ELSEVIER

Journal of Chromatography A, 830 (1999) 145–154

JOURNAL OF CHROMATOGRAPHY A

Ion-pair liquid chromatography–atmospheric pressure ionization mass spectrometry for the determination of quaternary ammonium herbicides[1]

R. Castro, E. Moyano, M.T. Galceran*

Dept. Quimica Analitica, Universitat de Barcelona, Avda. Diagonal 647, 08028 Barcelona, Spain

Received 15 September 1998; received in revised form 1 October 1998; accepted 13 October 1998

Abstract

High-performance liquid chromatography coupled with atmospheric pressure ionization mass spectrometry (electrospray and atmospheric pressure chemical ionization) has been used to characterize some quaternary ammonium herbicides (quats). The separation of these compounds was carried out using ion-pair chromatography with heptafluorobutyric acid (15 m*M*, pH 3.3) and acetonitrile gradient elution for successful coupling to mass spectrometry. Detection limits down to 0.1–4 μg l^{-1} were obtained for spiked tap water following a preconcentration step. Good reproducibilities (day-to-day and run-to-run) were also obtained.

Keywords: Interfaces, LC–MS; Water analysis; Liquid chromatography–mass spectrometry; Pesticides; Quaternary ammonium compounds

1. Introduction

Herbicides are an essential component of modern agriculture in developed countries and their use is increasing in the third world countries. There has been a great interest in the presence of these compounds in food, drinking water and soils. One particularly difficult type of herbicide is the group of quaternary ammonium salts, also known as quats. These compounds have been extensively used as herbicides (paraquat, diquat and difenzoquat) or as growth regulators (chlormequat and mepiquat); they are considered as potential water pollutants and have been classified as moderately hazardous. Their cationic character makes detection difficult and capillary electrophoresis (CE) [1–3] and ion-pair high-performance liquid chromatography (HPLC) using UV detection [1,4,5] are the methods of choice for these ionic species, although the use of spectrophotometric [6,7], ion-selective electrodes [8,9] and other chromatographic [10–13] methods have also been reported. An inherent disadvantage of these methods is the lack of analytical specificity, which may result in identification and quantification difficulties, especially in complex matrices. The US Environmental Protection Agency (EPA) recommends methods where identity is confirmed by mass spectrometry (MS). Some studies use mass spectrometry using HPLC–MS with both thermospray

*Corresponding author. Fax: +34-93-402-1233.

[1]Presented at the 5th International Symposium on Hyphenated Techniques in Chromatography and Hyphenated Chromatographic Analyzers, Bruges, 11–13 February 1998.

0021-9673/99/$ – see front matter
PII: S0021-9673(98)00846-2

[4,14] and electrospray ionization (ESI) [15] and CE–MS with electrospray [16] to characterize these compounds, but no references have been found to the use of atmospheric pressure chemical ionization (APCI).

Coupling ion-pair chromatography with MS is not a good approach, due to the high concentration of non-volatile conventional ion-pair reagents. Some of these problems can be overcome using phase-system switching with an ion-exchange-trapping column, as described by Vreeken et al. [17] and Barceló et al. [4], although these methods require additional equipment. Here we have used volatile acids (heptafluorobutyric acid, HFBA; pentafluoropropionic acid, PFPA; trifluoroacetic acid, TFA) as ion-pair reagents to couple LC to MS and post-column addition of acetonitrile to increase the organic content in the mobile phase. Chromatographic and mass spectrometry conditions have been established and mass spectra in both ESI and APCI have been obtained. In order to improve the detection limits, a preconcentration procedure had to be used. Different authors have studied solid-phase extraction (SPE) for quats using C_{18} or C_8 [18,19], silica [20–22] and porous graphitic carbon [23,24] sorbents. In this work, a SPE method with silica cartridges has been evaluated.

2. Experimental

2.1. Chemicals

The reagents were obtained from the following sources: diquat (DQ), difenzoquat (DF), mepiquat (MQ) and chlormequat (CQ) were all purchased from Chemservice (West Chester, PA, USA), paraquat (PQ) from Riedel-de Haën (Seelze, Germany) and HPLC-grade acetonitrile from J.T. Baker (Deventer, Netherlands). Water was purified using an Ellix and a on-line Milli-Q system (Millipore, Bedford, MA, USA). HFBA, PFPA and TFA were obtained from Sigma (Poole, UK). Formic acid and ammonia solution 25% (analytical grade) were purchased from Merck (Darmstadt, Germany). Silica Sep-Pak cartridges were obtained from Waters (Taunton, MA, USA). Ethyl viologen (Aldrich, Milwaukee, WI, USA) was used as internal standard in LC–UV analysis and heptyl viologen (TCI, Tokyo, Japan) was used as internal standard in LC–MS.

Stock standard solutions of quats, 1 mg ml^{-1}, were prepared in water. Working solutions were prepared by diluting the stock solutions in mobile phase. All solutions were stored in plastic vials to prevent adsorption and were passed through a 0.45-μm nylon filter before use.

2.2. Chromatographic and mass spectrometry conditions

Chromatographic separation was performed using a HP-1050 (Hewlett-Packard, Palo Alto, CA, USA) liquid chromatograph equipped with a quaternary solvent delivery system, an autosampler and a UV detector. The column used was a Kromasil C_8 (200× 21 mm, 5 μm; Tracer Analitica, Spain). Gradient elution was used for optimal separation of quats; solvent A was an HFBA aqueous solution (15 m*M*, pH 3.3) and solvent B was acetonitrile. The elution program consisted of a linear gradient from 0.5 to 40% of solvent B in 10 min, with an isocratic period of 2 min and a stepwise elution from 40 to 60%. The flow-rate was 200 μl min^{-1}. The temperature of the column was maintained at 50°C. The injection volume was 20 μl and the post-column acetonitrile addition of 800 μl min^{-1} for APCI and of 200 μl min^{-1} for ESI was carried out using a Phoenix 20 (Carlo-Erba) syringe pump and a Rheodyne Model 7000 (Cotati, CA, USA) two-position six-port switching valve. The mobile phase and the post-column acetonitrile were mixed in a tee (Valco).

MS was carried out using a VG Platform II (Fisons Instruments, VG Biotech, Altrincham, UK) quadrupole mass spectrometer equipped with both standard pneumatically-assisted ESI and APCI sources. Working conditions for ESI were the following: the source was heated to 160°C, the capillary potential was +3.5 kV and the extraction voltage varied between 30 and 60 V. APCI conditions were as follows: the temperature of the source was 160°C, that of the probe was 400°C, extraction voltage varied between 20 and 50 V and the corona voltage was +3.5 kV. Calibration and tuning were performed using a standard quats solution (10 μg ml^{-1}).

Full-scan data acquisition was performed from 50 to 400 m/z in centroid mode and using a cycle time

of 1 s and an interscan time of 0.1 s. The $[Cat]^+$ ion for MQ, CQ and DF and the $[Cat-H]^+$ ion for PQ and DQ were used in selected-ion monitoring (SIM) mode, with a dwell time of 100 ms and an inter-channel time of 1 ms. In order to optimize the APCI and ESI parameters, standard solutions of each quat (15 μg ml^{-1}) were introduced by flow injection analysis (FIA).

2.3. Sample treatment

Spiked tap water samples were treated using silica cartridges (Sep-Pak, silica, Waters) following the procedure described by Worobey [22]. Samples (250 ml) between 5 and 0.01 μg l^{-1} adjusted to pH 9 were passed through the cartridges without any previous conditioning at a flow-rate of 2–3 ml min^{-1} using a Visiprep System (Supelco, Bellefonte, PA, USA). Quats were eluted with 2 ml of 6 *M* HCl–8% MeOH. The eluate was evaporated to about 0.5 ml using a vacuum rotary evaporator (Resona Technics S300) at 50°C and LC mobile phase was added to a final volume of 1 ml.

3. Results and discussion

3.1. Preliminary studies

Different HPLC–UV tests were performed in order to establish the optimum quats separation conditions, although only PQ, DQ and DF were evaluated since MQ and CQ have no chromophore groups. The conditions thus obtained were used for coupling LC to MS, which were performed using a reversed-phase column (LiChrospher 60 RP-Select B, 125×4 mm, 5 μm; Merck) and a mobile phase consisting of an ion-pair reagent aqueous solution and acetonitrile. As coupling LC to MS requires volatile mobile phases; we examined some of the most volatile ion-pair reagents (HFBA, PFPA and TFA). Since the aqueous solutions of these reagents have low pH values (<1.8), it was necessary to use a buffer to increase the pH to the minimum value recommended in order to preserve the analytical column. Formic acid–ammonium formiate (100 m*M*, pH 3.3) was chosen as buffer.

The effects of the concentration of ion-pair reagent on the chromatographic separation were studied. Fig. 1 shows the chromatograms obtained for different PFPA concentrations. This parameter had a strong effect on the separation and the peak shape of PQ and DQ. An increased ion-pair reagent concentration produced an increase in the retention times and an improvement in the peak shapes, especially for DQ, which gave double peaks at low ion-pair reagent concentrations (see Fig. 1A) probably due to the presence of two different species. Nevertheless, 15 m*M* PFPA was used, as LC–MS coupling requires mobile phases with low salt content.

It was observed that whereas PQ and DQ required low organic modifier concentration, DF needed a higher elution strength. Different gradients were tested, and the best conditions were obtained using PFPA (15 m*M*, pH 3.3)–acetonitrile (98:2) as the mobile phase, a linear gradient from 2 to 8.6% of acetonitrile in 5 min and a subsequent increase of the acetonitrile content to 40%. Similar results were also obtained with HFBA (15 m*M*, pH 3.3) with an acetonitrile linear gradient from 5 to 15% in 13 min and a subsequent increase to 50%.

The LC–MS response depended mainly on the ionization efficiency in the source, which can be affected by the components of the mobile phase. In order to evaluate the effect of the ion-pair reagent in the LC–MS response of quats, individual standard solutions (10 μg ml^{-1}) were prepared in a mixture of an aqueous solution of the ion-pair reagent (15 m*M*, pH 3.3)–acetonitrile (50:50) and analyzed by FIA using both ionization techniques (ESI and APCI). Table 1 shows the relative responses obtained for the five quats with both techniques. The highest MS responses (>80%) were obtained using HFBA, although the differences in the response were greater in APCI than in ESI, possibly due to the more energetic nature of APCI. Moreover, no differences in the MS spectra were observed for the different ion-pair reagents and the base peak was always the molecular or pseudomolecular ion of each compound.

In summary, the use of HFBA (15 m*M*, pH 3.3) was recommended, since it gave a good enough separation and the LC–MS responses using both ionization techniques were higher than those obtained with PFPA.

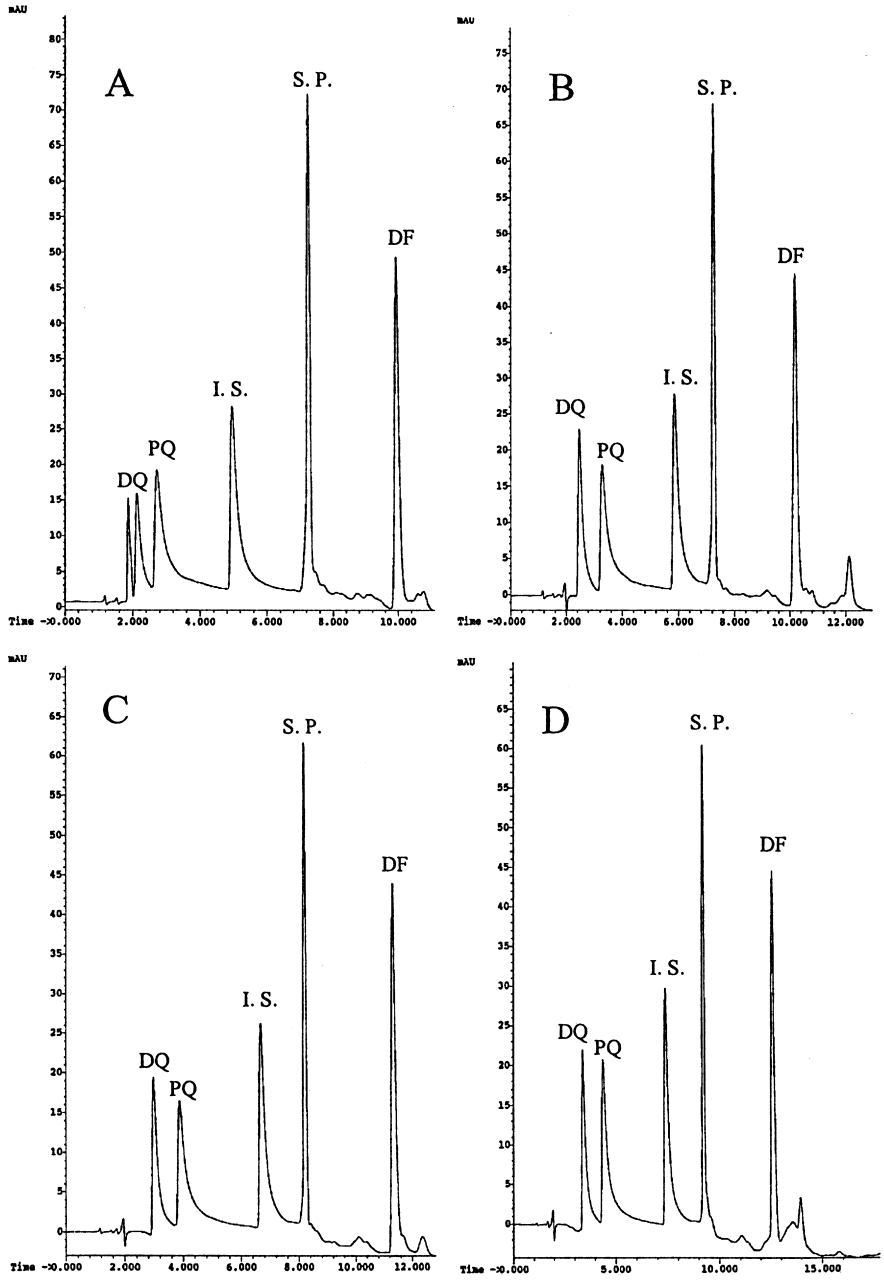


Fig. 1. LC–UV chromatograms of a standard solution (4 mg l^{-1}) of PQ, DQ and DF. Mobile phase: PFPA at different concentrations, pH 3.3. Acetonitrile linear gradient from 2 to 8.6% in 5 min and an increase to 40% at 5.01 min. (A) 10 m*M*, (B) 15 m*M*, (C) 20 m*M*, (D) 25 m*M*. I.S.: Internal standard, S.P.: system peak. Time scale in min.

3.2. LC–MS coupling

LC–MS coupling was performed using 15 m*M* HFBA, pH 3.3, although in these conditions MQ and CQ coeluted with DQ and PQ, respectively. Besides, an important decrease in the responses was observed

Table 1
Effect of ion-pair reagents on MS response

	Relative response (%)					
	APCI			ESI		
	HFBA	PFPA	TFAA	HFBA	PFPA	TFAA
DQ	87.42	100	81.69	100	60.01	62.54
PQ	100	59.16	52.43	100	77.97	58.77
MQ	100	58.05	33.85	83.40	100	84.58
CQ	100	57.92	33.77	95.29	100	98.61
DF	100	70.24	45.01	86.97	100	91.74

compared with those obtained for individual injections. To evaluate this decrease, the effect of coelution on the MS response was studied by FIA using standard solutions (10 μg ml^{-1}) of a single compound and mixtures of two compounds prepared in the mobile phase.

Fig. 2 shows the relative responses obtained with both ESI and APCI for each compound and for the mixtures of two quats, recorded at the m/z of the base peak for each compound. When quats coeluted, the responses showed a 25 to 90% decrease. The most important effect was observed with APCI when MQ coeluted, decreasing the signal measured for DQ, PQ and CQ. This may be related to the relative stability of the quats ion-pair in the gas phase. The effect was also observed with ESI, although the decrease in sensitivity was lower.

Due to the great effect of coelution on the MS response, LC separation had to be improved. Different conditions were tested, and the best separation was obtained with a C_8 column and a mobile phase consisting of HFBA (15 m*M*, pH 3.3) and an acetonitrile gradient (0.5 to 40% in 10 min and 60% in 12 min). In order to improve the peak shapes, the effect of column temperature was also studied. When the temperature increased, the retention time for MQ and CQ decreased significantly, whereas that for DQ and PQ were not affected. At 50°C the elution order was completely changed and CQ and MQ eluted before DQ and PQ. Fig. 3 shows the chromatograms obtained for a standard solution of 300 ng ml^{-1} of each compound in the best conditions and with post-column addition of acetonitrile to decrease surface tension and improve the MS (ESI and APCI) response of the quats.

The extraction voltage is an important parameter in LC–MS detection, since in-source fragmentation depends on this voltage. In order to establish the optimum conditions for the simultaneous analysis of quats using HFBA as ion-pair reagent, standard solutions (10 μg ml^{-1}) were injected at different extraction voltages, from 20 to 50 V (APCI) and from 30 to 60 V (ESI). Normalized absolute abundances of $[Cat]^+$ for CQ, MQ and DF and of $[Cat-H]^+$ for DQ and PQ vs. extraction voltage were studied, and most compounds showed a maximum value between 25 and 35 V for ESI and between 35 and 45 V for APCI. When the extraction voltage increased, fragmentation occurred due to collision in the source, thus decreasing the levels of molecular and pseudomolecular ions. Extraction voltages of 30 V (APCI) and 35 V (ESI) were used for quantification and 50 V for identification. Table 2 shows the mass spectra data obtained with both ESI and APCI using the quantification and identification extraction voltages. The spectra obtained with both techniques at low voltage for CQ, MQ and DF gave the single charged molecular ion $[Cat]^+$ at m/z 122, 114 and 249, respectively as the most abundant peak. At high voltages CQ was the compound which showed a higher level of fragmentation, with the base peak for the ion at m/z 59. These results are consistent with those previously published by Moyano et al. [16] using CE–MS–MS.

For PQ and DQ, the spectra generated by ESI (30 V, 50 V) gave as base peak the ion at m/z 185 and 183, respectively, corresponding to the deprotonated molecular ion $[Cat-H]^+$. Besides, using APCI, a more energetic technique than ESI, PQ gave a base peak at m/z 171 which has been assigned to $[Cat-CH_3]^+$ and DQ showed a peak at m/z 157 which has been attributed to the loss of –CNH. Although

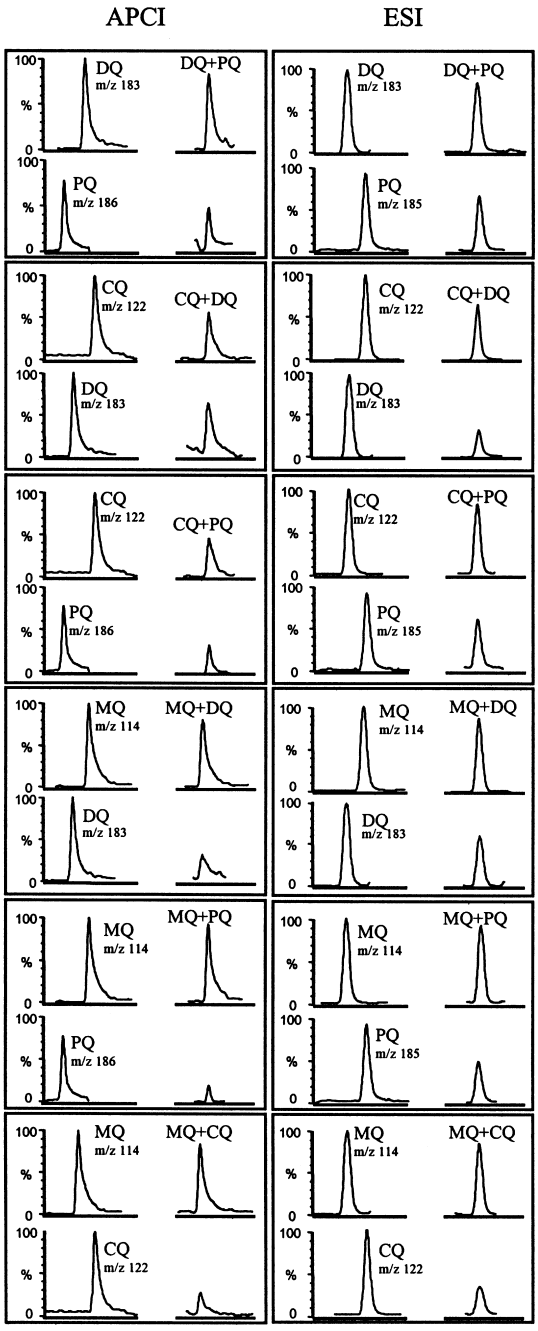


Fig. 2. Coelution effect. Individual standard solutions (20 μg ml^{-1}, 40 μl) and mixtures of two standards (20 μg ml^{-1} each, 40 μl) by FIA.

previous MS studies [15,16,25,26] reported the presence of a peak at m/z 92 for DQ and at m/z 93 for PQ possibly caused by the doubly charged cation $[Cat]^{2+}$, in our case this cation was not detected. The presence of both acetonitrile and HFBA may have enhanced the formation of the radical cation, as postulated by Marr and King [15].

3.3. Quality parameters

Precision, linearity and limits of detection (LODs) were determined using standard solutions in the mobile phase; the results obtained are shown in Table 3. Calibration curves were constructed for the standard solutions between 10 and 700 ng l^{-1}, and good linearity was observed ($r^2>0.99$) for all the compounds using both techniques.

Six replicate determinations of 300 ng l^{-1} standard solutions of each compound in the mobile phase were carried out on the same day under the optimum conditions to determine the run-to-run precision of LC–MS analysis using both ionization techniques. Relative standard deviations (R.S.D.s) in the range 6.6 to 7.4% for APCI and 5.7 to 8.1% for ESI were obtained (Table 3). Moreover, the day-to-day precision of LC–MS analysis using both ionization techniques was established with six replicate analyses of a 300 ng l^{-1} standard solution carried out on three different days. The R.S.D.s were between 8.1–8.9% for APCI and 7.7–9.4% for ESI (Table 3).

The detection limits, expressed as μg l^{-1} and based on a signal-to-noise ratio of 3:1, were determined using standard solutions and the SIM mode detection. These limits ranged from 0.1 to 3.8 μg l^{-1} in APCI and from 0.1 to 11 μg l^{-1} in ESI (Table 3). These detection limits are similar to those published by Marr and King using LC–ionspray MS–MS for PQ and DQ (5 and 1 μg l^{-1}). The values obtained for both ionization techniques are similar, except for PQ and DQ, which gave higher values in ESI.

3.4. Application

Spiked tap water was used in order to determine the applicability of the method in the analysis of water samples. The method is not sensitive enough (0.1–3.8 μg l^{-1} in APCI, 0.1–11 μg l^{-1} in ESI) to comply with the European Union directive, which

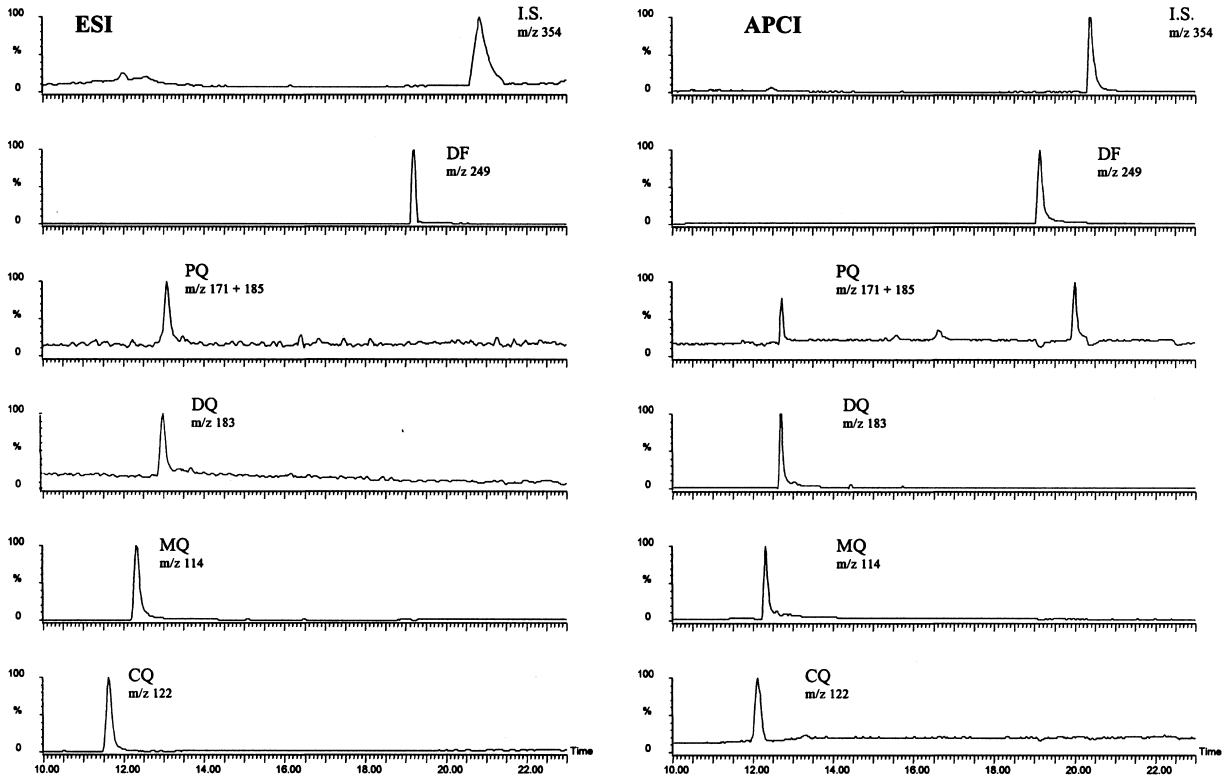


Fig. 3. LC–ESI-MS and LC–APCI-MS chromatogram of a quats mixture (20 μl standard solution of 300 ng ml^{-1}). MS: Acquisition data in SIM mode. Time scale in min.

sets a maximum admissible individual concentration of 0.1 μg l^{-1} for pesticides in drinking water, therefore, we evaluated the use of a preconcentration step with silica cartridges previous to LC–MS analysis. The maximum volume of sample that can be preconcentrated was established by passing a constant amount of 280 ng of each compound in different volumes (5 to 350 ml) through the silica cartridges, with a breakthrough volume of 250 ml. The recoveries were calculated from five different concentration levels of spiked tap water (0.1, 0.5, 1.0, 2.5 and 5.0 μg l^{-1}) and were higher than 85% for all compounds.

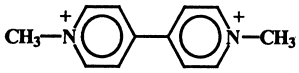
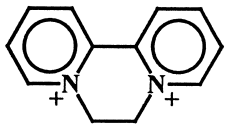
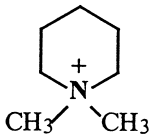
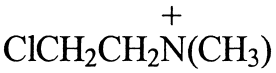
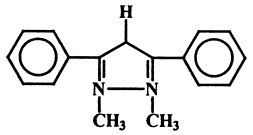
Fig. 4 shows the chromatograms obtained from a spiked water sample of 1.0 ng l^{-1}. The chromatograms are almost free of interfering peaks, thanks to the high selectivity and specificity of the mass spectrometry technique. Quality parameters for the determination of quats using LC–MS with a preconcentration step were determined (Table 3). Run-to-run precision was determined with six replicate analyses of 1.0 μg l^{-1} spiked tap water samples performed on the same day. R.S.D.s were in the range of 8 and 14% for ESI and 8 and 12% for APCI. The day-to-day precision was established with three replicate determinations of spiked tap water samples (1.0 μg l^{-1}) on three different days and R.S.D.s between 9–16 for ESI and 12–15% for APCI were obtained.

The preconcentration step improved detection limits significantly (0.05–1.8 μg l^{-1} for APCI and 0.05–4.7 μg l^{-1} for ESI). The results obtained with monocations were similar using both APCI and ESI, whereas for PQ and DQ better detection limits were obtained using APCI.

4. Conclusions

We have demonstrated the applicability of LC–

Table 2
Mass spectra data of quaternary ammonium herbicides in LC–ESI-MS and LC–APCI-MS

			Relative abundance (%)			
			ESI		APCI	
	Fragment	*m/z*	30 V	50 V	35 V	50 V
Paraquat (PQ)	$[Cat]^{+\cdot}$	186	12	18	22	12
	$[Cat-H]^{+}$	185	100	100	–	–
	$[Cat-CH_3]^{+}$	171	–	70	100	100
	$[Cat+2H]^{2+}$	94	–	–	–	4
Diquat (DQ)	$[Cat]^{+\cdot}$	184	55	20	29	26
	$[Cat-H]^{+}$	183	100	100	100	52
	$[Cat-NH_2+H]^{+\cdot}$	169	–	3	12	24
	$[Cat-CNH]^{+\cdot}$	157	–	20	72	100
	$[C_{10}H_{10}]^{+\cdot}$	130	–	–	2	22
Mepicuat (MQ)	$[Cat]^{+}$	114	100	100	100	100
	$[Cat-CH_3+H]^{+}$	100	6	–	12	7
	$[Cat-CH_3]^{+\cdot}$	99	–	–	–	8
	$[Cat-CH_3-H]^{+}$	98	–	–	–	17
	$[Cat-C_4H_8]^{+}$	58	–	–	–	10
Chlormequat (CQ)	$[Cat+2]^{+}$	124	36	35	35	31
	$[Cat]^{+}$	122	100	100	100	93
	$[Cat-Cl-CH_2-H]^{+}$	72	–	–	14	12
	$[Cat-N(CH_3)_3]^{+}$	63	–	6	–	29
	$[Cat-ClC_2H_4]^{+\cdot}$	59	–	22	–	100
	$[Cat-ClC_2H_4]^{+}$	58	–	–	–	95
Difenzoquat (DF)	$[Cat]^{+}$	249	100	100	100	100
	$[Cat-CH_3]^{+\cdot}$	234	–	–	13	12
	$[Cat-N(CH_3)_2+2H]^{+\cdot}$	193	–	2	–	24
	$[Cat-C_6H_5-CNCH_3]^{+\cdot}$	131	–	–	–	18
	$[Cat-C_6H_5-C_2HNCH_3]^{+}$	118	–	2	–	29
	$[Cat-C_6H_5-C_2HN+N]^{+\cdot}$	104	–	–	–	7
	$[C_6H_5CH_2]^{+}$	91	–	–	–	10

atmospheric pressure ionization (API) MS techniques in positive ion detection for the determination of quats in water samples in the low $\mu g\ l^{-1}$ level. Coelution had an important effect on the sensitivity of both ionization techniques; thus, for the analysis of quats a good chromatographic resolution is necessary. Besides, we used an acetonitrile post-column addition step to further increase sensitivity. At low working extraction voltages, single-charged molecular ions are predominant in ESI and APCI spectra for MQ, CQ and DF. For PQ and DQ the deprotonated molecular ion is the base peak in ESI, but in APCI the base peak for PQ is $[Cat-CH_3]^{+}$ and an important amount of fragmentation was observed for DQ. Good linearity and reproducibility were obtained for both sources and low detection limits were achieved (0.05 to 1.8 $\mu g\ l^{-1}$ for APCI and 0.05 to 4.7 $\mu g\ l^{-1}$ for ESI) for tap water using a preconcentration method. The analytical method proposed is a sensitive and reproducible procedure to identify and

Table 3
Quality parameters determined for quats under HPLC–API-MS conditions described in Section 2.2

	CQ		MQ		DQ		PQ		DF	
	ESI	APCI	ESI	APCI	ESI	APCI	ESI	APCI	ESI	APCI
LOD ($\mu g\ l^{-1}$)										
Standard solutions	0.9	0.5	0.4	0.5	6.0	0.7	11.0	3.8	0.1	0.1
Spiked tap water[a]	0.1	0.1	0.1	0.1	0.9	0.1	4.7	1.8	0.05	0.05
Reproducibilty (R.S.D., %)										
Run-to-run ($n=6$):										
Standard solutions	8.1	7.0	6.8	7.3	7.0	7.4	6.5	7.4	5.7	6.6
Spiked tap water[a]	14.3	10.5	8.7	9.3	8.5	10.9	8.1	11.6	7.7	8.5
Day-to-day ($n=3$):										
Standard solutions	9.4	8.5	7.7	8.1	8.2	8.9	7.7	9.1	7.7	8.9
Spiked tap water[a]	15.9	14.6	9.9	14.2	10.1	13.2	9.4	13.5	9.3	11.6
Recoveries[a]	95.8	94.6	98.4	96.6	92.7	94.2	89.1	91.6	87.3	85.2

Volume injected: 20 μl.
[a] Two hundred and fifty ml water preconcentrated to 1 ml.

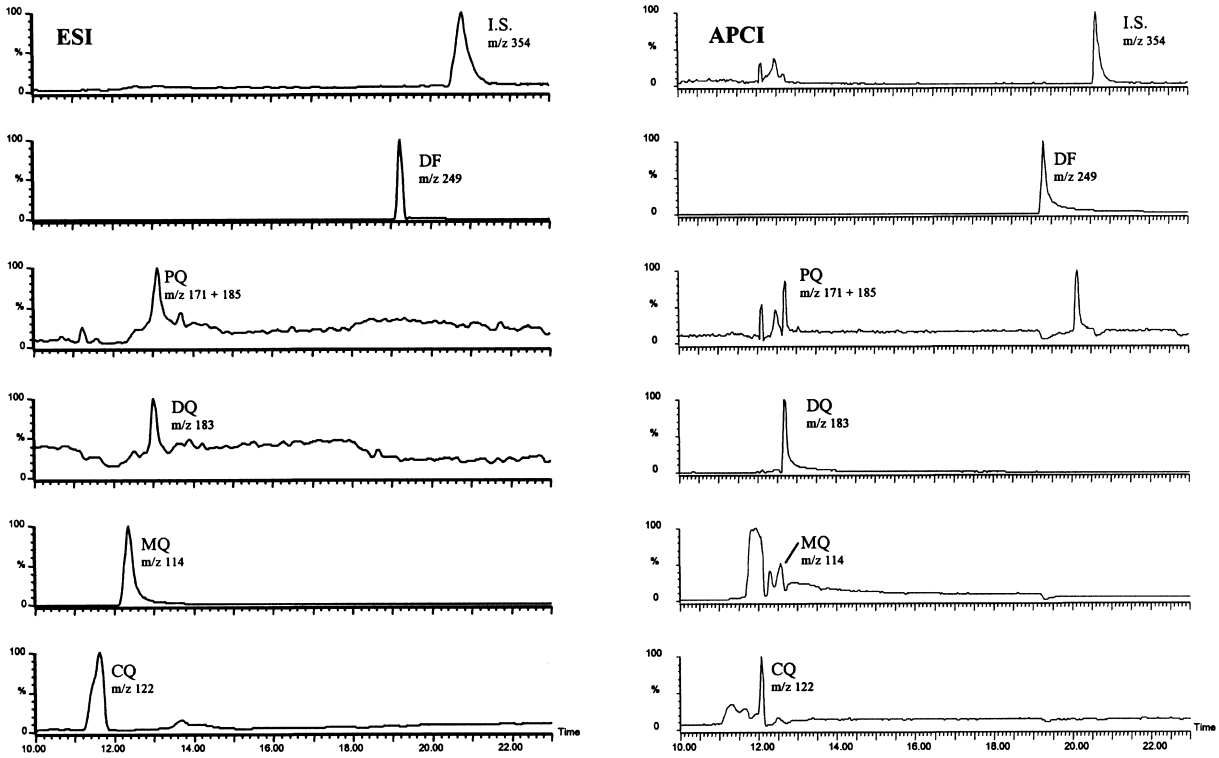


Fig. 4. LC–ESI-MS and LC–APCI-MS chromatogram of a tap water sample spiked with 1 ng l^{-1}. MS: Acquisition data in SIM mode. Time scale in min.

quantify these substances at low $\mu g\ l^{-1}$ levels, and is a suitable technique for the analysis of quats in water.

Acknowledgements

We are grateful to Dr. Isidre Casals from the Serveis Científico Tècnics of the University of Barcelona for LC–MS technical support and laboratory assistance. This project was supported by the CICYT, Spain (AMB97-0405). R.C. was the recipient of a grant provided by the Universidad Nacional Autónoma de México (DGAPA and Campus Iztacala).

References

[1] M.C. Carneiro, L. Puignou, M.T. Galceran, J. Chromatogr. A 669 (1994) 217.
[2] M.T. Galceran, M.C. Carneiro, M. Diez, L. Puignou, J. Chromatogr. A 782 (1997) 289.
[3] D. Kaniansky, F. Ivnyi, F.I. Onuska, Anal. Chem. 66 (1994) 1817.
[4] D. Barceló, G. Durand, R.J. Vreeken, J. Chromatogr. 647 (1993) 271.
[5] T. Itagaki, S.J. Lai, S.R. Binder, J. Liq. Chromatogr. Rel. Technol. 20 (1997) 3339.
[6] R. Kesari, M. Rai, V.K. Gupta, J. Assoc. Off. Anal. Chem. 80 (1997) 388.
[7] C. Fuke, K. Ameno, S. Ameno, et al., J. Anal. Toxicol. 16 (1992) 214.
[8] G.J. Moody, R.K. Owusu, J.D. Thomas, Anal. Lett. 21 (1988) 1653.
[9] K. Watabe, K. Okada, T. Katsu, J. Toxicol. Environ. Health 38 (1992) 142.
[10] K. Ameno, C. Fuke, et al., J. Liq. Chromatogr. 18 (1995) 2115.
[11] T.M. Chichila, S.M. Walters, J. Assoc. Off. Anal. Chem. 74 (1991) 961.
[12] B.L. Worobey, J. Assoc. Off. Anal. Chem. 76 (1993) 881.
[13] J. Hajslová, P. Cuhra, T. Davídek, K. Davídek, J. Chromatogr. 479 (1989) 243.
[14] H.J. Van der Hoeven, E.M. Reeuwijk, U.R. Tjaden, J. Van der Greef, J. Chromatogr. A 741 (1996) 75.
[15] J.C. Marr, J.B. King, Rapid Commun. Mass Spectrom. 11 (1997) 479.
[16] E. Moyano, D.E. Games, M.T. Galceran, Rapid Commun. Mass Spectrom. 10 (1996) 1379.
[17] R.J. Vreeken, W.D. Van Dongen, R.T. Ghijsen et al, Biol. Mass Spectrom. 21 (1992) 305.
[18] J. Hodgeson, W. Bashe, J. Eichelberger, Method 549.1, US EPA, Cincinnati, OH, 1992.
[19] M. Tomita, T. Okuyama, Y. Nigo, Biomed. Chromatogr. 6 (1992) 91.
[20] T.M. Chichila, D.M. Gilvydis, J. Assoc. Off. Anal. Chem. 76 (1993) 1323.
[21] M. Ibáñez, Y. Picó, J. Mañes, J. Chromatogr. A 727 (1996) 245.
[22] B.L. Worobey, Pestic. Sci. 18 (1987) 245.
[23] M.C. Carneiro, Doctoral Thesis, University of Barcelona, 1996.
[24] M. Ibáñez, Y. Picó, J. Mañes, Chromatographia 45 (1997) 402.
[25] X. Song, W.L. Budde, J. Am. Soc. Mass Spectrom. 7 (1996) 981.
[26] I. Kambaphati, K.S. Roinestad, T.G. Hartman, J.D. Rosen, E.K. Fukuda, R.L. Lippincott, R.T. Rosen, J. Chromatogr. A 688 (1994) 67.