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Application of a Tandem Mass Spectrometer and Core−Shell Particle Column for the Determination of 151 Pesticides in Grains

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ABSTRACT: A comparison of ultrahigh performance liquid chromatography (UHPLC) with a 2.6 μm core−shell particle column (Kinetex C_{18}) and conventional liquid chromatography (LC) with a 3 μm porous particle column (Atlantis dC_{18}), coupled with electrospray ionization tandem mass spectrometry (ESI-MS/MS), for the determination of 151 pesticides in grains is presented in this study. Pesticides were extracted from grain samples using a procedure known as QuEChERS (quick, easy, cheap, effective, rugged, and safe). Quantification, with an analytical range from 5 to 500 μg/kg, was achieved using matrix-matched standard calibration curves with isotopically labeled standards or a chemical analogue as internal standards. The method performance parameters that included overall recovery, intermediate precision, and measurement uncertainty were evaluated using a designed experiment, that is, the nested design. The UHPLC (Kinetex C_{18}) was superior to conventional LC (Atlantis dC_{18}) as it yielded a shorter analytical run time, increased method sensitivity, and improved method performance. For UHPLC/ESI-MS/MS (Kinetex C_{18}), 90% of the pesticides studied had recoveries between 81 and 110%, 88% of the pesticides had intermediate precision ≤20%, and 84% of the pesticides showed measurement uncertainty ≤40%. As compared to UHPLC/ESI-MS/MS (Kinetex dC_{18}), the LC/ESI-MS/MS (Atlantis dC_{18}) showed a relatively lower sensitivity, less repeatability, and larger measurement uncertainty. UHPLC/ESI-MS/MS with 2.6 μm core−shell particle column and scheduled MRM proved to be a good choice for quantification or determination of pesticides in grains.

KEYWORDS: UHPLC/ESI-MS/MS, LC/ESI-MS/MS, pesticides, grains, measurement uncertainty

INTRODUCTION

There are over 1100 pesticides from a broad range of classes that are widely used in various combinations at different stages of cultivation or during postharvest storage to protect crops against pests and fungi and to provide quality preservation. Pesticide residues that remain in the food supply could pose a risk to human health because of their potential subacute and chronic toxicity. In Canada, many food commodities such as fruits and vegetables, infant food, tea, etc. have been tested for pesticide residues under the federal government's Canadian National Chemical Residues Monitoring Program and Food Safety Action Plan. The Canadian Food Inspection Agency requires both sensitive and confirmatory methods to test pesticides in grains for chemical residue monitoring programs and for risk assessments of consumer exposure to pesticides.

Gas chromatography (GC) and liquid chromatography (LC) mass spectrometers are essential means for determination of pesticide residues in foods.[1] The applications of LC-MS for analysis of LC-amenable pesticides have been profound in the past few years because of its high sensitivity and good repeatability for trace level detection and quantification. The columns used for these kinds of applications were generally ≥3 μm porous C_{18} particles in the past, and the analytical time was relatively long.[2] The core−shell or fine porous shell particles, that is, Halo and Kinetex, represent a recent key technological advancement in the arena of fast LC separations.[3,4] Their development has brought significant improvements in column efficiency and thereby increases in resolution, throughput, sensitivity, etc. Core−shell particles, sometimes also referred to as fused-core silica stationary phases,[5] are made by fusing a < 0.5 μm porous silica layer, which is functionalized with a bonded phase such as C_{18}, C_8, etc. to <2 μm nonporous or solid silica cores. The reduced intraparticle flow path of the fused particles provides superior mass transfer kinetics and better performance at high mobile phase velocities, while the core−shell particles provide lower pressure than sub-2 μm particles.[5] For example, Kinetex C_{18} core−shell 2.6 μm particles used in this study were made of a 0.35 μm porous shell fused to a 1.9 μm solid core. Kinetex core−shell columns can operate on conventional LC systems with significant reductions in analytical run time and provide ultrahigh column efficiency in separation, which was close to sub-2 μm column chromatographic efficiency.[6]

In this paper, we present a study comparing 2.6 μm core−shell particles (Kinetex C_{18}) and 3 μm porous particles (Atlantis dC_{18}) columns for the determination of 151 pesticides in grains using the QuEChERs method. The methods were validated according to a designed experiment, that is, a nested design,[7,8] to evaluate its performance characteristics including overall recovery, intermediate precision, and measurement uncertainty for routine sample monitoring program.

MATERIALS AND METHODS

Materials and Reagents. Seven different whole grain matrices (pesticides free) for method development and validation, which

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included barley, basmati rice, rice flour, popcorn, wheat, seven grains, and buckwheat, were obtained from local markets. The individual grain samples were homogenized using a blender, and 500 g of each grain sample was prepared. One hundred grain samples (500−1000 g per sample) for a pilot study were also purchased from local supermarket stores. All samples were stored at room temperature. Ammonium acetate (reagent grade), LC-MS water (Chromasolv, 1 L), and LC-MS acetonitrile (Chromasolv, 2.5 L) were purchased from Sigma-Aldrich Corp. (Canada). ENVIRO CLEAN extraction columns [6.0 g of anhydrous magnesium sulfate ($MgSO_4$) and 1.5 g of sodium acetate, 50 mL centrifuge tubes] and ENVIRO CLEAN extraction columns [900 mg of $MgSO_4$, 150 mg of C_{18}, and 300 mg of primary secondary amine (PSA), 15 mL centrifuge tubes] were from United Chemical Technologies, Inc. (Bristol, PA). Acetic acid (glacial acetic acid, reagent grade, 99.7%), acetonitrile (distilled in glass), and methanol (distilled in glass) were obtained from Caledon Laboratories Ltd. (Canada). Water used for reagent and sample preparation was Milli-Q water, 18 MΩ cm from Milli-Q Reagent Water System (Millipore Corp., United States). Sodium acetate anhydrous (ACS reagent) was from Thermo Fisher Scientific Inc. (Canada). Pesticides standards (Table 1, column 1) were obtained from EQ Laboratories Inc. (United States), Riedel-de Haen AG (Germany), or Chem Service (United States). Internal standards carbendazim-d_4 and carbofuran-d_3 were purchased from EQ Laboratories Inc. (United States), and thiabendazole-d_4 was from Chemical Synthesis Services (Northern Ireland). LC vials were Mini-UniPrep syringeless filter device with polypropylene housing and PVDF 0.45 μm membrane (Whatman Inc., United States).

Preparation of Standards Solutions. Individual pesticide standard stock solutions were generally prepared in a concentration of 4000.0 μg/mL in methanol. Because of their poor solubility in methanol, carbendazim was prepared at 200.0 μg/mL, and a few of pesticides were prepared at 1000.0 or 2000.0 μg/mL (Table 1, column 1). An intermediate pesticide standard mix working solution was prepared as 10.0 μg/mL from stock solutions. Stock and intermediate solutions were stored at −20 °C. Six-level pesticide standard mix working solutions were prepared by transferring 0.1, 0.5, 2.0, 4.0, 6.0, and 10.0 mL of 10.0 μg/mL intermediate working solution into six separate 50 mL volumetric flasks and making them up to volume with methanol to prepare 0.02, 0.1, 0.4, 0.8, 1.2, and 2.0 μg/mL six-level standard solutions. They were used for constructing matrix-matched standard calibration curves. Four-level sample spike pesticide standard working solutions were prepared by transferring 1.0, 9.0, 24.0, and 40.0 mL of 10.0 μg/mL intermediate working solution into separate 50 mL volumetric flasks and making them up to volume with methanol to prepare 0.2, 1.8, 4.8, and 8.0 μg/mL four-level standard solutions for sample spikes. Internal standard working solutions (2.0 μg/mL) including carbofuran-d_3, carbendazim-d_4, and thiabendazole-d_4 were prepared in a mixture of acetonitrile and methanol (50:50, v/v). All working solutions were stored at 4 °C.

Preparation of Reagent Solutions. Acetonitrile/acetic acid (99 + 1, v/v) was prepared by mixing 990 mL of acetonitrile with 10 mL of acetic acid. Ammonium acetate (0.1 M) was prepared by weighing 7.7 g of ammonium acetate and dissolving it in approximately 800 mL of water. After it was transferred into a 1000 mL volumetric flask, the solution was made up to the volume with water. The solvent buffer was a mixture of 0.1 M ammonium acetate and methanol (50 + 50, v/v).

LC/ESI-MS/MS Parameters. The LC/ESI-MS/MS system utilized was an Agilent 1200 SL (Agilent, Germany) coupled with an API 5000 LC/MS/MS System (Applied Biosystem, Canada). The system was controlled using the Analyst 1.5 software. The mobile phase B was acetonitrile, and the mobile phase A was 10 mM ammonium acetate with 2% acetonitrile in water. The column oven temperature was set at 35 °C, and the autosampler temperature was set at 5 °C.

Core−Shell Particle Column. The core−shell particle or UHPLC column utilized was a Kinetex C_{18}, 100 mm × 2.1 mm, 2.6 μm column (Phenomenex, United States). The injection volume was 3 μL, when not specified, and the total run time was 12 min.

Porous Particle Column. The porous particle or conventional LC analytical column was an Atlantis dC_{18}, 100 mm × 2.1 mm, 3 μm column (Waters, United States), and the guard column was an Atlantis dC_{18}, 10 mm × 2.1 mm, 3 μm column (Waters). The injection volume was 5 μL, and the total run time was 35 min. Both conventional LC and UHPLC gradient profiles are shown in Table 2.

MS/MS Conditions. The ion source was TurboIonSpray or Turbo V electrospray ion source in positive mode. General mass spectrometric parameters are shown in Table 2. The pause time between mass ranges was 5 ms. Specific mass spectrometric parameters such as dwell time, declustering potential (DP), entrance potential (EP), collision energy (CE), collision cell exit potential (CXP), and multiple reaction monitoring transitions (MRM or Q1 and Q3) are listed in Table 1. Parameters such as DP, EP, CE, and CXP were optimized using the Quantitative Optimization bundled with the Analyst software by infusing each individual pesticide standard (10 or 50 μg/L) to the mass spectrometer. The syringe pump (Harvard Apparatus, United States) flow rate was set at 10 μL/min for infusion. For LC (Atlantis dC_{18}) column, nonscheduled MRM was used; that is, MRMs were acquired in one experiment period. The total scan time was 1.6211 s, and the duration was 24 min. For UHPLC (Kinetex C_{18}) column, when not specified, a scheduled MRM was used according to the retention time with a MRM detection window of 100 s. The total scan time was 1.6211 s, and the duration was 11 min.

Sample Extraction and Cleanup Procedures. Sample extraction and cleanup procedures followed the buffered QuEChERS[2] or AOAC Official Method 2007.01[9] with a slight modification. For the fortification experiment, grain samples (5.0 g/sample) were weighed into individual 50 mL polypropylene centrifuge tubes (VWR International, Canada). Two hundred fifty microliters per four-level sample spike pesticide standard working solution was added into four centrifuge tubes to provide 10.0, 90.0, 240.0, and 400.0 μg/kg of pesticides equivalent in samples. To each tube, 250 μL of 2.0 μg/mL internal calibration standard working solution (100.0 μg/kg equivalent in samples) was added along with 15 mL of water. Tubes were capped, mixed, and allowed to stand for 30 min at room temperature for the purpose of hydration. Then, 15 mL of acetonitrile/acetic acid (99 + 1, v/v) was added to individual samples and mixed, followed by the addition of 1.5 g of anhydrous sodium acetate and 6.0 g of anhydrous magnesium sulfate from ENVIRO CLEAN extraction columns. The centrifuge tubes were capped, shaken again for 45 s by hand, and then centrifuged at 3000 rpm (∼2100*g*) for 3 min using an Allegra 6 centrifuge (Beckman Coulter Inc., United States). Supernatants were transferred (6 mL/sample) into individual 15 mL polypropylene centrifuge tubes, that is, ENVIRO CLEAN extraction columns, which contain 900 mg of $MgSO_4$, 150 mg of C_{18}, and 300 mg of PSA. The centrifuge tubes were capped, shaken for 45 s, and centrifuged at 3000 rpm (∼2100*g*) for 3 min. Three milliliters of supernatants (1 g sample/3 mL) were transferred into individual 5 mL Pyrex brand centrifuge tubes, precalibrated with 1 mL volume accuracy (VWR International). Each of the sample extracts was evaporated to 0.1−0.2 mL, which took approximately 45 min, using an N-EVAP nitrogen evaporator (Organomation Associates Inc., United States) at 30 °C under a stream of nitrogen. The extracts were made up to 0.5 mL with methanol, vortexed for 30 s, and then made up to 1.0 mL with 0.1 M ammonium acetate and vortexed again for 30 s. One hundred microliters of each extract was transferred into a Mini-UniPrep vial (Whatman Inc.), and 500 μL of solvent buffer was added. The vials were capped, vortexed for 30 s, and pressed to filter. Sample extracts were analyzed by LC/ESI-MS/MS injection.

Table 1. LC/ESI-MS/MS Parameters and Method Performance Results

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
1[e]	2	3	4	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
abamectin B_{1a}[e]	$[M + H]^+$	891	305	111	10	37	37	30	6.6	30	96.5	19.5	39.3	12.26	**13(25)**	96.5[f]	14.5	30.7
		891	567	111	10	21		28										
		891	113	111	10	69		14										
acetochlor	$[M + H]^+$	270	224	66	10	15	15	14	5.41	14	94.5	8.4	16.9	9.58	7	95.3	11.6	23.3
		270	148	66	10	29		20										
		270	133	66	10	47		16										
aclonifen[e]	$[M + H]^+$	265	182	101	10	41	41	24	5.53	**6(100)**	99.0[g]	18.6	**43.8**	9.78	**6(100)**	98.6[g]	**22.8**	**45.8**
		265	218	101	10	35		22										
		265	194	101	10	27		18										
aldicarb	$[M + NH_4]^+$	208	116	26	10	13	13	16	3.94	55	99.4	9.5	19.2	7.21	34	98.0	15.4	31.0
		208	89	26	10	25		16										
		208	70	26	10	21		14										
aldicarb sulfone	$[M + NH_4]^+$	240	86	51	10	31	31	20	2.55	29	99.1	6.8	13.9	5.08	5	98.9	11.2	22.5
		240	148	51	10	21		14										
		240	76	51	10	19		30										
aldicarb sulfoxide	$[M + H]^+$	207	132	86	10	11	11	16	1.76	97	96.0	6.4	13.0	4.26	9	97.5	9.1	19.2
		207	89	86	10	21		14										
		207	41	86	10	49		18										
azaconazole	$[M + H]^+$	300	159	76	10	41	**27**	10	4.51	26	99.2	7.0	15.6	8.08	22	100.0	7.2	14.4
		300	231	76	10	25		14										
		300	89	76	10	97		34										
benoxacor[e]	$[M + H]^+$	260	149	76	10	29	29	22	5.09	**5(25)**	98.8[f]	10.1	22.6	9.05	**6(25)**	99.0[f]	12.0	24.0
		260	134	76	10	43		12										
		260	120	76	10	49		14										
bitertanol	$[M + H]^+$	338	99	61	10	23	23	12	5.26	34	97.1	11.1	27.6	9.34	15	97.2	11.7	29.9
		338	70	61	10	31		26										
		338	43	61	10	59		16										
bromuconazole	$[M + H]^+$	376	159	91	10	37	37	10	5.04	15	96.4	9.1	19.6	9.00	10	96.9	9.6	20.0
		376	70	91	10	31		28										
		376	89	91	10	123		12										
butafenacil	$[M + NH_4]^+$	492	331	46	10	33	**15**	34	5.42	40	97.8	13.2	26.5	9.49	35	101.4	12.2	24.6
		492	180	46	10	61		18										
		492	349	46	10	23		18										
butocarboxim sulfoxide	$[M + H]^+$	207	75	86	10	21	21	30	1.61	173	92.7	5.7	11.9	3.82	17	91.7	7.8	17.1
		207	132	86	10	13		6										
		207	43	86	10	31		16										
cadusafos	$[M + H]^+$	271	159	81	10	21	**12**	10	5.74	26	96.7	10.0	20.2	10.16	38	95.3	9.8	19.7
		271	131	81	10	33		16										
		271	97	81	10	49		12										
carbaryl	$[M + H]^+$	202	145	91	10	17	17	18	4.47	14	100.4	7.3	14.9	8.04	12	99.4	10.1	20.2
		202	127	91	10	43		16										

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
		202	117	91	10	33		16										
carbendazim	$[M + H]^+$	192	160	106	10	25	**13**	16	3.43	117	99.0	5.0	9.9	6.29	77	98.9	7.8	15.6
		192	132	106	10	45		18										
		192	105	106	10	49		14										
carbendazim d_4 (IS)	$[M + H]^+$	196	164	66	10	29	**21**	22	3.41					6.24				
carbofuran	$[M + H]^+$	222	165	81	10	19		20	4.36	16	103.1	7.6	15.2	7.84	27	102.2	7.2	14.4
		222	**123**	81	10	31	**20**	14										
		222	55	81	10	37		20										
carbofuran d_3 (IS)	$[M + H]^+$	225	123	96	10	33	33	14	4.35					7.79				
carfentrazone-ethyl	$[M + H]^+$	412	346	141	10	33	**29**	18	5.5	27	95.4	9.0	19.8	9.68	34	95.3	9.5	27.7
		412	366	141	10	25		28										
		412	384	141	10	21		30										
chlorbromuron[e]	$[M + H]^+$	293	125	101	10	51	51	16	5.09	**8(100)**	94.8[g]	13.5	27.1	9.27	**5(25)**	98.4[f]	10.7	21.5
		293	63	101	10	101		12										
		293	62	101	10	23		12										
chloridazon[i]	$[M + H]^+$	222	51	116	10	93	93	20	3.44	12	98.8	11.5	24.7	6.49	14	96.2	12.1	24.7
		222	65	116	10	53		14										
		222	104	116	10	37		12										
chlorimuron-ethyl	$[M + H]^+$	415	186	86	10	29	**15**	24	3.61	142	88.0	12.6	25.3	6.49	28	89.6	14.2	28.5
		415	185	86	10	37		10										
		415	83	86	10	65		16										
chloroxuron	$[M + H]^+$	291	72	106	10	31	**19**	16	5.01	54	96.7	10.1	21.2	8.91	126	95.7	7.9	15.9
		291	46	106	10	49		20										
		291	31	106	10	109		12										
chlortoluron	$[M + H]^+$	213	72	66	10	37	**15**	14	4.42	55	98.8	6.7	13.4	7.94	35	98.0	8.4	16.8
		213	46	66	10	29		20										
		213	56	66	10	71		6										
clodinafop-propargyl	$[M + H]^+$	350	266	121	10	23	**15**	26	5.6	22	93.2	10.0	22.0	9.83	49	95.3	10.5	25.1
		350	91	121	10	43		8										
		350	238	121	10	35		24										
cloquintocet-mexyl	$[M + H]^+$	336	238	76	10	25	**11**	14	6.06	53	101.2	15.1	38.4	10.70	14	98.3	19.2	38.5
		336	192	76	10	41		22										
		336	179	76	10	45		18										
clothianidin	$[M + H]^+$	250	169	61	10	21	21	16	3.33	30	95.8	8.4	17.0	6.20	12	95.1	11.3	22.7
		250	132	61	10	27		22										
		250	113	61	10	37		46										
cyanofenphos[e]	$[M + H]^+$	304	276	51	10	19	19	30	5.74	**7(25)**	**114.9**[f]	13.4	32.1	10.07	**7(25)**	**111.8**[f]	18.1	**40.4**
		304	157	51	10	33		24										
		304	120	51	10	31		10										
cycloxydim	$[M + H]^+$	326	280	111	10	21	21	32	4.86	17	99.9	14.2	30.3	9.15	11	99.0	**20.1**	**41.3**

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
		326	180	111	10	29		26										
		326	101	111	10	33		22										
cycluron	$[M + H]^+$	199	89	86	10	23	**15**	10	4.44	45	97.1	7.0	14.0	7.99	37	96.3	7.7	15.5
		199	72	86	10	33		12										
		199	69	86	10	31		16										
cyromazin	$[M + H]^+$	167	43	76	10	57	57	18	1.42	24	**62.2**	9.1	25.3	3.3	3	**65.5**	9.8	30.9
		167	68	76	10	49		14										
		167	60	76	10	29		24										
demeton-*S*-methyl sulfone[i]	$[M + H]^+$	263	169	111	10	23	23	10	2.98	83	98.9	5.4	10.9	5.57	50	99.1	8.2	16.6
		263	127	111	10	37		14										
		263	109	111	10	41		12										
demeton-*S*-methyl sulfoxide[i]	$[M + H]^+$	247	169	86	10	21	**13**	4	2.51	179	96.5	5.4	11.2	4.89	118	93.5	7.4	16.1
		247	127	86	10	37		16										
		247	105	86	10	21		12										
desmedipham	$[M + H]^+$	301	182	116	10	15	**19**	10	4.92	119	97.1	9.3	18.6	8.71	92	100.7	11.4	23.0
		301	136	116	10	35		8										
		301	65	116	10	77		26										
diclocymet[e]	$[M + H]^+$	313	173	116	10	25	25	24	5.42	**10**(**25**)	96.1[f]	9.4	19.2	9.54	4	98.5	12.3	25.1
		313	137	116	10	47		12										
		313	102	116	10	63		12										
diethofencarb	$[M + H]^+$	268	226	61	10	17	**23**	14	5.01	12	98.4	8.1	16.2	8.91	5	98.3	7.4	15.4
		268	124	61	10	45		14										
		268	152	61	10	31		20										
difenoconazole	$[M + H]^+$	406	251	136	10	39	**22**	26	5.55	445	96.7	13.4	31.9	9.85	45	98.2	13.9	27.9
		406	337	136	10	25		26										
		406	188	136	10	49		26										
dimethametryn	$[M + H]^+$	256	186	121	10	31		30	5.43	12	88.9	13.2	28.3	9.58	10	89.6	14.8	30.4
		256	**91**	121	10	43	**31**	14										
		256	96	121	10	45		12										
dimethomorph	$[M + H]^+$	388	301	76	10	31	**17**	16	4.82	60	98.3	8.2	16.5	8.57	67	97.5	9.0	18.1
		388	165	76	10	45		10										
		388	152	76	10	99		20										
diniconazole	$[M + H]^+$	326	70	136	10	37	**31**	28	5.4	41	95.2	9.8	20.0	9.58	24	95.6	9.9	22.6
		326	43	136	10	105		16										
		326	159	136	10	47		20										
dioxacarb	$[M + H]^+$	224	123	96	10	25	25	16	3.53	29	99.3	7.6	15.2	6.54	48	99.8	8.8	17.6
		224	167	96	10	15		10										
		224	95	96	10	39		12										
dipropetryn	$[M + H]^+$	256	144	101	10	41		14	5.52	11	90.5	15.5	31.1	9.73	5	90.6	13.1	26.2
		256	**214**	101	10	29	**17**	22										
		256	102	101	10	53		12										
diuron	$[M + H]^+$	233	72	56	10	35	35	28	4.58	5	99.9	7.5	15.8	8.18	5	102.2	7.3	17.4

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
		233	133	56	10	55		18										
		233	74	56	10	107		14										
dodemorph[e]	$[M + H]^+$	282	116	106	10	31	**21**	16	9.21	51	75.0	**28.8**	**62.6**	18.70	**63(25)**	**76.5**[f]	**23.5**	**49.8**
		282	98	106	10	39		14										
		282	41	106	10	73		16										
emamectin B_{1a}	$[M + H]^+$	886	158	41	10	47	**33**	18	**6.87**	20	97.0	**20.6**	**55.3**	**15.49**	16	95.0	**22.3**	**52.8**
		886	82	41	10	49		10										
		886	126	41	10	49		14										
epoxiconazole	$[M + H]^+$	330	121	91	10	29	**19**	24	5.09	33	97.0	10.8	24.0	9.05	29	94.6	12.0	38.3
		330	123	91	10	31		8										
		330	91	91	10	49		20										
ethiofencarb	$[M + H]^+$	226	107	86	10	25	25	14	4.57	13	89.2	7.3	30.3	8.18	9	90.6	9.3	34.4
		226	164	86	10	13		10										
		226	77	86	10	49		16										
ethiofencarb sulfone	$[M + NH_4]^+$	275	107	76	10	27		14	3.35	23	98.4	8.6	17.3	6.20	10	100.0	9.7	21.1
		275	**201**	76	10	17	17	0										
		275	77	76	10	79		32										
ethiofencarb sulfoxide	$[M + H]^+$	242	107	76	10	29	**15**	18	3.06	282	107.3	5.8	18.1	5.62	86	106.1	8.7	22.6
		242	77	76	10	67		32										
		242	79	76	10	53		32										
ethirimol[i]	$[M + H]^+$	210	140	56	10	33	**21**	20	3.93	17	88.0	11.3	22.7	7.02	10	88.4	10.8	24.0
		210	98	56	10	39		14										
		210	43	56	10	71		16										
ethoprop	$[M + H]^+$	243	131	86	10	29	**23**	14	5.2	9	96.4	7.9	15.8	9.25	19	93.7	9.7	20.0
		243	97	86	10	51		12										
		243	43	86	10	41		10										
etofenprox[e]	$[M+NH_4]^+$	394	177	31	10	21	**18**	18	7.17	11	119.3	**50.3**	**113.0**	12.83	**15(25)**	102.3[f]	**37.1**	**74.6**
		394	359	31	10	17		26										
		394	107	31	10	65		12										
etoxazole	$[M + H]^+$	360	141	101	10	49	**22**	14	6.46	30	102.7	18.0	**47.5**	11.47	17	99.9	**21.1**	**47.0**
		360	304	101	10	27		34										
		360	57	101	10	43		12										
fenamidone	$[M + H]^+$	312	92	81	10	33	**19**	10	5.11	69	93.5	7.4	19.3	9.00	105	98.2	7.9	16.6
		312	236	81	10	25		20										
		312	65	81	10	49		14										
fenazaquin	$[M + H]^+$	307	57	91	10	35	**23**	14	6.52	35	102.7	**33.7**	**82.3**	11.76	8	96.1	**29.1**	**65.6**
		307	161	91	10	25		18										
		307	91	91	10	93		20										
fenhexamid	$[M + H]^+$	302	97	106	10	33	33	20	5.11	45	90.3	8.7	20.2	9.05	5	92.9	10.1	20.3
		302	55	106	10	61		14										
		302	143	106	10	47		14										
fenoxanil	$[M + NH_4]^+$	346	302	36	10	23	23	28	5.51	5	97.3	10.3	22.7	9.73	12	95.8	11.1	25.3
		346	86	36	10	39		36										
		346	189	36	10	43		20										

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
fenpropidin	$[M + H]^+$	274	147	76	10	39	**29**	8	**5.86**	8	91.5	19.9	**45.3**	**12.45**	3	91.0	18.4	39.1
		274	117	76	10	73		16										
		274	86	76	10	41		10										
fenpropimorph	$[M + H]^+$	304	147	76	10	45	**28**	14	7.45	21	93.9	**43.8**	**94.9**	13.65	9	87.9	**21.6**	**51.5**
		304	117	76	10	81		16										
		304	91	76	10	113		12										
fenpyroximate[i]	$[M + H]^+$	422	366	126	10	27	**9**	36	6.42	38	108.3	**20.7**	**68.4**	11.42	29	104.6	**22.6**	**62.1**
		422	135	126	10	45		20										
		422	107	126	10	81		12										
fentrazamide	$[M + H]^+$	350	154	111	10	17	17	16	5.71	27	96.5	12.0	25.5	10.07	40	93.9	13.4	33.0
		350	83	111	10	35		16										
		350	197	111	10	13		24										
fluazifop-butyl	$[M + H]^+$	384	282	121	10	31	**17**	18	6.17	76	104.1	16.1	39.9	10.79	15	101.1	16.6	36.6
		384	328	121	10	25		30										
		384	91	121	10	49		10										
flucarbazone	$[M + NH_4]^+$	414	130	46	10	35	35	18	3.1	44	**63.2**	**25.8**	**51.9**	5.56	25	**68.2**	**27.1**	**55.6**
		414	115	46	10	49		18										
		414	73	46	10	49		30										
flutolanil	$[M + H]^+$	324	262	111	10	27	**17**	14	5.33	57	92.5	7.7	20.1	9.39	61	94.8	8.1	18.5
		324	242	111	10	35		12										
		324	65	111	10	63		30										
flutriafol	$[M + H]^+$	302	70	96	10	25	**17**	14	4.41	50	95.7	8.5	17.1	7.89	22	98.2	8.2	16.5
		302	123	96	10	37		16										
		302	75	96	10	110		32										
forchlorfenuron	$[M + H]^+$	248	129	31	10	27	**18**	14	4.46	56	95.8	8.2	17.0	7.94	41	93.8	8.2	17.6
		248	93	31	10	49		18										
		248	111	31	10	47		14										
fosthiazate	$[M + H]^+$	284	104	86	10	33	**16**	24	4.47	89	100.3	7.5	16.0	7.99	44	99.9	7.7	15.4
		284	228	86	10	17		22										
		284	200	86	10	25		10										
fuberidazole	$[M + H]^+$	185	157	96	10	33	**19**	14	3.81	8	93.2	8.4	19.1	6.87	8	96.2	10.5	31.4
		185	156	96	10	43		22										
		185	65	96	10	49		14										
furathiocarb	$[M + H]^+$	383	195	121	10	29	**13**	18	6.13	33	93.9	11.0	24.0	10.79	42	91.9	12.5	25.9
		383	167	121	10	39		22										
		383	162	121	10	49		16										
haloxyfop	$[M + H]^+$	362	316	121	10	29	29	36	3.87	9	**54.1**	**28.8**	**59.7**	6.73	11	**54.7**	**32.9**	**70.3**
		362	91	121	10	43		16										
		362	288	121	10	39		28										
3-hydroxycarbofuran	$[M + NH_4]^+$	255	163	46	10	27		16	3.36	15	97.4	7.5	16.3	6.20	10	97.7	11.6	24.1
		255	**220**	46	10	17	17	12										
		255	181	46	10	23		18										
imazamethabenz-methyl	$[M + H]^+$	289	144	66	10	49	**30**	10	4.04	53	99.0	8.1	16.2	7.26	37	102.5	11.0	26.7
		289	86	66	10	33		18										

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
		289	229	66	10	29		22										
imidacloprid	$[M + H]^+$	256	209	81	10	25	25	24	3.45	11	98.4	8.9	18.7	6.34	18	99.0	11.4	22.9
		256	175	81	10	29		22										
		256	84	81	10	25		12										
indoxacarb[h]	$[M + H]^+$	528	249	141	10	25	25	28	5.83	47	101.6	14.4	29.9	10.16	47	101.0	13.8	31.5
		528	293	141	10	21		20										
		528	203	141	10	49		20										
iprovalicarb	$[M + H]^+$	321	119	91	10	35	**11**	16	5.03	116	100.3	11.3	22.8	8.86	126	99.2	8.1	16.3
		321	91	91	10	73		14										
		321	116	91	10	31		14										
isocarbamide	$[M + H]^+$	186	87	86	10	25	25	14	3.34	47	96.8	10.0	21.0	6.15	17	96.9	7.7	16.3
		186	44	86	10	49		18										
		186	130	86	10	19		14										
isoprocarb	$[M + H]^+$	194	95	86	10	23	23	18	4.68	5	98.8	8.7	17.5	8.37	3	98.4	8.0	16.7
		194	137	86	10	13		14										
		194	77	86	10	49		32										
isoxathion[e]	$[M + H]^+$	314	105	111	10	23	23	12	5.86	**472(25)**	110.2[f]	16.6	34.5	10.31	**12(25)**	108.3[f]	14.7	33.4
		314	286	111	10	15		16										
		314	115	111	10	47		16										
linuron[e,i]	$[M + H]^+$	249	160	101	10	27	27	16	5.02	**9(25)**	98.4[f]	8.6	18.3	9.18	3	98.1	10.8	22.1
		249	182	101	10	23		18										
		249	133	101	10	47		18										
mepanipyrim	$[M + H]^+$	224	106	91	10	37	**31**	12	5.31	20	89.5	11.2	31.3	9.39	11	91.0	11.1	28.4
		224	77	91	10	49		16										
		224	42	91	10	49		16										
mephosfolan	$[M + H]^+$	270	140	91	10	33	**21**	16	3.99	54	100.0	6.2	12.7	7.21	56	99.2	6.7	13.4
		270	75	91	10	29		30										
		270	60	91	10	69		14										
methabenz-thiazuron	$[M + H]^+$	222	165	71	10	27		18	4.37	9	94.9	11.8	23.7	7.84	8	96.0	7.7	15.5
		222	**150**	71	10	45	**37**	20										
		222	124	71	10	45		28										
methidathion[i]	$[M + H]^+$	303	145	91	10	13	13	20	5	24	93.5	11.7	32.3	9.14	19	95.3	12.7	33.9
		303	85	91	10	31		18										
		303	58	91	10	47		26										
methiocarb	$[M + H]^+$	226	169	76	10	15	15	16	4.96	24	97.0	8.6	17.2	8.81	18	96.0	7.8	16.0
		226	121	76	10	27		20										
		226	122	76	10	33		16										
methiocarb sulfone	$[M + NH_4]^+$	275	122	46	10	35	35	16	3.76	9	94.2	8.5	24.0	6.87	3	96.4	11.4	29.4
		275	201	46	10	19		20										
		275	107	46	10	49		12										
methiocarb sulfoxide[i]	$[M + H]^+$	242	185	111	10	21	**10**	12	3.24	233	96.9	7.3	18.4	5.91	46	93.7	12.9	26.5
		242	122	111	10	39		14										
		242	170	111	10	35		14										

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
methomyl	$[M + H]^+$	163	88	41	10	15	15	10	2.77	93	**152.4**	7.4	19.0	5.42	31	**148.0**	10.4	22.3
		163	106	41	10	17		14										
		163	58	41	10	31		22										
methoxyfenozide	$[M + H]^+$	369	149	131	10	25	**19**	14	5.25	24	91.1	14.3	**40.7**	9.25	7	94.8	14.2	32.9
		369	313	131	10	13		32										
		369	91	131	10	65		22										
metolcarb	$[M + H]^+$	166	109	51	10	15	15	16	4.14	6	97.5	7.6	18.2	7.50	3	100.2	8.7	17.8
		166	94	51	10	45		16										
		166	65	51	10	59		30										
metoxuron	$[M + H]^+$	229	72	111	10	27	**15**	12	3.93	122	100.3	7.4	14.9	7.12	47	97.6	8.6	17.4
		229	46	111	10	33		18										
		229	56	111	10	71		12										
mexacarbate[i]	$[M + H]^+$	223	151	86	10	35	**20**	20	5.12	13	91.7	6.7	14.9	9.31	26	94.3	7.3	15.2
		223	166	86	10	23		22										
		223	136	86	10	53		18										
molinate[e]	$[M + H]^+$	188	126	41	10	21	21	18	5.22	**402(25)**	93.2[f]	9.5	19.2	9.29	3	91.6	11.3	22.8
		188	55	41	10	39		22										
		188	83	41	10	27		18										
monocrotophos[i]	$[M + H]^+$	224	127	71	10	23	**17**	16	2.76	150	96.3	5.3	10.7	5.3	24	96.1	7.7	15.4
		224	193	71	10	13		10										
		224	98	71	10	19		12										
napropamide	$[M + H]^+$	272	129	86	10	23	**14**	18	5.23	49	95.5	8.6	22.7	9.29	17	94.7	7.9	17.2
		272	171	86	10	29		18										
		272	58	86	10	43		6										
naptalam	$[M + H]^+$	292	144	91	10	15	15	14	3.24	163	**33.2**	**43.4**	**88.3**	5.7	93	**29.9**	**49.1**	**102.8**
		292	149	91	10	33		20										
		292	256	91	10	37		18										
neburon	$[M + H]^+$	275	88	106	10	25	**21**	20	5.47	52	94.3	9.8	19.7	9.63	69	94.7	10.2	23.0
		275	57	106	10	39		24										
		275	114	106	10	23		24										
ofurace	$[M + H]^+$	282	254	111	10	19	**13**	26	4.55	13	100.9	6.5	13.0	8.13	16	103.5	9.9	20.4
		282	160	111	10	37		22										
		282	236	111	10	23		22										
oxadixyl[i]	$[M + H]^+$	279	219	91	10	17	**11**	24	4.05	50	100.9	6.0	12.1	7.48	19	99.9	7.4	14.8
		279	132	91	10	47		18										
		279	133	91	10	31		18										
oxamyl	$[M + NH_4]^+$	237	72	21	10	25	25	30	2.6	52	97.2	6.1	12.2	5.08	36	96.7	8.2	16.8
		237	90	21	10	13		16										
		237	56	21	10	49		24										
oxamyl oxime	$[M + H]^+$	163	72	61	10	21	21	16	1.76	105	95.3	6.6	13.2	4.16	36	95.8	7.3	14.6
		163	90	61	10	27		18										
		163	115	61	10	21		16										
oxycarboxine[i]	$[M + H]^+$	268	175	91	10	23	**15**	18	3.87	53	96.8	7.5	15.1	7.21	26	97.9	8.1	16.2
		268	147	91	10	35		14										
		268	193	91	10	19		18										
paclobutrazol	$[M + H]^+$	294	70	86	10	25	**17**	28	4.86	17	97.2	8.9	17.9	8.62	40	100.4	9.0	18.1

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
		294	43	86	10	111		18										
		294	125	86	10	51		16										
pencycuron	$[M + H]^+$	329	125	96	10	39	**19**	16	5.79	64	95.2	11.2	22.5	10.16	25	94.6	9.4	19.8
		329	89	96	10	99		16										
		329	99	96	10	89		14										
penoxsulam	$[M + H]^+$	484	195	146	10	41	41	30	3.62	296	93.9	10.4	20.8	6.4	320	97.8	11.4	26.6
		484	444	146	10	35		26										
		484	164	146	10	49		20										
picolinafen	$[M + H]^+$	377	238	146	10	45	45	24	6.05	37	104.7	**20.3**	**47.1**	10.65	10	101.8	**21.1**	**44.9**
		377	256	146	10	33		10										
		377	284	146	10	27		28										
picoxystrobin	$[M + H]^+$	368	145	111	10	33	**19**	20	5.58	48	92.7	11.0	26.7	9.78	29	95.5	15.0	30.2
		368	205	111	10	15		18										
		368	102	111	10	93		20										
piperophos	$[M + H]^+$	354	171	96	10	31	**19**	8	5.9	49	97.3	9.6	22.9	10.36	95	95.1	11.5	24.6
		354	255	96	10	21		12										
		354	143	96	10	45		14										
pretilachlor	$[M + H]^+$	312	252	81	10	23	**10**	26	5.96	44	97.5	9.8	19.6	10.50	21	96.4	11.2	22.4
		312	176	81	10	39		24										
		312	147	81	10	49		20										
primisulfuron-methyl[h]	$[M + H]^+$	469	254	81	10	29	29	26	3.96	54	87.3	11.1	23.1	6.87	20	89.7	12.1	24.7
		469	199	81	10	33		10										
		469	437	81	10	19		46										
prodiamine[e]	$[M + H]^+$	351	250	31	10	41	41	26	6.09	**12(100)**	106.0[g]	12.2	34.4	10.70	**5(100)**	98.8[g]	15.7	35.6
		351	267	31	10	27		30										
		351	291	31	10	25		24										
propamocarb[e]	$[M + H]^+$	189	102	46	10	25	25	14	2.19	**860(25)**	**79.5**[f]	9.5	21.9	4.8	**180(25)**	**79.6**[f]	9.9	25.4
		189	74	46	10	37		16										
		189	144	46	10	19		14										
propoxur	$[M + H]^+$	210	111	76	10	23	**16**	12	4.33	22	98.6	7.2	15.4	7.79	12	99.1	6.4	14.5
		210	168	76	10	13		22										
		210	65	76	10	49		26										
pymetrozine	$[M + H]^+$	218	105	91	10	27	**19**	22	2.57	169	83.5	9.3	26.4	4.94	68	81.3	10.0	29.9
		218	78	91	10	49		18										
		218	79	91	10	47		18										
pyraclostrobin	$[M + H]^+$	388	194	81	10	19	**10**	10	5.71	72	97.5	10.6	21.3	10.02	25	96.5	10.8	22.9
		388	163	81	10	33		16										
		388	104	81	10	85		22										
pyraflufen-ethyl	$[M + H]^+$	413	339	136	10	29	**27**	22	5.58	36	95.3	11.0	22.0	9.83	44	96.9	12.2	24.4
		413	253	136	10	45		14										
		413	289	136	10	43		40										
pyridalyl[e,i]	$[M + H]^+$	490	109	126	10	43	43	12	7.72	39	**125.3**	**69.2**	**141.0**	14.09	**7(25)**	**122.7**[f]	**69.1**	**138.9**
		490	183	126	10	27		10										
		490	204	126	10	31		22										
pyridaphenthion[e]	$[M + H]^+$	341	189	141	10	30	30	22	5.16	**790(25)**	104.5[f]	8.4	20.1	9.15	4	90.7	9.3	**68.6**

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
		341	92	141	10	57		12										
		341	205	141	10	31		28										
pyridate[e]	$[M + H]^+$	379	207	76	10	23	**18**	10	7.23	30	**64.1**	**44.8**	**113.4**	13.05	**38(25)**	**53.4**[f]	**34.0**	**83.4**
		379	77	76	10	75		18										
		379	57	76	10	41		22										
pyrifenox[e]	$[M + H]^+$	295	93	106	10	37	**19**	10	5.33	70	87.1	11.0	25.7	9.54	**149(25)**	91.8[f]	10.0	27.2
		295	93	106	10	79		34										
		295	67	106	10	83		14										
pyrimethanil	$[M + H]^+$	200	107	91	10	35	35	14	5.01	10	92.6	10.8	22.6	8.91	9	92.9	10.7	22.5
		200	82	91	10	37		18										
		200	42	91	10	49		18										
pyriproxyfen	$[M + H]^+$	322	96	81	10	23	**13**	12	6.22	38	102.0	18.5	**48.8**	10.94	26	98.8	19.3	**43.3**
		322	78	81	10	81		32										
		322	51	81	10	111		22										
quinoxyfen	$[M + H]^+$	308	197	51	10	47	**35**	26	6.13	9	95.3	**20.9**	**51.4**	10.94	9	92.8	19.7	**47.6**
		308	214	51	10	49		22										
		308	272	51	10	39		30										
quizalofop[e]	$[M + H]^+$	345	299	61	10	27	27	38	3.69	**12(25)**	**45.1**[f]	**33.7**	**70.1**	6.44	**10(25)**	**46.1**[f]	**34.2**	**71.2**
		345	91	61	10	43		18										
		345	271	61	10	35		30										
quizalofop-ethyl[e]	$[M + H]^+$	373	299	126	10	29	**17**	34	5.96	**45(25)**	101.3[f]	14.1	34.4	10.50	84	97.6	**20.3**	**43.4**
		373	271	126	10	35		28										
		373	91	126	10	49		18										
schradan[h]	$[M + H]^+$	287	135	116	10	39	**21**	12	3.18	24	92.0	7.1	15.4	5.71	16	91.4	9.5	19.1
		287	242	116	10	19		24										
		287	44	116	10	69		10										
spinosyn A	$[M + H]^+$	732	142	186	10	41	41	20	7.58	120	93.6	**21.9**	**53.2**	15.54	58	93.3	**21.1**	**46.4**
		732	98	186	10	93		22										
		732	99	186	10	71		16										
spinosyn D	$[M + H]^+$	746	142	186	10	43	43	20	8.16	120	97.4	**25.1**	**68.0**	16.89	14	93.9	**23.1**	**54.0**
		746	99	186	10	75		12										
		746	98	186	10	101		18										
spirodiclofen[e]	$[M + H]^+$	411	71	136	10	33	33	12	6.79	13	97.0	**21.5**	**53.2**	12.10	**6(25)**	96.4[f]	19.0	**47.7**
		411	313	136	10	17		16										
		411	43	136	10	49		16										
spiromesifen	$[M + NH_4]^+$	388	273	51	10	21	**9**	26	6.69	80	88.2	16.1	**43.9**	11.91	36	85.9	**20.2**	**50.6**
		388	255	51	10	39		26										
		388	187	51	10	43		26										
spirotetramat	$[M + H]^+$	374	302	81	10	25	25	30	4.93	88	83.7	7.9	22.5	9.0	186	84.8	9.7	21.8
		374	216	81	10	47		22										
		374	330	81	10	25		26										
spiroxamine	$[M + H]^+$	298	144	86	10	31	**17**	16	**6.62**	91	82.5	19.4	**44.5**	**14.18**	62	83.7	17.1	36.8
		298	100	86	10	43		42										
		298	58	86	10	67		24										
sulfentrazone	$[M + H]^+$	387	307	146	10	31	31	18	4.16	15	99.5	7.1	14.2	7.50	19	100.6	9.7	20.9
		387	273	146	10	41		28										

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
		387	308	146	10	31		32										
tebufenozide	$[M + H]^+$	353	133	86	10	33		20	5.46	40	95.5	10.5	22.6	9.58	13	97.0	14.7	32.0
		353	**297**	86	10	13	**23**	32										
		353	105	86	10	59		40										
tebufenpyrad	$[M + H]^+$	334	145	121	10	39	**31**	18	6.01	23	98.3	13.3	28.1	10.60	24	97.7	15.6	32.8
		334	117	121	10	49		10										
		334	147	121	10	37		18										
tebupirimfos	$[M + H]^+$	319	277	51	10	21	**11**	22	6.31	19	94.5	14.4	39.4	11.13	20	92.8	13.2	36.1
		319	153	51	10	39		16										
		319	231	51	10	39		20										
tepraloxydim	$[M + H]^+$	342	250	61	10	19	19	34	3.57	20	**129.9**	8.4	21.5	6.63	12	**123.8**	8.9	21.1
		342	250	61	10	19		28										
		342	166	61	10	33		18										
tetraconazole	$[M + H]^+$	374	161	126	10	51	51	10	5.14	68	98.3	9.3	19.7	9.05	21	100.6	10.7	21.4
		374	70	126	10	37		28										
		374	89	126	10	109		18										
thiabendazole	$[M + H]^+$	202	175	51	10	39	**25**	18	3.71	12	101.1	6.6	13.4	6.68	6	99.0	7.2	16.6
		202	131	51	10	47		26										
		202	65	51	10	61		14										
thiabendazole d_4 (IS)	$[M + H]^+$	206	179	131	10	39	39	18	3.69					6.68				
thiacloprid	$[M + H]^+$	253	126	101	10	33	**20**	12	3.88	44	98.5	8.2	16.4	7.07	20	99.9	8.7	17.6
		253	90	101	10	49		12										
		253	99	101	10	49		12										
thiamethoxam	$[M + H]^+$	292	211	76	10	19		18	3.06	21	95.9	9.8	21.6	5.71	16	99.5	11.1	23.1
		292	**181**	76	10	33	33	18										
		292	132	76	10	33		8										
thiazopyr	$[M + H]^+$	397	377	146	10	31	**26**	36	5.71	151	99.5	8.6	17.3	10.02	69	98.7	9.5	19.1
		397	335	146	10	39		40										
		397	61	146	10	49		28										
thiodicarb[i]	$[M + H]^+$	355	88	106	10	23	23	16	4.23	83	**20.0**	**36.7**	**142.6**	7.55	120	**19.8**	**37.3**	**141.6**
		355	108	106	10	23		14										
		355	73	106	10	73		14										
thiofanox[e]	$[M + Na]^+$	241	184	76	10	17	17	18	4.5	**9(25)**	97.0[f]	7.2	17.9	8.08	**26(25)**	98.7[f]	13.1	29.1
		241	98	76	10	19		12										
		241	106	76	10	21		22										
thiofanox sulfone	$[M + NH_4]^+$	268	57	51	10	19	19	4	3.55	26	99.5	8.0	16.1	6.49	12	100.6	12.2	24.6
		268	76	51	10	17		10										
		268	41	51	10	55		6										
thiofanox sulfoxide	$[M + H]^+$	235	104	46	10	15	15	12	3.09	49	99.9	6.5	13.0	5.66	24	102.5	9.9	20.9
		235	57	46	10	29		14										
		235	64	46	10	41		12										
tralkoxydim	$[M + H]^+$	330	284	86	10	19	**15**	28	5.1	22	103.6	11.5	25.7	9.49	22	97.4	10.9	26.5
		330	138	86	10	31		14										

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Table 1. Continued

									Kinetex C_{18} column					Atlantis dC_{18} column				
pesticides	ionization	Q1 mass (amu)	Q3 mass[a] (amu)	DP (V)	EP (V)	CE (V)	CE[b] (V)	CXP (V)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)	retention time[c] (min)	LCL S/N PtP[d]	overall recovery[k] (%)	intermediate precision[l] (%)	measurement uncertainty[m] (%)
		330	96	86	10	45		20										
trichlorfon	$[M + H]^+$	257	127	101	10	29	29	18	3.19	6	95.6	9.1	18.3	5.91	4	94.1	14.7	31.7
		257	221	101	10	17		24										
		257	109	101	10	31		10										
tricyclazole[i]	$[M + H]^+$	190	163	111	10	33	**24**	16	3.61	28	92.6	8.7	19.1	6.74	20	94.5	8.2	22.1
		190	136	111	10	43		18										
		190	109	111	10	51		14										
trietazine	$[M + H]^+$	230	99	101	10	35	**30**	22	5.36	19	91.8	8.3	17.6	9.54	52	92.5	9.6	19.3
		230	43	101	10	49		18										
		230	202	101	10	29		10										
trifloxysulfuron	$[M + H]^+$	438	182	106	10	29	**14**	26	3.55	38	91.2	10.7	27.3	6.49	37	95.4	10.0	36.7
		438	257	106	10	29		28										
		438	176	106	10	47		18										
triforine[h,j]	$[M + H]^+$	435	390	71	10	19	19	12	4.53	19	96.3	14.0	29.6	8.08	11	92.2	14.3	29.2
		435	98	71	10	49		10										
		435	83	71	10	91		12										
trimethacarb[i]	$[M + H]^+$	194	137	86	10	17		18	4.68	10	98.1	7.9	16.2	8.37	4	98.1	10.0	20.3
		194	**122**	86	10	37	37	16										
		194	107	86	10	53		12										
zinophos[e]	$[M + H]^+$	249	97	51	10	41	41	12	4.87	**15**(**25**)	104.2[f]	7.5	17.4	8.71	**38**(**25**)	105.0[f]	8.2	18.2
		249	193	51	10	21		26										
		249	221	51	10	17		24										
zoxamide	$[M + H]^+$	336	187	131	10	33	**19**	20	5.68	22	93.2	9.6	19.4	10.02	24.5	96.3	10.0	20.0
		336	159	131	10	49		22										
		336	204	131	10	25		22										

[a] Bold and underlined are the second transition that is used for quantification. [b] Collision energy (bold and underlined) was attenuated to avoid the saturation of the detector at the highest concentration level, that is, 500.0 μg/kg. Transitions in the corresponding row were used for quantification. [c] Retention time may vary from column-to-column. Bold and underlined are pesticides whose retention times drifted within a batch run. [d] Signal-to-noise (peak-to-peak, PtP) ratio was determined at the lowest concentration level (μg/kg, in bracket) in a basmati rice. LCL, lowest concnentration level; S/N, signal-to-noise. Bold and underlined are pesticides whose signal-to-noise ratios were determined above 5 μg/kg. The injection volume was 3 μL on Kinetex C_{18} and 5 μL on Atlantis dC_{18}. [e] Column number. Bold are pesticides that typically have poor sensitivity. [f] Method performance was based on three spike levels, that is, 90.0, 240.0, and 400.0 μg/kg, due to its poor sensitivity. [g] Method performance was based on two spike levels, that is, 240.0 and 400.0 μg/kg, due to its poor sensitivity. [h] Pesticides have a relatively low solubility in methanol. A stock solution was prepared in 1000.0 μg/mL. [i] Pesticides have a relatively low solubility in methanol. A stock solution was prepared in 2000.0 μg/mL. [j] An ion with Cl^{37} was selected as a precursor ion. [k] Bold and underlined are pesticides with recoveries not in the range of 81−110%. [l] Bold and underlined are pesticides wtih intermediate precision >20%. [m] Bold and underlined are pesticides with MU > 40%.

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Table 2. Liquid Chromatographic Gradient Profiles and MS Parameters

Kinetex C_{18}				Atlantis dC_{18}			
total time	flow rate (μL/min)	A (%)	B (%)	total time	flow rate (μL/min)	A (%)	B (%)
0.0	300	92	8	0.0	200	92	8
4.0	300	10	90	7.0	200	10	90
8.0	300	10	90	25.0	200	10	90
9.0	500	0	100	28.0	300	0	100
9.5	500	0	100	28.1	300	92	8
10.0	500	92	8	35.0	200	92	8
12.0	300	92	8				

MS parameters		MS parameters	
collision gas (CAD)	7	collision gas (CAD)	7
curtain gas (CUR)	25	curtain gas (CUR)	20
ion source gas 1 (GS1)	60	ion source gas 1 (GS1)	50
ion source gas 2 (GS2)	60	ion source gas 2 (GS2)	50
ionspray voltage (IS)	5000	ionspray voltage (IS)	5000
temperature	550	temperature	500

For the pilot study of 100 samples, grain samples (5.0 g/sample) were weighed into individual 50 mL polypropylene centrifuge tubes (VWR International). To each sample, 250 μL of 2.0 μg/mL internal calibration standard working solution (100.0 μg/kg equivalent in sample) was added, and the extraction procedure was the same as that of the fortification experiment.

Preparation of Matrix-Matched Calibration Standards and Calculation. Matrix-matched calibration standards were prepared by adding standards and internal standards to blank sample extracts after sample extraction and cleanup. A blank grain sample (5.0 g/sample) was weighed into a 50 mL centrifuge tube, and the sample was processed through the extraction procedure as described above. To each of the six remaining 0.1−0.2 mL sample extracts, 250 μL of each six-level pesticide standard mix working solution was added, providing 5.0, 25.0, 100.0, 200.0, 300.0, and 500.0 μg/kg of standard equivalent in samples. Then, 50 μL of 2.0 μg/mL internal calibration working solution was added to each sample (100.0 μg/kg equivalent in samples). The extracts were made up to 0.5 mL with methanol, vortexed for 30 s, made up volume to 1.0 mL with 0.1 M ammonium acetate, and then vortexed again for 30 s. The extracts were diluted six times prior to LC/ESI-MS/MS injection using solvent buffer.

Quantification. Matrix-matched standard calibration curves for each individual pesticide were constructed using the "Quantitate" function bundled with the Analyst software. The quantification integration algorithm applied was IntelliQuan with no data smoothing. Deuterium-labeled standards carbendazim-d_4, carbofuran-d_3, and thiabendazole-d_4 were used as internal standards for their respective native compounds for quantification. All other pesticides used carbofuran-d_3 as an internal standard for quantification because it had consistent recovery around 90% and demonstrated linear response. A quadratic function was applied to the calibration curves based on the line of best fit. The $1/x$ weighting was used to accurately quantify pesticides at low concentrations. Responses for the unknown or fortified samples were compared to the curves to calculate the amount of pesticide residues, μg/kg, in samples.

Experimental Design and Method Validation. The method was validated with the nested experimental design, which was described elsewhere.[7,8] The main factors of variances associated with the method performance or measurement uncertainties of an in-house validated method using the spiked samples are concentrations or spike levels of analytes, matrix effects, day-to-day variation, and within day variation of the method. The last two factors are designated as the intermediate precision. In this study, there were a total of six grain matrices. For each matrix, samples were spiked at four levels, that is 10.0, 90.0, 240.0, and 400.0 μg/kg, in triplicate. Spike experiments were repeated by two analysts. Overall recovery, intermediate precision, and measurement uncertainty were calculated using a combined computer program that consisted of SAS codes (SAS Software Release 9.1, SAS Institute Inc., United States) along with a Microsoft Excel (Microsoft Office 2002) workbook.[7]

RESULTS AND DISCUSSION

Extraction. Pesticides were extracted from grain samples (5 g/sample) as described above. The whole procedure entailed step 1: hydration. Grain samples have to be hydrated to improve pesticide extraction efficiency as recommended in the QuEChERs method.[10] To determine the amount of water required to hydrate 5 g of grain sample, 5, 10, or 15 mL of water was tested. It was found that 15 mL of water was needed to wet an entire sample and yield consistent recoveries. Subsequently, the total water content in the sample (5 g) mixture should be >80% after the addition of 15 mL of water. Some grain samples required vortexing to completely break clumps present in the mixture. It was also important to allow samples to hydrate for 30 min at room temperature prior to the next step; step 2: extraction. This step entailed adding acetonitrile to samples and partitioning pesticides into acetonitrile using anhydrous $MgSO_4$. After the addition of 15 mL of acetonitrile and acetic acid (99 + 1, v/v) to the sample mixture, samples required 45 s of shaking before sodium acetate (1.5 g) and $MgSO_4$ (6.0 g) were added. This step was critical to ensure good method performance; otherwise, poor or inconsistent recoveries were observed. In general, 7−9 mL of initial acetonitrile extracts (15 mL), which was adequate for the cleanup, was yielded after centrifugation (3 min at 2100g); step 3: cleanup or dispersive solid-phase extraction (d-SPE). In an initial study, $MgSO_4$ and PSA; $MgSO_4$, PSA, and graphitized black carbon; or $MgSO_4$, PSA, and C_{18} were compared.

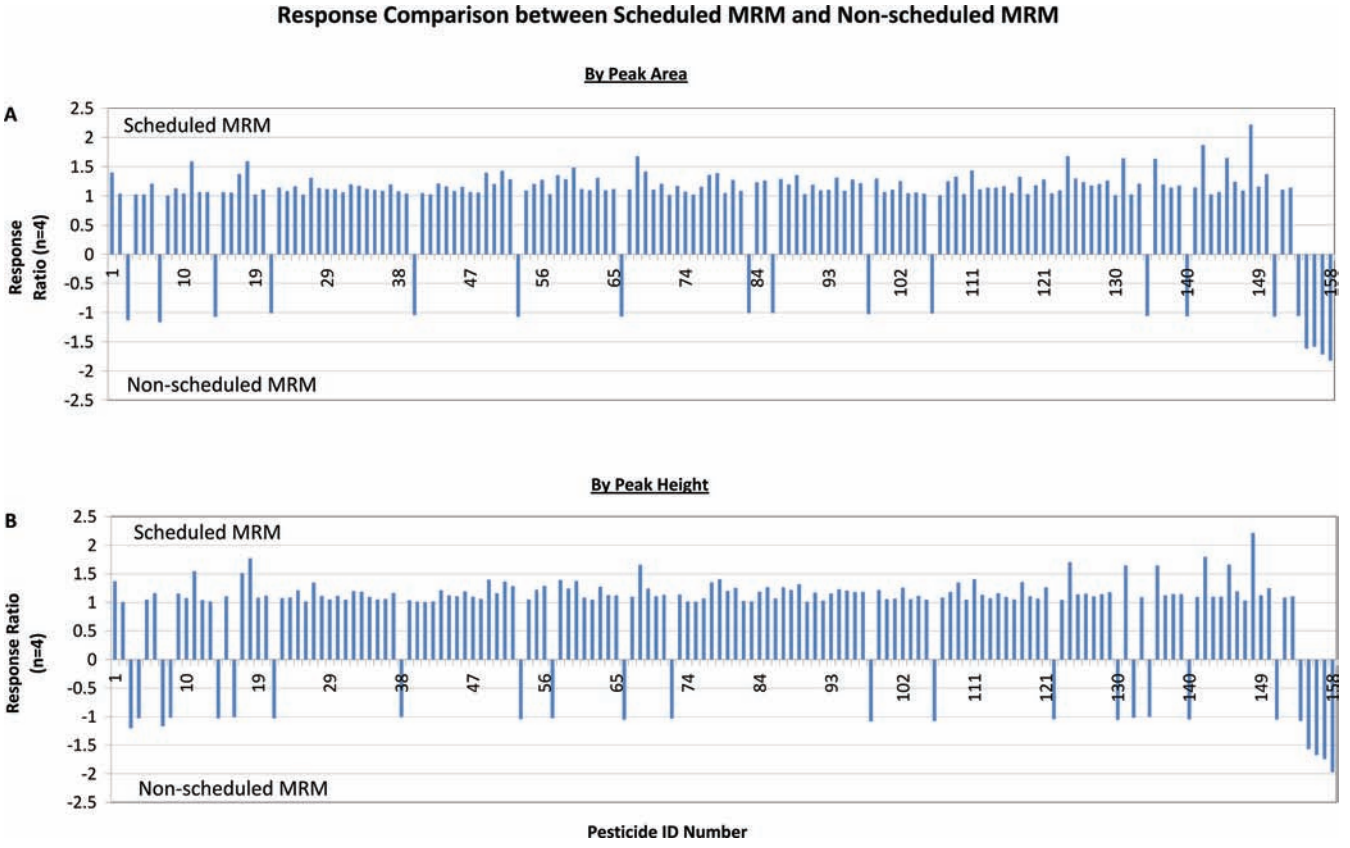

Figure 1. UHPLC/ESI-MS/MS (Kinetex C_{18}) 151 pesticide response comparison between scheduled MRM and nonscheduled MRM. The pesticides were prepared in solvent buffer at a concentration of 100 μg/kg equivalent in sample. Injection volume: 5 μL. (A) By peak area and (B) by peak height. Bars above *x*-axial (pesticide ID number) are response ratios (>1) of scheduled MRM over nonscheduled MRM. Bars below *x*-axial are response ratios (<−1) of nonscheduled MRM over scheduled MRM.

The combination of $MgSO_4$, PSA, and C_{18} proved to be more efficient for cleanup in terms of extraction efficiency (recovery) and repeatability than others. C_{18} helped for some relatively nonpolar compounds in matrices. After steps 2 and 3, normally >5 mL of extracts, which was required for the next step, was obtained; step 4: concentration, reconstitution, and filtration. This step helped further to remove coextractives. After concentration and reconstitution, the extracts turned turbid or cloudy, and filtration was necessary to get rid of precipitates in the final extracts prior to the LC injection by the Mini-UniPrep vials with a filtration membrane, that is, polyvinylidene difluoride (PVDF). Because 3 mL of supernatant was used to concentrate and reconstitute into 1 mL, the final extract was equivalent to 1 g matrix per mL at this point. The extracts were diluted six times prior to LC-MS injection.

MS/MS Data Acquisition. MS/MS data acquisition was based on the multiple reaction monitoring (MRM) transitions that were predetermined by infusing the 151 pesticides and three isotopically labeled standards (Table 1, column 1) into an API 5000 mass spectrometer. Table 1 (columns 3 and 4) lists MRM transitions of 151 pesticides for either quantification or confirmation. Pesticides were ionized in form of $[M + H]^+$, $[M + NH_4]^+$, or $[M + Na]^+$ (Table 1, column 2) in the positive electrospray mode depending on their chemical structures in the presence of ammonium acetate (10 mM) in LC mobile phase. In routine practice, the first transition, that is, the most intense product ion of its corresponding precursor, was used for quantification or screening, and the second or third transition along with retention time was utilized for confirmation. Some pesticides shared the same transitions and eluted at approximately the same retention time; therefore, the second transitions were chosen for quantification. For example, isoprocarb and trimethacarb both had 194/137 transition and eluted at 8.37 min; the second transition of trimethacarb, that is, 194/122, was selected for quantification; and its third transition was used for confirmation. The same scenarios were observed for methabenzthiazuron and carbofuran and dimethametryn and dipropetryn.

Scheduled MRM versus Nonscheduled MRM. MS/MS data acquisition can occur in either single or multiple retention time windows, which affect the instrument duty cycle and cycle time. Duty cycle is inversely proportional to the number of concurrent MRMs monitored, but the total cycle time is proportional to the number of MRMs in the same retention period. A high duty cycle provides good sensitivity, and a short cycle time increases the sampling rate across an LC peak, which results in a more reproducible quantitative result. The API 5000 LC/MS/MS System allows up to 300 MRM transitions concurring in single retention time window, and it also features the so-called scheduled-MRM, where individual transitions can be monitored in narrowly designated retention windows at the time when analytes are eluted. Therefore, with the scheduled MRM, the number of concurrent MRM transitions is significantly reduced, resulting in much higher duty cycles for each analyte. The software computes maximal dwell times for the coeluting analytes while maintaining the desired cycle time. As a result, a maximized dwell time, an optimal cycle time, and the highest possible duty cycle for each MRM ensure that the analytical

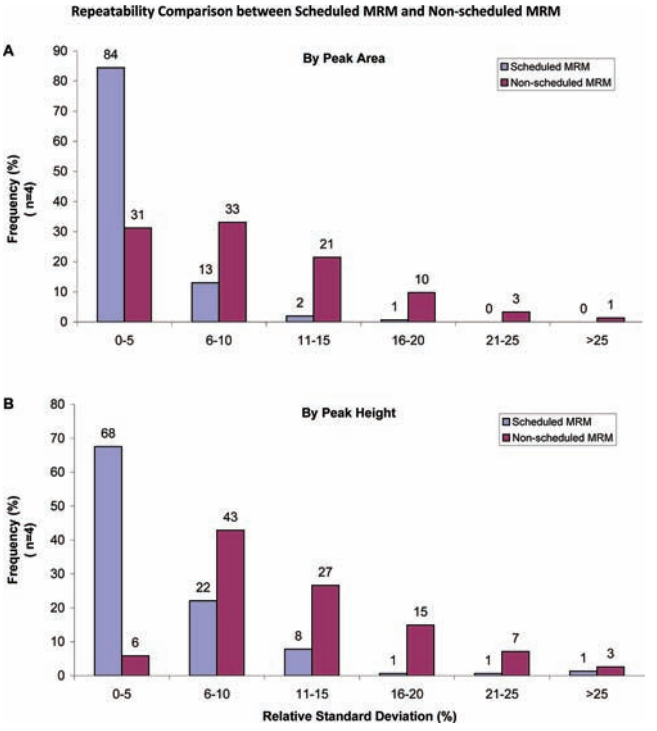

Figure 2. UHPLC/ESI-MS/MS (Kinetex C_{18}) 151 pesticide repeatability (relative standard deviation, %) comparison between scheduled MRM and nonscheduled MRM. The pesticides were prepared in solvent buffer at a concentration of 100 μg/kg equivalent in sample. Injection volume: 5 μL. (A) By peak area and (B) by peak height.

precision is maintained and sensitivity is improved at higher multiplexing.

Nonscheduled MRM has been used for conventional LC such as Atlantis dC_{18} in our routine applications. However, there was a concern that there might not be enough data points across a chromatographic peak for quantification, when nonscheduled MRM was used for Kinetex C_{18}, because the peak width was narrow and only a few seconds wide. Therefore, a study was carried out to determine to how scheduled MRM would help to improve method performance in terms of sensitivity and repeatability. As shown in Figure 1, bars above the *x*-axial or response ratios as positive numbers indicated that the responses from scheduled MRM were higher than those from nonscheduled MRM and vice versa. The scheduled MRM provided the improved responses or sensitivity overall because most of bars were above *x*-axial. Furthermore, by either peak area or height, the scheduled MRM provided much better repeatability than nonscheduled MRM (Figure 2). For example (by peak area), 84% pesticides had relative standard deviation ≤5% when scheduled MRM was applied, as compared to 31% from the nonscheduled MRM. The scheduled MRM became essentials to Kinetex C_{18} applications in this study to obtain adequate data points for quantification along with the benefit of the improved sensitivity.

UHPLC/ESI-MS/MS (Kinetex C_{18}) versus LC/ESI-MS/MS (Atlantis dC_{18}). The liquid chromatographic gradient profiles are shown in Table 2. For UHPLC (Kinetex C_{18}), the mobile phase B (acetonitrile) was ramped from 8 to 90% in 4 min, and then, it was kept at 90% until 8 min with a flow rate of 300 μL/min before the column was regenerated, and the total run time was 12 min. The first pesticide eluted from the Kinetex C_{18} column was cyromazin at 1.46 min, and the last pesticide was

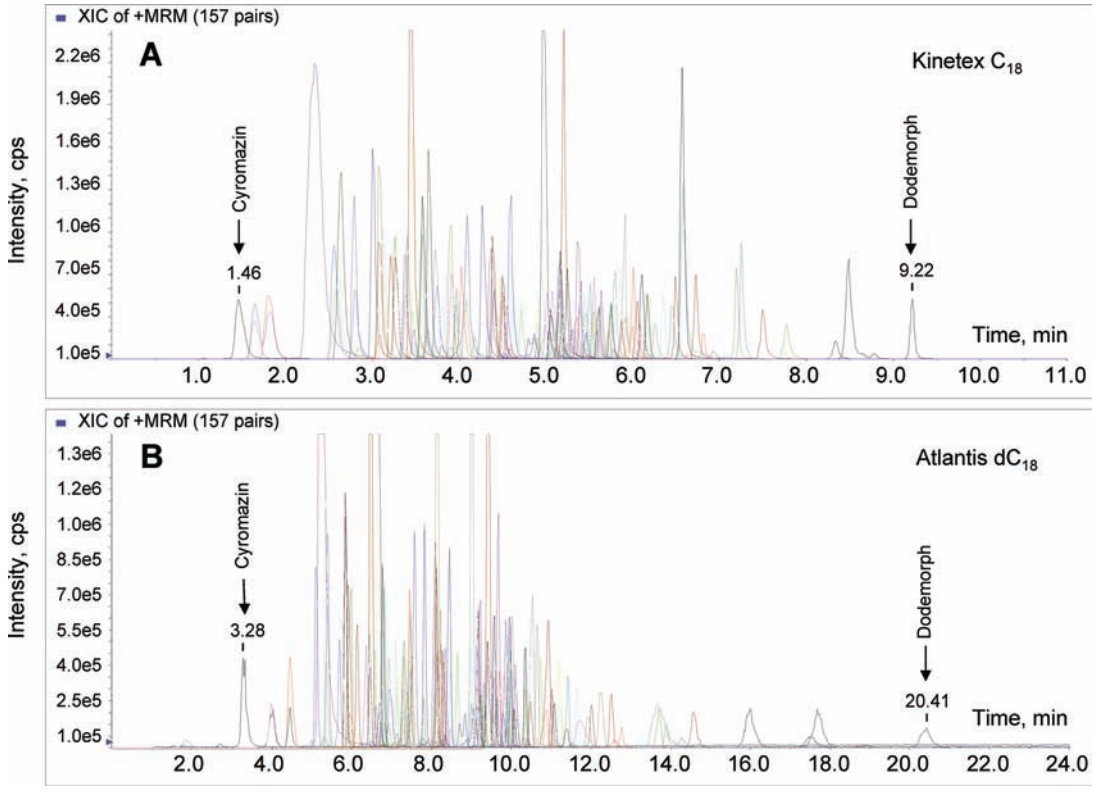

Figure 3. LC-MS chromatograms of 151 pesticides (200 μg/kg) and three internal standards (100 μg/kg) spiked in seven grain extracts. Injection volume: 5 μL. (A) A chromatogram from Kinetex C_{18} with a total run time of 12 min. (B) A chromatogram from Atlantis dC_{18} with a total run time of 35 min.

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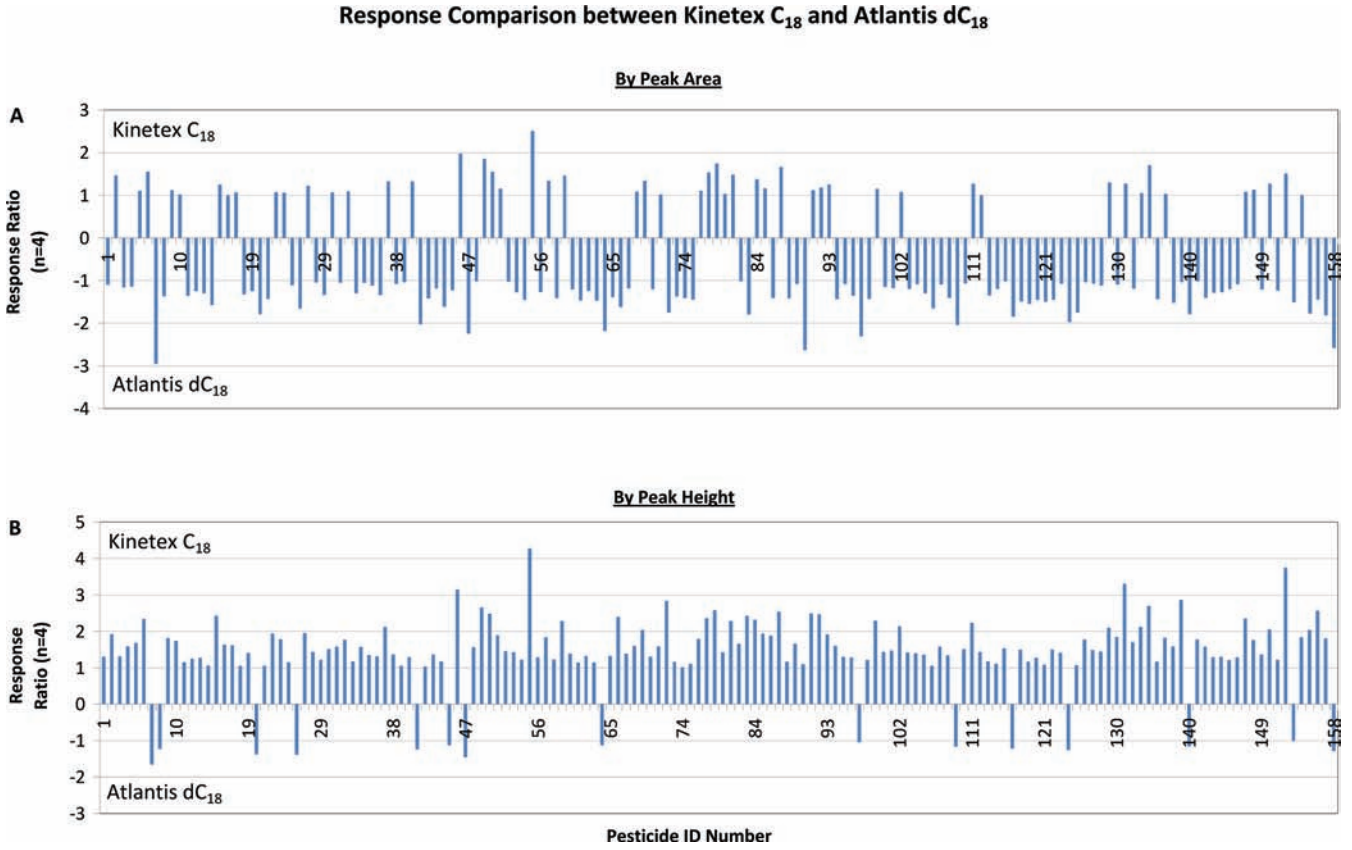

Figure 4. LC-MS 151 pesticide response comparison between Kinetex C_{18} and Atlantis dC_{18}. The pesticides were prepared in solvent buffer at a concentration of 100 μg/kg equivalent in sample. Injection volume: 5 μL. Data were acquired using nonscheduled MRM. (A) By peak area and (B) by peak height. Bars above *x*-axial (pesticide ID number) are response ratios (>1) of Kinetex C_{18} over Atlantis dC_{18}. Bars below *x*-axial are response ratios (<−1) of Atlantis dC_{18} over Kinetex C_{18}.

dodemorph at 9.22 min (Figure 3A). For LC (Atlantis dC_{18}), the mobile phase B (acetonitrile) was ramped from 8 to 90% in 7 min, and then, it was kept at 90% until 25 min with a flow rate of 200 μL/min before the column was regenerated, and the total run time was 35 min. The first pesticide eluted from the Atlantis dC_{18} column was cyromazin at 3.28 min, and the last pesticide was dodemorph at 20.41 min (Figure 3B). Both UHPLC and LC pesticide retention times are listed in Table 1 (columns 11 and 16). The retention times, within and between batches, were reproducible for most of the pesticides, except for emamectin B_{1a}, fenpropidin, and spiroxamine, which drifted within-batch analysis from both columns. Nevertheless, the tolerance of retention time matching did not exceed 2.5% relative to the retention time of a standard in the same batch under all circumstances. The total run time from Kinetex C_{18} was about 1/3 of that from Atlantis dC_{18}. Because the increased flow rate in Kinetex C_{18}, that is, 300 μL/min, the associated mass spectrometric desovaltion parameters (Table 2) such as curtain gas, ion source gas 1 and 2, and temperature were increased accordingly so as to maintain ionization efficiency and to reduce chance of contamination to the front end of mass spectrometer. It should be mentioned that Kinetex C_{18} (100 mm × 2.1 mm, 2.6 μm) produced a column back pressure up to 3500 psi during the course of a gradient, as compared to up to 1500 psi from Atlantis dC_{18} (100 mm × 2.1 mm, 3 μm).

Figure 4 showed the comparisons of responses between Kinetex C_{18} and Atlantis dC_{18} by peak area or height. The data were acquired according to the nonscheduled MRM, and 5 μL of extracts was injected on either column. In terms of peak areas, the responses from either Kinetex C_{18} or Atlantis dC_{18} were close to each other as shown in Figure 4A. However, when comparing peak heights (Figure 4B), the responses from Kinetex C_{18} were in general higher (bars above *x*-axial) than those from Atlantis dC_{18}. The Kinetex C_{18} provided narrower or shaper peaks, shortened the analytical run time by 2/3, and improved single-to-noise ratio or increased the sensitivity, as compared to Atlantis dC_{18} (Figure 3). Furthermore, the amount of sample extracts injected on Kinetex C_{18} column was reduced while still achieving the required sensitivity. Consequently, it helped to reduce ion source contamination, to extend column life, and to reduce matrix effects. As a good practice, 3 μL of sample extracts was used to inject on Kinetex C_{18} to generate data for method performance evaluation or method validation.

Matrix Effects. It was expected that the narrow or sharp chromatographic peaks would result in reduced matrix effects. Because of the improved chromatographic resolution of a core−shell column, analytes of interests should show improved separation from coextractives. However, this was not observed in the current study. Matrix effects were evaluated by comparing the responses of pesticides in sample extracts (post extraction spike) to those pesticide standards prepared in solvent buffer at the same concentration level, for example, 100 μg/kg equivalent in sample. The pesticides may encounter either ion suppression or enhancement in presence of grain matrices. Figure 5 showed the profile or distribution of matrix effects, and *x*-axial is the ratio, expressed as percentage, of pesticide responses in the presence of

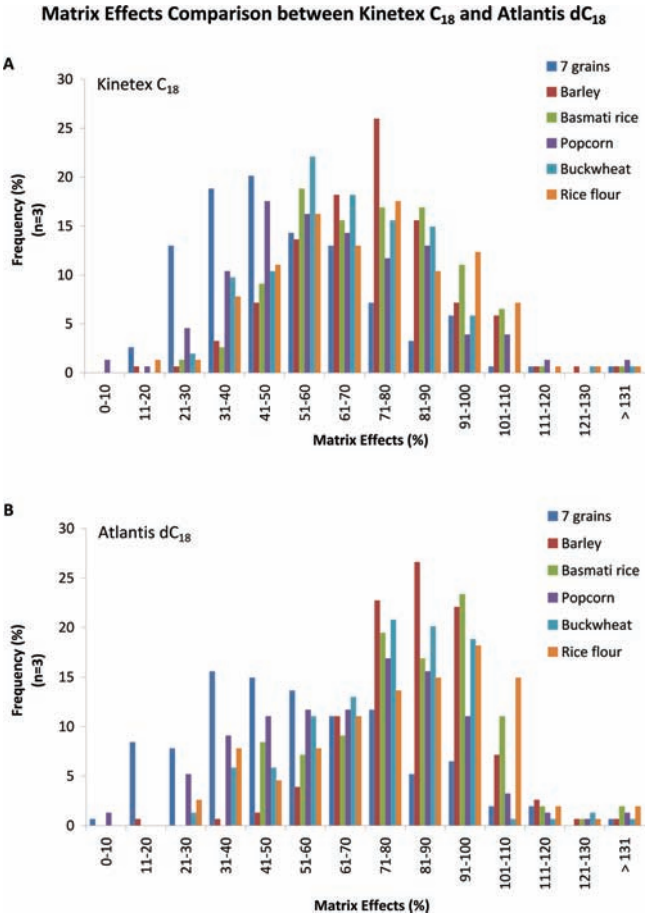

Figure 5. LC-MS matrix effects comparison between Kinetex C_{18} and Atlantis dC_{18}. The 151 pesticides were prepared in matrix extracts (six grain matrices) at a concentration of 100 μg/kg equivalent in sample. Injection volume: 5 μL. Data were acquired using nonscheduled MRM. (A) Kinetex C_{18} and (B) Atlantis dC_{18}.

matrix to those in solvent buffer. More ion suppression was observed from the Kinetex C_{18} (Figure 5A) than from Atlantic dC_{18} (Figure 5B). The distribution from Atlantic dC_{18} was skewed toward the range 71−110%, which was translated into less matrix effects. Therefore, Kinetex C_{18} may not end up with reduced matrix effects when injecting the same amount of samples as on Atlantis dC_{18}. Nevertheless, all matrices examined, except for seven grains, showed similar matrix effects profiles on either column. Therefore, in routine practice, grains (or nonmixed) may be used interchangeably to prepare matrix-matched standard calibration curves along with isotopically labeled internal standards to compensate matrix effects when analyzing samples.

Method Validation and Method Performance. Both UHPLC/ESI-MS/MS (Kinetex C_{18}) with scheduled MRM and LC/ESI-MS/MS (Atlantis dC_{18}) with nonscheduled MRM were validated according to a statistical experimental design or the nested design, which included four factors, that is, pesticide concentrations or spike levels, matrix effects, day-to-day variation, and within-day variation. The designed experiment provided validation data to study and evaluate method performance parameters in terms of accuracy expressed as overall recovery, intermediate precision, and measurement uncertainty (MU). Pesticides were spiked into six grain matrices at 10, 90, 240, and 400 μg/kg in triplicate, and each experiment was repeated by a different analyst on a separate day. The performance parameters were calculated using a combined SAS statistical program. Detailed calculations and equations were described elsewhere.[7,8] The method performance results are summarized in Table 1 (Kinetex C_{18}, table columns 13−15; Atlantis dC_{18}, table columns 18−20) and are depicted in Figure 6. Generally, 90 or 91% of the pesticides (Figure 6A) had recoveries between 81 and 110% by Kinetex C_{18} and Atlantis dC_{18}, respectively. However, Kinetex C_{18} provided better intermediate precision and less measurement uncertainty than Atlantis dC_{18}. For example, 54% of the pesticides had intermediate precision ≤10% by Kinetex C_{18}, whereas 41% by Atlantis dC_{18} (Figure 6B). Consequently, 45% of the pesticides possessed MU ≤ 20% by Kinetex C_{18}, as compared to 30% by Atlantis dC_{18} (Figure 6C). Using either column, the method was able to quantify 90% of the pesticides with MU ≤ 50% in grains, which was recommended as a default value in European Union Document SANCO/10684/2009 for pesticide analysis and enforcement decisions (MRL-exceedances).[11] The use of scheduled MRM may contribute to the better quantitative results from Kinetex C_{18}.

Sensitivity. The method sensitivity was evaluated according to signal-to-noise (S/N) ratios (peak-to-peak) at the lowest concentration level (Table 1, columns 12 and 17). Generally, most pesticides were detected and quantified below or at 5 μg/kg, except for abamectin $B1_a$, aclonifen, benoxacor, chlorbromuron, cyanofenphos, diclocymet, dodemorph, etofenprox, isoxathion, linuron, molinate, prodiamine, propamocarb, pyridalyl, pyridaphenthion, pyridate, pyrifenox, quizalofop, quizalofop-ethyl, spirodiclofen, thiofanox, and/or zinophos, the lowest concentration levels (LCLs) of which are bolded and underlined in Table 1 (columns 12 and 17), by either Kinetex C_{18} (3 μL injection) or Atlantis dC_{18} (5 μL injection). In general, Kinetex C_{18} provided better sensitivity than Atlantis dC_{18}, despite 3/5 injection volume was used.

Pilot Study. Because of its overall superior method performance, the UHPLC/ESI-MS/MS (Kinetex C_{18}) was used to analyze 100 samples in a pilot study to further evaluate method performance or applicability. Different kinds of grains including wheat, rice, corn, durum wheat, etc. were purchased, processed, and analyzed. No positive or incurred pesticide samples were found. As a control practice during the pilot study, a proficiency test (PT) sample was also analyzed for thiabendazole. The study showed that the method performed as it should and yielded a result of 178 μg/kg thiabendazole with a z-score +0.36.

In conclusion, both UHPLC/ESI-MS/MS (Kinetex C_{18}) and LC/ESI-MS/MS (Atlantis dC_{18}) methods reported in this paper can be routinely used to determine 151 pesticides in grain samples. The analytical range is 5−500 μg/kg with the lowest concentration level at 5 μg/kg for all pesticides (S/N > 10), except for a few pesticides. For UHPLC/ESI-MS/MS (Kinetex C_{18}) with scheduled MRMs, 90% of the pesticides studied had recoveries between 81 and 110%, 88% of the pesticides had intermediate precision ≤20%, and 84% of the pesticides showed measurement uncertainty ≤40%. As compared to UHPLC/ESI-MS/MS (Kinetex C_{18}), LC/ESI-MS/MS (Atlantis dC_{18}) showed a relatively lower sensitivity, less repeatability, and larger measurement uncertainty. Apparently, both 2.6 μm core−shell particle column (Kinetex C_{18}) and scheduled MRM contributed to the better performance of the UHPLC/ESI-MS/MS method, in addition to its shortened analytical run time. UHPLC/ESI-MS/MS (Kinetex C_{18}) proved to be an ideal means for the determination of pesticides in grains in routine monitoring programs.

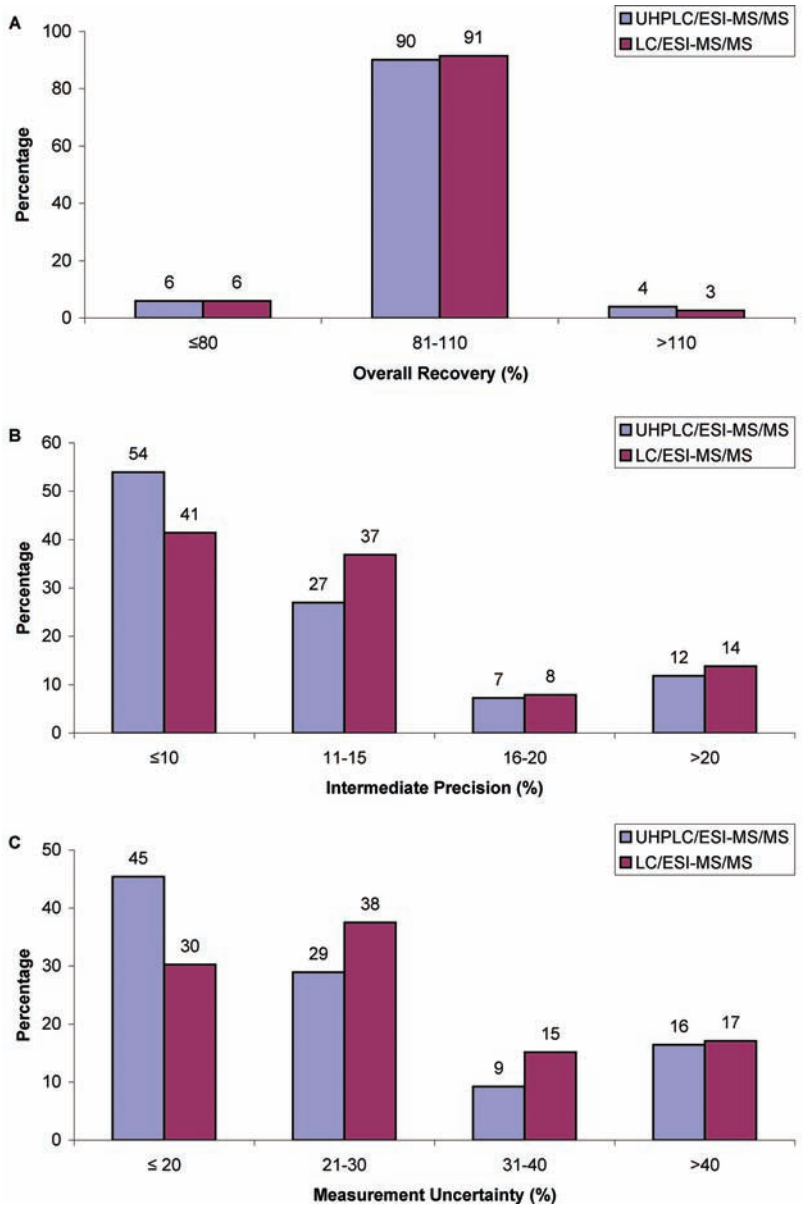

Figure 6. UHPLC/ESI-MS/MS (Kinetex C_{18}, scheduled MRM) and LC/ESI-MS/MS (Atlantis dC_{18}, nonscheduled MRM) method performance for analysis of pesticides in grains. (A) Overall recovery, (B) precision, and (C) measurement uncertainty. The injection volume was 3 μL on Kinetex C_{18} and 5 μL on Atlantis dC_{18}.

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DISCLOSURE

We indicate that the analytical columns described or mentioned in this paper do not in any way constitute an endorsement by the authors.

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