



# Determination of Personal Care Products in Fish Tissue Based on Matrix Solid-Phase Dispersion Combined with Programmable Split/Splitless Injector Gas Chromatography-Mass Spectrometry

Iran Ocaña-Rios<sup>1</sup> · Araceli Peña-Alvarez<sup>1</sup> · Elena Loeza-Fuentes<sup>2</sup> · Ignacio Zuñiga-Perez<sup>3</sup>

Received: 26 September 2017 / Accepted: 20 February 2018 / Published online: 6 March 2018  
© Springer Science+Business Media, LLC, part of Springer Nature 2018

## Abstract

An analytical method was developed and validated for the simultaneous determination in fish muscle of two kinds of emerging pollutants: polycyclic aromatic musks (galaxolide and tonalide) and UV filters [oxybenzone, 3-(4-methylbenzylidene) camphor, padimate-O, 2-ethylhexyl 4-methoxycinnamate, octocrylene], which are very common ingredients of personal care products, by programmable split/splitless injector gas chromatography-mass spectrometry (PSSI-GC-MS) using a matrix solid-phase dispersion (MSPD) for extraction and clean-up procedure in a single step. The method was evaluated for precision (relative standard deviation < 19%), linearity ( $r^2 > 0.9829$ ); accuracy, reported as % of recovery; limit of quantification (0.013 to 0.040  $\mu\text{g g}^{-1}$ , referred to dry mass); and limit of detection (0.004 to 0.012  $\mu\text{g g}^{-1}$ , referred to dry mass) for each of the analytes. The average recoveries in muscle samples spiked at two levels: 0.1  $\mu\text{g g}^{-1}$  and 1.0  $\mu\text{g g}^{-1}$  ranged between 77–111% and 55–108%, respectively. The method was applied for the determination of the mentioned pollutants in an exposure in vivo study with rainbow trout, and the results showed a larger absorption of musks (tonalide 43.0  $\mu\text{g g}^{-1}$ ) than UV filters (padimate-O, 1.0  $\mu\text{g g}^{-1}$ ). The proposed procedure has demonstrated to be able for simultaneous monitoring of these two different kinds of common emerging pollutants coming from personal care products, which would make it a useful tool for quality control and safety studies.

**Keywords** Musks · UV filters · PCPs · Fish muscle · MSPD · PSSI-GC-MS

## Introduction

In the last few decades, contamination impact in food has been focused on regulated contaminants such as metals, pesticides, and polycyclic aromatic hydrocarbons (PAHs). However, many other chemical compounds have been continuously released into the environment due to human activity; they come from several branches of industry and scientific research, and are closely related to lifestyle, such as household chemicals, pharmaceutical products, and personal

care products. All these non-regulated pollutants have been called emerging contaminants and could cause toxicity to human being as the regulated contaminants (Gros et al. 2008; Hansen 2007). Among the emerging contaminants, there are two kinds of compounds that are common ingredients of personal care products (PCPs) such as polycyclic aromatic musks and UV filters (Kümmerer 2011).

Polycyclic aromatic musks are frequently used for manufacture of perfumes, lotions, soaps, creams, and detergents because of their ability to improve fragrance fixation. Its use has increased in the last few years as substitutes for nitro musks, which are more toxic compounds than polycyclic aromatic musks (Dietrich and Hitzfeld 2004; Van Der Burg et al. 2008). In a cellular model, musks enhance the genotoxic effect of PAHs and increase susceptibility of humans to the health hazards of PAHs (Mersch-Sundermann et al. 2001). Polycyclic musks also inhibit multixenobiotic defense in aquatic organisms (Smital et al. 2004). UV filters are organic compounds commonly used in personal care products for protection against sun exposure to prevent skin

✉ Araceli Peña-Alvarez  
arpeal@unam.mx

<sup>1</sup> Facultad de Química, Departamento de Química Analítica, Universidad Nacional Autónoma de México, Ciudad de México, Mexico

<sup>2</sup> Facultad de Medicina, Veterinaria y Zootecnia, Departamento de Abejas, Conejos y Organismos Acuáticos, Universidad Nacional Autónoma de México, Ciudad de México, Mexico

<sup>3</sup> Perkin Elmer de México S. A, Ciudad de México, Mexico

cancer, and its use has increased in a great variety of products: shampoos, creams, cosmetics, lotions, etc. (Barber 2014; Birkholz et al. 2014). Musks and UV filters are both endocrine disruptors that enter into the aquatic environment because of human activity and can affect the safety of the food consumed by the humans with a potential impact on their health, this make necessary monitoring its incidence in biological and environmental samples (Fent et al. 2010; Rimkus 1999).

In recent years, there is a growing concern for evaluating the exposure to emerging contaminants and determine the potential adverse effects for humans that may result from food consumption containing contaminants. The contaminants can bioaccumulate, being stored faster than they are metabolized or excreted, leading to trophic magnification in aquatic organisms like fish due to its lipophilic character and, consequently, these contaminants enter into contact with humans by the consumption of contaminated fish. UV filters and musks have been already detected at  $\text{ng g}^{-1}$  levels in different kind of fishes by HPLC-MS, HPLC-MS-MS, and GC-MS; however, many of them used solvent extraction and an additional clean-up step (Gago-Ferrero et al. 2012; Marchal and Beltran 2016). The first step for evaluating the risk associated with food contaminated with these kinds of compounds is to develop and validate a method to quantitate them. The main problems for developing methods to evaluate emerging contaminants in biota are the low concentration at what they could be present and the complexity of the matrix of the samples (Farré and Barceló 2013).

In order to eliminate at maximum the matrix interferences, it is necessary to use sample preparation techniques that allow more selective extractions from fish prior to their introduction to the chromatographic system. Currently, sample preparation is mainly based on solvent extraction, which requires a clean-up process by gel permeation chromatography (GPC) or normal phase sorbents (alumina, silica, or florisil) to remove the interfering lipids that are co-extracted with the analytes to be determined. After performing solvent extraction and clean-up process, the analytes are determined with liquid or gas chromatography coupled with mass spectrometry (Balmer et al. 2005; Mottaleb et al. 2009). Among sample preparation techniques, matrix solid-phase dispersion used for extraction of organic compounds of solid or semi-solid samples, where the sample and a dispersant sorbent are blended in a mortar with a pestle for simultaneous disruption and extraction (Barker 2000), is a simpler and faster technique that can also be used for eliminating interferences of biota samples. In some case, co-columns with different sorbents (alumina, silica, florisil, C18, etc.) are used. These are placed at the

bottom of a polypropylene cartridge prior to addition of the MSPD blend to remove co-eluting interferences in the final eluate, which allows to perform extraction and clean-up simultaneously saving time and simplifying the sample treatment (Barker 2007). This technique has already been applied to the extraction of UV filters in fish (Negreira et al. 2013; Tsai et al. 2014).

The current trend in analytical chemistry is to reduce the sample size and solvent consumption to obtain the highest possible sensitivity, selectivity, accuracy, and precision; the combination of miniaturized sample preparation with modern chromatographic equipment has allowed monitoring target analytes at trace levels in a vast variety of food samples. Particularly, GC equipment with programmable split/splitless injector (PSSI) allows to pre-concentrate large volumes in the injector module of the chromatograph by solvent purging, removing the solvent from the sample prior to entering the column (Mol et al. 1996). This enables the analysis of thermally labile compounds while eliminating the discrimination of high boiling compounds (e.g., UV filters), achieving greater detection limits and cleaner chromatography.

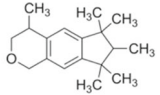
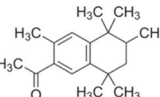
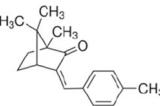
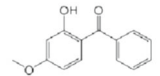
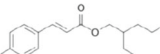
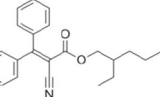
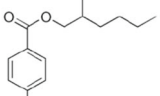
The objective of this work was to develop a sensitive, selective, and simple MSPD-PSSI-GC-MS method to determine simultaneously polycyclic aromatic musks (galaxolide and tonalide) and UV filters (4-MBC, 2-EHMC, padimate-O, oxybenzone, and octocrylene) in fish muscle. The validated method was used to determine the mentioned pollutants in rainbow trout artificially exposed to them in an *in vivo* study.

## Materials and Methods

### Chemicals, Reagents, and Materials

The polycyclic aromatic musks standards were purchased from Sigma-Aldrich with a certified purity >99% for tonalide (USA) and content >55% for galaxolide (solution at 50% in diethylphtalate, China). The UV filters standards were acquired from Sigma-Aldrich, 3-(4-methylbenzylidene) camphor (4-MBC, Germany), 2-ethylhexyl 4-methoxycinnamate (2-EHMC, Switzerland), octocrylene (Germany), oxybenzone (USA), and padimate-O, (USA) with a certified purity >98% (Table 1). Benzo[a]anthracene (B[a]A) was from Ultra Scientific, USA ( $100 \mu\text{g mL}^{-1}$  in dichloromethane). Water ( $18.2 \text{ M}\Omega \text{ cm}^{-1}$  resistivity) was obtained from a Millipore Direct-Q3 UV deionizer (USA), Silica CHROMABOND C<sub>18</sub> PAH (particle diameter 45  $\mu\text{m}$ ) from MACHEREY-NAGEL (USA), and florisil (60–100 mesh) from J.T. Baker (USA). The solvents used were acetonitrile (HPLC grade, VWR, France), methanol

**Table 1** Target analytes

Type	Analyte	Structure	Molecular formula	Molecular weight (g mol <sup>-1</sup> )	Log K <sub>OW</sub>	SIR monitoring ions (m/z)
Musks	Galaxolide		C <sub>18</sub> H <sub>26</sub> O	258.40	5.9 <sup>a</sup>	243, 258
	Tonalide		C <sub>18</sub> H <sub>26</sub> O	258.40	5.8 <sup>a</sup>	243, 258
UV filters	4-MBC		C <sub>18</sub> H <sub>22</sub> O	254.37	5.5 <sup>b</sup>	171, 211, 254
	Oxybenzone		C <sub>14</sub> H <sub>12</sub> O <sub>3</sub>	228.24	3.5 <sup>b</sup>	77, 151, 228
	2-EHMC		C <sub>18</sub> H <sub>26</sub> O <sub>3</sub>	290.40	5.8 <sup>b</sup>	161, 178, 290
	Octocrylene		C <sub>24</sub> H <sub>27</sub> NO <sub>2</sub>	361.48	6.9 <sup>b</sup>	204, 249, 360
	Padimate-O		C <sub>17</sub> H <sub>27</sub> NO <sub>2</sub>	277.40	5.8 <sup>b</sup>	148, 165, 277

<sup>a</sup> Geyer et al. 2000<sup>b</sup> Kameda et al. 2011

(HPLC grade, Tecsiquim, Mexico), ethyl acetate (analytical grade, J.T. Baker, Mexico), and acetone (for pesticide residue analysis, Sigma-Aldrich, Germany).

Polypropylene syringes (6-mL capacity) and 20 μm polyethylene frits were purchased from Supelco (USA) and Agilent Technologies (USA), respectively.

Extran MA 05 detergent for glassware cleaning was purchased from Merk (Mexico).

### GC-MS Analysis

All analyses were carried out using a Clarus 680 GC equipped with a programmable split/splitless injector (PSSI) coupled to a Clarus SQ 8C quadrupole mass spectrometer (Perkin Elmer), and data were collected using TurboMass 6.1.0 software. A Perkin Elmer Elite-5MS (30 m × 0.25 mm I.D.) 0.25-μm film thickness column was used. The gas chromatographic conditions were as

follows: the initial oven temperature was 80 °C for 1 min, then programmed at 10 °C min<sup>-1</sup> to 300 °C during 10 min, helium was used as carrier gas at 1 mL min<sup>-1</sup> for 20 min and programmed at 2 mL min<sup>-1</sup> during 13 min. For pre-concentration of the analytes in the PSSI injector, the following modes and temperatures were programmed: splitless (0.1 min), then split (50:1) during 1.5 min, again splitless (3 min) and split (50:1) 30 min, at initial temperature of 80 °C for 1.3 min, then programmed at 40 °C min<sup>-1</sup> to 320 °C for 31.7 min. Injection volume 5 μL. The MS ionization potential was 70 eV; the ion source and transfer line temperature were at 175 and 280 °C, respectively. Identification of target analytes was effected by comparing the retention times and spectral data with those of authentic compounds. Scan mode (50–400 m/z) was used for identification, while single ion recording (SIR) for quantification. Diagnostic fragments ions are shown in Table 1.

## Glassware Clean-up

To keep interferences at minimum level in all the experiments, glassware used for trace analysis was rinsed with methanol, then washed with Extran liquid alkaline phosphate-free detergent, then rinsed with deionized water, and finally heated at 550 °C one hour.

## Standard Solutions

Individual standard stock solutions were prepared by appropriate dilutions in methanol to obtain a concentration of 1.0 mg mL<sup>-1</sup> of each compound. From the individual analyte solution, a standard stock solution containing the seven analytes to be determined was prepared in methanol at an approximate concentration of 100 µg mL<sup>-1</sup> each. The solutions were stored in the dark at 4° C.

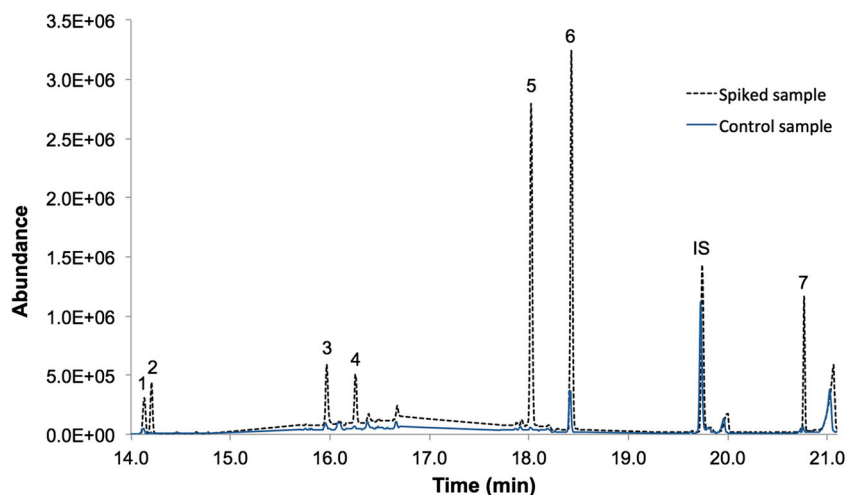
## Preparation of Spiked Fish Muscle

For method development and validation, rainbow trout muscle was obtained in a local market as filets and lyophilized (Freezone Triad freeze dry system model 7400040, Labconco). 0.2 g of lyophilized muscle were spiked with 100 µL of standard solution (prepared from the standard stock solution in methanol containing the seven analytes and then diluted in acetone) at different concentrations levels, the spiked sample was homogenized, and then allowed to air-dry at room temperature for 3 h.

## MSPD Extraction and Clean-up

0.2 g of lyophilized muscle sample was blended in an agate mortar with 1.0 g of florisisil (preconditioned at 130 °C for 24 h) until a homogeneous mixture was obtained.

**Fig. 1** Ionic chromatogram (SIR) for the analysis of a muscle sample control and spiked muscle sample at 1.0 µg g<sup>-1</sup>. Peak identification: 1. Galaxolide, 2. Tonalide, 3. Oxybenzone, 4. 4-MBC, 5. Padimate-O, 6. 2-EHMC, 7. Octocrylene; IS. B[a]A



The mixture was transferred to a 6-mL polypropylene cartridge containing 0.5 g of C18 PAH silica as co-column and clean-up sorbent, and then it was compressed and covered with a polyethylene frit. The analytes were eluted from the cartridge with 5 mL of acetonitrile by gravity. Finally, the acetonitrile extract was evaporated to dryness (40 °C) under a nitrogen stream, and the residue re-dissolved with 1.0 mL of ethyl acetate containing 100 ng mL<sup>-1</sup> of internal standard (B[a]A).

## MSPD-PSSI-GC-MS Validation

The following parameters were evaluated: precision, accuracy, limit of detection (LOD), limit of quantification (LOQ), and linearity.

Accuracy and precision were assessed by analyzing dry muscle samples spiked at two concentration levels: 0.1 and 1 µg g<sup>-1</sup>. For each concentration, three replicates were made in two different days and the recoveries and relative standard deviation (RSD) were calculated for each level. LOD and LOQ of each analyte were determined as a signal-to-noise ratio (S/N) of 3 and 10, respectively, in extracts from spiked freeze-dried muscle from 0.004 to 0.050 µg g<sup>-1</sup>.

Linearity of the method was evaluated using lyophilized muscle spiked at six concentration levels (0.05, 0.2, 0.4, 0.6, 0.8, and 1.0 µg g<sup>-1</sup>). For each concentration level, three sample replicates were made. The determination coefficients ( $r^2$ ), slopes and Y intercepts of the calibration curve were calculated for each analyte.

## Study of Exposure of Rainbow Trout to the Contaminants

The validated method was used for the determination of the seven analytes to which the rainbow trout (this kind

**Table 2** MSPD-PSSI-GC-MS validation data

Compound	Accuracy ( $n = 6$ ) % recovery		Precision ( $n = 6$ ) RSD		Linearity ( $n = 3$ ) $r^2$	LOD ( $\mu\text{g g}^{-1}$ )	LOQ ( $\mu\text{g g}^{-1}$ )
	0.1 $\mu\text{g g}^{-1}$	1.0 $\mu\text{g g}^{-1}$	0.1 $\mu\text{g g}^{-1}$	1.0 $\mu\text{g g}^{-1}$			
Galaxolide	89	108	18	13	0.9946	0.006	0.020
Tonalide	79	98	18	13	0.9987	0.008	0.025
Oxybenzone	80	55	8	16	0.9829	0.012	0.040
4-MBC	101	102	18	12	0.9872	0.006	0.025
Padimate-O	77	88	6	10	0.9982	0.008	0.025
2-EHMC	111	96	12	11	0.9841	0.004	0.013
Octocrylene	96	105	7	7	0.9929	0.012	0.040

of fish is considered a bioindicator in toxicity tests, EPA 1996) were exposed during an in vivo study. The experimental procedures for in vivo study in fish were approved by the Bioethics Committee for Animal Health (CICUAL, Faculty of Chemistry, UNAM). Juvenile rainbow trouts were obtained from a local aquatic farm (length  $16.4 \pm 1.0$  cm; weight  $40.7 \pm 7.6$  g,  $n = 6$ ). The trouts were conditioned in an aerated aquarium with 120 L of potable water for 1 week before the experiment (13:11-h light/dark photoperiod,  $13 \pm 2$  °C). Five rainbow trouts were exposed in 70 L of dechlorinated potable water spiked with standard solution of musks and UV filters in methanol to have a concentration of  $100 \mu\text{g L}^{-1}$  for each analyte, and one fish was maintained in dechlorinated potable water as control. To maintain stable concentrations of the analytes in the water, 50 L of the water was renewed with freshly spiked water every 24 h. After 4 days of exposure, the trouts were sacrificed. Bones, skin, and inner organs were discarded and only the muscle of the fish was used for the analysis. The fish muscle was lyophilized and analyzed by MSPD-PSSI-GC-MS validated method.

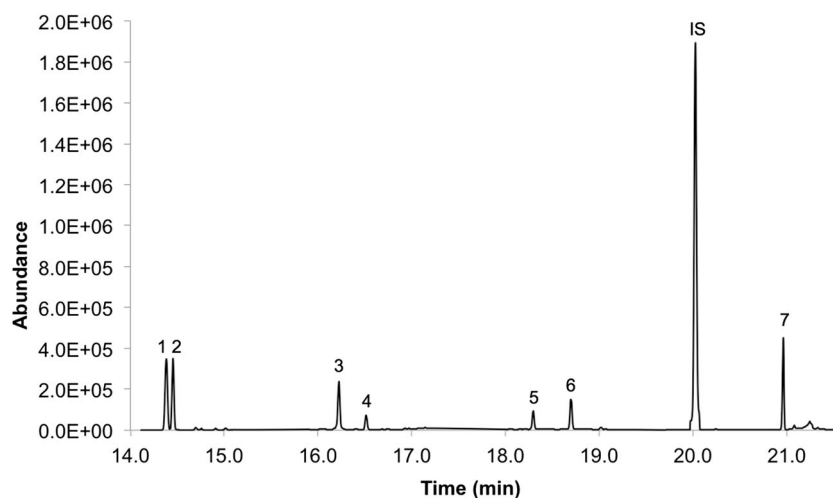
## Results and Discussion

### MSPD-PSSI-GC-MS Optimization

PSSI injector was used because it allows an increase in the injection volume with a solvent vent mode improving analytes detectability. Volume injection (3, 5, 7, and 10  $\mu\text{L}$ ), injector initial temperature (60 and 80 °C), and flow rate were evaluated. The results showed that the lowest RSD value ( $< 12\%$ ) was obtained with the following parameters: 5  $\mu\text{L}$  volume injection, injector initial temperature 80 °C, and flow rate program of  $1 \text{ mL min}^{-1}$  for 20 min and then  $2 \text{ mL min}^{-1}$  for 13 min, which diminished the octocrylene band broadening. Phenanthrene, benzo[a]anthracene (B[a]A), and benzo[a]pyrene (B[a]P) were evaluated as internal standards in order to decrease variations due to injector pre-concentration step and improve repeatability, especially for semivolatile analytes such as galaxolide and tonalide. The best repeatability was achieved with B[a]A.

Matrix solid-phase dispersion (MSPD) conditions were optimized by studying the ratio sample/dispersant 1:4

**Fig. 2** Analysis of rainbow trout muscle diluted extract by MSPD-PSSI-GC-MS in SIR mode. Peak identification as Fig. 1





**Table 3** Rainbow trouts data

Sample	Total length (cm)	Weight (g)	Lipid content (%)	Humidity (%)
Control	15.0	31.9	1.0	79.3
1	17.7	45.5	1.2	79.9
2	16.2	52.5	2.4	79.1
3	16.5	34.0	1.3	79.6
4	15.8	39.4	2.3	80.2
5	17.3	40.7	1.6	81.8

(0.5 and 2.0 g) and 1:5 (0.2 and 1 g); 0.5 g as co-column (C18 PAH and PSA) and volume elution solvent (3, 5, and 7 mL acetonitrile). The best conditions were as follows: 0.2 g of freeze-dried sample equivalent to 1 g of fresh tissue, approximately; 1 g of florisil as dispersant; 0.5 g of C18 PAH, as co-column; and 5 mL of acetonitrile as elution solvent.

Figure 1 shows the ionic chromatogram of muscle control sample and spiked muscle sample superimposed. In spite of the special precautions taken to avoid contamination, the ion chromatogram of the control sample shows some interfering peaks in the same retention time of galaxolide, tonalide, and 2-EHMC. This problem has been previously reported as they are ubiquitous due to their extended use in daily life (Bester 2009; Peck 2006; Meinerling and Daniels 2006). However, the contribution to the response was calculated to be well below the LOQ of the corresponding compounds. The ion chromatogram of spiked sample shows good resolution, efficiency, and selectivity for all the analytes.

### MSPD-PSSI-GC-MS Validation

Adequate precision (repeatability, inter-day) was found for all compounds; RSD values were < 19%. These values are in agreement with the United Nations guidance for testing biological specimens, which considers a method to be precise when RSD < 20% for trace concentration determinations (United Nations Office on Drugs and

Crime 2009). The mean recovery of analytes in spiked samples at 0.1  $\mu\text{g g}^{-1}$  ranged 77–111% and for 1.0  $\mu\text{g g}^{-1}$  ranged 88–108%; except for oxybenzone, that ranged 55–80%, being the most polar analyte, it is possible that it is more strongly retained than the others in dispersant florisil that has also a very polar nature (Moldoveanu and David 2015). These results confirm the adequate accuracy and precision of the MSPD-PSSI-GC-MS method. Limits of detection (LODs) and quantification (LOQs) were 0.004–0.012 and 0.013–0.040  $\mu\text{g g}^{-1}$ , respectively, referred to dry weight, all the limits were comparable with reported values (Mottaleb et al. 2009; Negreira et al. 2013; Gago-Ferrero et al. 2015). Linearity was studied from 0.05 to 1.0  $\mu\text{g g}^{-1}$ , obtaining determination coefficients ( $r^2$ ) for musks > 0.990 and for UV filters > 0.980 (Table 2).

### Rainbow Trout Study

The developed methodology was used for monitoring the content of the seven target analytes in rainbow trout muscle after an exposure study in vivo. The exposition time for the study was 4 days, based on previously reported studies for tilapia (Chen et al. 2015). The samples analyzed according to the method showed high absorption of analytes in rainbow trouts exposed; therefore, the extracts had to be diluted in order to keep them in the linear range for quantitation (Fig. 2). The results of the study showed that polycyclic aromatic musks content in fish is greater than UV filters, this could be due to musks being more soluble in water which increase the bioavailability. The lipid content of each trout (Table 3) was determined gravimetrically, and was observed that fish with lipid content > 1.6% (samples 2, 4, and 5) showed higher absorption of the compounds in the muscle than fish with low fat content (samples 1 and 3). These results (Table 4) suggest correlation between analyte absorption and lipid content; this is *high lipid content high absorption*. It remains open the possibility that these contaminants can enter in the food chain and biomagnify.

**Table 4** PCPs concentration in rainbow trout ( $\mu\text{g g}^{-1}$ )

Sample	Galaxolide	Tonalide	Oxybenzone	4-MBC	Padimate-O	2-EHMC	Octocrylene
Blank	<LOQ	ND	ND	ND	ND	ND	ND
1	13.2	24.8	<LOQ	2.8	ND	0.9	12.0
2	24.5	39.4	14.5	8.0	1.3	2.0	19.6
3	14.8	28.1	4.9	7.1	1.0	1.9	17.9
4	23.6	43.0	23.1	14.2	2.6	3.6	16.7
5	21.4	36.1	13.7	6.2	1.2	2.5	14.3

ND not detected

## Conclusions

A simple, sensitive, and fast methodology for the simultaneous determination of musks and UV filters in fish muscle based on matrix solid-phase dispersion (MSPD) followed by PSSI-GC-MS was developed. The matrix solid-phase dispersion provides an efficient extraction and clean-up in one step with maximal lipid removal. In addition, the sensitivity of the method developed for all the analytes was enhanced achieving very low LOD (trace level) using PSSI injector. The method was applied successfully to evaluate the concentration of the seven contaminants in rainbow trout, artificially exposed to these compounds, showing that the trout absorbs and bioaccumulates them which could cause health problems to humans by contaminated fish consumption. Therefore, this method could be an alternative to determine food quality and safety.

**Acknowledgments** The authors want to thank Consejo Nacional de Ciencia y Tecnología (CONACYT) for the scholarship awarded to Iran Ocaña-Rios (scholar number 273473), Rocío Juárez Cipres for technical support, and Perkin Elmer de México S.A.

**Funding information** This work was supported by Dirección General de Asuntos del Personal Académico from the Universidad Nacional Autónoma de México (DGAPA-UNAM) project PAPIIT: IN 218116 and Faculty of Chemistry PAIP: 5000-9026.

## Compliance with Ethical Standards

**Conflict of Interest** Iran Ocaña-Rios declares that he has no conflict of interest. Elena Loeza-Fuentes declares that she has no conflict of interest. Ignacio Zuñiga-Perez declares that he has no conflict of interest. Araceli Peña-Alvarez declares that she has no conflict of interest.

**Ethical Approval** All institutional and national guidelines for the care and use of laboratory animals were followed. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution at which the studies were conducted.

**Informed Consent** Informed consent was not applicable.

## References

- Balmer ME, Buser HR, Müller MD, Poiger T (2005) Occurrence of some organic UV filters in wastewater, in surface waters, and in fish from Swiss lakes. *Environ Sci Technol* 39:953–962
- Barber LB (2014) Emerging contaminants. In: Ahuja S (ed) *Comprehensive water quality and purification*. Vol. 1, status and trends of water quality worldwide. Elsevier, United States, pp 245–266
- Barker SA (2000) Matrix solid-phase dispersion. *J Chromatogr A* 885: 115–127
- Barker SA (2007) Matrix solid phase dispersion (MSPD). *J Biochem Biophys Methods* 70:151–162
- Bester K (2009) Analysis of musk fragrances in environmental samples. *J Chromatogr A* 1216:470–480
- Birkholz DA, Stilson SM, Elliott HS (2014) Analysis of emerging contaminants in drinking water—a review. In: Ahuja S (ed) *Comprehensive water quality and purification*. Vol. 2, assuring purity of drinking water. Elsevier, United States, pp 212–229
- Chen G, Jiang R, Qiu J, Cai S, Zhu F, Ouyang G (2015) Environmental fates of synthetic musks in animal and plant: an *in vivo* study. *Chemosphere* 138:584–591
- Dietrich DR, Hitzfeld BC (2004) Bioaccumulation and ecotoxicity of synthetic musks in the aquatic environment. In: Rimkus GG (ed) *Series anthropogenic compounds. The handbook of environmental chemistry*, vol Vol. 3X. Springer, Berlin, pp 233–244
- EPA Environmental Protection Agency (1996) Ecological effects test guidelines OPPTS 850.1075 fish acute toxicity test, freshwater and marine, United States of America <https://www.epa.gov/sites/production/files/2015-07/documents/850-1075.pdf>. Accessed 10 Jan 2018
- Farré M, Barceló D (2013) Analysis of emerging contaminants in food. *Trends Anal Chem* 43:240–253
- Fent K, Zenker A, Rapp M (2010) Widespread occurrence of estrogenic UV-filters in aquatic ecosystems in Switzerland. *Environ Pollut* 158: 1817–1824
- Gago-Ferrero P, Díaz-Cruz MS, Barceló D (2012) An overview of UV-absorbing compounds (organic UV filters) in aquatic biota. *Anal Bioanal Chem* 404:2597–2610
- Gago-Ferrero P, Díaz-Cruz MS, Barceló D (2015) UV filters bioaccumulation in fish from Iberian river basins. *Sci Total Environ* 518–519: 518–525
- Geyer HG, Rimkus GG, Scheunert I, Kaune A, Schramm K, Ketrup A, Zeeman M, Muir DCG, Hansen LG, Mackay D (2000) Bioaccumulation and occurrence of endocrine disrupting chemicals (EDCs), persistent organic pollutants (POPs), and other organic compounds in fish and other organisms including humans. In: Beek B (ed) *Bioaccumulation new aspects and developments*, 1st edn. Springer, Heidelberg Berlin, pp 1–66
- Gros M, Petrovic M, Barceló D (2008) Analysis of emerging contaminants of municipal and industrial origin. In: Barceló D, Petrovic M (eds) *The handbook of environmental chemistry*. Springer, Berlin, pp 37–104
- Hansen PD (2007) Risk assessment of emerging contaminants in aquatic systems. *Trends Anal Chem* 26:1095–1099
- Kameda Y, Kimura K, Miyazaki M (2011) Occurrence and profiles of organic sun-blocking agents in surface waters and sediments in Japanese rivers and lakes. *Environ Pollut* 159:1570–1576
- Kümmerer K (2011) Emerging contaminants. In: Wilderer P (ed) *Treatise on water science*, Vol. 3, aquatic chemistry and biology. Elsevier, United States, pp 69–83
- Marchal M, Beltran J (2016) Determination of synthetic musk fragrances. *Int J Environ Anal Chem* 96:1213–1246
- Meinerling M, Daniels M (2006) A validated method for the determination of traces of UV filters in fish using LC–MS/MS. *Anal Bioanal Chem* 386:1465–1473
- Mersch-Sundermann V, Schneider H, Freywald C, Jenter C, Parzefall W, Knasmüller S (2001) Musk ketone enhances benzo(a)pyrene induced mutagenicity in human derived Hep G2 cells. *Mutat Res* 495:89–96
- Mol HGJ, Janssen H, Cramers CA, Brinkman UAT (1996) Large-volume injection in gas chromatographic trace analysis using temperature-programmable (PTV) injectors. *Trends Anal Chem* 15:206–214
- Moldoveanu S, David V (2015) Modern sample preparation for chromatography. Elsevier, Amsterdam
- Mottaleb MA, Usenko S, O'Donnell JG, Ramirez AJ, Brooks BW, Chambliss KC (2009) Gas chromatography–mass spectrometry screening methods for select UV filters, synthetic musks, alkylphenols, an antimicrobial agent, and an insect repellent in fish. *J Chromatogr A* 1216:815–823
- Negreira N, Rodríguez I, Rodil R, Rubi E, Cela R (2013) Optimization of matrix solid-phase dispersion conditions for UV filters determination in biota samples. *Int J Environ Anal Chem* 93:1174–1188

- Peck AM (2006) Analytical methods for the determination of persistent ingredients of personal care products in environmental matrices. *Anal Bioanal Chem* 386:907–939
- Rimkus G (1999) Polycyclic musk fragrances in the aquatic environment. *Toxicol Lett* 111:37–56
- Smital T, Luckenbach T, Sauerbom R, Hamdoun AM, Vega RL, Epel D (2004) Emerging contaminants-pesticides, PPCPs, microbial degradation products and natural substances as inhibitors of multixenobiotic defense in aquatic organisms. *Mutat Res* 552:101–117
- Tsai D, Chen C, Ding W (2014) Optimization of matrix solid-phase dispersion for the rapid determination of salicylate and benzophenone-type UV absorbing substances in marketed fish. *Food Chem* 154:211–216
- United Nations Office on Drugs and Crime (2009) Guidance for the validation of analytical methodology and calibration of equipment used for testing of illicit drugs in seized materials and biological specimens. United Nations, New York. [https://www.unodc.org/documents/scientific/validation\\_E.pdf](https://www.unodc.org/documents/scientific/validation_E.pdf). Accessed 10 Jan 2018
- Van Der Burg B, Schreurs R, Van Der Linden S, Seinen W, Brouwer A, Sonneveld E (2008) Endocrine effects of polycyclic musks: do we smell a rat? *Int J Androl* 31:188–193