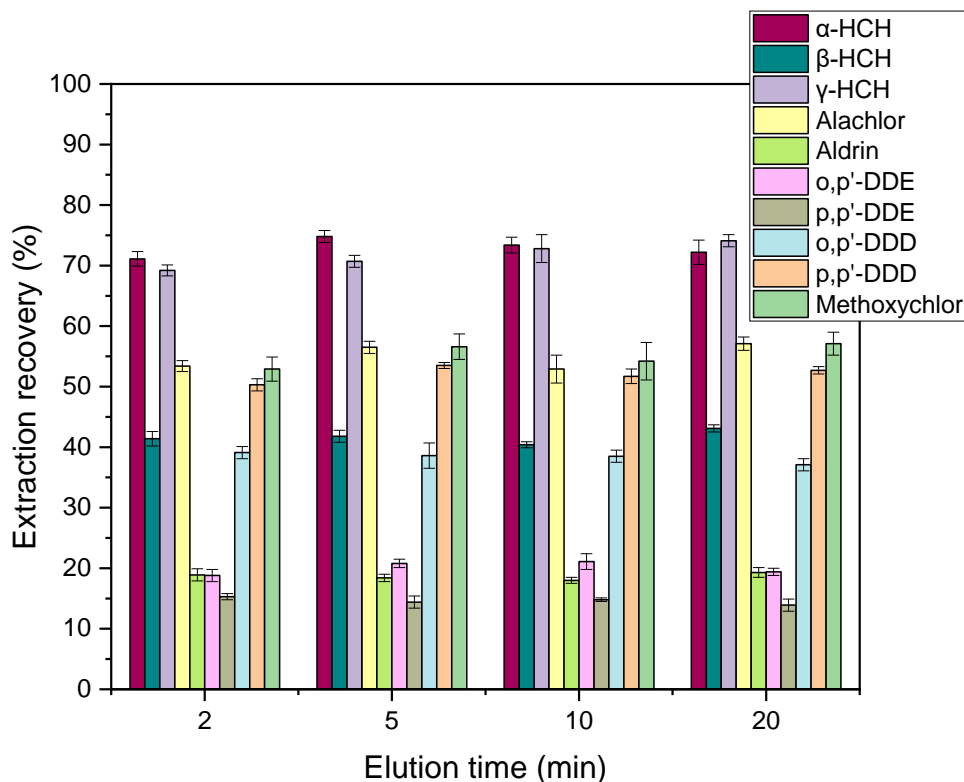
267

268

### 269 3.2.3 Optimization of the elution step

270 The main parameters that influence the performance of the elution step (*i.e.*,  
271 type/volume of eluent and elution time) were also investigated and optimized. Different  
272 solvents were examined for their performance to elute the adsorbed analytes from the  
273 CPME device. During method optimization, ACN was used as eluent, however its use  
274 is not recommended from an environmental aspect [29]. For this purpose, MeOH and  
275 ACE were also examined, since these solvents are “preferred” organic solvents  
276 according to the Pfizer solvent selection guide [30]. Although the usage of MeOH  
277 resulted in decreased elution efficiency, ACE exhibited similar performance as ACN  
278 (Figure S6). Thus, ACE was chosen as eluent taking into consideration the principles  
279 of GAC regarding the utilization of more environmentally-friendly chemicals [14].  
280 Accordingly, the usage of different aliquots (*i.e.*, 250  $\mu\text{L}$ , 500  $\mu\text{L}$  and 1000  $\mu\text{L}$ ) of ACE  
281 was evaluated, aiming to reduce the quantity of chemicals used in this study. In  
282 principle, it is desirable to use the lowest possible quantity of organic solvent to ensure  
283 low waste generation and low cost [14]. Meanwhile, the quantity of the solvent must be  
284 enough for the complete analyte elution and for avoiding potential carry over effects.  
285 As shown in Figure S7, an aliquot of 250  $\mu\text{L}$  of ACE was sufficient for the elution of  
286 OCPs. Lower solvent amounts were not studied to ensure complete immersion of the  
287 capsule in the eluent and to ensure sufficient contact between the eluent and the sol-gel  
288 sorbent. Thus, further experiments were carried out using this quantity of solvent.  
289 Finally, different elution times were studied to ensure the development of a rapid  
290 method with high sample throughput. A time span of 2 min was sufficient (Figure 4)  
291 for the elution of the OCPs from the CPME device.

292



293

294 **Figure 4.** Evaluation of the effect of different elution times. Sample volume: 20 mL,  
 295 salt content: 5% w/v, extraction time: 50 min, stirring rate: 800 rpm, eluent: acetone,  
 296 volume of eluent: 500 μL.

297

### 298 3.3. Figures-of-merit

299 In order to assess the linearity of the proposed methodology, spiked samples  
 300 were subjected to the optimum extraction protocol and linear regression analysis was  
 301 performed by plotting the peak area of each analyte versus its respective concentration.  
 302 For each OCP pesticide, the determination coefficient, the slope, and the intercept of  
 303 the regression lines were calculated. In Table 1, the regression analysis results are  
 304 presented. The coefficients of determination were 0.9939-0.9993 indicating good  
 305 method linearity. The lowest point of the calibration curve for each pesticide that had a  
 306 signal-to-noise ratio higher than 10 was considered to be the limit of quantification  
 307 (LOQ) and the limit of detection (LOD) was the concentration that corresponded to a  
 308 signal-to-noise ratio of 3 [31]. For the studied analytes, the LOD values were 0.01-0.03  
 309 ng mL<sup>-1</sup> and the LOQ values were 0.02-0.10 ng mL<sup>-1</sup>.

310 Accordingly, the preconcentration factor (PF), the enhancement factor (EF) and  
 311 the extraction recovery (ER%) were calculated [32]. PFs were calculated as ratio of the

312 sample volume (20 mL) compared to the eluent amount (250  $\mu$ L). Thus, the theoretical  
 313 PF for each analyte is 80. The EF values of each analyte were calculated as the ratio of  
 314 the slope derived from the calibration curve of the respective analyte prior and after the  
 315 CPME method. Finally, the ER% values were calculated by dividing the EF with the  
 316 theoretical PF \*100. As shown in Table 1, the EF values for each analyte were in the  
 317 range 11.5-59.9. Finally, the ER% values were obtained by dividing the EF values by  
 318 the PF values and multiplying with 100. The ER% values of the OCPs were in the range  
 319 of 14.4-74.8%

320

321 **Table 1.** Figures-of-merit for the proposed CPME GC-MS protocol

OCP	Regression Analysis	R <sup>2</sup>	Linear range (ng mL <sup>-1</sup> )	LOD <sup>1</sup> (ng mL <sup>-1</sup> )	LOQ <sup>2</sup> (ng mL <sup>-1</sup> )	ER <sup>3</sup> (%)	EF <sup>4</sup>
$\alpha$ -HCH	$y = 4884.6x + 765.51$	0.9993	0.05-50.0	0.02	0.05	74.8	59.9
$\beta$ -HCH	$y = 3808.1x + 2789.5$	0.9975	0.10-50.0	0.03	0.10	41.8	52.9
$\gamma$ -HCH	$y = 3722.5x + 550.9$	0.9991	0.10-50.0	0.03	0.10	70.7	59.4
Alachlor	$y = 14054x - 1809.6$	0.9989	0.05-50.0	0.02	0.05	56.5	45.2
Aldrin	$y = 2887x + 2850.8$	0.9939	0.05-50.0	0.01	0.02	18.4	14.7
o,p'-DDE	$y = 10197x + 1204.2$	0.9986	0.02-20.0	0.01	0.02	20.8	16.6
p,p'-DDE	$y = 6404.8x + 1222$	0.9970	0.02-20.0	0.01	0.02	14.4	11.5
o,p'-DDD	$y = 5885.3x + 3022.2$	0.9949	0.02-50.0	0.01	0.02	38.6	30.9
p,p'-DDD	$y = 20404x + 5194.9$	0.9973	0.02-50.0	0.01	0.02	53.5	42.8
Methoxychlor	$y = 33202x - 11634$	0.9989	0.05-50.0	0.02	0.05	56.6	45.3

322 <sup>1</sup>LOD: Limit of detection

323 <sup>2</sup>LOQ: Limit of quantification

324 <sup>3</sup>ER: Extraction recovery

325 <sup>4</sup>EF: Enhancement factor

326

327 Method accuracy and method precision was investigated by analyzing spiked  
 328 samples (*i.e.*,  $c=2.00$  and  $10.00$  ng mL<sup>-1</sup>). For the intra-day studies, five replicate  
 329 measurements ( $n=5$ ) of each spiked concentration level were conducted in the same  
 330 day, while for the inter-day studies triplicate analysis of each spiked concentration level  
 331 were performed on four consecutive days ( $n=3 \times 4$ ) [33]. Method accuracy was  
 332 expressed in terms of relative recovery (RR%) between the found and added

333 concentration of each pesticide. Method precision was expressed in terms of relative  
 334 standard deviation (RSD%). The results of the assessment of method trueness and  
 335 method precision are summarized in Table 2. As it can be observed, the RR% values  
 336 for intra-day study were between 90.5% and 105.2% and the RSD% values were less  
 337 than 5.3% for all analytes. As for the inter-day study, the RR% values were 93.0% and  
 338 105.0% and the RSD% values were less than 9.2%, indicating good method trueness  
 339 and precision.

340

341 **Table 2.** Intra-day ( $n=5$ ) and inter-day ( $n=4 \times 3$ ) performance studies of the CPME GC-  
 342 MS method

Analyte	Added (ng mL <sup>-1</sup> )	Intra-Day ( $n=5$ )			Inter-Day ( $n=4 \times 3$ )		
		Found (ng mL <sup>-1</sup> )	RSD% <sup>1</sup>	RR% <sup>2</sup>	Found (ng mL <sup>-1</sup> )	RSD%	RR%
$\alpha$ -HCH	2.00	1.99 ± 0.04	1.8	99.5	2.09 ± 0.14	6.7	104.5
	10.00	9.74 ± 0.21	2.1	97.4	9.31 ± 0.56	6.0	93.1
$\beta$ -HCH	2.00	1.95 ± 0.07	3.6	97.5	2.03 ± 0.08	3.9	101.5
	10.00	9.78 ± 0.24	2.4	97.8	9.30 ± 0.45	4.8	93.0
$\gamma$ -HCH	2.00	2.03 ± 0.06	3.2	101.5	2.06 ± 0.09	4.2	103.0
	10.00	9.78 ± 0.30	3.1	97.8	9.36 ± 0.54	5.8	93.6
Alachlor	2.00	1.96 ± 0.07	3.5	98.0	2.02 ± 0.11	5.3	101.1
	10.00	9.66 ± 0.30	3.1	96.6	9.61 ± 0.35	3.6	96.1
Aldrin	2.00	1.81 ± 0.06	3.3	90.5	1.95 ± 0.09	4.8	97.5
	10.00	9.88 ± 0.28	2.9	98.8	9.51 ± 0.58	6.1	95.1
o,p-DDE	2.00	1.82 ± 0.08	4.5	91.0	1.94 ± 0.07	3.7	97.0
	10.00	9.85 ± 0.24	2.4	98.5	9.62 ± 0.47	4.9	96.2
p,p-DDE	2.00	1.94 ± 0.08	4.2	97.0	2.10 ± 0.15	7.2	105.0
	10.00	10.11 ± 0.14	1.4	101.1	9.79 ± 0.42	4.3	97.9
o,p-DDD	2.00	1.99 ± 0.07	3.5	99.5	2.00 ± 0.13	6.3	100.0
	10.00	10.00 ± 0.16	1.6	100.0	9.88 ± 0.67	6.7	98.8
p,p-DDD	2.00	2.03 ± 0.05	2.7	101.5	1.96 ± 0.14	7.4	98.0
	10.00	9.97 ± 0.14	1.4	99.7	9.84 ± 0.32	3.2	98.4
ethoxychlor	2.00	2.10 ± 0.06	2.7	105.0	2.02 ± 0.06	3.1	101.0
	10.00	9.42 ± 0.50	5.3	94.2	9.84 ± 0.90	9.2	98.4

343 <sup>1</sup>RSD: Relative standard deviation

344 <sup>2</sup>RR: Relative recovery

345

346

#### 347 **3.4. Reusability of the sol-gel PEG 300 CPME media**

348 In a further step, the reusability of the sol-gel PEG 300 CPME media was  
349 studied to provide a more comprehensive assessment regarding the performance of the  
350 proposed method. In green sample preparation, the utilization of reusable materials over  
351 those of disposable nature is of high importance to promote the reduction of waste  
352 aiming to develop more environmentally-friendly and low-cost methods [34]. For this  
353 study, one capsule was used for 20 repeated extraction cycles using a spiked sample  
354 ( $c = 10 \text{ ng mL}^{-1}$ ) and the criterion of a reduction of  $\geq 10\%$  of the recovery compared to  
355 the initial recovery was set. As shown in Figure S8, the performance of the CPME  
356 device was unaffected after 20 consecutive extraction cycles. Thus, the capsules are  
357 reusable for at least 20 times.

358

#### 359 **3.5. Evaluation of method's green character and comparison with other** 360 **approaches**

361 The herein developed method was compared with previously reported methods  
362 for the extraction of OCPs, as shown in Table 3.

363

364 **Table 3.** Comparison of the proposed method with other methodologies.

Sample preparation <sup>1</sup>	Instrumentation <sup>2</sup>	Sample amount (mL)	Filtration	Extraction time (min)/Elution time(min)	Eluent	Evaporation/reconstitution	RSD% <sup>3</sup>	LODs <sup>4</sup> (ng mL <sup>-1</sup> )	Ref.
HS-SBSE using PDMS	GC-MS	15	No	120/15	1.5 mL of toluene: acetonitrile (20:80 v/v)	Required	<14.8	0.02-0.38	[18]
DMIP-SPE	GC-MS	100	No	-	12 mL of dichloromethane	Required	<6.69	0.007-0.126	[35]
d-SPE using SWCNTs	GC-ECD	20	No	10/15	5 mL of ethyl acetate	Required	<5.6	0.025-0.049	[36]
μ-SPE using TiO <sub>2</sub> nanotube arrays	GC-ECD	10	Required	40/7	dichloromethane	Required	<9.88	0.0076-0.10	[37]
MSPE using (M-M-ZIF-67)	GC-MS	5	Required	20/5	4 mL of acetonitrile	Required	<8.5	0.07-1.03	[38]
MSPE using γO/Fe <sub>3</sub> O <sub>4</sub> @Au	GC-μECD	10	Required	10/2	250 μL of acetonitrile	No	<7.3	0.4-4.1 x 10 <sup>-3</sup>	[39]
CPME	GC-MS	20	No	50/2	250 μL of acetone	No	<5.3 (intra-day) <9.2 (inter-day)	0.01-0.03	This study

365

366 <sup>1</sup>HS-SBSE: Headspace-stir bar sorptive extraction, DMIP: Dummy template molecularly imprinted polymer, SWCNTs: single-walled  
367 carbon nanotubes, M-M-ZIF-67: zeolitic imidazolate framework based on magnetic multi-walled carbon nanotubes, RGO/Fe<sub>3</sub>O<sub>4</sub>@Au:  
368 reduced graphene oxide/ Fe<sub>3</sub>O<sub>4</sub>@gold nanocomposite,  
369 <sup>2</sup> GC-ECD: Gas chromatography-electron capture detector, GC- $\mu$ ECD: Gas chromatography- micro electron capture detector  
370 <sup>3</sup> RSD: Relative standard deviation  
371 <sup>4</sup> LODs: Limits of detection  
372



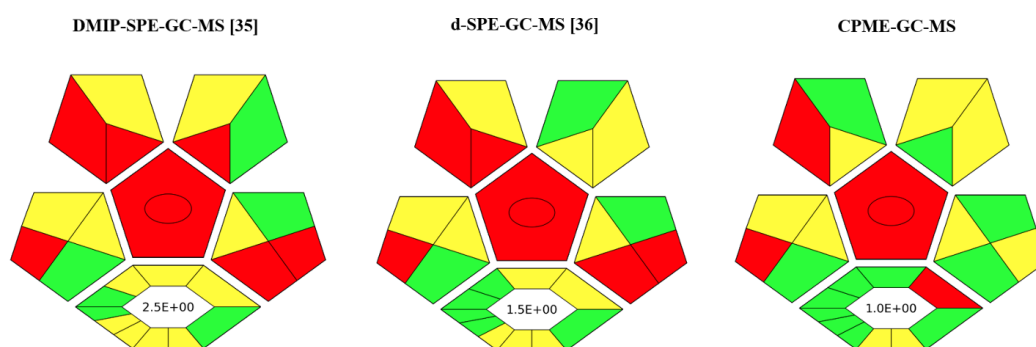
373 The sample amount used during the extraction procedure was higher than the  
374 sample amount used in refs. [18,37–39], similar to the sample amount used in ref. [36]  
375 and lower than the sample amount used in ref. [35]. The overall extraction time was  
376 comparable with the extraction time required in ref. [37], higher than the extraction  
377 time required in refs. [36,38,39] but lower than the extraction time required in ref. [18].  
378 Moreover, the sensitivity of the proposed method (in terms of LOD values) was  
379 comparable to those of refs. [18,35–37], higher than the sensitivity of ref. [38] but lower  
380 than the sensitivity of ref. [39].

381 A significant advantage of the proposed procedure is the utilization of a small  
382 amount of organic solvent as eluent. In this work, elution is performed using 250  $\mu$ L of  
383 acetone, while the organic solvent requirements in most of the other studies are above  
384 1.5 mL (*i.e.*, refs. [18,36,38] and they range up to 12 mL (*i.e.*, ref. [35]). Only in ref.  
385 [39] the same amount (*i.e.*, 250  $\mu$ L) of organic solvent is employed; however  
386 acetonitrile is used which is not recommendable from an environmental perspective  
387 [29]. On the other hand, acetone is considered to be a “preferred” solvent, as already  
388 discussed in section 3.2.3 [30]. The proposed method does not require acetonitrile (used  
389 in ref. [18] and [38]), toluene (used in ref. [18]) and chlorinated solvents (used in refs.  
390 [35] and [37]) which are more hazardous chemicals. Thus, the proposed method meets  
391 the requirements of GAC [14] regarding the low consumption of organic solvents and  
392 the replacement of chemicals with less hazardous ones.

393 Another advantage of CPME is that it overcomes the need for sample filtration  
394 prior to the extraction procedure and the need for sample evaporation following the  
395 extraction procedure. Sample filtration was required in refs. [37–39], while sample  
396 evaporation and reconstitution were required in refs. [18,35–38]. In principle, a multi-  
397 step sample preparation procedure may result in reduced precision and accuracy, while  
398 it can be time-consuming and demand high expenditures of chemicals and energy [34].  
399 Thus, the reduction of sample preparation steps is a significant factor towards the  
400 development of greener methods. An additional benefit of CPME is the increased  
401 simplicity of the method, because the microextraction capsules can be removed from  
402 the eluent and the sample solution using tweezers. Thus, they overcome the need of  
403 magnetic separation that is necessary in MSPE [38,39] and centrifugation that is  
404 necessary in d-SPE [36] processes.

405 A usefull tool to make the greenness of an analytical method visible and  
406 comparable are CompleGAPI pictograms [40]. In this tool, the environmental

407 friendliness of an analytical method is assessed by evaluating the sample preparation  
408 procedure, the instrumentation used for the analytical determination, the reagents and  
409 chemicals used and the overall method type. Moreover, the hexagonal field of the  
410 ComplexGAPI pictogram examines the impact of the yield and conditions, chemicals,  
411 instrumentation purification and workup used during the manufacturing of extraction  
412 materials which in this case includes the CPME device. Figure 5 depicts the  
413 ComplexGAPI pictogram that corresponds to the herein developed CPME GC-MS  
414 method, as well as to two of the other existing methodologies for the monitoring of  
415 OPCs in water samples found in the literature. With regard to the preparation of the  
416 microextraction capsules most of the assessment criteria are met (green colour). The  
417 synthesis was characterized by a high process yield and reduced waste generation, as  
418 well as a low E-factor. As for the extraction, the proposed scheme is characterized by  
419 low chemical consumption and waste generation since microextraction is used. Future  
420 recommendations towards the reduction of the environmental impact of the herein  
421 developed method include the utilization of more environmentally-friendly chemicals  
422 (*i.e.*, deep eutectic solvents, DESs) instead of conventional organic solvents.



423  
424 **Figure 5.** ComplexGAPI pictogram of the developed method (right), compared to other  
425 selected methods (left and middle) [35, 36]

426  
427  
428

429 **3.6. Analysis of real-world water samples**

430 Following method development and measurement of the figures-of-merit of the  
431 proposed method, water samples of different origin (*i.e.*, tap, river, pond and lake water)  
432 were analysed. Each sample was spiked at two different concentration levels (*i.e.*,  
433  $c=2.00\text{ ng mL}^{-1}$  and  $10.00\text{ ng mL}^{-1}$ ) to investigate the applicability of the proposed  
434 methodology to different water samples. As shown in Table 4, the relative recoveries  
435 in the examined spiked levels ranged between 80.1-112.5% indicating good method  
436 applicability of the proposed scheme in different environmental water samples. The  
437 absence of interferences in the blank samples shows that the proposed method is  
438 characterized by specificity, while no contamination occurred during sample analysis.  
439

440 **Table 4.** Analysis of environmental water samples through CPME GC-MS.

Analyte	Added	Lake water 1		Lake water 2		Pond water		River water		Tap water	
	(ng mL <sup>-1</sup> )	Found (ng mL <sup>-1</sup> )	RR% <sup>1</sup>	Found (ng mL <sup>-1</sup> )	RR%	Found (ng mL <sup>-1</sup> )	RR%	Found (ng mL <sup>-1</sup> )	RR%	Found (ng mL <sup>-1</sup> )	RR%
α-HCH	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	2.01±0.04	100.3	1.82±0.04	91.0	1.71±0.01	85.5	2.22±0.09	111.0	1.98±0.02	99.1
	10.00	10.16±0.06	101.6	9.57±0.18	95.7	10.22±0.38	102.2	9.89±0.16	98.9	9.92±0.18	99.2
β-HCH	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.90±0.02	95.2	1.80±0.03	90.2	1.75±0.02	87.4	1.77±0.03	88.6	1.92±0.02	96.1
	10.00	10.52±0.12	105.2	9.28±0.34	92.8	10.38±0.22	103.8	9.97±0.22	99.7	10.12±0.25	101.2
γ-HCH	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.97±0.02	98.3	1.85±0.07	92.4	2.06±0.02	103.0	2.21±0.04	110.5	1.91±0.04	95.4
	10.00	9.71±0.09	97.1	9.25±0.07	92.3	9.77±0.28	97.7	9.88±0.17	98.8	9.23±0.27	92.3
Alachlor	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.64±0.05	82.0	1.96±0.05	98.1	1.95±0.05	97.4	2.03±0.01	101.3	2.01±0.03	100.5
	10.00	9.74±0.44	97.4	9.14±0.28	91.4	9.89±0.30	98.9	9.58±0.60	95.8	10.73±0.24	107.3
Aldrin	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.62±0.02	81.2	2.01±0.01	100.6	1.93±0.06	96.4	1.97±0.02	98.6	1.98±0.03	99.0
	10.00	10.51±0.04	105.1	10.25±0.15	102.5	8.90±0.37	89.0	9.65±0.01	96.5	10.25±0.27	102.5





Analyte	Added	Lake water 1		Lake water 2		Pond water		River water		Tap water	
	(ng mL <sup>-1</sup> )	Found (ng mL <sup>-1</sup> )	RR% <sup>1</sup>	Found (ng mL <sup>-1</sup> )	RR%	Found (ng mL <sup>-1</sup> )	RR%	Found (ng mL <sup>-1</sup> )	RR%	Found (ng mL <sup>-1</sup> )	RR%
o,p-DDE	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.72±0.01	86.0	1.91±0.06	95.5	1.60±0.01	80.1	1.76±0.06	87.8	2.10±0.11	105.1
	10.00	10.98±0.05	109.8	9.95±0.07	99.5	10.05±0.19	100.5	9.51±0.13	95.1	10.25±0.27	102.5
p,p-DDE	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.97±0.01	98.7	1.75±0.05	87.6	1.70±0.07	85.2	1.74±0.01	87.1	2.15±0.05	107.3
	10.00	9.53±0.14	95.3	9.68±0.17	96.8	8.87±0.45	88.7	9.25±0.20	92.5	10.87±0.15	108.7
o,p-DDD	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.85±0.01	92.7	2.11±0.03	105.3	2.00±0.09	99.8	2.06±0.02	102.8	2.07±0.05	103.4
	10.00	10.34±0.15	103.4	11.17±0.16	111.7	8.91±0.20	89.1	8.51±0.07	85.1	11.25±0.16	112.5
p,p-DDD	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.81±0.04	90.4	1.93±0.02	96.4	1.81±0.10	90.6	1.94±0.03	97.2	1.98±0.06	98.8
	10.00	8.79±0.02	87.9	8.24±0.30	82.4	8.04±0.02	80.4	8.61±0.01	86.1	10.72±0.16	107.2
γ-thoxychlor	0	<LOD	-	<LOD	-	<LOD	-	<LOD	-	<LOD	-
	2.00	1.70±0.003	85.1	1.82±0.03	90.9	1.74±0.07	87.1	1.93±0.05	96.5	1.96±0.02	98.2
	10.00	9.15±0.90	91.5	8.43±0.82	84.3	8.89±1.05	88.9	8.79±0.10	87.9	9.94±0.81	99.4

441 <sup>1</sup>RR: Relative recovery

#### 442 4. Conclusions

443 In this work, CPME was used for the extraction of OCPs in environmental water  
444 samples. Among the examined sorbents, the monolithic sol-gel poly(ethylene glycol)-  
445 based CPME device resulted in the highest extraction efficiency. Under optimum  
446 sample preparation conditions, the proposed method showed good linearity, accuracy,  
447 precision, and sensitivity. Moreover, the capsules could be reused for at least 20 times.  
448 The proposed scheme exhibits multiple benefits including handling simplicity, rapid  
449 extraction kinetics, and low consumption of organic solvents. CPME efficiently  
450 overcomes the need for sample pretreatment (*i.e.*, filtration) prior to sample preparation,  
451 while it also reduces the need for sample manipulation (*e.g.*, evaporation/reconstitution)  
452 after the sample preparation. Moreover, the integration of stirring mechanism results in  
453 a less error prone and more powerful extraction device, that prevents potential loss of  
454 analytes due to their retention on external devices (*e.g.*, magnetic rods).

455

#### 456 Declaration of Competing Interest

457 The authors declare no conflict of interest

458

#### 459 References

460

- 461 [1] G.R. Van Der Hoff, P. Van Zoonen, Trace analysis of pesticides by gas  
462 chromatography, *J. Chromatogr. A.* 843 (1999) 301–322.  
463 [https://doi.org/10.1016/S0021-9673\(99\)00511-7](https://doi.org/10.1016/S0021-9673(99)00511-7).
- 464 [2] W. Aktar, D. Sengupta, A. Chowdhury, Impact of pesticides use in agriculture:  
465 Their benefits and hazards, *Interdiscip. Toxicol.* 2 (2009) 1–12.  
466 <https://doi.org/10.2478/v10102-009-0001-7>.
- 467 [3] P. Zhu, H. Miao, J. Du, J. Zou, G.-W. Zhang, Y.-F. Zhao, Y. Wu,  
468 Organochlorine Pesticides and Pyrethroids in Chinese Tea by Screening and  
469 Confirmatory Detection Using GC-NCI-MS and GC-MS/MS, *J. Agric. Food*  
470 *Chem.* 62 (2014) 7092–7100.
- 471 [4] M. Pirsahab, H. Hossini, F. Asadi, H. Janjani, A systematic review on  
472 organochlorine and organophosphorus pesticides content in water resources,  
473 *Toxin Rev.* 36 (2017) 210–221.  
474 <https://doi.org/10.1080/15569543.2016.1269810>.
- 475 [5] A. Ashesh, S. Singh, N. Linthoingambi Devi, I. Chandra Yadav,  
476 Organochlorine pesticides in multi-environmental matrices of India: A  
477 comprehensive review on characteristics, occurrence, and analytical methods,  
478 *Microchem. J.* 177 (2022) 107306.  
479 <https://doi.org/10.1016/j.microc.2022.107306>.

- 480 [6] X. Zang, Q. Chang, Y. Pang, L. Wang, S. Zhang, C. Wang, Z. Wang, Solid-  
 481 phase microextraction of eleven organochlorine pesticides from fruit and  
 482 vegetable samples by a coated fiber with boron nitride modified multiwalled  
 483 carbon nanotubes, *Food Chem.* 359 (2021) 129984.  
 484 <https://doi.org/10.1016/j.foodchem.2021.129984>.
- 485 [7] B.Y. Durak, D.S. Chormey, M. Firat, S. Bakirdere, Validation of ultrasonic-  
 486 assisted switchable solvent liquid phase microextraction for trace determination  
 487 of hormones and organochlorine pesticides by GC–MS and combination with  
 488 QuEChERS, *Food Chem.* 305 (2020).  
 489 <https://doi.org/10.1016/j.foodchem.2019.125487>.
- 490 [8] E.A. Moawed, A.M. Radwan, Application of acid modified polyurethane foam  
 491 surface for detection and removing of organochlorine pesticides from  
 492 wastewater, *J. Chromatogr. B.* 1044–1045 (2017) 95–102.  
 493 <https://doi.org/10.1016/j.jchromb.2016.12.041>.
- 494 [9] R. Jayaraj, P. Megha, P. Sreedev, Review Article. Organochlorine pesticides,  
 495 their toxic effects on living organisms and their fate in the environment,  
 496 *Interdiscip. Toxicol.* 9 (2016) 90–100. [https://doi.org/10.1515/intox-2016-](https://doi.org/10.1515/intox-2016-0012)  
 497 [0012](https://doi.org/10.1515/intox-2016-0012).
- 498 [10] Y. Liu, Z. Gao, R. Wu, Z. Wang, X. Chen, T.W.D. Chan, Magnetic porous  
 499 carbon derived from a bimetallic metal–organic framework for magnetic solid-  
 500 phase extraction of organochlorine pesticides from drinking and environmental  
 501 water samples, *J. Chromatogr. A.* 1479 (2017) 55–61.  
 502 <https://doi.org/10.1016/j.chroma.2016.12.014>.
- 503 [11] Q. Zhoua, Y. Wu, Y. Sun, X. Sheng, Y. Tong, J. Guo, B. Zhou, J. Zhao,  
 504 Magnetic polyamidoamine dendrimers for magnetic separation and sensitive  
 505 determination of organochlorine pesticides from water samples by high-  
 506 performance liquid chromatography, *J. Environ. Sci. (China)*. 102 (2021) 64–  
 507 73. <https://doi.org/10.1016/j.jes.2020.09.005>.
- 508 [12] N. Manousi, A. Kabir, G.A. Zachariadis, Recent advances in the extraction of  
 509 triazine herbicides from water samples, *J. Sep. Sci.* 45 (2021) 113–133.  
 510 <https://doi.org/10.1002/jssc.202100313>.
- 511 [13] M. Sajid, C. Basheer, M. Daud, A. Alsharaa, Evaluation of layered double  
 512 hydroxide/graphene hybrid as a sorbent in membrane-protected stir-bar  
 513 supported micro-solid-phase extraction for determination of organochlorine  
 514 pesticides in urine samples, *J. Chromatogr. A.* 1489 (2017) 1–8.  
 515 <https://doi.org/10.1016/j.chroma.2017.01.089>.
- 516 [14] S. Armenta, S. Garrigues, M. de la Guardia, Green Analytical Chemistry, *TrAC*  
 517 *- Trends Anal. Chem.* 27 (2008) 497–511.  
 518 <https://doi.org/10.1016/j.trac.2008.05.003>.
- 519 [15] S. Liu, L. Xie, J. Zheng, R. Jiang, F. Zhu, T. Luan, G. Ouyang, Mesoporous  
 520 TiO<sub>2</sub> nanoparticles for highly sensitive solid-phase microextraction of  
 521 organochlorine pesticides, *Anal. Chim. Acta.* 878 (2015) 109–117.  
 522 <https://doi.org/10.1016/j.aca.2015.03.054>.
- 523 [16] X. Jiang, M. Wu, W. Wu, J. Cheng, H. Zhou, M. Cheng, A novel dispersive

- 524 micro-solid phase extraction method combined with gas chromatography for  
 525 analysis of organochlorine pesticides in aqueous samples, *Anal. Methods*. 6  
 526 (2014) 9712–9717. <https://doi.org/10.1039/c4ay02302a>.
- 527 [17] R. Kaur, R. Kaur, S. Rani, A.K. Malik, A. Kabir, K.G. Furton, V.F.  
 528 Samanidou, Rapid monitoring of organochlorine pesticide residues in various  
 529 fruit juices and water samples using fabric phase sorptive extraction and gas  
 530 chromatography-mass spectrometry, *Molecules*. 24 (2019) 1–16.  
 531 <https://doi.org/10.3390/molecules24061013>.
- 532 [18] P. Grossi, I.R.B. Olivares, D.R. De Freitas, F.M. Lancas, A novel HS-SBSE  
 533 system coupled with gas chromatography and mass spectrometry for the  
 534 analysis of organochlorine pesticides in water samples, *J. Sep. Sci.* 31 (2008)  
 535 3630–3637. <https://doi.org/10.1002/jssc.200800338>.
- 536 [19] M.I. Leong, S. Da Huang, Dispersive liquid-liquid microextraction method  
 537 based on solidification of floating organic drop for extraction of organochlorine  
 538 pesticides in water samples, *J. Chromatogr. A*. 1216 (2009) 7645–7650.  
 539 <https://doi.org/10.1016/j.chroma.2009.09.004>.
- 540 [20] J. Cai, G. Chen, J. Qiu, R. Jiang, F. Zeng, F. Zhu, G. Ouyang, Hollow fiber  
 541 based liquid phase microextraction for the determination of organochlorine  
 542 pesticides in ecological textiles by gas chromatography-mass spectrometry,  
 543 *Talanta*. 146 (2016) 375–380. <https://doi.org/10.1016/j.talanta.2015.08.069>.
- 544 [21] N. Manousi, V. Alampanos, I. Priovolos, A. Kabir, K.G. Furton, E. Rosenberg,  
 545 G.A. Zachariadis, V.F. Samanidou, Designing a moderately hydrophobic sol-  
 546 gel monolithic Carbowax 20 M sorbent for the capsule phase microextraction  
 547 of triazine herbicides from water samples prior to HPLC analysis, *Talanta*. 234  
 548 (2021) 122710. <https://doi.org/10.1016/j.talanta.2021.122710>.
- 549 [22] N. Manousi, A. Kabir, K.G. Furton, V.F. Samanidou, C.K. Zacharis, Exploiting  
 550 the capsule phase microextraction features in bioanalysis: Extraction of  
 551 ibuprofen from urine samples, *Microchem. J.* 172 (2022) 106934.  
 552 <https://doi.org/10.1016/j.microc.2021.106934>.
- 553 [23] S. Cárdenas, R. Lucena, Recent advances in extraction and stirring integrated  
 554 techniques, *Separations*. 4 (2017) 6.  
 555 <https://doi.org/10.3390/separations4010006>.
- 556 [24] J. Carles, F. Borrull, K.G. Furton, A. Kabir, N. Fontanals, R. Maria, Selective  
 557 monitoring of acidic and basic compounds in environmental water by capsule  
 558 phase microextraction using sol-gel mixed-mode sorbents followed by liquid  
 559 chromatography-mass spectrometry in tandem, *J. Chromatogr. A*. 1625 (2020)  
 560 461295. <https://doi.org/10.1016/j.chroma.2020.461295>.
- 561 [25] V. Kazantzi, A. Anthemidis, Fabric sol-gel phase sorptive extraction  
 562 technique: A review, *Separations*. 4 (2017) 20.  
 563 <https://doi.org/10.3390/separations4020020>.
- 564 [26] W. Wojnowski, M. Tobiszewski, F. Pena-Pereira, E. Psillakis, AGREEprep –  
 565 Analytical greenness metric for sample preparation, *TrAC Trends Anal. Chem.*  
 566 149 (2022) 116553. <https://doi.org/10.1016/j.trac.2022.116553>.
- 567 [27] N. Manousi, A. Kabir, K.G. Furton, P.D. Tzanavaras, C.K. Zacharis, In situ



- 568 synthesis of monolithic sol–gel polyethylene glycol-based sorbent encapsulated  
569 in porous polypropylene microextraction capsules and its application for  
570 selective extraction of antifungal and anthelmintic drugs from human urine,  
571 *Microchem. J.* 180 (2022) 107594.  
572 <https://doi.org/10.1016/j.microc.2022.107594>.
- 573 [28] N. Manousi, A. Kabir, G. A Zachariadis, Green bioanalytical sample  
574 preparation: Fabric phase sorptive extraction, *Bioanalysis.* 13 (2021) 693–710.  
575 <https://doi.org/10.4155/bio-2021-0004>.
- 576 [29] C. Capello, U. Fischer, K. Hungerbühler, What is a green solvent? A  
577 comprehensive framework for the environmental assessment of solvents, *Green*  
578 *Chem.* 9 (2007) 927–93. <https://doi.org/10.1039/b617536h>.
- 579 [30] D.R. Joshi, N. Adhikari, An Overview on Common Organic Solvents and Their  
580 Toxicity, *J. Pharm. Res. Int.* 28 (2019) 1–18.  
581 <https://doi.org/10.9734/jpri/2019/v28i330203>.
- 582 [31] E.G. Karageorgou, V.F. Samanidou, Development and validation according to  
583 European Union Decision 2002/657/EC of an HPLC-DAD method for milk  
584 multi-residue analysis of penicillins and amphenicols based on dispersive  
585 extraction by QuEChERS in MSPD format, *J. Sep. Sci.* 34 (2011) 1893–1901.  
586 <https://doi.org/10.1002/jssc.201100194>.
- 587 [32] H.İ. Ulusoy, K. Köseoğlu, A. Kabir, S. Ulusoy, M. Locatelli, Fabric phase  
588 sorptive extraction followed by HPLC-PDA detection for the monitoring of  
589 pirimicarb and fenitrothion pesticide residues, *Microchim. Acta.* 187 (2020)  
590 337. <https://doi.org/10.1007/s00604-020-04306-7>.
- 591 [33] N.P. Kalogiouri, A. Kabir, B. Olayanju, K.G. Furton, V.F. Samanidou,  
592 Development of highly hydrophobic fabric phase sorptive extraction  
593 membranes and exploring their applications for the rapid determination of  
594 tocopherols in edible oils analyzed by high pressure liquid chromatography-  
595 diode array detection, *J. Chromatogr. A.* 1664 (2021) 462785.  
596 <https://doi.org/10.1016/j.chroma.2021.462785>.
- 597 [34] Á.I. López-Lorente, F. Pena-Pereira, S. Pedersen-Bjergaard, V.G. Zuin, S.A.  
598 Ozkan, E. Psillakis, The ten principles of green sample preparation, *TrAC -*  
599 *Trends Anal. Chem.* 148 (2022). <https://doi.org/10.1016/j.trac.2022.116530>.
- 600 [35] X. Gao, M. Pan, G. Fang, W. Jing, S. He, S. Wang, An ionic liquid modified  
601 dummy molecularly imprinted polymer as a solid-phase extraction material for  
602 the simultaneous determination of nine organochlorine pesticides in  
603 environmental and food samples, *Anal. Methods.* 5 (2013) 6128–6134.  
604 <https://doi.org/10.1039/c3ay41083h>.
- 605 [36] P. Sun, Y. Cui, R. Yan, Y. Lian, Determination of organochlorine pesticides in  
606 water using GC combined with dispersive solid-phase extraction with single-  
607 walled carbon nanotubes, *Acta Chromatogr.* 33 (2021) 202–207.  
608 <https://doi.org/10.1556/1326.2020.00840>.
- 609 [37] Q. Zhou, Y. Huang, J. Xiao, G. Xie, Micro-solid phase equilibrium extraction  
610 with highly ordered TiO<sub>2</sub> nanotube arrays: A new approach for the enrichment  
611 and measurement of organochlorine pesticides at trace level in environmental

- 612 water samples, *Anal. Bioanal. Chem.* 400 (2011) 205–212.  
613 <https://doi.org/10.1007/s00216-011-4788-7>.
- 614 [38] X. Huang, G. Liu, D. Xu, X. Xu, L. Li, S. Zheng, H. Lin, H. Gao, Novel  
615 zeolitic imidazolate frameworks based on magnetic multiwalled carbon  
616 nanotubes for magnetic solid-phase extraction of organochlorine pesticides  
617 from agricultural irrigation water samples, *Appl. Sci.* 8 (2018) 959.  
618 <https://doi.org/10.3390/app8060959>.
- 619 [39] A. Mehdinia, S. Rouhani, S. Mozaffari, Microwave-assisted synthesis of  
620 reduced graphene oxide decorated with magnetite and gold nanoparticles, and  
621 its application to solid-phase extraction of organochlorine pesticides,  
622 *Microchim. Acta.* 183 (2016) 1177–1185. <https://doi.org/10.1007/s00604-015-1691-5>.  
623
- 624 [40] J. Płotka-Wasyłka, W. Wojnowski, Complementary green analytical procedure  
625 index (ComplexGAPI) and software, *Green Chem.* 23 (2021) 8657–8665.  
626 <https://doi.org/10.1039/d1gc02318g>.
- 627



**Monolithic capsule phase microextraction prior to gas chromatography-mass spectrometry for the determination of organochlorine pesticides in environmental water samples**

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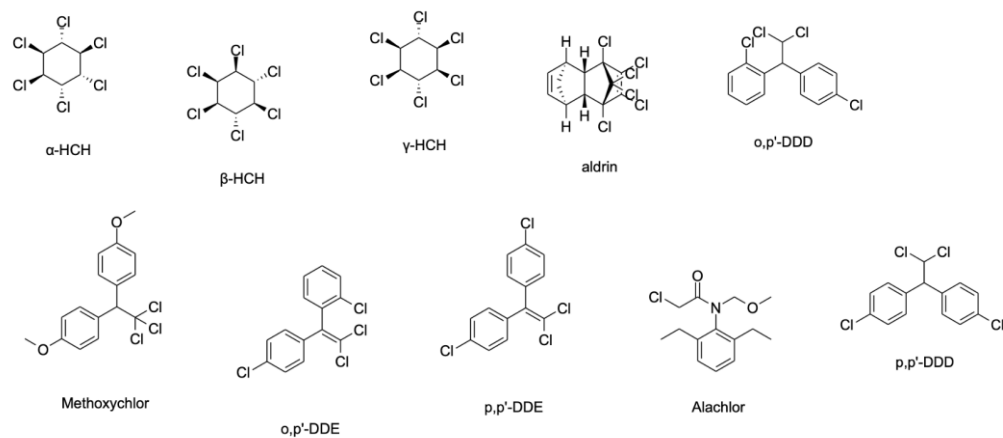
### **Preparation of the capsule phase microextraction devices**

First, Accurel® polypropylene S6/2 porous membranes were cut into 3 cm pieces. The porous capillary membranes were then cleaned with methylene chloride for 30 min under sonication and subsequently, air dried at room temperature for 30 min. A cylindrical magnet (3/4" x 1/16") was used in each of the CPME device. The magnet was inserted into an empty polypropylene capsule. Subsequently, one empty capsule and a capsule containing the magnet were fused together by the ends using an impulse heat-sealing machine. As a result, both the capsules were connected to each other by their ends. The CPME devices were then ready for the sol-gel sorbent coating process.

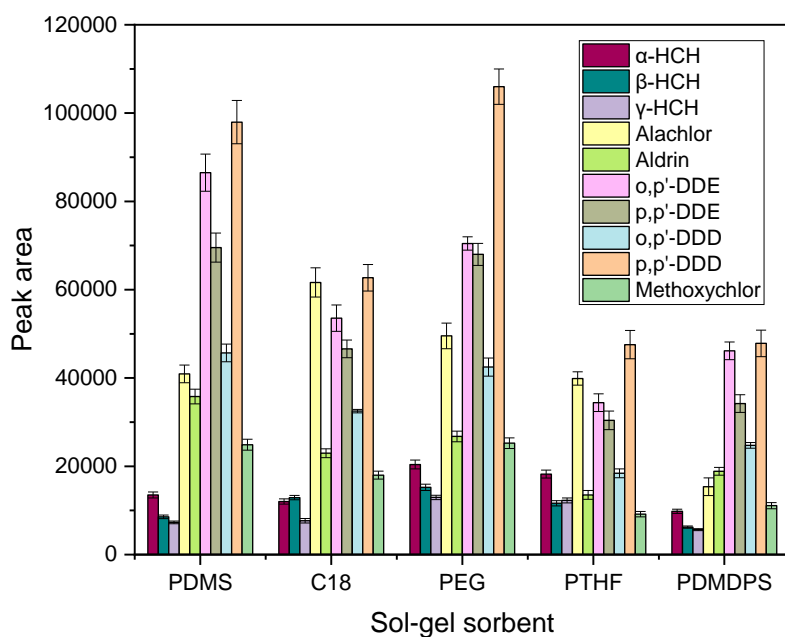
Sol solutions for in situ creation of sol-gel PDMS/sol-gel PEG 300/ sol-gel C<sub>18</sub>/sol-gel PDMDPS monolithic sorbent bed within the lumen of the empty propylene capsule were prepared by the sequential addition of tetramethyl orthosilicate (TMOS), methyl trimethoxysilane (MTMS), polymer, isopropanol, hydrochloric acid catalyst and deionized water at a molar ratio: 1: 1: 0.2: 30: 0.04: 8, respectively in a 50mL amber glass reaction container. The mixture was kept at room temperature for 12 h so that acidic hydrolysis of the sol-gel precursors moves towards completion. Subsequently, the sol solution was centrifuged and the supernant particle free fraction was transferred into a wide-mouth glass reaction vessel. Successively, NH<sub>4</sub>OH (1 M) was added to the solution in droplets at a molar ratio between TMOS and NH<sub>4</sub>OH at 1: 0.10 with continuous stirring to achieve a homogeneous mixture. The process allows creation of batch of 30 units of CPME devices at once that can be even expanded by extending the size of the reaction vessel. A batch of 30 CPME devices were submerged into the sol solution and then at the reaction vessel containing the submerged CPME devices was sonicated for 5 min to remove air bubbles from the system. The gelation of the sol solution begins with the addition of the base catalyst and the sol solution turns into solid gel in 1 h at room temperature. The sol solution formed a solid monolithic bed within the lumen of the capsules and a mesh-like network on the surface of the porous polypropylene capsules and inside the pores of its thick walls. The CPME devices were then subjected to aging and thermal conditioning at 50°C for 24 h. The CPME devices were subsequently cleaned by scrubbing the sol-gel sorbent from their outer surface and rinsing with a mixture of methanol: methylene chloride (50:50 v/v) under sonication for 30 min. The monolithic bed of the sol-gel sorbent was disintegrated into fine microparticles by



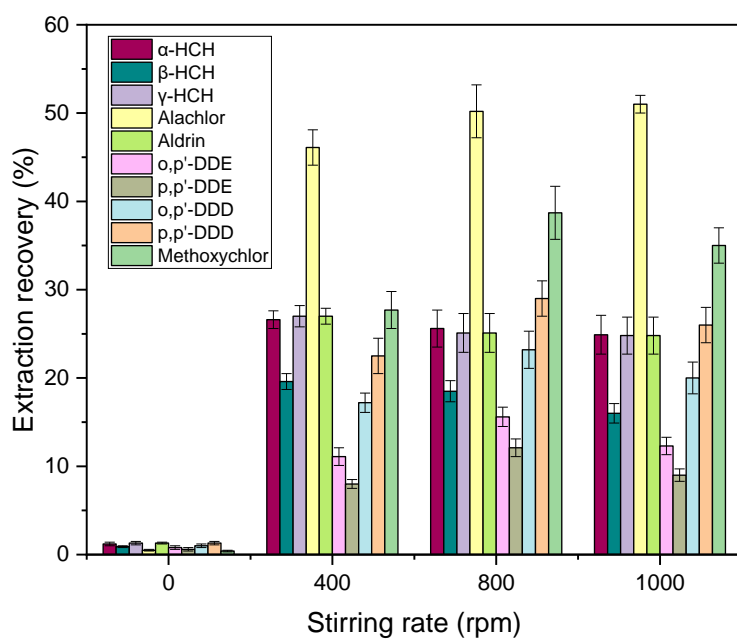
sonication. The CPME devices were then dried in an oven at 50°C. Finally, the CPME devices were ready for the analyte extraction.



**Figure S1.** Chemical structures of the target analytes

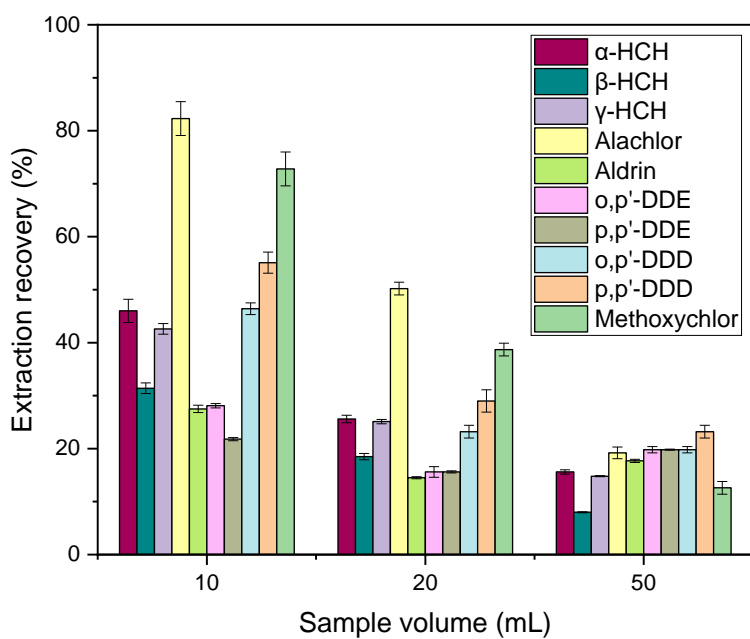


**Figure S2.** Evaluation of the effect of different monolithic sol-gel coated microextraction capsules. Sample volume: 20 mL, extraction time: 30 min, stirring rate: 800 rpm, salt content: 0% *w/v* NaCl, eluent: methanol, volume of eluent: 1000  $\mu$ L, desorption time: 5 min.

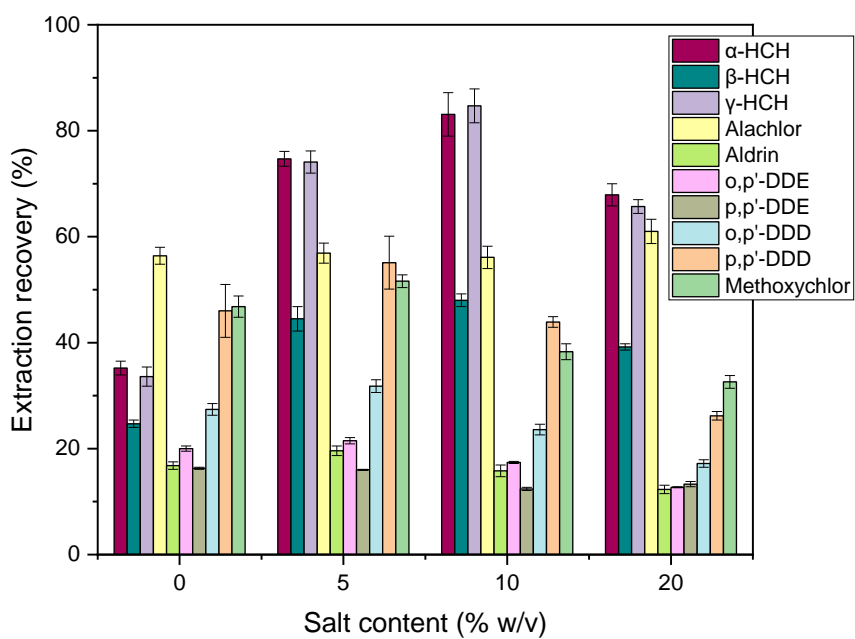


**Figure S3.** Evaluation of the effects of different stirring rates on extraction recovery. Sample volume: 20 mL, extraction time: 30 min, salt content: 0% *w/v* NaCl, eluent: acetonitrile, volume of eluent: 500  $\mu$ L, desorption time: 5 min.

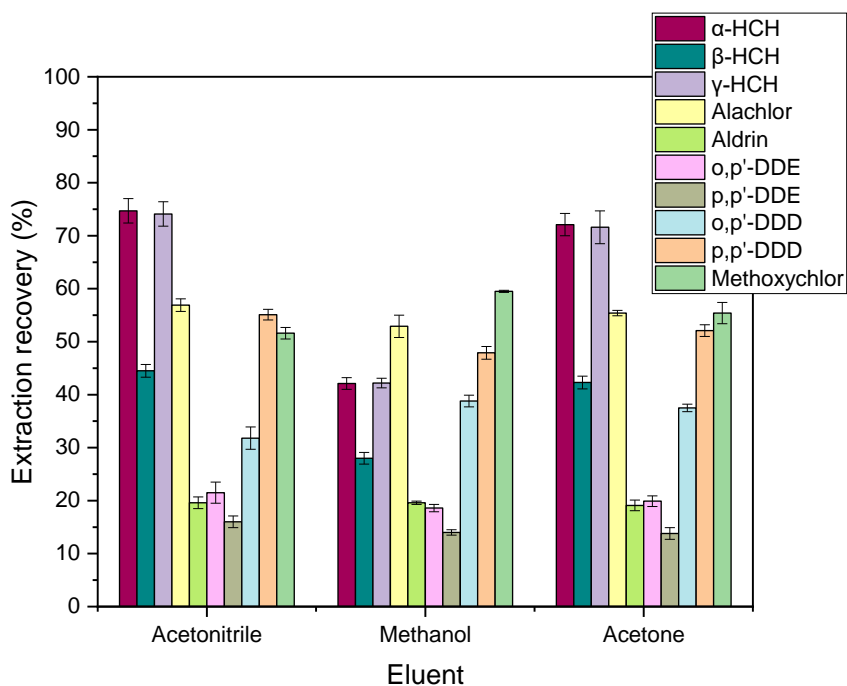




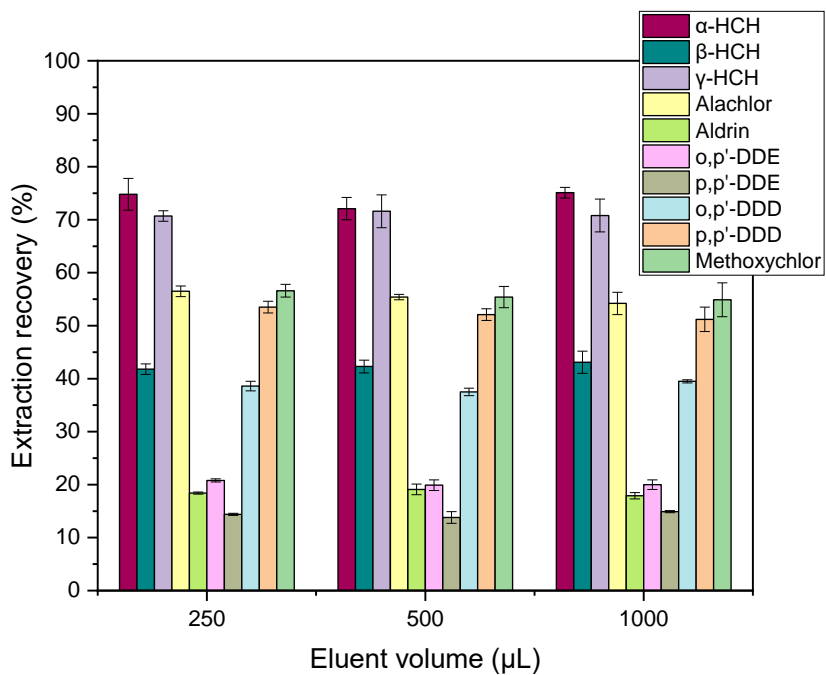
**Figure S4.** Evaluation of the effect of different sample volumes on extraction recovery. Extraction time: 30 min, salt content: 0% *w/v* NaCl, eluent: acetonitrile, stirring rate: 800 rpm, volume of eluent: 500  $\mu$ L, desorption time: 5 min.



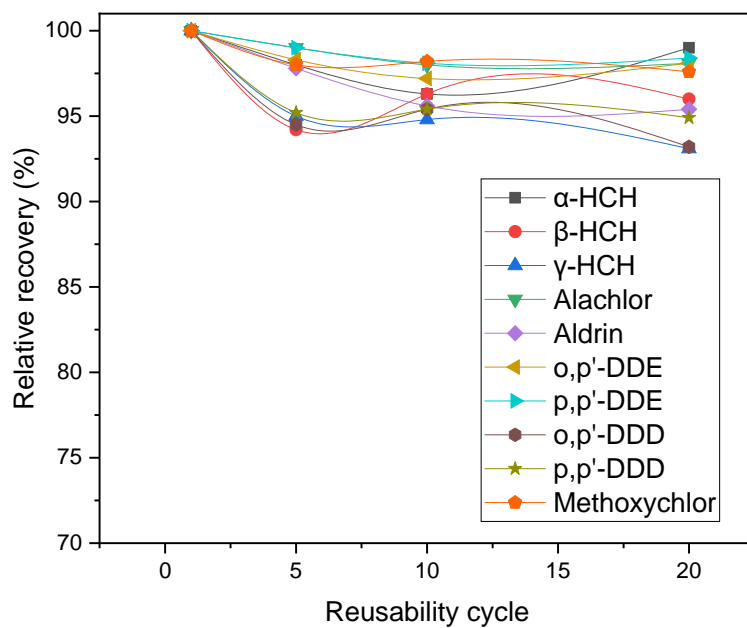
**Figure S5.** Evaluation of the effect of salt content on extraction recovery. Sample volume: 20 mL, extraction time: 50 min, eluent: acetonitrile, stirring rate: 800 rpm, volume of eluent: 500  $\mu$ L, desorption time: 5 min.



**Figure S6.** Evaluation of the effect of different eluents. Sample volume: 20 mL, salt content: 5% *w/v*, extraction time: 50 min, stirring rate: 800 rpm, volume of eluent: 500  $\mu$ L, desorption time: 5 min.



**Figure S7.** Evaluation of the effect of eluent volume on extraction yield. Sample volume: 20 mL, salt content: 5% *w/v*, extraction time: 50 min, stirring rate: 800 rpm, eluent: acetone, desorption time: 5 min.



**Figure S8.** Results of the reusability study of sol-gel PEG 300 microextraction capsules

**Table S1.** Retention times and  $m/z$  values used for the OCPs.

<b>Analyte</b>	<b>Retention time (min)</b>	<b>Target Ion (m/z)</b>	<b>Reference Ions (m/z)</b>
$\alpha$ -HCH	10.45	181	109 219
$\beta$ -HCH	11.00	181	109 219
$\gamma$ -HCH	11.80	181	109 219
Alachlor	12.46	160	146 188
Aldrin	13.46	66	91 263
o,p'-DDE	15.02	246	318 176
p,p'-DDE	15.87	246	318 176
o,p'-DDD	16.14	235	165 199
p,p'-DDD	17.11	235	165 199
Methoxychlor	19.98	227	153 212

**Table S2.** Initial parameters, interval studies and optimum/selected values for the CPME method using monolithic sol-gel PEG 300 microextraction capsules.

<b>Variable</b>	<b>Initial value</b>	<b>Interval studied</b>	<b>Optimum/selected value</b>		
<i>Adsorption step</i>					
<b>Sample amount (mL)</b>	20	10-50	<b>20</b>		
<b>Stirring rate (rpm)</b>	800	0-1200	<b>800</b>		
<b>Extraction time (min)</b>	30	10-60	<b>50</b>		
<b>Salt content (% w/v)</b>	0	0-20	<b>5</b>		
<i>Elution step</i>					
<b>Eluent<sup>1</sup></b>	ACN	ACN, ACE, MeOH	<b>ACE</b>		
<b>Volume of eluent (μL)</b>	500	250-1000	<b>250</b>		
<b>Elution time (min)</b>	5	2-20	<b>2</b>		
<sup>1</sup> ACN:	Acetonitrile,	ACE:	Acetone,	MeOH:	Methanol

