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Determination of some organic contaminants in water samples by solid-phase extraction and liquid chromatography–tandem mass spectrometry

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ABSTRACT

Independent methods for determination of organic contaminants such as pharmaceuticals and pesticides in drinking water samples, using SPE as the extraction technique and LC–MS/MS in the MRM mode with electrospray ionization, were developed and validated. Different SPE sorbents were evaluated, including lab-made fluorinated and phenyl and commercial Oasis HLB and C18, with the commercial phases being more suitable for the target compounds. Recoveries in the range of 70–120% were obtained for all target compounds, with the exception for paracetamol (acetaminophen), and precision values (inter-day and intra-day), expressed in terms of relative standard deviations (RSD), lower than 20% were obtained for all target compounds. Quantification limits were in the range of 0.006–0.208 $\mu g\ L^{-1}$ and the methods developed were successfully applied for the analysis of drinking water samples, detecting some pharmaceuticals and pesticides, but at concentration levels lower than the MRL.

1. Introduction

The presence of organic contaminants in the environment has recently become a great concern of Environmental Protection Agencies around the world, with special attention for pharmaceuticals and pesticides that are included in the so-called emerging contaminants [1–7]. These compounds are continuously introduced into the environment and are found at trace or ultra-trace concentrations ($\mu g\ L^{-1}$ or $ng\ L^{-1}$), but, even so, can affect water quality and cause a potential impact on drinking water, aquatic ecosystems and human health. Major concerns about the presence of organic contaminants in the environment involve endocrine disruptors, development of bacterial resistance to antibiotics, carcinogenic activity and the still uncertain human risks of long-term chronic exposure at trace levels [2,8–11]. The main pathways through which the pharmaceuticals and pesticides enter the aquatic environment are, respectively, effluents from domestic sewage and industrial, hospital and animal waste, and agricultural activities, with the courses of surface water and groundwater being the principal destinations, either by direct discharge or by runoff and lixiviation of the compounds [3,12–15].

In this context, to properly monitor the organic contaminants in an aquatic environment and to permit risk evaluation, effective analytical methods capable of detecting traces of these compounds in complex environmental matrices are necessary. Nowadays, liquid chromatography–tandem mass spectrometry (LC–MS/MS) has generally been used for the analysis of trace organic contaminants, such as pesticides and pharmaceuticals. Among the particularities of analyses by LC–MS/MS, electrospray ionization (ESI) is the most suitable ionization mode, as it is reliable, robust and sensitive, while the use of multiple reaction monitoring (MRM), as the analysis mode, permits confirming and quantifying the analytes and also provides low detection limits, due to the increases in signal to noise ratio [4,16–20].

Although there is much progress and other advances in the instrumental techniques, sample preparation remains one of the most important parts of the analytical process in environmental analysis. The main goals in this step are: to concentrate the analytes, to remove interferences from the matrix and to prepare the analytes in a suitable form for subsequent chromatographic analysis. Solid phase extraction (SPE) is still the most widely accepted technique for isolation, concentration and clean-up of analytes from water samples. The continuous development of novel sorbents, including the polymeric hydrophilic–lypophilic balance ones, such as Oasis HLB and Strata-X sorbents, and the polymeric mixed-mode sorbents, which are cationic/anionic exchangers, e.g., Oasis MXC, Oasis MAX, Strata-X-C and Strata-X-A, that allow the extraction of multi-residue compounds with different physical and

Abbreviations: DMMPS, Copolymer of (52–48%)dimethyl-(48–52%)methylphenylsiloxane; PMTFS, Poly(methyl-3,3,3-trifluoropropylsiloxane)

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chemical characteristics and different polarities, has made this technique a preferred one over many years. Moreover, in the case of water sample analyses, the concentration capacity of this technique is another fundamental aspect for its wide use [4,18,21–25].

In the present study, we have investigated the potential use of lab-made fluorinated and phenyl sorbents, prepared by immobilizing siloxane polymers onto silica supports, which present differential interaction characteristics derived from the C–F bonds and the capability of forming π–π bonds, respectively [26,27], comparing them with the commercial polymeric Oasis HLB and traditional reversed-phase C18 sorbents, for the solid-phase extraction of the proposed compounds. Independent methodologies for the determination of pharmaceuticals and pesticides in water samples using SPE as the extraction technique and LC–MS/MS analysis, with electrospray ionization and triple quadrupole in MRM mode detection, were developed, validated and applied for analyses of drinking water samples from five regions of Campinas/SP/Brazil, supplied from different water treatment plants (WTP).

2. Materials and methods

2.1. Materials

The pharmaceutical standards atenolol, acetaminophen (paracetamol), chloramphenicol, clofibric acid, diazepam, diclofenac sodium salt and ibuprofen were purchased from Sigma-Aldrich (St Louis, MO, USA) and propranolol was purchased from Sanofi (São Paulo, SP, Brazil). The pesticide standards atrazine, diuron, carbaryl and simazine were purchased from Chem Service (West Chester, PA, USA), carbendazim, carbofuran, linuron and chlorpyrifos were purchased from Pestanal (Germany) and bentazone was purchased from BASF (Ludwigshafen, Germany). All reference standards presented purity higher than 98%. The pesticide classes and pharmaceutical therapeutic groups are presented in Table 1.

Stock standard solutions of individual compounds (1000 mg L^{-1} for all compounds, with the exception of carbendazim and simazine, 200 mg L^{-1}) were prepared in methanol and stored at −18 °C in the dark. Working standard mixture solutions were prepared by appropriate dilution of the stock solutions in methanol.

Methanol, acetonitrile and ethyl acetate (HPLC-grade), dichloromethane and chloroform (ACS) were purchased from Tedia (Rio de Janeiro, Brazil). Ultrapure water was obtained from a Milli-Q Plus system from Millipore (Bedford, MA, USA). Formic acid, used in the mobile phase, and phosphate buffers salts, used in the extraction procedure, were purchased from Synth (Diadema, SP, Brazil).

Sílica gel, irregular 35–70 μm with 60 nm pore size was supplied by Acros Organics (Geel, Belgium). The copolymer (52–48%)dimethyl-(48–52%)methylphenyl-siloxane (DMMPS), viscosity: 125 cSt, was obtained from Aldrich and poly(methyl-3,3,3-trifluoropropylsiloxane) (PMTFS), viscosity: 1000 cSt, was obtained from Gelest (Morrisville, PA, USA). Commercial cartridges used for SPE were Oasis HLB (60 mg)

Table 1
Selected ion transitions and instrumental parameters for the compounds under study.

Compounds	Therapeutic group or Class	ESI mode	t_R (min)	SRM transition (m/z)[a]	Cone voltage (V)	Collision energy (eV)
Pharmaceuticals						
Atenolol (ATN)	β-blocker	+	1.7	267.25→144.6	31	26
				267.25→189.8		18
Paracetamol (PCT)	Analgesic/Antiinflammatory	+	2.5	152.05→109.5	29	17
				152.05→92.1		22
Propranolol (PPN)	β-blocker	+	4.3	260.31→115.6	31	18
				260.31→182.8		18
Chloramphenicol (CFC)	Antibiotics	_	5.3	321.14→151.6	25	17
				321.14→256.9		12
Clofibric acid (CFB)	Lipid regulator	_	11.6	213.40→126.5	20	10
				213.40→84.2		8
Diazepam (DZP)	Psychiatric drug	+	11.7	285.21→153.7	38	25
				285.21→192.9		32
Diclofenac (DFC)	Analgesic/Antiinflammatory	+	13.5	296.13→214.8	21	18
				296.13→249.9		12
Ibuprofen (IBF)	Analgesic/Antiinflammatory	_	14.0	205.19→160.8	16	8
Pesticides						
Carbendazim (CBD)	Fungicide	+	5.1	192.16→159.7	25	15
				192.16→131.6		30
Carbofuran (CBF)	Insecticide/Acaricide	+	12.4	222.27→164.8	19	11
				222.27→122.6		20
Simazine (SMZ)	Herbicide	+	12.6	202.17→131.6	35	18
				202.17→123.6		18
Carbaryl (CBR)	Insecticide	+	12.7	202.17→144.6	17	7
				202.17→126.5		27
Bentazone (BTZ)	Herbicide	-	13.1	239.2→131.8	37	25
				239.2→196.8		17
Atrazine (ATZ)	Herbicide	+	13.3	216.19→173.8	32	16
				216.19→103.3		29
Diuron m(DUR)	Herbicide	+	13.5	233.10→71.0	24	17
				233.10→159.7		27
Linuron (LNR)	Herbicide	+	14.1	249.17→159.7	26	15
				249.17→181.8		13
Chlorpyrifos (CPF)	Insecticide/Formicide/Acaricide	+	21.6	352.05→199.8	22	19
				352.05→124.5		18

Ibuprofen showed poor fragmentation and only one transition could be monitored, so the confirmation was performed by comparing the retention time in the samples with the one in standard solutions.

[a] The first transition of each compound was used for quantification and the second one for confirmation purposes.

from Waters (Milford, MA, USA) and Supelclean LC-18 (500 mg) from Supelco (Bellefonte, PA, USA).

The solid-phase extraction methods were optimized using Bonafont bottled water purchased from Danone Ltda. (Fazenda 7 de abril, Alto Alegre, Jacutinga, MG, Brazil).

2.2. Preparation and characterization of SPE sorbents

The preparation and the physical–chemical characterization of the sorbents will be briefly described below, since a complete description has already been published by our research group [26,27], where stationary phases were prepared with the same polymers.

The sorbents were prepared with a 50% loading of the polymers. To load the polymer into the silica pore system, a 10% (w/v) solution of each polymer in dichloromethane was added to the appropriate quantity of silica, previously dried at 140 °C for 12 h. This mixture was slowly stirred at room temperature for 3 h, and then placed in a fume hood for evaporation of the dichloromethane at room temperature (6 day).

Each of the materials was placed in stainless steel tubes (150 mm × 10 mm) and thermally immobilized in a model EDG 10P FT-20 tubular oven under a nitrogen atmosphere. The thermal immobilization conditions were: heating at 220 °C for 10 h for the PMTFS, and heating at 140 °C for 4.5 h for the DMMPS. Following this, the stainless steel tube containing the sorbent was connected to a Waters 510 pump (Milford, MA, USA) for extraction of non-immobilized polymer by passing dichloromethane at 0.5 mL min^{-1} for 4 h for the PMTFS, and by passing chloroform at 1.0 mL min^{-1} for 2 h, followed by methanol at 1.0 mL min^{-1} for 2 h for the DMMPS.

The SPE cartridges were prepared by dry-packing 500 mg of sorbent into 3 mL poly(propylene) syringes, retaining it with two polyethylene frits (20 μm pore size). The physical–chemical characterization was carried out by elemental analysis and by solid-state ^{29}Si nuclear magnetic resonance measurements (^{29}Si NMR).

2.3. Sample preparation

Several procedures were evaluated during the optimization of the extraction method. For this the following variables were investigated: type of sorbent, sample volume, pH and elution conditions. These early experiments were carried out following a generic procedure: conditioning the sorbent with methanol (MeOH) and after with Milli-Q water. Then a water sample, spiked with a mixed working solution to give a final concentration of 3 × IQL (instrumental quantification limit) of each compound, was passed through the cartridge, using a SPE vacuum manifold (Supelco). After drying for 30 min the elution step was carried out. The solvent was evaporated under gentle stream of nitrogen and the extract was reconstituted with 400 μL of methanol.

2.3.1. Pharmaceuticals recommended SPE procedure

Oasis HLB cartridges were conditioned with 3 mL of MeOH and 3 mL of Milli-Q water. Then 240 mL of water samples, spiked with a mixed solution of pharmaceuticals, were passed through the cartridges followed by vacuum drying for 30 min. The cartridges were eluted with 5 × 3 mL of MeOH, the solvent was then evaporated and the extract was reconstituted with 400 μL of methanol.

2.3.2. Pesticides recommended SPE procedure

C18 cartridges were conditioned with 3 mL of MeOH and 3 mL of Milli-Q water (acidified with 0.1% formic acid). Then 140 mL of water samples, spiked with a mixed solution of pesticides, (acidified with 0.1% formic acid) were passed through the cartridges followed by vacuum drying for 30 min. The cartridges were eluted with 3 × 3 mL of ethyl acetate and 1 × 3 mL of MeOH, the solvents were then evaporated and the extract was reconstituted with 400 μL of methanol.

2.4. Liquid chromatography

HPLC analyses were carried out using an Alliance 2695 system (Waters, Milford, MA, USA). Chromatographic separation was performed using a 3.5 μm XTerra® MS C18 column (100 mm × 3 mm i.d.) from Waters at a flow rate of 0.3 mL min^{-1}. The column was kept at 25 ± 2 °C and the sample injection volume was 7 μL. The mobile phase was (A) H_2O (acidified with 0.1% formic acid) and (B) MeOH:H_2O (90:10 v/v). Gradient elution was used for both methodologies, and the organic solvent ((MeOH:H_2O (90:10 v/v)) percentage was changed linearly as follows: (i) pharmaceuticals: 0 min, 50%; 4 min, 50%; 6 min, 90%; 15 min, 90%; 18 min, 50%; 25 min, 50%; and (ii) pesticides: 0 min, 20%; 5 min, 20%; 7 min, 85%; 10 min, 90%; 23 min, 90%; 26 min, 20%; 31 min, 20%.

2.5. Mass spectrometry

A Waters Micromass Quattro Micro™ API triple quadrupole mass spectrometer, equipped with a Z-spray ESI interface operating in both positive and negative mode (Manchester, UK), was used.

MS/MS parameters for the analysis were as follow: (i) pharmaceuticals: capillary voltage, 2.0 kV; extractor voltage, 2.0 V; source temperature, 130 °C and desolvation gas temperature, 500 °C. The cone gas and desolvation gas (both nitrogen) flow-rates were set at 50 and 400 L h^{-1}, respectively; and (ii) pesticides: capillary voltage, 2.0 kV; extractor voltage, 2.0 V; source temperature, 130 °C and desolvation gas temperature, 500 °C. The cone gas and desolvation gas (both nitrogen) flow-rates were set at 70 and 800 L h^{-1}, respectively. Argon (99.8%) from Air Liquide (Rio de Janeiro, Brazil) was used as the collision gas at a constant pressure of 2.45×10^{-3} mbar. For instrument control, data acquisition and processing, MassLynx and QuanLynx software version 4.1 (Waters) were used.

The mass spectrometer was operated in MS/MS mode using multiple reaction monitoring (MRM). Table 1 summarizes the acquisition window definition, precursor and product ions, and the mass spectrometry parameters selected.

2.6. Validation study

The methods developed were validated according to the European SANCO guideline [28]. Linearity was studied using matrix-matched calibration by analyzing water samples at five concentration levels, between 7.0 and 625 μg L^{-1} and between 1.4 and 150 μg L^{-1}, for the pharmaceuticals and pesticides, respectively. Method accuracy, estimated by means of recovery, and precision (intra-day and inter-day), expressed in terms of relative standard deviations (RSD), were evaluated at two concentration/spiked levels (MQL and 3 × MQL for each compound) (MQL is the method quantification limit), analyzing five replicates at each concentration. The inter-day precision was evaluated on two consecutive days. Instrumental quantification limits (IQL) were estimated based on the resulting areas and RSD from injections of the compounds in a concentration range from 1 to 100 μg L^{-1}. The estimated values were defined and/or confirmed after extraction procedures at these concentration levels, when satisfactory recoveries and precision values were obtained.

2.7. Analysis of samples

Drinking water samples from five regions of Campinas/SP, supplied from different water treatment plants (WTP), were analyzed by the proposed methods. The WTP of Campinas are named as: WTP 1 and 2, supplied by the Atibaia River (2 samples collected in 2 different regions inside this area); WTP 3 and 4, also supplied by the Atibaia River (2 samples collected in 2 different regions inside this area) and WTP 5, supplied by the Capivari River (1 sample colleted inside this area).

3. Results and discussion

3.1. Characterization of the lab-made sorbents

The sorbents were prepared by deposition of PMTFS or DMMPS onto silica particles at a 50% (w/w) polymer loadings, and resulted in carbon percents of 9 and 7% respectively. The RSD of the percent polymer coating was 1% for the fluorinated and 6% for the phenyl sorbents. The carbon percent confirms that the immobilization of the polymer onto the chromatographic support occurred and the low values of RSD confirm the repeatability of the preparation procedure of the sorbents. The ^{29}Si NMR spectra of the prepared sorbents, Fig. S1 (see supplementary data), show that the quantity of residual silanol groups was reduced after the thermal immobilization, since Q^2 and Q^3 species decreased when compared with the spectrum of pure silica, indicating that some of the silanol groups have reacted with the adsorbed polysiloxane and that the polymer chains are both physically adsorbed ($D^{2''}$ and D^2_H) and chemically bonded (D^1_H and $D^{2'}$) to the chromatographic support.

3.2. Solid-phase extraction

A detailed study was carried out on the most relevant parameters – type of sorbent, pH of the sample and elution conditions – that affect the recovery of the target compounds. Initial tests were carried out as screening tests, and after that more specific experiments were carried out to reach satisfactory recovery and precision values for the set target compounds.

3.2.1. Pharmaceuticals

Preliminary tests to evaluate the elution solvents as well as elution solvent volume were carried out. For this, two commercial sorbents, Oasis HLB and C18, a polymeric and a non-polar one, respectively, water samples acidified with 0.1% formic acid and 3 elution solvents, methanol, ethyl acetate and acetonitrile (elution volumes of 5×1 mL), were used. These tests, based on recovery values, showed that the polar solvents are more adequate than the non-polar one, and between methanol and acetonitrile, methanol presented better selectivity. Further tests showed that an increase of the methanol volume (3×3 mL and 5×3 mL) also resulted in an increase of the recovery values, principally with the Oasis HLB sorbents. Having established the volume and the elution solvent (5×3 mL of methanol), all proposed sorbents, commercial and lab-made phenyl and fluorinated, were tested under two pH conditions, pH=2.7 (acidified with 0.1% formic acid) and pH=6.4 (without additives), as a strategy to reach satisfactory recovery values for the target pharmaceuticals. In Fig. 1 the performance of the sorbents tested are summarized. As it can be observed in Fig. 1a, in an acidic condition, atenolol and paracetamol were poorly recovered with all evaluated sorbents, and propranolol and chloramphenicol presented the same behavior when phenyl and fluorinated

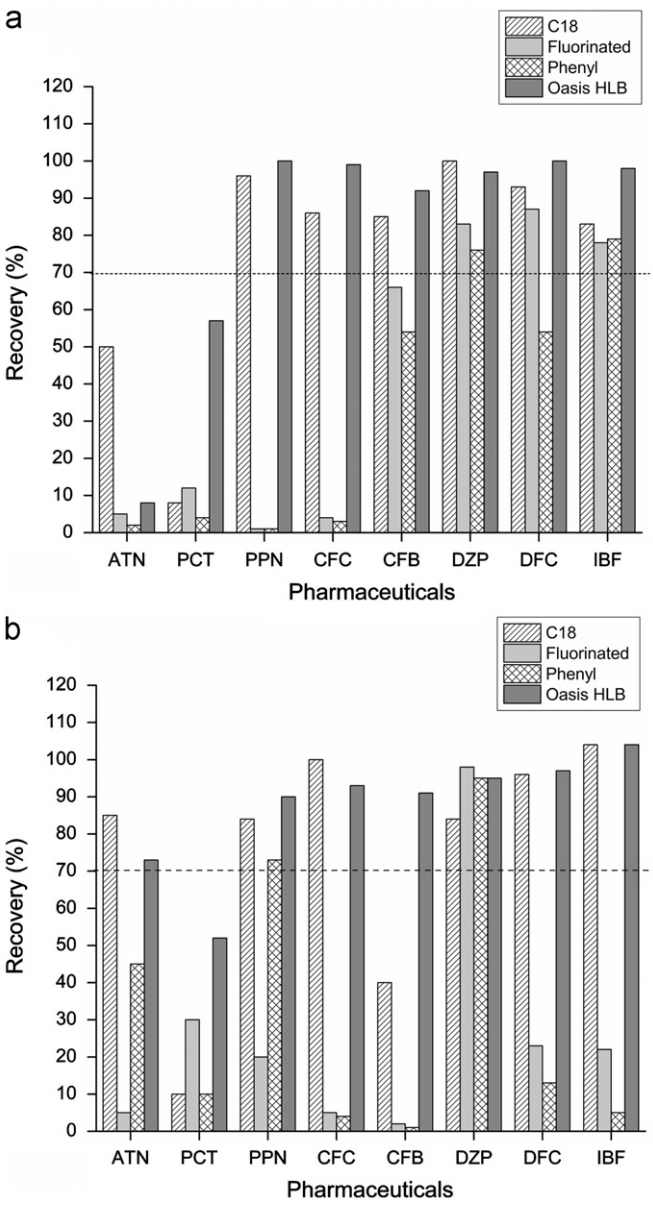

Fig. 1. Performance of the commercial C18 and Oasis HLB and the lab-made phenyl and fluorinated sorbents in terms of recovery values ($n=2$) for pharmaceuticals, under different pH conditions: (a) pH=2.7 (acidified with 0.1% formic acid) and (b) pH=6.4 (without additives).

sorbents were used. When a water sample without additives was used, as shown in Fig. 1b, most compounds were poorly recovered with the prepared sorbents. These results show that neither pH condition tested would extract the target pharmaceuticals in a single experiment, due to the different interaction characteristics of these compounds with the sorbents. In both pH conditions evaluated, C18 provided good results for the majority of compounds, but in comparison to Oasis HLB, the latter was more efficient, yielding higher recoveries with emphasis for atenolol. This sorbent, with the combination of the hydrophilic–lipophilic polymer, can extract acidic, neutral and basic analytes over a wide range of pH, including neutral pH.

Further experiments were carried out in order to increase the recovery values of paracetamol. For this, Oasis HLB sorbents with methanol (5×3 mL) as elution solvent were chosen based on the preliminary tests results, and a wider range of sample pH was evaluated: pH=4.0 (acidified with formic acid), pH=6.4 (without

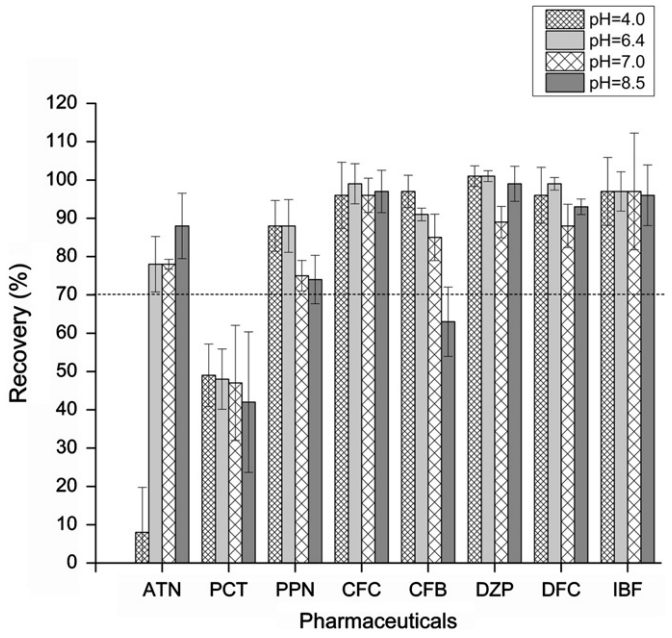

Fig. 2. Performance of Oasis HLB sorbents in terms of recovery values ($n=3$) and precision (RSD) for pharmaceuticals under different pH conditions: pH=2.7 (acidified with 0.1% formic acid), pH=6.4 (without additives), pH=7.0 and pH=8.5 (adding 1% of 100 mmol phosphate buffers previously adjusted to pH=7.0 and 8.5, respectively).

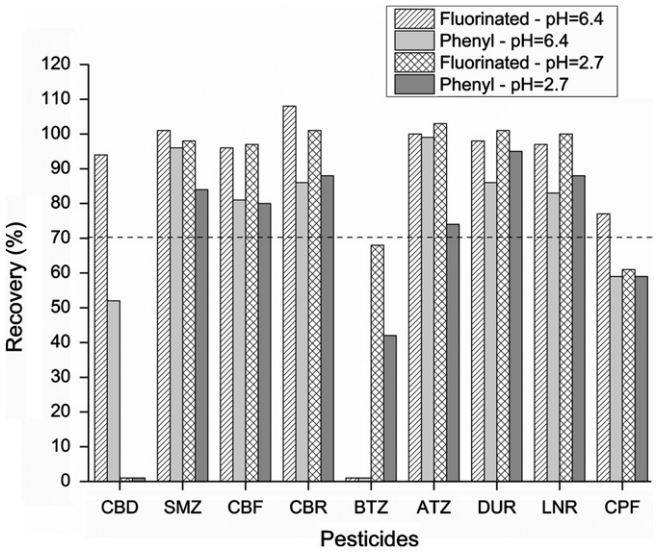

Fig. 3. Performance of lab-made phenyl and fluorinated sorbents in terms of recovery values ($n=2$) for pesticides under different pH conditions: pH=2.7 (acidified with 0.1% formic acid), pH=6.4 (without additives).

additives), pH=7.0 and pH=8.5, which were obtained by the addition of 1% of 100 mmol phosphate buffers previously adjusted to pH=7.0 and 8.5, respectively. The recovery and precision values are shown in Fig. 2. These results show that the pH variation practicably did not affect paracetamol recoveries, but has a fundamental role on atenolol recoveries and also influences propranolol and clofibric acid recoveries, which can or cannot be recovered depending on the pH. Based on these results, it is possible to conclude that the best pH condition for extraction of the set of target pharmaceuticals was pH=6.4, i.e., water samples without any pH adjustment. Although the paracetamol recovery values were below 70%, the low RSD values permit a reliable quantification.

3.2.2. Pesticides

The same criteria described above were used during the optimization of the extraction conditions for the target pesticides. Preliminary tests were carried out to evaluate the performance of two elution solvents, ethyl acetate and methanol, using C18 and lab-made phenyl and fluorinated sorbents, and water samples acidified with 0.1% formic acid (pH=2.7). These experiments indicated that both solvents had potential to elute most of the compounds with satisfactory recovery values when C18 sorbents were used, with methanol being more effective for elution of polar compounds with higher recovery values, while ethyl acetate was better for the non-polar ones. For the lab-made sorbents, both solvents presented potential, but for some compounds satisfactory recovery values were not obtained, although ethyl acetate was somewhat better. Following this, the performances of the phenyl and fluorinated sorbents were evaluated, using ethyl acetate as the elution solvent (5×1 mL) and water samples in two pH conditions, pH=2.7 (acidified with 0.1% formic acid) and pH=6.4 (without additives). The results are shown in Fig. 3 and, based on these results, it is possible to conclude that, in general, most compounds were recovered using both evaluated conditions, with the exception of carbendazim, bentazone and chlorpirifos. In the case of carbendazim and bentazone, it is possible to verify that an inversion of retention occurs depending on the pH of the water sample. Carbendazim was recovered with values up to 70% with the fluorinated sorbent in unmodified pH conditions, but bentazone was only recovered when acidic conditions were used, and also presented better recovery results with the fluorinated sorbent. This fact can be explained based on the characteristics of the prepared materials, suggesting that carbendazim interacts with the sorbents by an ion exchange mechanism and so is recovered at neutral conditions, and bentazone interacts with the sorbents by a reverse phase mechanism and is recovered when acidic conditions are used. Overall, the fluorinated sorbent presented a better performance than the phenyl one, however, the target pesticides could not be recovered with a single experiment, so further tests to increase the recovery values with these sorbents were not carried out.

New experiments were realized using C18 sorbents in order to increase the recovery values obtained in the preliminary tests. For this, water samples acidified with 0.1% formic acid were used and the elution volumes (methanol and ethyl acetate) as well as a combination of these solvents were evaluated. The recovery and precision values are shown in Fig. 4. These results show that a single elution solvent is quite satisfactory to recover all compounds, however the combination of two solvents, one more polar than the other, can promote satisfactory recovery and precision values for the target pesticides. Thus, the selected elution condition for method validation was 3×3 mL of ethyl acetate $+ 1 \times 3$ mL of methanol, since similar results were obtained when compared with the procedure that used larger solvent volumes.

3.3. Method validation

The methods developed were validated in terms of selectivity, linearity, trueness, precision and limits of quantification. Table 2 summarizes the method validation data.

Matrix-matched calibration at five concentration levels (0.7, 1, 2, 3 and $5 \times$ IQL), in a range of 7.0–625 $\mu g\ L^{-1}$ and 1.4–150 $\mu g\ L^{-1}$ for the pharmaceuticals and pesticides, respectively, were used to determine method linearity. As shown in Table 2, the methods developed present good linearity for all the selected compounds

with correlation coefficients higher than 0.99 for the target compounds and deviations of the individual points from the calibration curve lower than 20%.

The QL values were defined for the instrument (IQL) and for the method (MQL) and are shown in Table 2. The MQL were obtained for 600 and 350 times concentration for the pharmaceuticals and pesticides, respectively. Both methods were developed in order to be able to quantify the target compounds at concentration levels equal to or lower than the maximum residue limits (MRL) established by the European Union for pesticides in drinking water (0.1 μg L^{-1}) [29], since there is no legislation that establishes the MRL for pharmaceuticals in water samples. Based on this, a higher concentration level for the pharmaceuticals was necessary due to their lower detectabilities. MQL for all pesticides were lower than the MRL and, for the pharmaceuticals, only the ibuprofen MQL was higher than 0.1 μg L^{-1}.

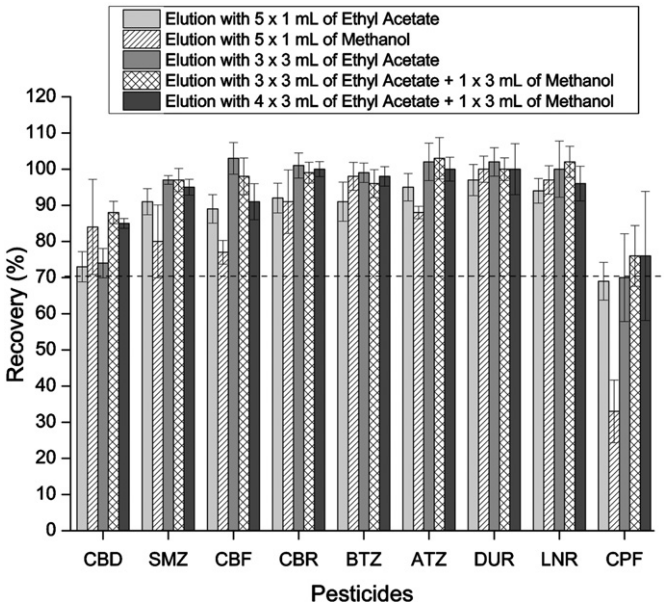

Fig. 4. Performance of C18 sorbents in terms of recovery values ($n=3$) and precision (RSD) for pesticides, at pH=2.7 (acidified with 0.1% formic acid) with single elution volumes (methanol or ethyl acetate) and with a combination of solvents.

Trueness was estimated through recovery studies at two concentration levels (MQL and 3 × MQL of each compound) and the results obtained are shown in Table 2. Satisfactory recoveries, in the range of 70–120%, were obtained for all pesticides and also for all pharmaceuticals, with the exception for paracetamol, at both concentration levels evaluated.

Precision was calculated in terms of intra-day and inter-day precision and expressed in terms of RSD. The results are presented in Table 2, and show that RSD values were lower than 20% for all compounds under study. Based on these results, even though paracetamol presented recoveries lower than 70%, a reliable quantification can be carried out.

Finally, the selectivity of the method was evaluated comparing chromatograms obtained from the injection of blank samples and fortified blank samples. The absence of any chromatographic peak, at the same retention time as target compounds, indicated there were no matrix compounds that can affect the quantification.

3.4. Analysis of real samples

The SPE-LC–MS/MS methods developed were applied for the determination for the 17 organic contaminants in drinking water samples collected from different WTP of Campinas/SP. In most water samples analyzed, pharmaceuticals such as atenolol, paracetamol, diazepam and ibuprofen, and the pesticides carbofuran and diuron were detected, but at concentration levels lower than the QL. Moreover, atrazine was determined in the following concentration range, 0.0093–0.081 μg L^{-1}, but even so, at concentration levels lower than the MRL established for pesticides in drinking water.

Table 2
Performance and validation data of the analytical methods developed.

Compounds	Concentration range (μg L^{-1})	Linearity (r)	IQL (μg L^{-1})	MQL[a,b] (μg L^{-1})	Recovery (%)[c]		Inter-day[c] precision (%RSD)	
					F1	F2	F1	F2
Pharmaceuticals								
Atenolol (ATN)	42–300	0.9987	60	0.10	84 (5)[c,d]	81 (7)	8	8
Paracetamol (PCT)	28–200	0.9945	40	0.067	47 (14)	55 (12)	14	14
Propranolol (PPN)	7–50	0.9995	10	0.017	83 (2)	85 (8)	6	7
Chloramphenicol (CFC)	35–250	0.9974	50	0.083	90 (4)	111 (5)	7	5
Clofibric Acid (CFB)	35–250	0.9992	50	0.083	102 (6)	96 (2)	6	6
Diazepam (DZP)	7–50	0.9973	10	0.017	106 (3)	97 (2)	5	5
Diclofenac (DFC)	21–150	0.9970	30	0.050	103 (4)	96 (3)	6	6
Ibuprofen (IBF)	87.5–625	0.9941	125	0.208	84 (8)	98 (6)	8	7
Pesticides								
Carbendazim (CBD)	7–50	0.9995	10	0.028	72 (4)	81 (7)	5	7
Simazine (SMZ)	3.5–25	0.9977	5	0.014	95 (6)	103 (6)	5	5
Carbofuran (CBF)	7–50	0.9998	10	0.028	99 (4)	101 (4)	4	6
Carbaryl (CBR)	10.5–75	0.9978	15	0.043	90 (5)	94 (7)	6	6
Bentazone (BTZ)	7–50	0.9992	10	0.028	96 (5)	103 (4)	5	5
Atrazine (ATZ)	1.4–10	0.9956	2	0.006	88 (6)	93 (6)	9	8
Diuron (DUR)	10.5–75	0.9974	15	0.043	89 (6)	97 (7)	6	5
Linuron (LNR)	14–100	0.9932	20	0.057	97 (6)	102 (2)	6	3
Chlorpyrifos (CPF)	21–150	0.9991	30	0.086	71 (8)	82 (9)	8	9

F1: MQL; F2: 3 × MQL.

[a] after 600 times concentration for pharmaceuticals.

[b] after 350 times concentration for pesticides.

[c] Recovery and precision values (intra and inter-day) values obtained analyzing five replicates at each concentration ($n=5$).

[d] Intra-day values expressed as RSD are given in parentheses.

4. Conclusion

The methods developed based on SPE-LC–MS/MS allowed the accurate determination of 17 organic contaminants in drinking water at low concentration levels (0.006–0.208 $\mu g\ L^{-1}$). Recoveries (in the range of 70–120%) and precision values ($\leq 20\%$) were obtained for all target compounds with the exception for paracetamol, which presented recoveries in the range of 50%, but with RSD values lower than 15% and so does not compromise its quantification.

The lab-made phenyl and fluorinated sorbents were not able to extract the target pharmaceuticals or pesticides with satisfactory recoveries. This fact can be related to the characteristics of these materials, ion exchange and hydrophobic characteristics, and to the characteristics of the proposed compounds, which are from a wide range of polarities and, depending on the sample pH, they can or cannot be retained by the sorbents. However, these sorbents have potential to extract specific classes of pesticides and/or pharmaceuticals and even single compounds. Comparing the lab-made sorbents, the fluorinated one presented a greater potential to be used in these types of analyses. On the other hand, commercial Oasis HLB and C18 sorbents were suitable to extract the desired pharmaceuticals and pesticides, respectively.

In most drinking water samples analyzed some pesticides and pharmaceuticals were determined, but at concentration levels lower than the MRL.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.talanta.2012.08.006.

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