A miniaturized, economical sample preparation method based on EN 12393 methodology for the determination of pesticide residues by gas chromatography-mass spectrometry

Philipp Steinbach[1] and Wolfgang Schwack[2,*]

[1]CLF-Central Laboratories Friedrichsdorf, Bahnstr. 14-30, 61381 Friedrichsdorf, Germany;
[2]University of Hohenheim, Institute of Food Chemistry, Garbenstr. 28, 70599 Stuttgart, Germany.

ABSTRACT

Based on the methodology of EN 12393, a miniaturized multi-method for the determination of pesticide residues in food products by gas chromatography-mass spectrometry was developed. Using reduced sample weights and solvent volumes, the new method provides a simplified extraction and partitioning step by automatic shaking. Cleanup was performed by gel permeation chromatography on a PSS GRAM 30 Å column followed by a solid-phase extraction with Silicycle SiliaPrep Diamine cartridges that selectively remove fatty acids. The method was validated on four representative matrices (vegetable mixture, orange juice, high fat milk powder and oat flour) for more than 300 pesticides. Recoveries of 70-120% were obtained for most pesticides. Limits of quantitation ranged between 0.01 mg kg^{-1} and 0.05 mg kg^{-1}. The new method outperforms the original EN 12393 method in terms of solvent consumption, analysis time and cleanup efficiency, while validation results were comparable. Therefore, the method provides an excellent alternative to the existing multi-residue methods for the analysis of different food products.

KEYWORDS: EN 12393, cleanup, SPE, GRAM, HR-GPC, Silicycle SiliaPrep Diamine, pesticides, miniaturization, GC-EI-MS

*Corresponding author
wolfgang.schwack@uni-hohenheim.de

1. INTRODUCTION

Pesticides are widely used in agricultural production of food and feed. Some compounds that were used in the past are ubiquitary found in the environment. In total more than 1500 active ingredients are known [1], and the maximum residue limits (MRLs) for more than 500 pesticides are regulated in the European Union (EU) for food and feed of plant or animal origin [2]. For all pesticides that are not regulated, MRLs were set to 0.01 mg kg^{-1}. A regular analysis of pesticide residues in various food products is necessary to ensure the safe and efficient use and to protect consumers and the environment [3]. The physical and chemical properties of pesticides differ considerably; therefore, the most efficient approach for pesticide residue analysis is the use of multiclass, multi-residue methods (MRMs) [4]. In Europe, one of the best-established MRMs is EN 12393 [5, 6, 7], also known as "DFG-S19", which was developed by Specht and Tillkes in the beginning of the 1980s. Since this time, only a few modifications were reported. Stan and Linkerhägner modified the original method for a state-of-the-art use by reducing the extraction volumes, omitting the mini silica gel columns, and using a selective atomic emission detector for analysis [8]. In recent years, there is a trend towards greener analytical methods [9] and towards using GC-MS or GC-MS/MS for pesticide screening and quantitation. The development of more sensitive and highly selective GC or LC instruments necessitates a

review of EN 12393 sample extraction procedure for a state-of-the-art use. Large solvent consumption (> 600 mL), long analysis times per sample (> 120 min for sample preparation), laborious operations and high expenditures are the main drawbacks of EN 12393-2. Reduction of analysis time and solvent consumption could be achieved by modifying both the extraction and the GPC cleanup as recently reported in [10]. Additionally, the EN 12393 cleanup on mini silica gel columns was substituted by a solid phase extraction (SPE) on a silica diamine phase to remove fatty acids [11].

In the present study, a fast and cost attractive MRM based on the results obtained from former extraction/partitioning, GPC, and SPE experiments is provided. The sample preparation procedure is based on EN 12393-2/N methodology, but was miniaturized. Therefore, improvements were achieved in terms of automation, ecology and economy, resulting in the applicability of the method for routine testing. The method was fully validated for more than 300 pesticides determined by GC-MS in four matrices of different degrees of difficulty.

2. MATERIALS AND METHODS

2.1. Reagents and materials

Methanol (LiChrosolv, LC-MS grade), acetone, toluene, ethyl acetate and cyclohexane (all SupraSolv for GC analysis), disodium hydrogencitrate x 1.5 H_2O (GR for analysis), sodium hydrogen carbonate (GR for analysis), anhydrous sodium sulphate (Ph. Eur) and sodium chloride (GR for analysis) were purchased from Merck (Darmstadt, Germany). Folded filters (597 ½) and filter units (0.2 µm) were obtained from Whatman (Dassel, Germany). The folded filters were soxhlet extracted for 2 h with acetone. De-ionized water was used for sample preparation.

Certified pesticide standards with purity > 90%, except for etrimphos (64.0%), formothion (74%) and triazophos (78.5%), as well as standard solutions of chlordane-oxy, cyhalofop-butyl, famoxadon, phenkapton, prothoat and a PCB mixture containing PCBs 28, 52, 101, 118, 138, 153 and 180 (0.01 g L^{-1} each) were obtained from Dr. Ehrenstorfer (Augsburg, Germany). Triamiphos

(0.1 g L^{-1}) was purchased from Riedel de Haën (Seelze, Germany) and fensulfothion (96.0%) from Sigma Aldrich (Munich, Germany). Standard (1.0 g L^{-1}) and spiking solutions (0.2, 0.5 and 1.0 mg L^{-1}) were prepared in toluene. Isotope labelled internal standards, $^{13}C_6$-hexachlorobenzene and d$_8$-p-DDE were purchased from Dr. Ehrenstorfer (100 mg L^{-1} each). A spiking mixture of both internal standards was prepared in toluene (0.25 mg L^{-1}).

Organic vegetables (carrot, courgette, broccoli, cauliflower and spinach) were purchased at a local supermarket and homogenized by a Grindomix GM 200 (Retsch, Haan, Germany). A vegetable mixture was prepared by blending 0.2 kg of each commodity. German oat grains, with spelt, were ground by a Grindomix GM 200 to fine flour. Organic orange juice (BioSonne, Rottaler Fruchtsaft eG, Rotthalmünster, Germany) was purchased at a local supermarket. A high fat infant milk formula base powder (HIFA) was provided by Nutricia Poland (Krotoszyn, Poland). Apples were provided by Sady Tuchoraz spol. s. r. o. (Český Brod, Czech Republic) and homogenized by a Grindomix GM 200 after freezing. The absence of pesticide residues was checked for all samples. A proficiency test material (milk powder) was obtained from FAPAS (York, UK).

2.2. Instrumentation

The GC-MS system consisted of a 7890A gas chromatograph equipped with a 7683B series injector tower (Agilent, Waldbronn, Germany) and a PTV injector CIS4 (Gerstel, Mülheim, Germany), which was connected to an Agilent 5975C inert quadrupole MS detector. ChemStation software was used for instrument control and data analysis. Each sample was acquired in combined SIM/SCAN mode, whereupon SIM data were used for quantitation and SCAN data (scan range 50-500 m/z) to obtain total ion current chromatograms.

Separation of the samples was conducted on a HP-5ms (30 m x 0.25 mm i.d., 0.25 µm) column, connected to a HP-5ms (1.5 m x 0.32 mm, 0.25 µm) pre-column at the inlet end. Temperature programme: 70 °C (2.0 min), 25 °C min^{-1} to 150 °C, 3 °C min^{-1} to 200 °C, 8 °C min^{-1} to 280 °C held for 10 min, and 35 °C min^{-1} to 325 °C held for 3 min. The transfer line temperature was 280 °C.

PTV injection was conducted with the following parameters: injection volume 5 µL; vent time 0.35 min; vent flow 100 mL min^{-1}; vent pressure 3.8 psi; temperature programme 70 °C for 0.38 min, 720 °C min^{-1} to 250 °C, which was maintained during the total GC-MS run; injection liner: Gerstel 1.5 mm i.d., baffled and deactivated glass liner. A retention time locking (RTL) program was used to set helium carrier gas at a constant flow of approx. 2.5 mL min^{-1}. Chlorpyriphos-methyl (16.59 min) was the RTL reference substance. For quantitation, an adequate target ion was selected; one or two qualifier ions were additionally selected to ensure correct identification of the pesticide. Solvent standards at the corresponding spiking levels were used for external calibration. Matrix compounds were identified by automatic comparison of the obtained mass spectra with the spectra of NIST database. Bracketing calibrations were done with solvent standards at the expected concentration levels depending on the respective spiking level and sample weight.

Preparative GRAM 30 Å, 7 µm HR-GPC columns (300 mm x 20 mm i.d., 50 mm x 20 mm i.d. precolumn) were purchased from Polymer Standard Services (Mainz, Germany). The columns were operated on an AccuPrep GPC system (equipped with peek tubing for high pressure applications) connected to an automatic evaporation system AccuVap FLX (Antec, Sindelsdorf, Germany); a 2.0-mL sample loop was used. The flow rate was 7.5 mL min^{-1} using ethyl acetate/ cyclohexane/methanol (45:45:10). Dump time was 10.8 min and collecting time, 14.2 min.

2.3. Sample preparation

Samples were prepared according to the scheme presented in Figure 1. Sample materials were weighed into 100 mL screw capped glass centrifuge tubes (vegetable mix: 10 g; orange juice: 10 g; HIFA: 3 g; oat: 5 g; FAPAS milk powder: 5 g; apples: 10 g). Water was added to adjust total water amount of 10 g for all matrices. The pH was adjusted to 7 using sodium hydrogencarbonate or disodium hydrogencitrate, if necessary. For milk based products (HIFA, FAPAS), pH was adjusted to 6.5 using disodium hydrogencitrate to avoid protein precipitation during extraction. All samples
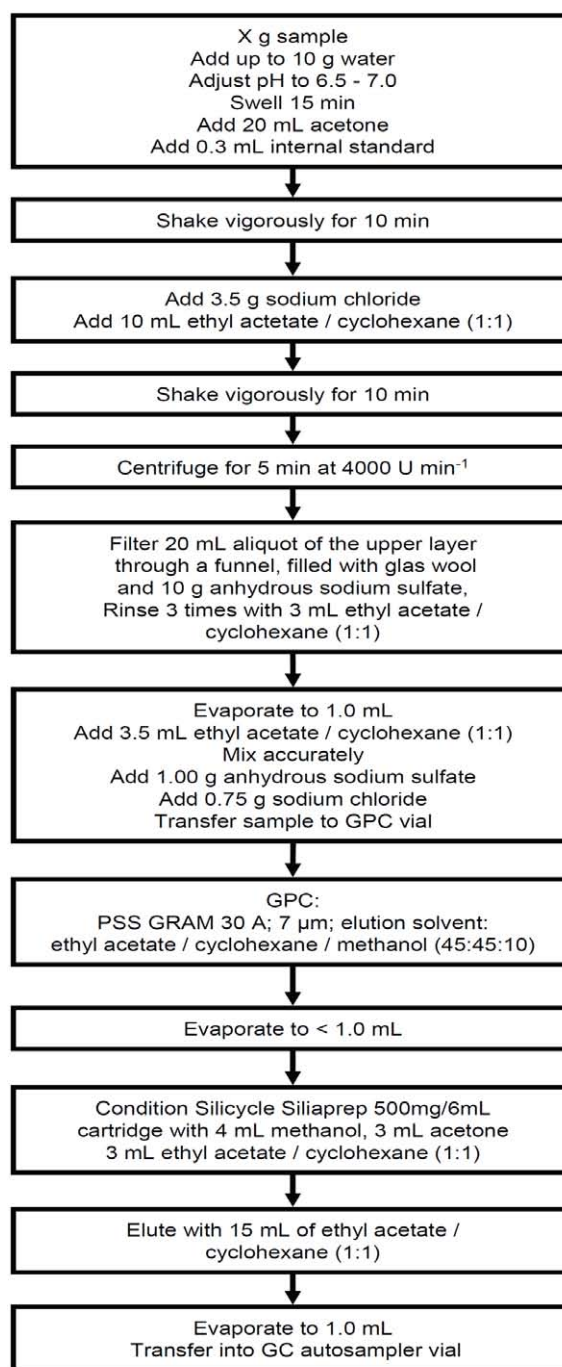

Figure 1. Flowchart of miniaturized method based on EN 12393-2/N methodology.

were rested for 15 min. Acetone (20 mL) and internal standard (0.3 mL) were added, and the samples were extracted by shaking for 10 min on a two dimensional shaker at 225 rpm (Edmund Bühler, Hechingen, Germany). Subsequently, 3.5 g

sodium chloride and 10 mL ethyl acetate/cyclohexane (1:1) were added, and the samples were shaken again for 10 min. After centrifugation at 4000 rpm for 5 min (Megafuge 1.0R, Thermo Fisher Scientific, Langenselbold, Germany), 20 mL of the upper layers were dried by passing through 10 g of disodium sulfate in a folded filter held by a small glass funnel followed by rinsing three times with 3 mL ethyl acetate/cyclohexane (1:1). The filtrates were collected in graduated 200 mL tubes with 1.0 mL stems and evaporated by TurboVap II (Caliper Life Sciences, Mainz, Germany). The residue was dissolved in 4.5 mL ethyl acetate/cyclohexane (1:1) and dried by adding 1.75 g of a salt mixture (sodium chloride/disodium sulphate, 1:1.3). After filtration through filter units, 2.0 mL was injected into the GPC system.

After GPC cleanup, the collected fractions were pre-evaporated by AccuVap to 2 mL and transferred to graduated 25 mL tubes with a 1 mL stem. The evaporation chamber was automatically rinsed twice with 5 mL ethyl acetate/cyclohexane (1:1). The combined solutions were finally rotary evaporated (35 °C, 0.2 bar) to approximately 1 mL, which then was transferred onto a Silicycle SiliaPrep Diamine cartridge (500 mg, 6 mL; Dichrom, Marl, Germany), which was pre-conditioned with methanol (4 mL), acetone (3 mL) and ethyl acetate/cyclohexane (3 mL). Elution of pesticides (2 drops sec^{-1}) was performed by adding 15 mL ethyl acetate/cyclohexane (1:1), whereat the first 5 mL was used to rinse the 25 mL concentration tube. The eluate was rotary evaporated to a volume of 0.5-0.9 mL and filled up to 1 mL with ethyl acetate/cyclohexane (1:1) to be analyzed by GC-MS.

2.4. Reference method

For method comparison, all matrices were fortified at 0.01 mg kg^{-1} and prepared by a slightly modified version of EN 12393-2 procedure N [6]. Modifications included reduction of extraction time to 2 min, evaporation of the crude extract to 1 mL, and addition of 10 mL ethyl acetate/cyclohexane (1:1) consecutively. After GPC cleanup on BioBeads SX-3 installed on an AccuPrep GPC system in combination with AccuVap FLX (Antec GmbH, Sindelsdorf, Germany), the eluate was evaporated and filled up to 1.0 mL to be analyzed by GC-MS without any further cleanup. Sample amount was reduced to 25 g for vegetable mix, orange juice and apples, to 10 g for oat and to 7.5 g for HIFA.

3. RESULTS AND DISCUSSION

Based on the methodology of EN 12393, a miniaturized and rapid sample preparation procedure was successfully developed for pesticide screening by GC-MS or GC-MS/MS. Especially, automatic shaking for both extraction and liquid-liquid partitioning (phase separation) enabled treatment of multiple samples in parallel, thus improving the economical efficiency. Additionally, a high-resolution GPC column, never used before in pesticide residue analysis, improved cleanup, and saved time and solvents. Cleanup was further optimized by an SPE step on silica diamine cartridges to remove fatty acids that mainly cause strong matrix effects during GC-MS [11].

3.1. Performance data

Recoveries were determined for 310 pesticides at two fortification levels (0.01/0.05 mg kg^{-1}) on three different representative matrices according to SANCO commodity groups [12]. The representative matrices were a vegetable mixture containing five different vegetable commodities (high water content), an organic orange juice (high water, high acid content) and an oat flour (high starch content). As an additional representative matrix a high fat infant milk formula base powder, HIFA (> 30% fat, high oil content), was validated for 309 pesticides at the same fortification levels.

For orange juice and HIFA, the average recoveries of both fortification levels were in an acceptable range of 70-120% for more than 80% of the tested pesticides (Figure 2). Due to matrix related effects, especially superimposition in the SIM chromatograms, the number of pesticides with recoveries of 70-120% was slightly lower (about 65%) for the vegetable mixture and the oat flour. Eight of the tested pesticides (acephate, butylate, chlorothalonil, dimethipin, fenhexamid, fenpropimorph, folpet and naled) unfortunately were recovered with less than 20% (Table 1). This reduced recovery can be attributed to the different modifications that have been established within
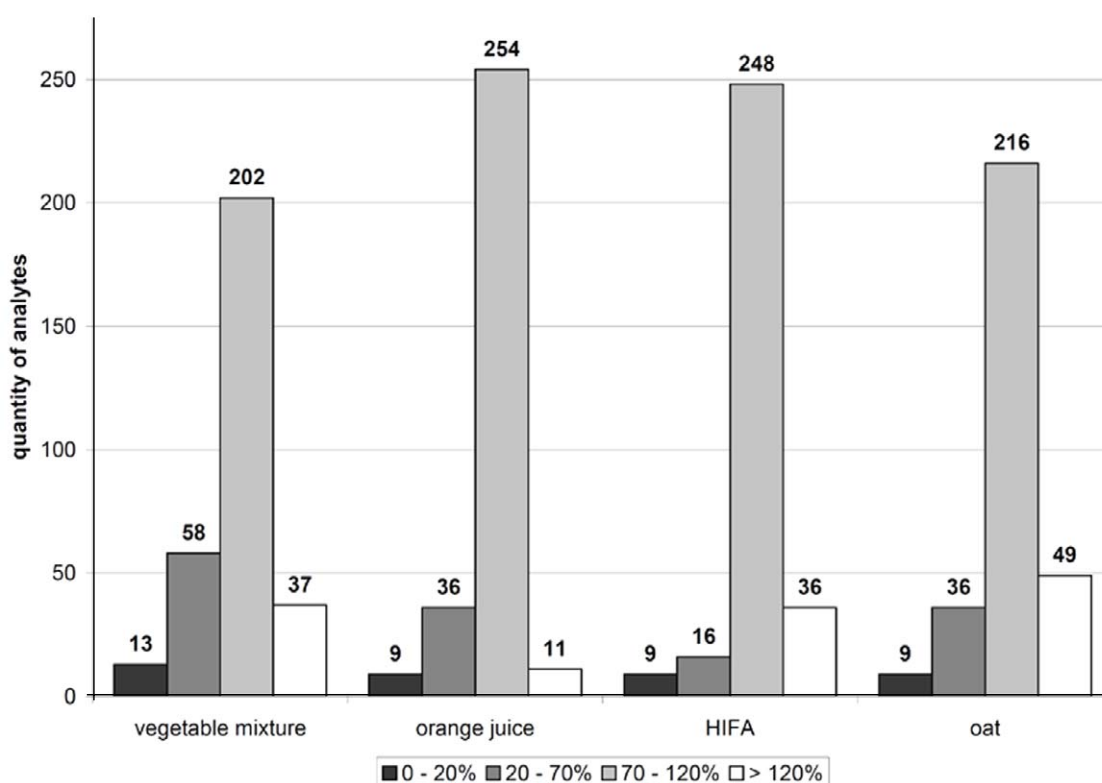
Figure 2. Distribution of recoveries for all four reference matrices; 310 pesticides validated on a vegetable mixture, an orange juice and an oat, 309 pesticides validated on high fat infant milk formula base powder.

the miniaturized method. Acephate and fenhexamid are susceptible to adsorption onto SiliaPrep Diamine SPE cartridge (SPD) resulting in low recoveries. Low recoveries of folpet and chlorothalonil may also be due to adsorption effects on SPD, but degradation under basic conditions is more likely. Naled was not detectable in all matrices, which can also be explained based on its pH sensitivity, degradation during injection or by its adsorption onto SPD. Recoveries of base sensitive chlorothalonil and folpet were higher for HIFA, in which pH was adjusted to 6.5 prior to extraction, while all other matrices were adjusted to pH 7. Butylate and fenpropimorph could not be recovered due to their early elution (≤ 10.8 min) from the GRAM HR-GPC column, when they co-eluted with the lipid fraction. Dimethipin is the only tested pesticide that took more than 25 min for elution from the GRAM HR-GPC column.

For the most frequently represented substance classes, mean recoveries for all matrices and fortification levels were in the range of 90-110%.

The group of organophosphates (75 pesticides) provided a mean recovery of 99%, ranging from 0% (naled) to 313% (crotoxyphos), while 51 pesticides were recovered in a range of 70-120%. For some of these organophosphates low recoveries had to be expected, because they are known to get affected by SPD (e.g. methamidophos, dichlorvos) or by the GRAM GPC column (e.g. terbufos, diazinon). The recovery range for organochlorine pesticides (39 pesticides) varied less; the mean recovery was 93% with the lowest average recovery for HCB (49%) and the highest for β-HCH (170%). Recoveries in the range of 70-120% were obtained for 35 of the tested 39 organochlorine pesticides. Triazoles (19 pesticides) were recovered with a mean of 104% and with small variations from 83% for hexaconazole to 126% for triadimenol. Pyrethroids (18 pesticides) revealed a slightly lower mean recovery of 87% with a variation from 23% for tefluthrin through 68% for permethrin to 110% for fenpropathrin and allethrin. This was expected as pyrethroids

Table 1. Average recoveries (REC, %), relative standard deviations (RSD, %) and LOQs for four representative commodities, fortified at 0.01 mg kg⁻¹ and 0.05 mg kg⁻¹, recoveries of 70-120% in bold.

Analyte	RT [min]	Target ion [m/z]	HR-GPC from [min]	HR-GPC to [min]	Veg. 0.01 REC	RSD	Veg. 0.05 REC	RSD	LOQ [mg kg⁻¹]	OJ 0.01 REC	RSD	OJ 0.05 REC	RSD	LOQ [mg kg⁻¹]	HIFA 0.01 REC	RSD	HIFA 0.05 REC	RSD	LOQ [mg kg⁻¹]	Oat 0.01 REC	RSD	Oat 0.05 REC	RSD	LOQ [mg kg⁻¹]
2,4-D methyl ester	10.79	199	14.5	16.5	55	5	51	3	0.01*	**78**	14	**77**	4	0.01	**100**	5	**108**	3	0.01	**82**	3	**84**	6	0.01
2,4-D-butoyl	23.53	220	12.5	14.5	**118**	5	**106**	4	0.01	**104**	4	**103**	2	0.01	**107**	10	**106**	4	0.01	**113**	9	**106**	9	0.01
2,4-D-butyl	16.40	185	11.5	13.5	59	7	67	7	0.01*	**79**	4	**72**	3	0.01	**96**	11	**81**	9	0.01	**90**	6	**103**	7	0.01
4,4'-Dichlorobenzophenone	19.22	139	12.5	15.5	**107**	5	**99**	6	0.01	145	13	161	17	0.01*	131	11	**119**	6	0.01*	139	4	127	7	0.01*
acephate^G	7.68	94	16.5	18.5	0		10	34	n.d.	0		2	33	n.d.	0		0		n.d.	0		13	15	n.d.
acetochlor	16.47	174	12.5	14.5	**89**	6	**84**	5	0.01	**76**	4	**99**	9	0.01	156	17	153	34	0.01*	**88**	10	**101**	6	0.01
aclonifen	25.70	264	16.5	19.5	126	6	**115**	10	0.05	163	2	132	2	0.01*	**84**^D	7^D	57	10^D	0.01	**82**	14	**93**	7	0.01
α-endosulfan	22.64	237	12.5	14.5	**73**	4	**105**	7	0.01	**86**	6	**92**	9	0.01	**97**	12	**98**	4	0.01	**110**	6	**105**	4	0.01
alachlor	17.01	188	12.5	14.5	44	11^C	57	13	0.01*	68	25	**78**	5	0.05	**98**	4	**105**	4	0.01	66	4	**73**	7	0.01*
aldrin	18.50	263	10.5	13.5	64	8	55	6	0.01*	**103**	19	69	6	0.01	**80**	12	**71**	8	0.01	**73**	6	**82**	9	0.01
allethrin	21.74	123	10.5	13.5	**104**	10	**91**	4	0.01	123	13	**112**	6	0.05	**113**	11	**87**	3	0.01	129	11	**118**	6	0.01*
ametryn	17.14	185	12.5	14.5	**89**	3	**87**	5	0.01	**96**	3	**90**	3	0.01	**94**	8	**104**	5	0.01	**90**	10	**111**	5	0.01
atrazin	13.20	200	12.5	15.5	**78**	9	**78**	6	0.01	**73**	4	**82**	3	0.01	**120**	4	**103**	2	0.01	**103**	4	**88**	7	0.01
atrazin-desethyl	11.28	172	15.5	18.5	**107**	6	**99**	4	0.01	67	6	**80**	3	0.05	**109**	10	**110**	2	0.01	**105**	5	**100**	6	0.01
azinphos-ethyl	30.71	132	15.5	17.5	**120**	8	**117**	7	0.01	41	13	**92**	5	0.01*	**114**	4	**119**	4	0.01	**107**	9	159	10	0.05*
azoxystrobin	36.58	344	17.5	20.5	**80**	8	**88**	4	0.01	**92**	8	**88**	6	0.01	**110**	5	**87**	3	0.01	**90**	3	**92**	7	0.01
benalaxyl	26.72	148	13.5	14.5	**102**	7	**96**	5	0.01	**108**	2	**101**	4	0.01	**118**	2	**111**	3	0.01	**107**	3	**107**	5	0.01
bendiocarb	11.55	151	13.5	15.5	**76**	5	**82**	10	0.01	61	7	67	12	0.01*	**94**	5	**102**	9	0.01	**98**	5	**104**	5	0.01
β-endosulfan	25.19	237	14.5	16.5	**98**	5	**101**	7	0.01	**100**	6	**94**	2	0.01	**95**	8	**72**	5	0.01	**92**	12	**110**	5	0.01
benfluralin	11.73	292	11.5	13.5	**74**	13	65	7	0.01	**95**	16	**85**	7	0.01	66	36^C	**77**	61^C	RSD	54	19	**70**	6	0.01*
benoxacor	15.41	120	14.5	17.5	**80**	16	64	6	0.01	**71**	11	**79**	8	0.01	**118**	11	**115**	13	0.01	**101**	6	**105**	8	0.01
bifenox	29.17	341	15.5	16.5	138	4	135	15	0.01*	**114**	4	**112**	3	0.01	**106**	8	**109**	5	0.01	**109**	10	**118**	9	0.01
bifenthrin	28.80	165	10.5	12.5	**115**	5	**101**	9	0.01	**79**	5	**89**	5	0.01	40	7	44	14	0.01*	52	26	60	12	0.05*

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	HR-GPC elution time to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
biphenyl	7.17	152	12.5	14.5	34	18	29	11	0.01*	88	12	95	13	0.01	99	10	84	8	0.01	100	34	67	9	0.05
bitertanol	31.31	168	13.5	14.5	140	7	143	8	0.01*	89	9	109	5	0.01	197	25^A)	149	16^A)	0.05*	0^B)		0^B)		n.d.
boscalid	32.82	140	15.5	18.5	92	10	91	8	0.01	75	6	80	5	0.01	112	8	114	5	0.01	109	9	109	8	0.01
bromacil	18.41	205	13.5	15.5	0^B)		0^B)		n.d.	105	6	111	4	0.01	112	13	113	10	0.01	119	3	115	5	0.01
bromophos-ethyl	22.46	97	10.5	12.5	109	5	107	5	0.01	85	9	96	9	0.01	107	13	115	7	0.01	113	10	119	3	0.01
bromophos-methyl	20.06	331	11.5	14.5	84	8	82	7	0.01	103	3	86	2	0.01	95	6	80	4	0.01	111	5	105	8	0.01
bromopropylate	28.62	341	11.5	13.5	111	5	99	3	0.01	116	4	110	2	0.01	98	8	100	3	0.01	112	5	122	7	0.01
bromoxynil-octanoat	26.85	127	11.5	13.5	64	28	66	5	0.05*	80	13	55	18	0.05*	0^B)		76	8	0.05*	0^B)		53	17	0.05*
bupirimate	24.80	273	12.5	14.5	76	14	82	11	0.01	95	11	85	10	0.01	108	14	86	34	0.01	60	15	42	20	0.01*
buprofezin	24.58	105	10.5	12.5	104	10	102	4	0.01	105	7	93	7	0.01	112	6	93	5	0.01	120	7	124	18	0.05*
butralin	20.18	224	11.5	12.5	116	4	127	5	0.01*	116	7	115	3	0.01	77	36	107	6	0.05	136	6^C)	152	8^C)	0.01*
butylate^F)	7.61	146	10.5	11.5	0		0		n.d.	15	5	13	17	n.d.	0		14	10	n.d.	24	32	19	9	0.05*
cadusafos	11.75	159	10.5	12.5	91	20	80	5	0.01	77	10	73	8	0.01	112	6	111	4	0.01	90	3	81	9	0.01
carbaryl	16.86	115	15.5	16.5	200	9	332	5	0.01*	131	6	123	5	0.01*	119	14	101	6	0.01	71	6	37	19	0.05*
carbaryl-phenol	8.77	144	15.5	17.5	29	20	9	44	n.d.	36	7	42	8	0.01*	97	11	68	8	0.01	240	5	261	9	0.01*
carbofuran	13.04	149	14.5	15.5	151	11	212	13	0.01*	202	13	192	20	0.01*	102	12	91	10	0.01	86	9	100	17	0.01
carbofuran-phenol	6.37	149	10.5	16.5	77	6	82	9	0.01	53	10	73	3	0.01*	180	21	132	3	0.01*	173	14	287	7	0.01*
carbophenthion	26.69	157	11.5	13.5	118	3	106	4	0.01	103	8	99	4	0.01	100	11	87	2	0.01	117	10	125	8	0.05*
carfentrazon-ethyl	26.99	312	13.5	15.5	132	7	133	9	0.01*	119	7	117	3	0.01	118	5	122	4	0.01	103	6	77	3	0.01
chlorbensid	21.83	125	12.5	14.5	87	22	60	9	0.05	88	8	99	2	0.01	76	22	76	27	RSD	104	11	114	8	0.01
chlorbromuron	21.04	206	13.5	17.5	86	11	149	98	0.01	76	9	54	4	0.05*	123	8	117	4	0.05	116	8	96	9	0.01
chlordan	22.13/22.90	373	11.5	14.5	99	7	91	10	0.01	106	10	94	6	0.01	87	7	93	4	0.01	106	4	88	6	0.01
chlordan-oxy	20.72	387	12.5	13.5	83	7	79	5	0.01	103	7	89	7	0.01	–**)		–**)		0.01*	99	11	85	7	0.01
chlorfenapyr	25.27	247	12.5	14.5	129	11	116	7	0.05*	105	7	99	3	0.01	82	8	93	5	0.01	101	6	106	6	0.01

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC from [min]	HR-GPC to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
chlorfenprop-methyl	10.01	125	12.5	15.5	57	6	56	11	0.01*	105	6	87	7	0.01	195	17[A)	148	6[A)	0.01*	99	10	100	4	0.01
chlorfenson	23.40	175	14.5	16.5	90	5	86	5	0.01	86	8	85	3	0.01	112	7	96	4	0.01	125	16	121	6	0.01*
chlorfenvinphos	20.91/ 21.51	267	11.5	14.5	135	6	117	5	0.05*	105	7	109	4	0.01	110	9	112	8	0.01	124	9	120	8	0.01*
chlormephos	7.74	154	12.5	13.5	45	23	31	8	0.05*	69	10	58	9	0.05*	89	10	74	3	0.01	80	12	62	7	0.01
chlorobenzilate / chloropropylate	25.41	139	11.5	14.5	96	7	87	4	0.01	101	4	93	8	0.01	95	6	82	2	0.01	105	3	99	6	0.01
chloroneb	8.73	191	13.5	15.5	74	5	50	4	0.01*	78	17	70	14	0.01	141	33	122	10	0.05*	126	13	93	6	0.05
chlorothalonil[G)	14.91	266	20.5	24.5	0		0		n.d.	5	42	4	55	n.d.	45	25	45	9	0.05*	0		0		n.d.
chlorpropham	11.07	153	11.5	14.5	91	14	91	17	0.01	110	6	105	5	0.01	120	9	117	11	0.01	145	6[A)	150	10[A)	0.01*
chlorpyrifos-ethyl	19.22	314	11.5	13.5	78	7	75	6	0.01	64	11	77	4	0.05	99	7	99	2	0.01	111	2	106	6	0.01
chlorpyrifos-methyl	16.63	286	12.5	14.5	67	12	79	8	0.05	71	15	63	6	0.05*	118	10	119	6	0.01	128	7	129	8	0.01*
chlorthal-dimethyl	19.39	301	12.5	15.5	73	7	68	4	0.01	68	10	70	2	0.01*	117	6	123	3	0.01	98	4	92	8	0.01
chlorthiophos	26.15	269	11.5	13.5	111	5	104	3	0.01	89	6	90	4	0.01	106	14	104	8	0.01	96	15	135	10	0.01
chlozolinat	21.39	259	12.5	14.5	75	29	75	15	0.05	83	10	72	3	0.01	116	23	93	20	0.05	86	18	91	7	0.01
cinidon-ethyl	33.18	188	13.5	16.5	133	13	128	9	0.01*	103	6	113	5	0.01	91	9	101	22	0.01	121	4	108	7	0.01
clodinafop-propargyl	27.23	238	14.5	16.5	124	8	116	9	0.05	124	6	102	7	0.05	98	11	97	4	0.01	106	9	102	6	0.01
clomazon	13.22	125	12.5	14.5	87	17	80	17	0.01	71	5	66	15	0.05*	128	16	95	17	0.05	90	14	94	6	0.01
cloquintocet-1-methylhexyl	28.90	192	11.5	14.5	103	5	96	7	0.01	93	5	92	6	0.01	106	13	110	4	0.01	114	11	122	9	0.01
coumaphos	31.74	226	15.5	17.5	127	7	109	7	0.05	81	9	101	4	0.01	117	4	117	2	0.01	108	5	159	5	0.05*
crotoxyphos[A)	22.30	127	12.5	14.5	361	10	636	11	0.01*	179	18	178	12	0.01*	209	11	160	13	0.01*	569	18	212	7	0.01*
cyanacine	19.42	225	13.5	15.5	97	6	93	3	0.01	84	11	80	13	0.01	114	8	90	3	0.01	68	8	51	11	0.01*
cyanofenphos	26.82	157	13.5	15.5	82	7	80	3	0.01	101	9	88	4	0.01	99	5	88	1	0.01	87	9	95	6	0.01
cyanophos	13.78	109	15.5	17.5	42	14	43	6	0.01*	98	20	79	6	0.01	92	11	89	8	0.01	106	13	93	6	0.01
cycloate	10.74	83	10.5	12.5	33	7	36	10	0.01*	37	14	53	7	0.01*	88	13	71	5	0.01	77	12	79	8	0.01

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
cycluron	13.59	72	11.5	14.5	95	5	87	4	0.01	72	8	78	2	0.01	114	8	111	3	0.01	114	4	114	4	0.01
cyflufenamid	25.23	223	11.5	13.5	95	6	81	6	0.01	89	7	91	5	0.01	119	7	115	4	0.01	80	11	105	8	0.01
cyfluthrin	32.40	163	11.5	13.5	106	9	113	6	0.01	116	4	96	4	0.01	0^D		85	7	0.05*	0^D		69	9	0.05*
cyhalofop-butyl	30.11	229	12.5	14.5	112	4	113	7	0.01	111	5	108	3	0.01	104	8	116	5	0.01	83	4	70	6	0.01
cyhalothrin-lambda	30.38	197	11.5	12.5	103	8	90	5	0.01	96	5	80	5	0.01	93	8	71	18	0.01	74	10	62	2	0.05*
cypermethrin	32.70	163	11.5	13.5	130	4	110	7	0.05	112	4	113	4	0.01	0^D		178	6^A	0.05	0^D		99	9	0.05*
cyphenothrin	30.99	123	11.5	12.5	115	4	100	5	0.01	72	44	108	5	0.05	93	20	92	7	0.01	0^B		99	8	0.05*
cyproconazol	24.90	139	13.5	15.5	130	5	108	6	0.05	114	5	114	3	0.01	100	6	107	8	0.01	93	10	93	10	0.05
cyprodinil	20.67	224	12.5	14.5	89	5	88	5	0.01	82	8	88	4	0.01	121	15	104	12	0.01	119	12	126	8	0.05*
DDD, o-, p'-	24.36	235	11.5	14.5	97	4	94	16	0.01	89	3	79	2	0.01	89	11	85	17	0.01	84	6	100	11	0.01
DDD, p-, p'-	25.71	235	11.5	15.5	81	7	78	3	0.01	98	7	93	4	0.01	123	5	119	4	0.01*	109	6	110	6	0.01
DDE, o-, p'-	22.48	246	11.5	13.5	75	13	79	11	0.01	81	6	86	9	0.01	87	12	76	16	0.01	104	3	98	10	0.01
DDE, p-, p'-	24.01	246	11.5	13.5	73	7	69	4	0.01	81	12	79	6	0.01	78	11	71	33	0.01	78	4	93	7	0.01
DDT, o-, p'-	25.74	246	11.5	13.5	103	5	120	6	0.01	110	7	115	2	0.01	95	8	100	6	0.01	82	14	99	10	0.01
DDT, p-, p'-	27.00	235	11.5	13.5	124	8	108	5	0.05	91	7	82	4	0.01	77	6	60	4	0.05*	78	5	73	5	0.01
deltamethrin	35.97	181	12.5	13.5	95	8	95	3	0.01	74	4	80	6	0.01	93	8	87	3	0.01	65	7	53	6	0.01*
demeton-S-metyl	10.47	88	13.5	15.5	93	14	74	3	0.01	47	8	49	8	0.01*	82	12	84	6	0.01	59	5	71	6	0.01*
desmetryn	16.10	171	13.5	15.5	83	7	89	5	0.01	71	8	86	4	0.01	118	8	110	6	0.01	117	11	106	7	0.01
dialifos	30.83	208	13.5	14.5	94	11	90	3	0.01	124	5	101	4	0.05	103	7	84	2	0.01	117	12	95	6	0.01
di-allate	11.94/12.27	86	10.5	12.5	64	4	59	4	0.01*	103	14	81	5	0.01	84	8	81	6	0.01	65	6	64	9	0.01*
diazinon	14.46	179	10.5	12.5	53	12	74	11	0.05*	59	15	50	4	0.01*	110	10	117	4	0.01	90	5	89	6	0.01
dichlobenil	6.83	171	14.5	16.5	40	13	30	7	0.01*	73	12	53	9	0.05*	86	12	77	5	0.01	82	4	55	7	0.05*
dichlofluanid	18.39	167	13.5	16.5	0^H		0^H		n.d.	70	20	74	6	0.01	83	14	105	5	0.01	189	7^A	74	14	0.01*

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	HR-GPC elution time to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
dichlorimid	6.87	124	14.5	15.5	0[B]		49	10	0.05*	105	5	91	20	0.01	95	16	69	12	0.01	0[B]		95	10	0.05*
dichlorvos	5.92	109	13.5	15.5	31	9	32	28	0.01*	54	7	61	12	0.01*	90	11	93	3	0.01	72	20	90	11	0.01
diclofop-methyl	27.63	253	12.5	14.5	110	7	105	5	0.01	102	6	91	3	0.01	98	15	96	9	0.01	131	16	116	7	0.01*
dicloran	12.61	176	16.5	19.5	104	7	94	5	0.01	113	4	85	5	0.01	102	8	106	15	0.01	77	13	106	10	0.01
dicofol	28.24	139	11.5	13.5	91	12	105	5	0.01	97	10	113	6	0.01	104	6	104	7	0.01	0[B]		108	11	0.05*
dieldrin	23.83	79	12.5	14.5	97	5	80	21	0.01	87	12	77	11	0.01	91	11	94	17	0.01	94	10	100	10	0.01
diethofencarb	19.23	225	12.5	13.5	107	3	96	6	0.01	95	25	112	4	0.05	121	8	110	3	0.05	124	8	122	7	0.01*
difenconazol	35.24	265	13.5	16.5	133	13	128	9	0.01*	106	10	111	5	0.01	102	10	105	5	0.01	113	4	105	6	0.01
diflufenican	27.78	266	12.5	14.5	114	5	102	5	0.01	101	4	96	2	0.01	105	9	105	5	0.01	115	5	115	7	0.01
dimepiperat	21.57	119	11.5	13.5	111	10	100	7	0.01	112	5	102	7	0.01	103	9	106	4	0.01	191	18	96	11	0.01*
dimethachlor	16.16	134	13.5	15.5	42	7	60	11	0.01*	89	21	87	18	0.05	89	6	98	4	0.01	63	4	87	16	0.05
dimethenamid	16.16	154	12.5	15.5	78	9	71	4	0.01	71	11	68	2	0.01	118	8	119	6	0.01	92	2	101	6	0.01
dimethipin[E]	13.22	118	29.5	30.5	0		0		n.d.	0		0		n.d.	0		0		n.d.	0		0		n.d.
dimethoat	12.68	87	16.5	18.5	121	8	108	7	0.05	101	16	80	3	0.01	134	44	102	32	RSD	109	10	77	16	0.01
dimethomorph	36.66/37.43	301	15.5	19.5	108	6	118	7	0.01	116	7	99	5	0.01	112	7	106	5	0.01	106	4	106	4	0.01
dimoxystrobin	28.72	116	12.5	14.5	106	4	99	8	0.01	103	9	94	4	0.01	107	6	108	8	0.01	202	31[A]	130	10	0.05*
dioxathion	13.52	97	11.5	13.5	99	7	100	6	0.01	80	8	78	6	0.01	124	18	118	12	0.01*	105	4	95	12	0.01
diphenylamin	10.58	167	13.5	15.5	75	7	68	6	0.01	95	8	83	7	0.01	85	13	96	5	0.01	98	13	100	6	0.01
disulfoton	14.54	88	11.5	13.5	58	5	35	9	0.01*	93	26	74	8	0.05	93	7	99	6	0.01	58	10	47	7	0.01*
disulfoton-sulfon	22.95	125	15.5	17.5	206	41[A]	161	27[A]	RSD	112	17	117	7	0.01	158	28[A]	118	6	0.05*	89	7	88	14	0.01
ditalimfos	23.18	130	13.5	16.5	38	24	26	17	0.05*	26	16	34	11	0.01*	35	16	28	5	0.01*	41	11	41	11	0.01*
DMSA	11.22	108	16.5	19.5	115	12	124	6	0.01	108	9	127	16	0.01	105	8	99	3	0.01	116	14	125	5	0.01
DMST	13.45	106	15.5	18.5	103	11	85	50	0.01	83	8	79	4	0.01	0[B]		0[B]		n.d.	114	26	80	48	RSD
endosulfan-sulfate	26.77	237	17.5	21.5	115	10	112	6	0.01	214	125	109	5	0.05*	97	11	96	10	0.01	0[B]		89	10	0.05*

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	HR-GPC elution time to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
endrin	24.78	263	13.5	14.5	97	7	111	6	0.01	86	9	93	4	0.01	121	6	103	4	0.01	100	17	111	5	0.01
endrin ketone	28.24	317	13.5	19.5	109	8	107	6	0.01	106	6	108	3	0.01	121	7	107	5	0.01	114	3	112	5	0.01
EPN	28.66	157	14.5	16.5	119	19	142	17	0.05*	86	5	99	2	0.01	143	9	106	2	0.01*	100	7	121	8	0.01
epoxiconazol	28.03	192	15.5	17.5	90	6	86	9	0.01	86	7	108	4	0.01	105	9	101	16	0.01	95	6	95	17	0.01
EPTC	6.87	128	10.5	12.5	42	11	26	14	0.01*	30	28	31	9	0.05*	33	13	28	9	0.01*	0 ᴮ⁾		27	18	n.d.
esfenvalerat	34.72	167	12.5	13.5	92	9	95	5	0.01	107	5	105	2	0.01	103	9	71	3	0.01	102	6	69	8	0.01
ethion	25.99	231	11.5	12.5	104	7	84	3	0.01	112	10	90	4	0.01	91	4	73	2	0.01	101	2	93	5	0.01
ethofenprox	33.18	135	10.5	12.5	111	3	79	4	0.01	101	10	96	6	0.01	80	15	67	7	0.01	90	13	102	9	0.01
ethofumesate	18.29	161	13.5	16.5	80	16	66	10	0.01	87	10	86	4	0.01	94	9	94	4	0.01	75	2	72	7	0.01
ethoprophos	10.75	158	10.5	12.5	103	7	64	4	0.01	49	7	73	4	0.01*	91	11	114	5	0.01	79	6	84	11	0.01
ethoxyquin	12.83	174	11.5	13.5	39	6	39	25	0.01*	73	29	72	12	0.05	111	18	116	28	0.01	8	14	42	15	0.05*
etoxazol	29.09	204	10.5	12.5	83	8	93	9	0.01	83	8	82	5	0.01	106	15	94	6	0.01	109	17	112	7	0.01
etrimfos	15.14	181	11.5	12.5	90	11	74	6	0.01	98	7	77	3	0.01	101	10	117	3	0.01	96	12	101	6	0.01
famoxadon	36.81	197	17.5	20.5	99	4	127	9	0.01	87	10	109	7	0.01	115	11	116	5	0.01	97	4	102	7	0.01
famphur	26.64	125	18.5	20.5	109	6	101	3	0.01	134	8	103	12	0.05	123	4	107	2	0.05	95	5	83	6	0.01
fenamiphos	23.57	154	11.5	14.5	162	8	118	3	0.05*	94	9	106	2	0.01	105	13	112	3	0.01	106	9	75	78	0.01
fenarimol	30.42	139	13.5	16.5	112	5	107	4	0.01	100	2	106	4	0.01	104	5	110	2	0.01	104	5	109	5	0.01
fenbuconazol	32.19	129	15.5	19.5	111	4	103	5	0.01	95	6	104	3	0.01	112	4	121	3	0.01	111	3	105	5	0.01
fenchlorphos	17.32	285	11.5	13.5	69	7	68	6	0.01*	86	3	79	3	0.01	94	9	92	4	0.01	100	5	102	7	0.01
fenhexamid ᴳ⁾	26.89	97	11.5	14.5	0	10	20		n.d.	0		5	29	n.d.	0		0		n.d.	0		0		n.d.
fenitrothion	18.03	260	14.5	17.5	192	9	152	5	0.01*	107	8	109	3	0.01	124	13	130	5	0.01*	139	9	155	11	0.01*
fenoxaprop-ethyl	30.98	288	12.5	14.5	98	8	96	6	0.01	102	6	94	5	0.01	107	6	93	4	0.01	97	3	96	5	0.01
fenpropathrin	28.97	97	11.5	13.5	128	8	104	9	0.05	107	14	110	6	0.01	105	16	113	23	0.01	116	12	99	12	0.01
fenpropidin	17.60	98	12.5	13.5	37	18	29	12	0.01*	28	33	55	18	0.05*	112	3	107	9	0.01	108	17	79	11	0.01

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
fenpropimorph[F]	19.17	128	10.5	12.5	0		1	29	n.d.	0		1	9	n.d.	0		0		n.d.	0		0		n.d.
fenson	19.66	141	14.5	17.5	100	12	90	4	0.01	86	10	93	11	0.01	158	18[A]	149	22[A]	0.01*	93	4	107	4	0.01
fensulfothion	25.63	293	14.5	16.5	169	5	119	6	0.05*	111	7	118	8	0.01	121	5	113	3	0.01	128	9	154	8[A]	0.01*
fenthion	19.16	125	13.5	15.5	94	6	94	5	0.01	99	11	86	5	0.01	125	17	103	6	0.05	48	16	116	4	0.05
flamprop-isopropyl	25.80	77	11.5	13.5	99	7	85	7	0.01	92	5	87	6	0.01	109	8	109	4	0.01	100	14	103	17	0.01
flamprop-methyl	24.49	77	13.5	15.5	112	12	111	4	0.01	102	6	112	2	0.01	110	7	132	6[A]	0.05*	147	8[A]	119	10	0.01*
fluazifop-butyl	25.37	282	10.5	12.5	101	3	95	6	0.01	96	5	93	4	0.01	106	7	91	3	0.01	114	6	119	7	0.01
flucythrinat	33.14/33.47	199	12.5	14.5	103	10	109	8	0.01	79	7	84	4	0.01	104	7	101	3	0.01	107	8	103	8	0.01
fludioxonil	24.22	154	13.5	16.5	117	10	91	6	0.01	112	3	104	4	0.01	114	6	93	2	0.01	108	7	103	9	0.01
flufenacet	19.72	123	12.5	14.5	116	3	112	4	0.01	110	5	110	5	0.01	101	5	109	15	0.01	124	6	119	8	0.01*
fluopicolid	27.42	209	14.5	16.5	104	5	93	7	0.01	93	6	92	5	0.01	83	21	59	29[C]	RSD	113	14	145	14[C]	0.05*
fluotrimazol	27.99	311	11.5	14.5	102	6	91	4	0.01	107	6	96	2	0.01	114	7	110	3	0.01	102	6	102	6	0.01
fluquinconazol	31.67	340	16.5	19.5	91	7	90	6	0.01	98	4	90	4	0.01	121	8	108	3	0.05	99	3	97	6	0.01
flurochloridone	20.00	311	14.5	17.5	147	16	117	3	0.05*	95	3	107	9	0.01	117	12	96	19	0.01	108	11	116	10	0.01
fluroxypyr-1-methylheptylester	27.77	209	11.5	12.5	97	6	100	6	0.01	92	4	97	4	0.01	110	20	90	22	0.01	97	11	113	11	0.01
flurtamon	29.64	120	13.5	15.5	175	13	114	4	0.05*	109	6	107	1	0.01	128	8	118	3	0.01*	94	7	107	6	0.01
flusilazole	24.61	233	13.5	15.5	86	9	80	3	0.01	105	4	93	4	0.01	102	2	91	2	0.01	98	7	93	6	0.01
flutriafol	23.20	123	15.5	17.5	151	12	114	5	0.05*	101	6	95	3	0.01	103	11	101	4	0.01	153	11[A]	132	8	0.01*
fluvalinate	34.87	250	11.5	13.5	108	5	116	7	0.01	124	20	108	4	0.05	86	9	74	5	0.01	77	9	65	6	0.01
folpet	21.70	260	17.5	19.5	7	34	13	18	n.d.	30	36	47	23	RSD	82	20	72	8	0.01	9	21	35	22	n.d.
fonofos	13.83	109	12.5	14.5	71	8	52	18	0.01*	78	10	75	3	0.01	105	9	108	3	0.01	99	8	96	9	0.01
formothion	15.57	125	20.5	22.5	88	9	68	6	0.01	54	19	61	19	0.01*	89	8	83	6	0.01	0[B]		94	13	0.05*
fosthiazate	20.21	166	13.5	15.5	173	4[A]	155	6[A]	0.01*	126	11	109	5	0.05	198	38[A]	134	5	0.05*	204	9[A]	177	8	0.01*

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	HR-GPC elution time to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	0.01 mg kg⁻¹ RSD	0.05 mg kg⁻¹ REC	0.05 mg kg⁻¹ RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	0.01 mg kg⁻¹ RSD	0.05 mg kg⁻¹ REC	0.05 mg kg⁻¹ RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	0.01 mg kg⁻¹ RSD	0.05 mg kg⁻¹ REC	0.05 mg kg⁻¹ RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	0.01 mg kg⁻¹ RSD	0.05 mg kg⁻¹ REC	0.05 mg kg⁻¹ RSD	LOQ mg kg⁻¹
fluberidazole	16.67	184	14.5	16.5	67	12	63	5	0.01*	92	5	107	8	0.01	111	11	86	17	0.01	22	24	101	7	0.05*
Furalaxyl	21.85	152	13.5	15.5	96	8	91	15	0.01	85	12	106	13	0.01	104	8	112	3	0.01	81	11	89	20	0.01
halfenprox	32.78	183	10.5	12.5	83	8	85	4	0.01	111	4	98	7	0.01	76	10	68	8	0.01	86	5	86	4	0.01
haloxyfop-2-ethoxyethyl	28.10	302	11.5	12.5	83	7	78	3	0.01	102	8	79	6	0.01	89	12	75	12	0.01	98	3	93	6	0.01
haloxyfop-methyl	22.85	316	12.5	14.5	95	7	92	6	0.01	105	3	96	3	0.01	102	6	88	2	0.01	103	6	101	7	0.01
α-HCH	12.11	183	14.5	17.5	75	9	68	4	0.01	79	3	85	4	0.01	119	19	127	30	RSD	88	3	89	7	0.01
β-HCH	13.41	183	14.5	19.5	97	2	98	5	0.01	100	5	112	2	0.01	307	9^A)	232	41^A)	0.01*	204	11^A)	210	9^A)	0.01*
δ-HCH	14.76	219	15.5	19.5	90	10	90	7	0.01	87	3	103	11	0.01	111	8	101	4	0.01	79	3	71	4	0.01
heptachlor	16.75	270	11.5	13.5	65	9	67	14	0.01*	105	9	81	5	0.01	95	11	91	7	0.01	71	8	91	6	0.01
heptachlor-epoxid	20.70/20.95	353	12.5	15.5	63	16	62	5	0.01*	107	13	84	12	0.01	101	7	96	4	0.01	81	4	87	9	0.01
heptenophos	9.72	124	12.5	14.5	88	11	68	5	0.01	56	7	56	7	0.01*	102	10	105	5	0.01	100	3	97	9	0.01
hexachlorobenzene	12.37	282	11.5	13.5	44	10	36	4	0.01*	52	4	40	5	0.01*	61	10	50	18	0.01*	52	5	58	6	0.01*
hexaconazole	23.53	214	12.5	14.5	90	9	80	2	0.01	92	6	103	7	0.01	91	11	95	12	0.01	57	12	59	8	0.01*
iodofenphos	23.56	377	12.5	14.5	117	7	103	5	0.01	86	5	101	4	0.01	101	8	83	3	0.01	122	6	99	7	0.05
iprodione	28.44	187	12.5	14.5	80	17	78	3	0.01	80	4	81	5	0.01	111	11	82	9	0.01	61	9	53	14	0.01*
isodrin	20.02	193	11.5	13.5	74	16	85	5	0.01	95	13	68	6	0.01	111	8	106	9	0.01	102	15	105	7	0.01
isofenphos	21.54	185	11.5	14.5	98	6	95	7	0.01	87	3	94	2	0.01	94	6	94	6	0.01	85	11	103	5	0.01
isofenphos-methyl	20.70	199	11.5	13.5	78	7	83	8	0.01	73	6	96	5	0.01	107	8	111	3	0.01	89	4	102	9	0.01
isoprothiolan	23.84	162	13.5	15.5	108	6	98	5	0.01	98	8	92	3	0.01	112	7	108	6	0.01	100	5	102	5	0.01
isoxadifen-ethyl	26.58	165	13.5	16.5	116	3	109	4	0.01	110	6	103	3	0.01	104	11	108	6	0.01	112	9	114	5	0.01
kresoxim-methyl	24.92	116	12.5	14.5	102	8	104	7	0.01	104	5	97	5	0.01	121	10	112	2	0.05	148	8^A)	124	7	0.01*
leptophos	29.74	171	11.5	13.5	103	8	95	3	0.01	117	6	95	3	0.01	84	9	98	3	0.01	93	3	82	6	0.01
lindane	13.48	181	15.5	19.5	78	5	57	9	0.01*	84	5	57	6	0.01	245	9^A)	263	4^A)	0.01*	207	11^A)	184	5^A)	0.01*
linuron	18.23	160	13.5	15.5	194	19^A)	227	22^A)	0.01*	92	5	109	8	0.01	124	6	115	4	0.05	140	9^A)	128	10	0.01*

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC from [min]	HR-GPC to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
malaoxon	16.88	127	13.5	15.5	115	4	121	4	0.01	75	9	74	17	0.01	113	4	113	7	0.01	122	22	150	14[A]	0.05*
malathion	18.77	125	12.5	13.5	91	16	108	5	0.01	89	9	84	12	0.01	114	15	124	12	0.01	89	7	92	7	0.01
MCPA, 2-ethylhexyl	22.96	200	10.5	12.5	88	5	85	5	0.01	88	8	82	5	0.01	93	10	79	6	0.01	116	7	113	8	0.01
mecarbam	21.77	131	12.5	14.5	107	16	106	12	0.01	122	8	98	6	0.05	119	7	119	11	0.01	114	10	120	9	0.01
mefenpyr-diethyl	28.32	253	12.5	14.5	103	7	93	6	0.01	91	6	89	4	0.01	118	9	113	3	0.01	112	9	116	7	0.01
mepanipyrim	23.20	221	14.5	16.5	101	13	109	11	0.01	110	7	107	6	0.01	105	13	105	6	0.01	119	22	116	8	0.05
metalaxyl	17.32	206	13.5	15.5	70	9	80	3	0.01	96	11	87	5	0.01	136	25	112	15	0.05*	170	24[A]	116	2	0.05*
metazachlor	20.80	132	15.5	17.5	72	8	64	4	0.01*	87	9	95	4	0.01	103	3	89	2	0.01	98	4	82	5	0.01
metconazol	29.11	138	13.5	14.5	81	10	107	2	0.01	119	9	117	4	0.01	0[A]		109	14	0.05*	82	19	94	17	0.01
methacrifos	8.55	180	12.5	14.5	59	13	44	6	0.01*	78	9	58	8	0.05*	110	6	113	2	0.01	110	3	82	6	0.01
methamidophos[G]	5.73	94	16.5	18.5	0		46	12	0.05*	19	104	45	24	RSD	0		29	13	n.d.	0		27	16	n.d.
methidathion	22.30	145	15.5	17.5	132	11	137	6	0.01*	94	12	104	4	0.01	109	3	84	2	0.01	121	4	130	10	0.05*
methoxychlor	28.93	228	13.5	15.5	94	14	80	16	0.01	86	2	87	5	0.01	85	48	90	29	RSD	116	12	116	7	0.01
metolachlor	18.84	162	12.5	14.5	95	6	91	5	0.01	79	9	84	2	0.01	149	10[A]	142	2[A]	0.01*	110	5	111	6	0.01
metribuzin	16.38	198	16.5	18.5	91	3	98	8	0.01	78	9	90	6	0.01	119	15	100	22	0.01	84	15	108	5	0.01
mevinphos	7.62	127	13.5	15.5	24	14	30	7	0.01*	38	9	43	16	0.01*	100	8	72	4	0.01	99	6	111	6	0.01
molinat	9.11	55	11.5	13.5	35	17	29	9	0.01*	54	19	47	13	0.01*	98	9	132	6	0.01	78	20	79	19	0.01
monalid	15.57	127	11.5	13.5	82	8	101	8	0.01	74	10	93	7	0.01	134	5	130	5	0.01*	103	12	111	4	0.01
monocrotophos	11.75	109	14.5	15.5	271	18[A]	355	9[A]	0.01*	249	18[A]	276	11[A]	0.01*	104	12	92	4	0.01	153	5[A]	82	50	RSD
monolinuron	13.13	126	14.5	15.5	47	9	47	14	0.01*	68	20	71	6	0.01	78	3	77	7	0.01	87	7	96	5	0.01
myclobutanil	24.49	179	14.5	16.5	103	7	104	12	0.01	101	5	90	4	0.01	114	7	109	6	0.01	91	13	101	14	0.01
naled	11.21	109	14.5	15.5	0		0		n.d.	0		0		n.d.	0		0		n.d.	0		0		n.d.
nitrofen	24.88	202	13.5	16.5	105	8	112	6	0.01	89	6	83	11	0.01	125	29	103	33	RSD	107	13	88	9	0.01
nuarimol	27.46	107	14.5	16.5	108	12	95	8	0.01	95	9	100	3	0.01	140	30[C]	89	16	0.05	105	9	108	6	0.01

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
omethoate	10.02	110	12.5	21.5	49	15	57	11	0.01*	41	18	44	7	0.01*	83	10	36	5	0.05*	87	23	60	8	0.05
o-phenylphenol	8.84	141	13.5	15.5	68	10	50	5	0.01*	119	14	88	3	0.01	96	20	96	10	0.01	70	8	73	7	0.01
oxadiazon	24.41	302	10.5	12.5	77	6	75	3	0.01	89	9	85	3	0.01	85	4	76	3	0.01	101	2	94	6	0.01
oxyfluorfen	24.73	252	12.5	14.5	109	7	125	7	0.01	106	8	91	6	0.01	143	44^C)	99	10	0.05*	70	23	64	18	0.05*
paraoxon	17.34	109	14.5	16.5	230	34^A)	205	16^A)	0.05*	95	6	123	10	0.01	160	9^A)	162	13^A)	0.01*	117	18	129	15	0.05*
paraoxon-methyl	14.56	109	15.5	19.5	199	31^A)	268	30^A)	RSD	103	10	91	9	0.01	264	37^A)	163	20^A)	0.05*	96	10	102	6	0.01
parathion-ethyl	19.32	109	13.5	15.5	98	9	107	8	0.01	102	6	103	8	0.01	125	11	105	7	0.05	122	12	127	13	0.01*
parathion-methyl	16.59	109	15.5	19.5	155	13^A)	135	12^A)	0.01*	91	18	94	3	0.01	124	17	114	6	0.05	163	21^A)	173	20^A)	0.01*
PBO	27.94	176	10.5	12.5	96	14	90	9	0.01	96	9	89	4	0.01	109	7	96	5	0.01	103	5	114	7	0.01
PCB 101	22.68	324	11.5	13.5	84	7	86	7	0.01	97	8	94	5	0.01	82	16	68	11	0.01	113	6	86	3	0.01
PCB 118	25.44	326	11.5	13.5	99	6	100	7	0.01	108	4	102	3	0.01	80	10	78	4	0.01	89	6	72	4	0.01
PCB 138	27.19	360	11.5	13.5	96	4	97	8	0.01	105	4	97	2	0.01	70	10	73	5	0.01	84	5	72	3	0.01
PCB 153	26.27	360	11.5	13.5	109	4	113	6	0.01	117	3	114	3	0.01	78	7	76	11	0.01	85	5	75	5	0.01
PCB 180	29.27	360	11.5	13.5	104	7	104	8	0.01	87	5	93	7	0.01	104	16	86	5	0.01	103	6	82	7	0.01
PCB 28	16.20	256	11.5	13.5	67	8	63	7	0.01*	85	15	70	5	0.01	81	9	86	4	0.01	91	7	77	4	0.01
PCB 52	17.98	290	11.5	13.5	71	7	67	8	0.01*	88	16	77	6	0.01	89	8	92	4	0.01	100	7	81	4	0.01
penconazole	21.03	248	12.5	14.5	77	6	73	3	0.01	94	7	85	5	0.01	108	3	88	4	0.01	94	3	91	6	0.01
pencycuron	11.63	125	13.5	14.5	77	18	58	9	0.01*	95	6	88	6	0.01	108	8	106	10	0.01	68	4	59	14	0.01*
pendimethalin	21.03	252	12.5	13.5	99	4	106	7	0.01	102	9	104	7	0.01	121	11	104	3	0.01	128	8	130	9	0.01*
pentachloranisol	12.56	265	11.5	13.5	56	5	52	7	0.01*	82	5	59	5	0.01	92	10	89	5	0.01	99	3	82	6	0.01
pentachlorobenzol	8.98	248	11.5	13.5	37	8	29	7	0.01*	63	11	40	8	0.01*	58	9	54	6	0.01*	57	6	57	7	0.01*
pentanochlor	18.40	141	11.5	13.5	101	6	98	6	0.01	106	6	106	4	0.01	130	12	112	6	0.01*	119	6	117	5	0.01
permethrin	31.37/ 31.56	163	10.5	13.5	103	8	92	5	0.01	113	4	106	6	0.01	0^D)		44	12	0.05*	0^D)		88	9	0.05*
perthane	25.14	165	11.5	13.5	87	9	90	2	0.01	82	6	99	3	0.01	98	11	81	9	0.01	96	5	97	7	0.01

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
phenkapton	28.97	376	11.5	13.5	154	6[A]	161	7[A]	0.01*	152	5[A]	142	3[A]	0.01*	101	8	104	3	0.01	115	5	79	4	0.01
phenothrin	29.44/ 29.61	123	10.5	12.5	110	9	107	6	0.01	98	7	100	6	0.01	94	14	94	8	0.01	94	23	106	7	0.05
phenthoat	21.64	246	12.5	14.5	99	11	83	7	0.01	85	5	87	3	0.01	113	10	99	12	0.01	87	15	98	11	0.01
phorat	11.94	121	11.5	12.5	31	10	27	20	0.01*	92	9	66	12	0.01	99	8	87	8	0.01	72	21	77	5	0.05
phosalon	29.75	182	14.5	16.5	124	8	125	8	0.01*	102	7	108	4	0.01	114	6	113	5	0.01	135	13	160	14	0.01*
phosphamidon	14.37/ 16.16	109	13.5	14.5	218	14[A]	179	11[A]	0.01*	100	6	91	12	0.01	89	10	98	11	0.01	138	13	112	8	0.01*
picoxystrobin	23.75	145	12.5	14.5	92	4	93	6	0.01	108	5	98	2	0.01	106	5	95	2	0.01	91	7	105	5	0.01
pirimicarb	15.62	166	12.5	14.5	110	7	78	9	0.01	79	9	86	2	0.01	108	13	116	8	0.01	94	4	95	8	0.01
pirimiphos methyl	18.26	290	11.5	13.5	49	11	60	9	0.01*	80	9	84	9	0.01	98	7	93	4	0.01	77	6	85	7	0.01
pirimiphos-ethyl	20.63	304	10.5	12.5	55	12	67	6	0.01*	95	6	85	2	0.01	93	7	82	3	0.01	99	9	95	7	0.01
pretilachlor	24.10	162	11.5	13.5	99	7	83	4	0.01	83	5	90	12	0.01	108	5	95	12	0.01	93	3	87	8	0.01
prochloraz	31.76	180	14.5	16.5	75	8	73	3	0.01	115	6	98	7	0.01	112	3	90	4	0.01	92	12	71	6	0.01
procymidon	21.98	96	14.5	16.5	130	10	137	11	0.01*	98	5	116	4	0.01	120	12	118	4	0.01	94	14	107	6	0.01
profenofos	23.96	208	11.5	13.5	110	6	108	5	0.01	103	7	100	4	0.01	113	4	101	2	0.01	110	6	121	3	0.01
prometryn	17.34	184	11.5	13.5	109	3	102	5	0.01	93	3	99	4	0.01	117	5	131	6	0.05*	108	4	113	7	0.01
propachlor	10.34	120	13.5	15.5	68	11	56	5	0.01*	56	6	53	5	0.01*	104	9	105	2	0.01	89	9	79	7	0.01
propanil	16.27	161	11.5	14.5	119	5	117	6	0.01	124	7	118	4	0.01	111	7	112	3	0.01	115	14	111	4	0.01
propaquizafop	40.56	299	12.5	14.5	121	6	115	15	0.01	73	5	99	10	0.01	125	11	112	9	0.05	119	10	115	6	0.01
propargite	27.72	173	11.5	13.5	155	9	141	13	0.01*	81	11	118	3	0.01	110	5	94	4	0.01	107	12	107	3	0.01
propazine	13.40	214	12.5	14.5	65	5	67	5	0.01*	108	17	104	11	0.01	109	31	134	27	RSD	82	10	105	7	0.01
propetamphos	13.96	194	11.5	13.5	66	9	79	8	0.05	62	15	63	6	0.01*	126	9	128	3	0.01*	117	4	105	6	0.01
propham	7.98	137	12.5	14.5	48	11	57	15	0.01*	100	13	107	14	0.01	111	7	116	3	0.01	105	15	89	14	0.01
propiconazol	26.98/ 27.19	173	13.5	14.5	114	8	101	16	0.01	96	9	102	4	0.01	112	11	107	11	0.01	122	13	120	8	0.01*

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
propyzamide	14.01	173	12.5	14.5	80	23	74	20	0.05	74	12	92	3	0.01	104	33	95	35	RSD	99	15	101	4	0.01
prothiofos	23.75	267	10.5	12.5	73	8	69	4	0.01	86	15	80	4	0.01	64	5	65	4	0.01*	89	6	91	5	0.01
prothoat	16.54	115	12.5	14.5	109	8	110	7	0.01	98	9	96	5	0.01	245	58⁾ᴬ⁾	158	17⁾ᴬ⁾	0.05*	138	8⁾ᴬ⁾	93	5	0.05
pyraclostrobine	34.41	132	13.5	15.5	121	8	137	4	0.01*	116	2	120	4	0.01	129	9	112	4	0.01*	100	6	99	5	0.01
pyrazophos	30.69	221	12.5	14.5	116	5	105	6	0.01	114	2	118	2	0.01	121	8	100	3	0.01	111	6	96	5	0.01
pyridaben	31.51	147	11.5	13.5	116	2	106	5	0.01	106	4	91	3	0.01	84	9	91	8	0.01	102	6	112	3	0.01
pyridaphenthion	28.52	188	14.5	15.5	122	29	95	8	0.05	114	6	119	6	0.01	117	10	113	12	0.01	94	8	102	6	0.01
pyrifenox	21.16/22.58	262	12.5	14.5	115	6	101	4	0.01	108	4	106	4	0.01	108	9	110	4	0.01	112	6	109	8	0.01
pyrimethanil	14.16	198	13.5	15.5	44	7	42	4	0.01*	59	26	80	6	0.05	111	25	89	38	RSD	91	10	96	11	0.01
quinalphos	21.64	146	12.5	14.5	71	8	73	4	0.01	100	6	79	5	0.01	101	6	90	3	0.01	98	5	85	5	0.01
quinoxyfen	26.85	237	12.5	14.5	106	4	99	5	0.01	102	5	101	4	0.01	117	3	101	4	0.01	115	6	120	7	0.01
quintozen	13.73	237	13.5	17.5	72	8	72	6	0.01	109	6	73	2	0.01	102	4	106	5	0.01	108	3	96	7	0.01
quizalofop-ethyl	32.99	299	12.5	14.5	96	4	90	7	0.01	78	5	81	4	0.01	105	9	102	8	0.01	132	9	112	8	0.01*
resmethrin	27.79/27.99	123	10.5	12.5	0⁾ᴮ⁾		16	24	n.d.	115	10	109	6	0.01	78	11	95	6	0.01	73	15	70	10	0.01
rotenon	41.69	191	17.5	19.5	116	15	73	1	0.01	0⁾ᴰ⁾		161	6	0.05	0⁾ᴰ⁾		79	7	0.05*	0⁾ᴰ⁾		91	13	0.05*
simazin	12.95	186	13.5	15.5	72	5	98	7	0.01	90	8	86	17	0.01	100	13	122	28	0.01	127	6	102	5	0.05
spirodiclofen	31.35	312	11.5	13.5	58	17	42	12	0.01*	79	7	74	5	0.01	109	11	94	11	0.01	103	8	78	10	0.01
sulfotep	11.82	202	10.5	12.5	47	15	67	7	0.01*	70	6	64	9	0.05*	116	6	110	6	0.01	89	9	69	10	0.01
tebuconazole	27.47	250	12.5	15.5	108	7	90	2	0.01	111	7	92	10	0.01	123	40	74	29	RSD	88	15	98	9	0.01
tebufenpyrad	29.08	171	10.5	12.5	88	6	82	5	0.01	98	4	105	4	0.01	100	6	85	8	0.01	117	13	94	6	0.01
tecnazene	10.26	203	13.5	15.5	47	49	47	6	0.05*	87	7	46	7	0.05*	111	5	85	6	0.01	78	4	75	5	0.01
tefluthrine⁾ᶠ⁾	15.03	177	10.5	11.5	38	15	24	33	0.01*	17	3	18	8	n.d.	21	15	20	6	0.01*	21	8	24	6	0.01*
terbacil	14.78	160	13.5	15.5	202	10⁾ᴬ⁾	168	3⁾ᴬ⁾	0.01*	142	9⁾ᴬ⁾	152	5⁾ᴬ⁾	0.01*	126	10	121	3	0.01*	148	12⁾ᴬ⁾	166	6	0.01*

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC from [min]	HR-GPC to [min]	Veg. mix 0.01 mg kg^{-1} REC	RSD	Veg. mix 0.05 mg kg^{-1} REC	RSD	LOQ mg kg^{-1}	OJ 0.01 mg kg^{-1} REC	RSD	OJ 0.05 mg kg^{-1} REC	RSD	LOQ mg kg^{-1}	HIFA 0.01 mg kg^{-1} REC	RSD	HIFA 0.05 mg kg^{-1} REC	RSD	LOQ mg kg^{-1}	Oat 0.01 mg kg^{-1} REC	RSD	Oat 0.05 mg kg^{-1} REC	RSD	LOQ mg kg^{-1}
terbufos	13.77	231	10.5	12.5	57	6	47	20	0.01*	71	4	86	18	0.01	83	7	77	9	0.01	74	4	82	9	0.01
terbufos-sulfone	21.00	153	13.5	15.5	108	7	105	6	0.01	121	4	105	2	0.05	112	4	104	2	0.01	123	6	121	3	0.01*
terbuthylazine	13.84	214	12.5	14.5	72	8	72	6	0.01	58	8	77	5	0.01*	103	7	108	3	0.01	106	3	90	7	0.01
terbutryn	17.99	226	11.5	13.5	81	9	82	15	0.01	88	12	87	12	0.01	111	23	97	22	RSD	104	5	99	8	0.01
tetrachlorvinphos	22.92	329	13.5	15.5	192	5	151	6	0.01*	112	5	106	5	0.01	122	7	120	2	0.01*	107	5	119	6	0.01
tetraconazol	19.90	336	13.5	15.5	101	7	99	9	0.01	96	4	97	4	0.01	122	9	114	3	0.05	116	2	109	5	0.01
tetradifon	29.41	159	14.5	17.5	74	9	70	7	0.01	80	7	99	4	0.01	72	12	85	6	0.01	124	10	104	5	0.05
tetrahydrophthalimide (THPI)	8.31	151	17.5	22.5	112	18	141	6	0.05*	89	5	116	8	0.01	108	10	115	4	0.01	153	22[A]	178	19[A]	0.05*
tetramethrin	28.86/28.64	123	11.5	13.5	104	5	105	7	0.01	97	8	96	7	0.01	110	7	108	9	0.01	111	18	111	3	0.01
tetrasul	26.07	252	11.5	13.5	97	9	96	11	0.01	85	3	83	5	0.01	57	10	57	7	0.01*	101	3	101	5	0.01
thiamethoxam	20.08	182	11.5	14.5	109	7	99	30	0.01	102	11	108	16	0.01	84	15	104	34	0.01	197	27[C]	234	42[C]	RSD
thiobencarb	18.58	100	11.5	13.5	69	7	68	6	0.01*	83	4	80	3	0.01	105	7	86	3	0.01	87	5	108	6	0.01
thionazin	10.25	143	12.5	15.5	68	13	67	4	0.01*	78	5	98	7	0.01	109	9	158	9	0.05*	91	9	111	2	0.01
tolclofos-methyl	16.76	265	12.5	14.5	79	13	72	8	0.01	69	17	75	6	0.05	132	12[A]	138	5[A]	0.01*	103	4	102	10	0.01
tolylfluanid	21.23	238	14.5	15.5	0[B]		0[B]		n.d.	66	13	72	5	0.01*	82	12	95	22	0.01	31	22[D]	27	27[D]	RSD
triadimefon	19.44	208	12.5	15.5	89	6	89	8	0.01	131	6	95	10	0.05	107	13	85	8	0.01	140	16	204	9	0.01*
triadimenol	21.72/22.14	112	12.5	14.5	134	8	115	8	0.05*	158	11	123	6	0.01*	126	18	106	4	0.05	128	10	121	3	0.01*
tri-allate	14.96	86	10.5	12.5	78	11	86	10	0.01	96	10	64	4	0.01	116	3	109	6	0.01	97	9	90	8	0.01
triamiphos	26.01	160	13.5	15.5	115	4	101	6	0.01	103	8	103	4	0.01	0[D]		0[D]		n.d.	116	7	124	7	0.01
triazophos	26.48	313	14.5	15.5	124	5	135	7	0.01*	109	4	93	5	0.01	117	8	114	3	0.01	126	8	135	10	0.01*
trichloronat	19.80	109	10.5	12.5	68	9	61	18	0.01*	82	15	78	5	0.01	245	15	117	5	0.01*	101	5	92	6	0.01
tricyclazole	23.65	161	23.5	25.5	83	23	76	34	RSD	0[B]		0[B]		n.d.	96	10	93	11	0.01	83	10	76	12[J]	0.01
trifloxystrobin	27.26	116	11.5	13.5	122	6	110	3	0.05	116	4	97	3	0.01	87	12	91	4	0.01	98	7	111	7	0.01

Table 1 continued..

Analyte	RT [min]	Target ion [m/z]	HR-GPC elution time from [min]	HR-GPC elution time to [min]	Vegetable mix. (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Orange juice (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	HIFA (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹	Oat (n = 6) 0.01 mg kg⁻¹ REC	RSD	0.05 mg kg⁻¹ REC	RSD	LOQ mg kg⁻¹
triflumizol	22.34	278	11.5	13.5	92	28	65	14	0.05	121	6	97	5	0.01	107	21	113	16	0.05	99	9	80	11	0.01
trifluralin	11.68	306	12.5	13.5	78	10	91	7	0.01	106	7	75	4	0.01	99	11	95	6	0.01	99	3	81	7	0.01
triticonazol	29.59	217	13.5	15.5	100	10	100	8	0.01	111	6	96	6	0.01	113	11	110	9	0.01	98	13	106	6	0.01
vinclozolin	16.63	212	13.5	15.5	65	14	55	17	0.01*	89	20	75	6	0.01	96	18	92	35	0.01	81	6	87	14	0.01
zoxamide	28.06	187	13.5	15.5	95	6	89	3	0.01	125	6	104	6	0.05	113	4	82	18	0.01	81	7	53	11	0.05*

RT = retention time (GC-MS).
[A] Quantifier and/or qualifier superimposed by matrix, enhanced but evaluable signal.
[B] Quantifier and/or qualifier superimposed by matrix, not evaluable signal.
[C] recovery/RSD enhanced, peak at the end of an acquisition window, bad peak shape.
[D] n = 4.
[E] HR-GPC elution time > 25 min.
[F] HR-GPC elution time < 10.8 min.
[G] SPD susceptible.
[H] pH sensitive.
[I] no peak (<LOD).
[J] n = 2.
*) average recovery is not within 70-120%, RSD: RSD > 20%.
**) solvent standard not evaluable.
n.d. LOQ is not defined (average recovery < 20%).

elute close to the lipid fraction from GRAM HR-GPC column and were partially lost by this cleanup step. Thiocarbamates (8 pesticides) as a group of substances showed the lowest mean recoveries of 67%, ranging from 11% (butylate) to 115% (dimepiperat). Half of the thiocarbamates were not recovered with more than 70%, i.e. butylate, EPTC, cycloate, and molinate. Except molinate, they eluted with the lipid fraction from the GRAM column.

For more than 94% of the calculated recoveries the relative standard deviations (RSD, n = 6) were < 20%, which fulfil the recommendations by SANCO. The limit of quantitation (LOQ), defined as the lowest fortification limit providing recoveries of 70-120% and an RSD < 20%, differed for each matrix. For 185 (60%, vegetable mixture), 233 (75%, orange juice), 220 (71%, HIFA) and 201 (64%, oat) of the tested pesticides the LOQ was 0.01 mg kg^{-1}, based on the above definition (Table 1). In the presence of vegetable mixture, orange juice, HIFA and oat, 16, 21, 18 and 13 pesticides revealed an LOQ of 0.05 mg kg^{-1}, respectively. The rest of the pesticides did not provide recoveries of 70-120% at any tested spiking level, and therefore did not fulfil the recovery requirements of the SANCO criteria for LOQs. However, especially for multi-residue methods, recoveries outside the range are generally accepted [12]. Thus, further 75 (vegetable mixture), 33 (orange juice), 31 (HIFA) and 51 (oat) pesticides achieved an "extended" LOQ of 0.01 mg kg^{-1} based on their RSD performance. Substances with an RSD > 20% and a recovery < 20% were classified as not quantifiable. Comparing the LOQs of all four matrices, 176 pesticides provided an excellent LOQ of 0.01 mg kg^{-1} in all tested matrices.

To prove the applicability of the developed method, a FAPAS proficiency test material (milk powder) was prepared by the miniaturized sample preparation procedure and consecutively analyzed by GC-MS. Z-scores were calculated using the results provided by FAPAS (Table 2). All fortified pesticides were correctly identified and quantified with z-scores between -1.3 and 0.1. These were excellent results clearly proving the applicability for a real sample.

3.2. Method comparison

For comparison purposes, all four validation matrices were spiked at 0.01 mg kg^{-1} level and prepared by the reference method EN 12393 followed by GC-MS analyses. However, without any further cleanup after GPC on BioBeads SX-3, the oat sample extract showed immense matrix effects (superimpositions in SIM, matrix induced signal enhancement) due to the presence of fatty acids. This resulted in both too-high recoveries and false negative results for many pesticides interfering with fatty acids in the chromatograms, which did not allow a correct identification and quantification. Therefore, the oat sample could unfortunately not be used for comparison. However, it should be pointed out that especially for this matrix, the modified miniaturized method showed superior cleanup performance.

Concerning the results for the three other samples, 150 (48%) of the 309 validated pesticides showed worse recoveries as compared to the miniaturized method. For 113 pesticides (37%), recoveries were in the same range (± 10%) as obtained with the miniaturized method. Chlorothalonil, methamidophos and naled, which showed low recovery results with the miniaturized method, also revealed low recoveries with the reference method. Only 46 pesticides (15%) provided better recoveries when sample preparation was conducted following the reference method (Table 3). Pyrethroids like flucythrinate, λ-cyhalothrin and fluvalinate, which

Table 2. Results for FAPAS proficiency test material.

Pesticide	Assigned value (standard deviation) [mg kg^{-1}]	Result miniaturized method [mg kg^{-1}]	Calculated z-score
α-HCH	0.0709 (0.01560)	0.0742	0.2
chlorfenvinphos	0.0262 (0.00576)	0.0266	0.1
endosulfan-sulfate	0.0447 (0.00984)	0.0453	0.1
PCB 138	0.0317 (0.00697)	0.0224	-1.3

Table 3. Comparison of recoveries [%] for reference method (ref. method) and miniaturized method (miniat. method) fortification level 0.01 mg kg^{-1}; only shown for selected pesticides.

Pesticide	Vegetable mix.		Orange juice		HIFA		Average recoveries (vegetable mix., orange juice, HIFA)	
	Ref. method	Miniat. method	Ref. method	Miniat. method	Ref. method	Miniat. method	Ref. method	Miniat. method
	n = 1	n = 6	n = 1	n = 6	n = 1	n = 6	n = 1	n = 6
Recoveries of miniat. method better than ref. method								
benfluralin	57	74	41	95	28	66	42	78
carbaryl	1047	200	980	131	798	119	942	150
cycloate	47	33	56	37	43	88	49	53
λ-cyhalothrin	27	103	29	96	10	93	22	97
di-allate	83	64	59	103	60	84	67	84
dichlobenil	39	40	32	73	32	86	35	66
DMSA	0	115	63	108	82	105	48	109
EPTC	0	42	22	30	40	33	21	35
flucythrinat	37	103	43	79	18	104	33	95
fluvalinate	12	141	14	124	7	86	11	117
Fosthiazat	185	173	257	126	194	198	212	166
α-HCH	47	75	46	79	39	119	44	91
molinat	0	35	45	54	42	98	29	62
phorat	39	31	40	92	54	99	44	74
pyraclostrobin	134	121	178	116	189	129	167	122
tecnazen	68	47	63	87	53	111	61	81
tefluthrine	16	38	13	17	5	21	11	25
terbacil	0	202	283	142	266	126	183	157
terbufos	32	57	30	71	20	83	27	70
tetrachlorvinphos	171	192	202	112	186	122	186	142
thiamethoxam	13	109	31	102	53	84	32	98
thiobencarb	81	69	79	83	63	105	74	86
triadimenol	216	134	161	158	239	126	205	139
triflumizol	43	92	84	121	48	107	58	107
Recoveries of both methods in the same range (± 10 %)								
chlorothalonil	0	0	22	5	46	45	23	17
DDD, o-, p'-	81	97	106	89	79	89	89	92
dichlofluanid	3	0	79	70	87	83	56	51
dieldrin	111	97	110	87	83	91	102	92
fluquinconazol	90	91	116	98	98	121	101	103

Table 3 continued..

Pesticide	Vegetable mix.		Orange juice		HIFA		Average recoveries (vegetable mix., orange juice, HIFA)	
	Ref. method	Miniat. method	Ref. method	Miniat. method	Ref. method	Miniat. method	Ref. method	Miniat. method
	n = 1	n = 6	n = 1	n = 6	n = 1	n = 6	n = 1	n = 6
hexachlorbenzol	61	44	76	52	39	61	59	52
methamidophos	0	0	11	19	0	0	4	6
parathion-methyl	193	155	108	91	82	124	128	123
PCB 138	83	96	115	105	69	70	89	90
pyridaben	86	116	107	106	76	84	90	102
tri-allat	125	78	111	96	99	116	112	97
Recoveries of ref. method better than miniat. method								
butylat	39	0	27	15	22	0	29	5
crotoxyphos	112	361	94	179	390	209	199	249
dimethipin	0	0	113	0	141	0	85	0
fenhexamid	105	0	138	0	158	0	134	0
fenpropimorph	87	0	74	0	40	0	67	0
β-HCH	94	97	174	100	138	307	136	168
paraoxon	94	230	182	95	154	160	143	162

are known to have low recoveries by EN 12393, could be recovered in a satisfying range of 70-120% by the miniaturized method. For thiocarbamates, which generally showed lowest recoveries, an improvement of recovery rates could be achieved with the newly developed miniaturized method for five of the eight tested pesticides of this class (EPTC, cycloate, molinat, di-allate and thiobencarb). For several other pesticides, such as benfluralin, triflumizol, dmsa or α-HCH, the miniaturized method showed improved recoveries.

3.3. Matrix effects and cleanup efficiency

Matrix effects were not investigated by a separate experimental setup. But the number of pesticides with recoveries > 120% gives a good estimation of enhancement effects. Disregarding the results for oat, matrix enhancement effects were less pronounced with the miniaturized method. The reference method showed enhanced average recoveries for 50 pesticides at a fortification level

of 0.01 mg kg^{-1}, while the miniaturized method provided enhanced average recoveries at the same fortification level for only 31 pesticides. Out of these 50 and 31 pesticides, 10 pesticides showed enhanced recoveries for both methods (carbaryl, crotoxyphos, fosthiazat, β-HCH, paraoxon, parathion-methyl, pyraclostrobin, terbacil, tetrachlorvinphos and triadimenol; Table 3).

The advantage concerning cleanup efficiency in comparison to the reference method is the removal of di- and triacylglycerides with a chain length of > C_{14}. Furthermore, separation of sterols, which do have high boiling points and may deposit in the injection liner or on the GC column, and β-carotene by GRAM HR-GPC cleanup was observed. The total ion chromatogram obviously showed no matrix peaks at a retention time > 33 min. (Figures 3 and 4). In addition to the GPC cleanup, SPD removes further matrix compounds like free fatty acids and flavour compounds (e.g. iberin, sulphoraphone) (Figure 3).
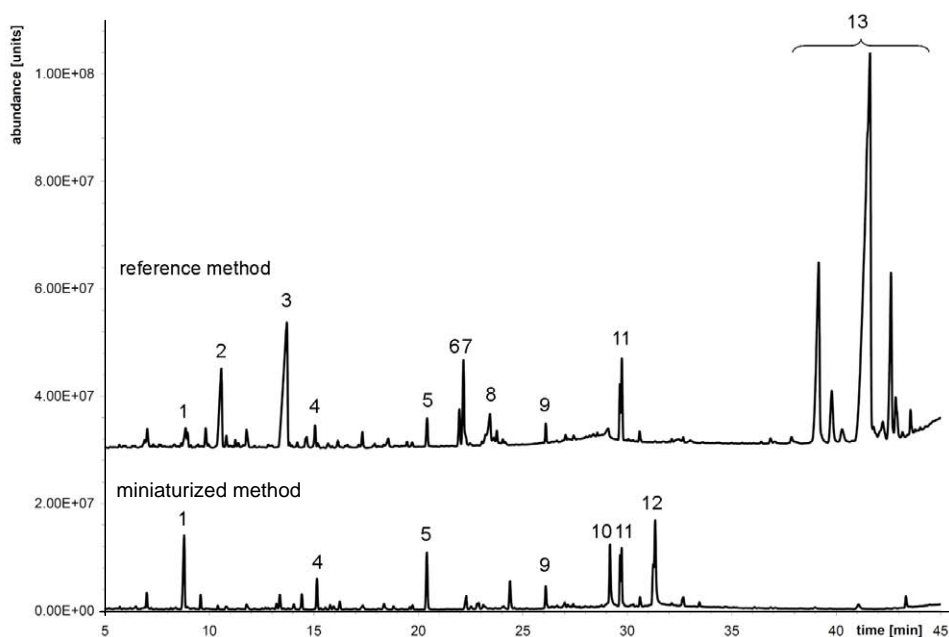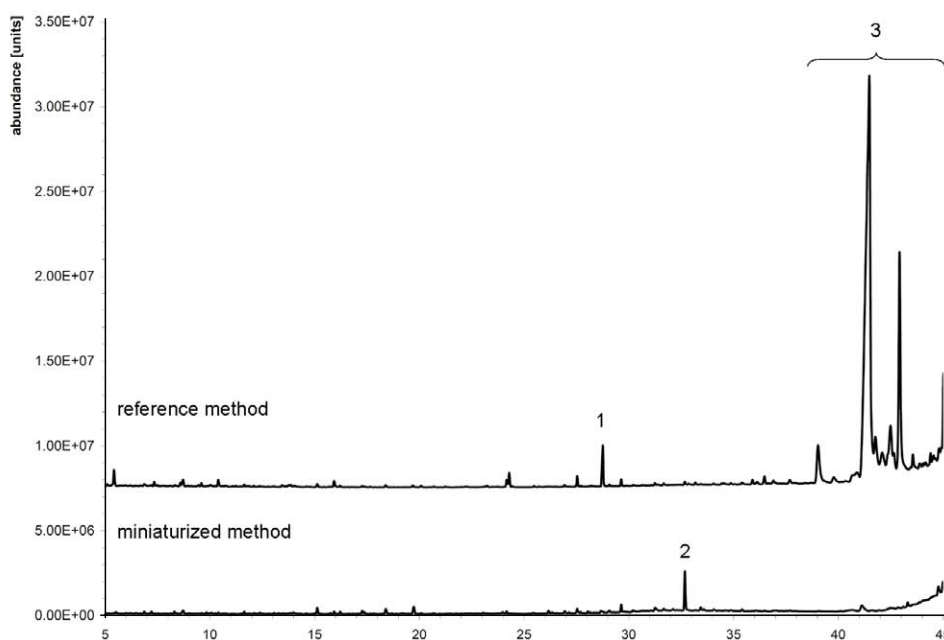
Figure 3. GC-EI-MS total ion current chromatogram of a vegetable mixture prepared by reference method (8.68 g sample mL^{-1}) and miniaturized method (3.09 g sample mL^{-1}); all compounds were identified by comparison with NIST library database with match quality (mq) of > 85%, 1 = sulphoraphone-nitril, 2 = iberin, 3 = sulphoraphone, 4 = 3,7,11,15-tetramethyl-2-hexadecen-1-ol, 5 = falcarinol, 6 = linoleic acid-methylester, 7 = linolenic acid-methylester, 8 = linoleic acid, 9 = retinal (mq = 71.2%), 10 = 2-mono-palmitin, 11 = DNOP (60%), 12 = 2-mono-linolein, 13 = phytosterols.

Figure 4. GC-EI-MS total ion current chromatogram of an apple sample prepared by reference method (8.68 g sample mL^{-1}) and miniaturized method (3.09 g sample mL^{-1}); all compounds were identified by comparison with NIST library database with match quality of > 80%, 1 = triethylene-glycol-di-2-ethylhexanoat (plasticiser), 2 = squalene, 3 = phytosterols.

3.4. Economical efficiency

As for the miniaturized method the ratio of sample weight and extraction solvent volume is 2-3 times lower than for the reference method; the final measuring solutions of the miniaturized method accordingly contain less matrix substances. Although a reduction of the respective sample amount in the final measuring solutions of the reference method can be done by dilution, the miniaturized method provides further advantages in terms of solvent consumption, costs and analysis time per sample. As compared to the original EN 12393 and the reference method, solvent consumption per sample was reduced by 59% and 56%, respectively (Table 4). Expenditures for consumables used in sample preparation, calculated based on average prices in 2010, could be reduced to less than 60% by applying the miniaturized method (Table 4). Analysis times were calculated based on the number of samples that can be processed efficiently in a shift of eight working hours, and also considering that the GPC cleanup is executed automatically over night. Due to the simultaneous extraction of samples by an automatic shaker and due to reduced solvent volumes, which speeded up evaporation and an accelerated GPC cleanup by GRAM column, 20 samples could be prepared easily in one shift by the miniaturized method, while only a maximum of 14 samples could be prepared by the reference method. This led to a reduction of analysis time per sample by 25% for extraction, partitioning and GPC cleanup (Table 5). Considering also the SPE and mini silica gel cleanup, analysis time per sample could be reduced by 45%, which allows the increase of samples prepared per shift from 14 to up to 24 samples. Fractionation on the mini silica gel columns helps in the identification of pesticides using GC-ECD/FPD/NPD systems; the miniaturized method with its selective SPD cleanup and only one single final measuring solution requires more selective GC-MS systems for analysis. However, replacing the time consuming mini silica gel cleanup by the quicker SPD cleanup saves time during sample preparation, but does not necessarily reduce runtime and time for evaluation of the chromatograms as only a limited number of analytes can be covered by

Table 4. Comparison of solvent consumption and material costs per sample for different modifications of EN 12393-N, material costs including solvents and salts, and GPC and SPE cleanup columns.

	Solvent consumption [mL]			Material costs [€]		
	EN 12393	Mod. EN 12393 (reference method)	Miniat. EN 12393	EN 12393	Mod. EN 12393 (reference method)	Miniat. EN 12393
Extraction & partitioning	380	375	38	15.4	15.2	1.5
GPC sample prep. & cleanup	195	210	197	8.4	8.6	9.8
SPE or mini silica gel cleanup	66	38	25	2.3	1.47	2.72
Sum	**641**	**623**	**260**	**26.1**	**25.3**	**14.0**

Table 5. Comparison of analysis and hands on times for different modifications of EN 12393-N.

	Analysis time [min]		Hands on time [min]	
	Mod. EN 12393 (reference method)	Miniaturized EN 12393	Mod. EN 12393 (reference method)	Miniaturized EN 12393
Extraction & partitioning	21.7	12.0	11.7	4.8
GPC sample prep. & cleanup	66.5	50.5	2.5	2.5
SPE or mini silica gel cleanup	58.8	18.3	58.8	18.3
Sum	**147**	**80.8**	**73**	**25.5**

SIM GC-MS methods and repeated injection of the same sample is required.

In summary, due to the acceleration of sample preparation and the possibility of simultaneous extraction of a number of samples, sample throughput could be increased by up to 70%, resulting in a throughput of 24 samples, while solvent consumption and expenditures per sample were reduced. Finally, the high cleanup efficiency allowed calibration with solvent standards instead of matrix-matched standards.

4. CONCLUSIONS

The described miniaturized multi-pesticide residue method based on EN 12393-2/N methodology greatly excels the original method in solvent consumption, costs and analysis time. The method was validated for more than 300 pesticides on different representative matrices (high fat infant milk formula base powder (HIFA), a vegetable mixture, orange juice and oat flour). Recoveries were obtained in the range of 70-120% for more than 240 pesticides fortified to HIFA and orange juice as well as for more than 200 pesticides fortified to vegetable mixture and oat flour. As compared to the reference method, 263 pesticides showed better or the same average recoveries at a fortification level of 0.01 mg kg^{-1}. Besides other pesticides, improvements were mainly obtained for pyrethroids and thiocarbamates. Only eight of the tested pesticides showed low (< 20%) or no recoveries; six of them were affected by the new GPC and/or SPE cleanup. The performance of the miniaturized method was also validated by analyzing a FAPAS proficiency test material, when pesticides were identified and quantified with z-scores between -1.3 and 0.1. Limits of quantitation of 0.01 mg kg^{-1} were obtained for 185 to 201 pesticides, depending on the matrix, with recoveries of 70-120%. Due to the easy and automated sample preparation procedure, the developed method is suitable for high-throughput analysis of all kind of food products, clearly saving cost of consumables and time of analysis. Especially for laboratories with a high sample throughput, the developed method provides, complementary to other extraction methods like QuEChERS, a robust and reliable procedure for GC-amenable pesticides in complex and fatty matrices.

CONFLICT OF INTEREST STATEMENT

The authors of this publication declare that there are no conflicts of interest.

REFERENCES

1. Tomlin, C. D. S. The Pesticide Manual – Fourteenth Edition, 2006, British Crop Production Council, Alton, Hampshire, UK.
2. Regulation (EC) No. 396/2005 of the European Parliament and of the council of 23 Februrary 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin amending Council Directive 91/414/EEC, 2005, Official Journal of the European Union, L 70, 1.
3. Ambrus, A. and Thier, H. P. 1986, Pure Appl. Chem., 58, 1035.
4. Sannino, A. 2008, Compr. Anal. Chem., 51, 258.
5. EN 12393-1 Foods of plant origin – Multiresidue methods for the gas chromatographic determination of pesticide residues – Part 1: General considerations. 2008, European Committee for Standardisation, Brussels, Belgium.
6. EN 12393-2 Foods of plant origin: Multiresidue methods for the gas chromatographic determination of pesticide residues – Part 2: Methods for extraction and clean-up. 2009, European Committee for Standardisation, Brussels, Belgium.
7. EN 12393-3 Foods of plant origin – Multiresidue methods for the gas chromatographic determination of pesticide residues – Part 3: Determination and confirmatory tests. 2009, European Committee for Standardisation, Brussels, Belgium.
8. Stan, H. J. and Linkerhägner, M. 1996, J. Chromatogr. A, 750, 369.
9. Armenta, S., Garrigues, S. and de la Guardia, M. 2008, Trends Anal. Chem., 27, 497.
10. Steinbach, P. and Schwack, W. 2013, Trends in Chromatography, 8, 113.
11. Steinbach, P. and Schwack, W. 2014, J. Chromatogr. A, 1323, 28.
12. Commission Directive 2006/141/EC on infant formulae and follow-on formulae and amending Directive 199/21/EC. 2006, Official Journal of the European Union, L 141, 1.