Validation of an IC-MS/MS method for the determination of polar compounds at ng/L level in water samples

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Goal
To develop and validate a direct injection, single run, multi-residue analysis of AMPA, CMBA, ethephon, fosetyl-aluminum, glyphosate, glufosinate, maleic hydrazide, and bromate for different types of water by IC-MS/MS

Introduction
The analysis of glyphosate and other polar anionic pesticides and their metabolites presents an analytical challenge. Their polarity does not allow the direct analysis by reversed-phase HPLC, so alternative methods need to be applied. Before analysis or using specific chromatographic columns, like the porous graphitic carbon (PGC)-based Thermo Scientific™ Hypercarb™ column, derivatization of glyphosate is common. Other laboratories analyze polar anionic pesticides on HILIC or hybrid columns without FMOC derivitization. With those approaches, routine laboratories report varying method robustness and results, mainly when applied in high-throughput analysis of samples with rather complex matrix compositions. In France, the limits of quantification (LOQ) are 30 ng/L for AMPA and glyphosate and 100 ng/L for fosetyl-aluminum and maleic hydrazide.[1] LOQs for glufosinate and ethephon are targeted at 30 ng/L, while 3 µg/L is sufficient for bromate.[2]

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Recent developments in the hyphenation of ion chromatography (IC) and mass spectrometry (MS) facilitated novel options to determine polar pesticides. IC is the preferred separation technique for polar ionic analytes, such as anions, cations, ionic metabolites, and sugars. In triple quadrupole MS/MS systems, MS offers low detection limits and high detection selectivity when operated in selected reaction monitoring (SRM) mode. This work aimed to develop and validate an IC-MS/MS method for direct analysis of polar ionic pesticides in different water samples and assess the applicability under routine conditions. This method allows a direct injection of 30 µL of different types of water samples to determine aminomethylphosphonic acid (AMPA), 2-chloro-4-methylsulfonylbenzoic acid (CMBA), ethephon, fosetylaluminum, glyphosate, glufosinate, maleic hydrazide, and bromate in a single chromatographic run, without derivatization or a concentration step.

In bottled, tap, ground, and surface waters, LOQs were validated at 10 ng/L; CMBA and maleic hydrazide had LOQs of 30 ng/L and 50 ng/L, respectively. Expanded uncertainties were satisfactory, with values lower than 30% at LOQ and 15–20% for the levels from 100 ng/L up to 5 µg/L except for maleic hydrazide (30% to 60%). Stability studies showed that samples could be stored for one month at temperatures below 0 °C.

Experimental

Equipment

- Thermo Scientific™ Dionex™ ICS-6000™ system, including:

  – DP Pump, Iso/Iso with Degas (P/N 22181-60011)

  – DC Low-Temperature DC (Dual Zones, Two Injection Valves, Microbore (P/N 22181-60059))

  – EG Module (P/N 22181-60019)

  – EG Cartridge Kit: HP Degasser and Tubing (Analytical) (P/N 075522)

  – CD Conductivity Detector (analytical) and Integrated Cell (P/N 079829)

  – EO Eluent Organizer Tray with two 2 Liter bottles (P/N 072057)

  – Thermo Scientific™ Dionex™ AS-AP Autosampler, with tray temperature control option (P/N 074926) with three vial trays (P/N 074936)

- Thermo Scientific™ TSQ Altis™ triple quadrupole mass spectrometer (P/N TSQ02-10002)

- Peak Scientific™ Genius™ 1022 nitrogen generator (P/N 1R77606-3230)

Software

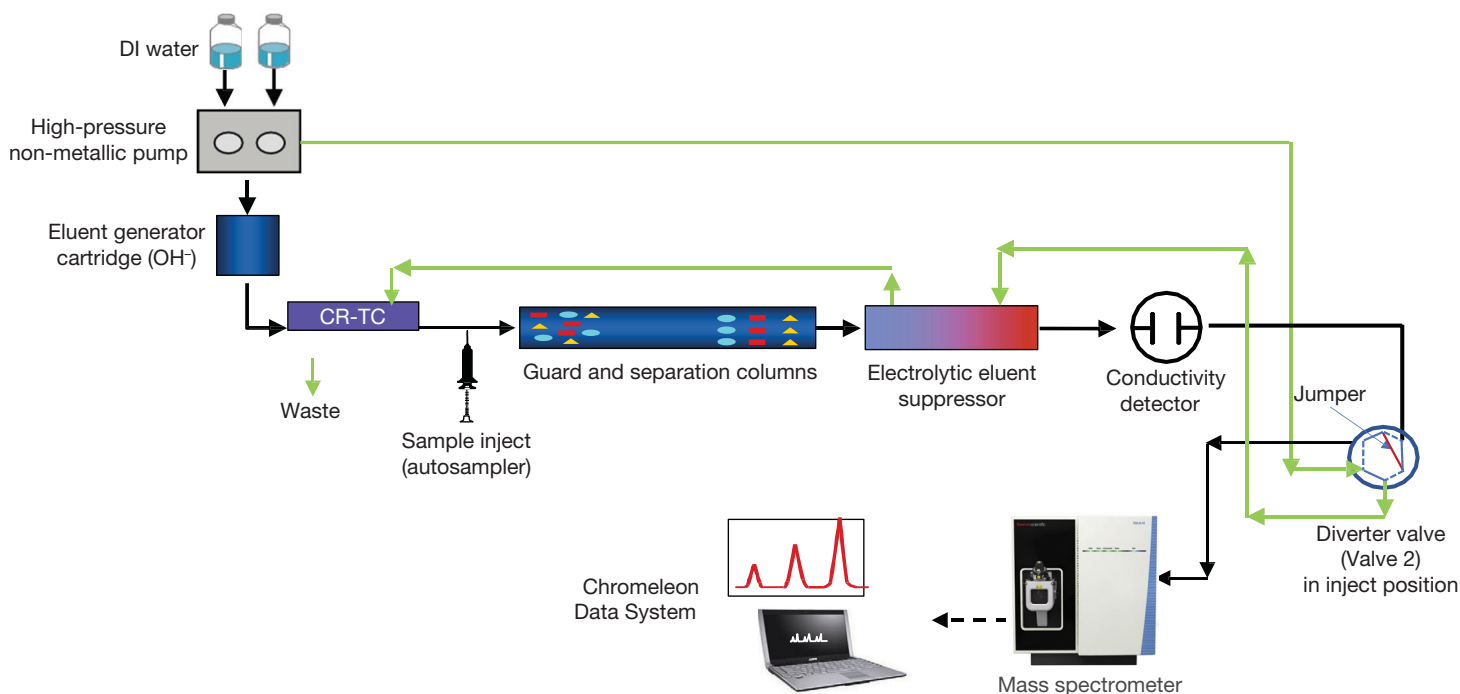Thermo Scientific™ Chromeleon™ Chromatography Data System (CDS), version 7.2.9

Figure 1. Schematic flow path for the IC-MS/MS setup

Consumables

- Dionex AS-AP Autosampler Vials 1.5 mL, Polypropylene with Caps and Septa (P/N 079812)

- Thermo Scientific™ IC PEEK Viper™ Fitting Kit for Dionex ICS-6000 with CD (MB), (P/N 302965)

- Thermo Scientific™ Dionex™ EGC 500 KOH Eluent Generator Cartridge (P/N 075778)

- Thermo Scientific™ Dionex™ CR-ATC 600 Continuously Regenerated Anion Trap Column (P/N 088662)

- Thermo Scientific™ Dionex™ AERS™ 500e 2 mm suppressor (P/N 302662)

Reagents and standards

Analytical and internal standards were purchased from different reference material producers. AMPA, ethephon, fosetyl-aluminum, glufosinate-ammonium, glufosinate-D$_3$, and glyphosate were from HPC Standards GmbH (Germany); CMBA, fosetyl-aluminum-D$_{15}$, and maleic hydrazide from LGC Standards GmbH (Germany); bromate from CPAchem Ltd (Bulgaria); and ethephon-D$_4$, AMPA-^{13}C,^{15}N and glyphosate-^{13}C$_2$,^{15}N from A2S Analytical Standard Solutions (France). Ultrapure water (18.2 MΩ·cm, TOC <5 µg/L) was delivered by a Milli-Q™ system (Merck KGaA). Propane-2-ol (IPA) was sourced from J.T. Baker, Merck KGaA, and Fisher Scientific.

Method

The method is outlined in Tables 1–4.

Table 1. IC setup for validation

Parameter	Setting
Column	Thermo Scientific Dionex™ IonPac™ AS24 column 250 × 2 mm (P/N 064153) Thermo Scientific Dionex™ IonPac™ AG24 column 50 × 2 mm (P/N 064151)
Eluent	KOH gradient from 22 to 100 mM (Table 2)
Eluent source	Dionex EGC 500 KOH cartridge with Dionex CR-ATC 600 trap column
Flow rate	0.30 mL/min
Injection volume	30 µL
Temperature	20 °C (column compartment), 10 °C (autosampler tray), 15 °C (detector compartment)
System backpressure	~2,000 psi (100 psi = 0.6894 MPa)
Detection	Suppressed conductivity, Dionex AERS-500e 2 mm suppressor, external water mode at 0.6 mL/min, regeneration current: 75 mA
Background conductance	<1 µS/cm
Run time	20 min

Table 2. KOH gradient

Time	Concentration (mM)
0	22
4.1	22
7.0	25
7.1	40
9.5	60
12.0	80
14.5	80
15.0	100
16.0	100
16.1	22
20.0	22

Table 3. Mass spectrometric detection

Parameter	Setting
Run time	20 min
Ion source	HESI Negative
Spray voltage	3,000 V
Sheath gas	45
Auxiliary gas	15
Sweep gas	1
Ion transfer tube temperature	325 °C
Vaporizer temperature	350 °C
Experiment type	SRM
Cycle time	1.2 s
Chromatography peak width	15 s
Collision gas pressure (argon)	1.5 mTorr
Q1 resolution	0.7 FHMW
Q3 resolution	1.2 FHMW
Postcolumn addition ("Make-up" solvent)	No
Divert valve time to the MS	0 to 20 min

Sample preparation

For development, validation testing, and comparison, water samples, routinely analyzed by LC-MS/MS after derivatization with 9-fluorenyl methyl chloroformate (FMOC-Cl), were used (FMOC-LC-MS/MS). Before analysis, the samples were membrane filtered (PES, 0.45 µm); the pH was not adjusted.

The main ions in the water samples were present in the following concentration ranges: 1–218 mg/L for chloride, 9–131 mg/L for sulfate, 0.5–70 mg/L for nitrate, 13–110 mg/L for calcium, 2–28 mg/L for magnesium, 2–170 mg/L for sodium, and 1–28 mg/L for potassium.

Table 4. SRM parameters for each compound

Compound name	RT (min)	Precursor (m/z)	Quantification ion (m/z)	Collision energy (V)	Confirmation ion (m/z)	Collision energy (V)	RF lens (V)
AMPA	7.0	110.0	63.0	20	79.0 81.0	27 13	42
AMPA (ILIS)	7.0	112.0	63.0	20	79.0 81.0	22 12	42
Bromate	6.7	127.0	110.9	22	112.9 -	22 -	38
CMBA	10.0	233.0	189.0	8	191.0 -	8 -	30
Ethephon	9.8	143.0	107.0	7	79.0 -	19 -	30
Ethephon (ILIS)	9.8	147.0	111.0	7	- -	- -	30
Fosetyl-Aluminum	4.0	109.0	63.0	29	81.0 -	12 -	34
Fosetyl-Aluminum (ILIS)	4.0	114.0	82.0	12	- -	- -	34
Glufosinate	6.5	180.0	63.0	38	94.9 84.9	17 19	53
Glufosinate (ILIS)	6.5	183.0	63.0	38	- -	- -	53
Glyphosate	13.6	168.0	62.9	23	78.9 149.9	40 10	38
Glyphosate (ILIS)	13.6	171.0	62.9	28	- -	- -	38
Maleic Hydrazide	7.6	111.0	82.1	18	83.1 42.1	14 41	30

For higher concentrations, e.g., high sulfate levels (>1 g/L, like in typical local mineral water) or seawater, the samples were diluted to avoid column overload, resulting in higher LOQs.

The reference control matrix was Evian™ mineral water. The analytical standards were successively diluted with ultrapure water; the final working standard was prepared in the reference control matrix.

An aliquot (20 µL) of the mix of ILISs was added to 1 mL of pure or diluted sample. The vials were placed in a temperature-controlled autosampler at 10 °C, and a small sample volume (30 µL) was injected into the IC-MS/MS system.

Results and discussion

Based on previously published results, the Dionex IonPac AS24 column was used.[3,5] Separation of selected anionic polar pesticides and bromate was achieved by applying a KOH-gradient (Table 2). Major mineral anions present in water were detected by suppressed conductivity at retention times listed in Table 5.

Fosetyl-aluminum was chromatographically separated from fluoride. Maleic hydrazide eluted at the beginning of the chloride peak. CMBA and ethephon co-eluted with carbonate. Figure 2 shows the conductivity traces of water samples and the SRM data of glufosinate, AMPA, and glyphosate at a level of 100 ng/L. The LOQs were around 10 ng/L for these three compounds, each with a signal-to-noise (S/N) ratio >10. Different injection volumes were examined during the validation. An injection volume of 30 µL resulted in high sensitivity and increased column life, guard column life, ionization source robustness, and instrument up-time.

Table 5. Retention times of inorganic ions commonly found in the investigated water samples. Thiosulfate was added to chlorinated drinking waters as a quenching agent to remove free chlorine.

	Fluoride	Chloride	Carbonate	Sulfate	Thiosulfate	Nitrate
RT (min)	3.8	8.3	9.5	11.3	15.1	15.5
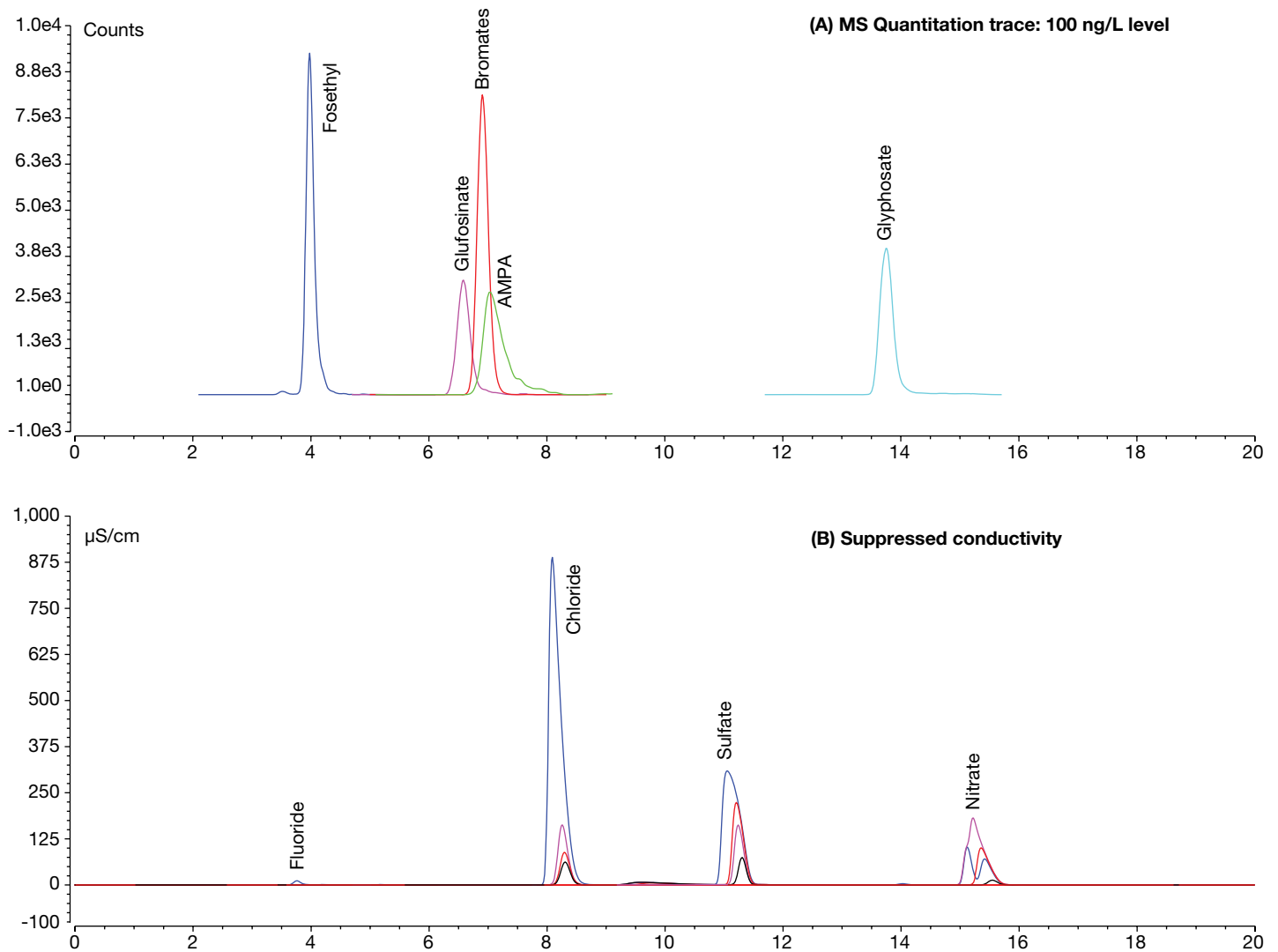
Figure 2. Chromatographic separation of fosetyl-aluminum, glufosinate, AMPA, bromate, and glyphosate – 100 ng/L standard in Evian water (A), and overlay of the conductivity traces for the four water matrices selected for validation B)

Post-column make-up solvent addition

In anion exchange chromatography combined with suppressed conductivity, the effluent, after passing through the suppressor, is an aqueous solution of various acids. The desolvation of an entirely aqueous solution is not as efficient as the one composed of organic solvent mixtures. To improve this process, an organic solvent can be infused into the suppressor effluent. Methanol, acetonitrile, or IPA are often used as "make-up" solvents.[3-8] Response enhancement can be compound-dependent, so all compounds should be investigated for a multi-residue method. IPA was chosen for the evaluation, as initial tests with acetonitrile were unsuccessful. LC-MS quality IPAs from three different providers were examined. The flow rate was fixed at 0.1 mL/min, and the MS-source conditions were as in Table 3.

The make-up-solvent tests for the three IPAs consisted of triplicate injections of the calibration solutions and an Evian blank. Bias calculations were based on the five highest calibration levels (50, 100, 250, 500, 1000 ng/L). The impact of adding IPA as a make-up solvent and the effect of different IPA qualities are summarized in Table 6. The influence of IPA on the detection sensitivity was compound-specific. At the same time, the IPA quality affected the overall detection sensitivity significantly. We observed dramatic losses in sensitivity for AMPA, glufosinate, glyphosate, and maleic hydrazide.

Conversely, peak areas for bromate, CMBA, ethephon, and fosetyl-aluminum increased. However, if the S/N ratio is examined, only the values for bromate and fosetyl-aluminum improved. AMPA, glufosinate, and glyphosate showed smaller S/N values. The other components, CMBA, ethephon, and maleic hydrazide, were not significantly impacted. The effect of the IPA quality on sensitivity is illustrated in Figure 3 for glufosinate. Glufosinate solutions at concentrations of 10 ng/L and 20 ng/L were injected with and without make-up solvent addition. As shown, the glufosinate peak disappears with post-column addition. The IPAs from different sources had inconsistent effects on the analytical determination of anionic polar pesticides, their metabolites, and oxyhalides. Consequently, we decided to forgo make-up solvent to prevent undesired and unpredictable effects on sensitivity and recovery.

Table 6. Effect of different IPAs on sensitivity compared to experiments without make-up solvent

Component	Quantification MRM signal type	Isopropanol source 1	Isopropanol source 2	Isopropanol source 3
AMPA	Area	-13% to -7%	-70% to -68%	-54% to -50%
	Height	-12% to -6%	-70% to -68%	-52% to -47%
Bromate	Area	+158% to +166%	+33% to +35%	+18% to +29%
	Height	+150% to +168%	+32% to +39%	+20% to +39%
CMBA	Area	+158% to +164%	+89% to +99%	+72% to +82%
	Height	+151% to +165%	+85% to +110%	+73% to +88%
Ethephon	Area	+108% to +116%	+40% to +43%	+16% to +20%
	Height	+105% to +119%	+40% to +47%	+16% to +24%
Fosetyl-Al	Area	+149% to +161%	+54% to +57%	+34% to +37%
	Height	+140% to +156%	+68% to +70%	+45% to +49%
Glufosinate	Area	-15% to -6%	-88% to -79%	-83% to -75%
	Height	-10% to -1%	-81% to -78%	-77% to -75%
Glyphosate	Area	+57% to +69%	-52% to -46%	-54% to -52%
	Height	+54% to +62%	-52% to -47%	-56% to -52%
Maleic Hydrazide	Area	+23% to +26%	-11% to -4%	-42% to -36%
	Height	+15% to +24%	-16% to -6%	-46% to -39%
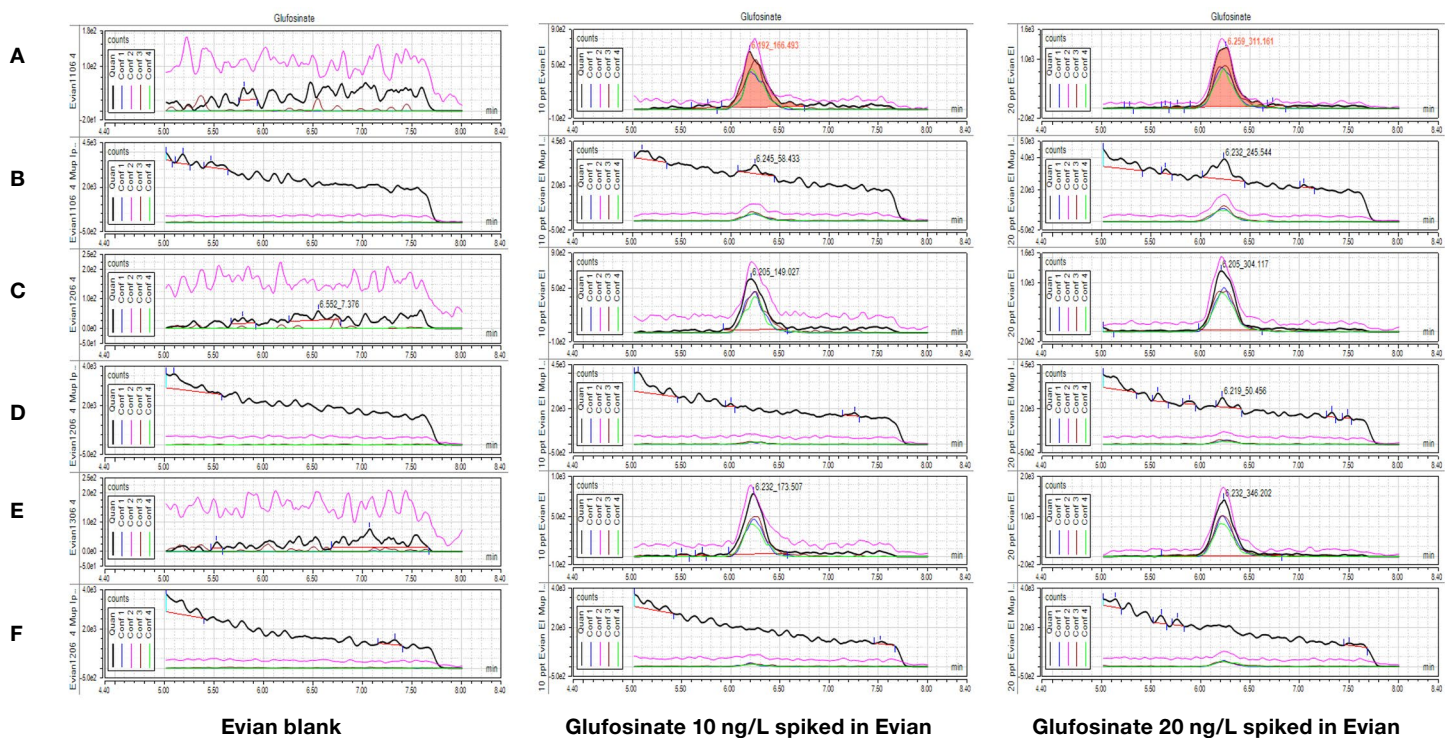
Figure 3. Glufosinate comparison results. Traces A), C), E): without make-up solvent; B): with make-up solvent (source 1); D): with make-up solvent (source 2); F): with make-up solvent (source 3)

Statistical evaluation and method validation

Validation data and results must follow the French accreditation guidance document requirements on analytical water quality control and the requirements of the validation procedure for micropollutant analysis of water (NF T90-210[9]). Calibration curves were generated to evaluate calibration quality; trueness was fixed at 40% for levels ≤ LOQ and 20% for levels > LOQ (Figure 4). To best assess matrix effects, validation was carried out using six different samples for each water type. The method's trueness (bias) and precision were evaluated by preparing six spiked samples of each type of water at three fortification levels, with two replicates under reproducibility conditions (six days). Blank samples were also analyzed in duplicate on each day. According to ISO 13528:2015,[10] the operator must establish acceptable tolerances for each level. 60% and 40% were chosen, respectively, for LOQ level and higher levels; this represents precision. Validation criteria for trueness were set at 25% for LOQ and 20% for higher levels. Validation results are shown in Table 7. Graphic representations of validation profiles allow one to visualize complete results (Figure 4) for calibration and spiked matrices. For five compounds, internal calibration was used with isotope-labeled analogs.

In contrast, for bromate, CMBA, and maleic hydrazide, external calibration was applied. Correlation coefficients (r) were greater than 0.999 for each curve per day for all calibration functions. The average coefficient of determination (r^2) of the six curves was always between 0.9995 and 0.9999. Figure 4 shows the fulfillment of acceptable tolerance, which was fixed at the beginning of validation. Regardless of the concentration, the observed bias was smaller than ±20%, except for CMBA and ethephon with ±30% for values ≤LOQ.

In all matrices, excellent recoveries (92–106%) were obtained for all compounds, except for bromate (84% at LOQ for groundwaters, otherwise 91–99%) and maleic hydrazide (71–103%), which were externally calibrated without an ILIS. The latter two recoveries represent the ion source matrix effect (ME). For the other components, this suggests that the ME is corrected through an ILIS.

Across all matrices, the individual recoveries based on their ILIS responses were: AMPA 51–118%, ethephon 50–135%, fosetyl-aluminum 57–140%, glufosinate 26–112%, and glyphosate 41–102%. For most measurements, RSD was lower than 10% and did not exceed 25%. The most

significant MEs were observed in tap water and surface water. Some exceptions were noticed in bottled waters for fosetyl-aluminum (57% and 64% for two samples, 140% for one sample, the others near 110%), for ethephon (135% for one sample, the others near 100%), and in groundwaters for fosetyl-aluminum (60, 61, and 66% for three, the others near 105%).

For compounds calibrated externally, CMBA gave excellent results with no observed ME. For bromate, all water types were validated as shown in Figure 4; ME was negligible. The use of the stable-isotope labeled analog $Br^{18}O_3^-$ could be warranted if a notable deviation is observed. Maleic hydrazide showed higher values for the expanded uncertainties and was not validated. However, the validation profile for tap water was satisfactory at an assumed recovery of 80%, with similar performance for ground and surface waters with recoveries between 85 and 86%. Using a stable deuterium or ^{13}C-ILIS for maleic hydrazide could be judicious to correct MEs.

Validation profiles were suitable with low uncertainties over the concentration range evaluated. RSD values for repeatability and reproducibility showed sufficient method precision with values often smaller than 10% and rarely between 10% and 20%.

Stability evaluation

A sample storage stability study was carried out for four weeks to complete the method validation, with two different storage conditions (temperature -18 °C and +4 °C), for one sample of each matrix type. All matrices contained 40 mg/L sodium thiosulfate as the quenching agent to remove chlorine, mainly for treated drinking water. With a backward planning process, matrices were spiked at Day -28, Day -21, Day -14, Day -7, Day -3, Day -1, and Day 0, with two repeated standard addition experiments. Table 8 lists the number of days during which the examined component was stable, i.e., the concentration determined was within 70%–130% of the initial amount.
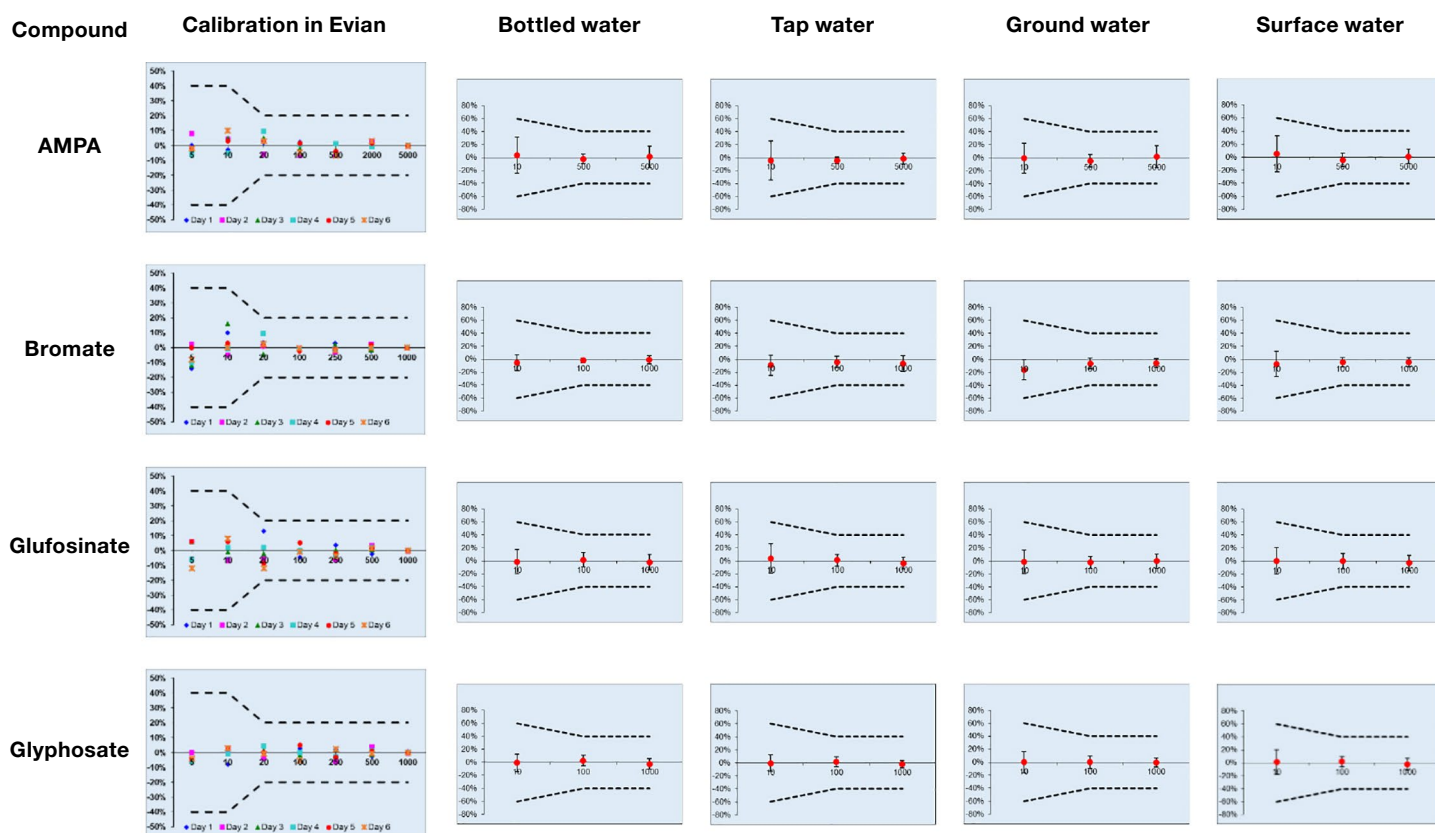

Figure 4. Graphic representations of some validation profiles. Dotted line = acceptable tolerance (%); red point (matrix) = average bias (trueness) (%); concentration unit (x-axis) = ng/L; error bars represent variability of data.

Table 7. Validation results obtained for bottled mineral water, tap water, groundwater, and surface water (for the quantification MRM), with validated LOQ

	Concentration (ng/L)		
	Low level = LOQ (LL)	Middle level (ML)	Upper level (UL)
AMPA	10	500	5,000
CMBA	30	100	1,000
Maleic hydrazide	50	500	5,000
Others	10	100	1,000

Component	Matrix	LOQ (ng/L)	Recovery (%)			RSD (%) repeatability			RSD (%) reproducibility			U (%) expanded uncertainty (k=2) ISO 11352		
			LL	ML	UL	LL	ML	UL	LL	ML	UL	LL	ML	UL
AMPA Internal calibration	Bottled water	10	103	98	101	13.5	3.8	8.1	13.5	3.4	4.3	31	14	20
	Tap water	10	95	96	98	15.8	2.8	4.3	15.8	2.0	4.3	36	15	14
	Ground water	10	99	95	102	11.6	5.2	8.2	11.6	5.1	4.9	26	18	21
	Surface water	10	105	96	101	13.2	5.2	5.5	11.3	2.8	1.9	31	17	16
Bromate External calibration	Bottled water	10	94	98	99	4.6	1.8	0.5	6.4	2.0	3.3	20	12	13
	Tap water	10	91	96	93	4.9	2.5	1.9	8.5	4.6	6.4	28	16	22
	Ground water	10	84	94	94	1.7	2.4	0.7	9.4	4.4	3.8	39	19	17
	Surface water	10	93	96	96	10.0	1.8	1.6	10.6	3.8	3.7	28	16	16
CMBA External calibration	Bottled water	30	98	102	103	6.3	4.4	1.3	6.3	5.9	8.8	17	17	22
	Tap water	30	95	95	90	5.6	2.6	2.1	8.4	6.5	8.9	23	20	29
	Ground water	30	95	97	95	3.4	4.5	1.6	5.1	4.5	2.6	18	15	15
	Surface water	30	97	95	96	4.6	1.4	3.4	7.1	9.6	5.5	19	25	17
Ethephon Internal calibration	Bottled water	10	95	101	97	9.5	6.4	4.1	12.0	6.4	11.9	29	17	28
	Tap water	10	99	101	102	5.8	4.1	4.9	9.4	6.2	9.6	23	17	23
	Ground water	10	92	98	100	9.4	7.2	7.1	9.4	7.2	8.8	27	19	21
	Surface water	10	98	98	99	9.0	5.2	5.2	9.3	7.1	10.9	22	19	26
Fosetyl-Al Internal calibration	Bottled water	10	104	105	101	5.6	4.9	3.9	11.2	4.9	4.0	27	17	13
	Tap water	10	104	104	101	8.2	2.6	1.2	9.4	7.2	3.0	23	20	12
	Ground water	10	105	104	105	5.5	6.0	6.0	8.2	8.5	6.1	22	22	19
	Surface water	10	101	101	99	7.2	3.2	4.2	9.9	4.5	5.5	23	14	16
Glufosinate Internal calibration	Bottled water	10	99	102	98	6.5	5.6	2.7	9.4	5.6	6.1	22	16	17
	Tap water	10	104	101	97	10.9	4.5	3.3	10.9	4.5	4.6	26	14	16
	Ground water	10	99	98	100	9.4	4.8	3.8	9.4	4.8	5.6	22	15	16
	Surface water	10	100	100	97	7.6	6.0	3.6	10.3	6.0	6.2	24	16	18
Glyphosate Internal calibration	Bottled water	10	99	103	97	6.7	3.9	2.2	6.7	4.0	4.2	17	14	14
	Tap water	10	100	101	98	3.8	2.4	2.5	6.2	4.0	2.9	17	13	12
	Ground water	10	100	100	100	6.8	3.3	3.1	8.2	5.0	3.5	20	15	12
	Surface water	10	101	102	98	8.9	2.0	3.4	9.4	4.0	4.5	22	14	15
Maleic Hydrazide External calibration	Bottled water	50	96	103	102	10.2	3.2	2.1	19.0	15.2	14.6	43	35	34
	Tap water	50	71	81	77	11.4	2.5	2.1	24.7	16.4	18.6	79	53	62
	Ground water	50	76	86	85	9.6	3.1	1.6	19.0	8.2	5.5	64	35	34
	Surface water	50	80	87	85	12.7	3.8	1.7	20.9	10.6	10.6	61	35	39

Table 8. Stability evaluation - number of days without significant change of amount in different matrices

Component	Matrix	Spiked concentration (ng/L)	Storage at -18 °C in days	Storage at +4 °C in days
AMPA	Bottled water	1,000	28	28
	Tap water	1,000	28	28
	Ground water	1,000	28	7 (-40% after 14 days)
	Surface water	1,000	28	14 (-40% at 21 days, -85% at 28 days)
Bromate	Bottled water	100	28	28
	Tap water	100	28	28
	Ground water	100	28	28
	Surface water	100	28	28
CMBA	Bottled water	100	28	28
	Tap water	100	28	28
	Ground water	100	28	28
	Surface water	100	28	28
Ethephon	Bottled water	100	28	7 (-40% at 14 days, -63% at 28 days)
	Tap water	100	28	7 (-40% at 14 days, -55% at 28 days)
	Ground water	100	28	3 (-35% at 7 days, -55% at 28 days)
	Surface water	100	28	1 (-75% after 3 days)
Fosetyl-Al	Bottled water	100	28	28
	Tap water	100	28	28
	Ground water	100	28	28
	Surface water	100	28	28
Glufosinate	Bottled water	100	28	14 (-55% after 21 days)
	Tap water	100	28	28
	Ground water	100	28	28
	Surface water	100	28	14 (-40% after 21 days)
Glyphosate	Bottled water	100	28	28
	Tap water	100	28	28
	Ground water	100	28	28
	Surface water	100	28	28
Maleic Hydrazide	Bottled water	500	28	28
	Tap water	500	28	28
	Ground water	500	28	28
	Surface water	500	28	28

At -18 °C, all compounds were stable, while three compounds decomposed at +4 °C. For two of the four matrices, AMPA and glufosinate were stable between 7 and 14 days. The most critical compound is ethephon, as it decomposes in all matrices, fastest in surface water (-75% after three days). Depending on pH and temperature, ethephon can rapidly lose ethylene and form the degradation product HEPA (2 hydroxyethanephosphonic acid). Even in a cooled autosampler (+10 °C), degradation is observed in calibration standards. The degradation is significant but can be compensated, as the concentration ratio with ethephon-D_4 (ILIS) stays nearly constant. However, the samples should be measured within 24 h under these conditions to avoid false-negative results due to complete degradation of ethephon.

Results of proficiency testing by interlaboratory comparison

The IC-MS/MS method was applied to wastewater samples and successfully validated with LOQ at 50 ng/L for all components, except for CMBA and maleic hydrazide, with LOQs at 250 ng/L. Stability was also evaluated for wastewater effluent and influent, concluding that with a sample storage temperature of -18 °C there was one-month stability.

To evaluate the quality of quantification results, the individual laboratory performance can be assessed in terms of z-scores following ISO 13528[10]. A result is acceptable with a z-score value between -2 and +2.

Table 9 shows compliant results for all matrices and components, except for ethephon. Furthermore, all |z-score| values are less than 2 and often less than 1. Ethephon was tested in one proficiency test, but 24 laboratories did not report their results, and one reported a result lower than their LOQ (200 ng/L). The ethephon stability in the sample may be the cause (vide supra).

The new IC-MS/MS method results were tested against the traditional FMOC-LC-MS/MS method during validation testing. The low z-scores document the comparability of results. Bromate analysis by IC-MS/MS was confirmed by a recalculated z-score of +0.62 from the data comparison with classical IC using suppressed conductivity detection.

Table 9. 2020 proficiency testing results with IC-MS/MS for six compounds

Component	Matrix	Assigned value (ng/L)	Own result (ng/L)	z-score
AMPA	Bottled water	137.5	175.5	0.76
	Tap water	132.3	107.7	-0.62
	Wastewater	3,211.2	3,523.5	0.62
	Wastewater	1,229.6	1,053.3	-0.48
Ethephon	Surface water	75*	109	n.a.
Fosetyl-Aluminum	Surface water	601	470	-0.73
Glufosinate	Bottled water	196.5	268.0	1.65
	Tap water	267.3	283.3	0.20
Glyphosate	Bottled water	193.1	228.0	1.08
	Tap water	319.1	287.7	-0.33
	Wastewater	1,007.4	794.8	-0.65
	Wastewater	2,201.3	2,004.0	-0.52
Maleic Hydrazide	French bottled water	506*	651	1.01**

* Spiking value
** z-score value obtained with less than eight laboratories

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Conclusion

- Ion chromatography substantially facilitated multi-residue analysis of polar compounds, especially ionic pesticides and inorganic ions. No derivatization was necessary, contrary to the conventional FMOC-LC-MS/MS method.

- An IC-MS/MS method with direct injection of 30 µL water sample was developed, validated, and accredited, considering French guidelines and the NF-T90-210 norm. No make-up solvent was used to prevent unwanted effects on sensitivity and recovery and achieve satisfactory LOQs. This also simplifies the setup.

- In bottled, tap, ground, and surface waters, LOQs were validated at 10 ng/L; CMBA and maleic hydrazide had a LOQ of 30 ng/L and 50 ng/L, respectively. Expanded uncertainties were satisfactory, with values lower than 30% at LOQ and 15-20% for the levels from 100 ng/L up to 1–5 µg/L except for maleic hydrazide (30% to 60%). Stability studies showed that samples could be stored for one month at temperatures below 0 °C

- This method was successfully validated for effluent and influent wastewaters (data not shown), with LOQs at 50 ng/L for all compounds, except for CMBA and maleic hydrazide (250 ng/L). Proficiency testing by interlaboratory comparison allowed the evaluation of the method's trueness and robustness. More than 2,000 water samples were analyzed since accreditation, representing over about six months of continuous use. In addition, a time savings for an operator of a minimum of one working day per week has been estimated, compared to the conventional FMOC-LC-MS/MS approach. The method proved to be robust, reliable, and efficient.

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