Implementing new LC-MS technologies for the analysis of pesticide residues: Dual-channel chromatography

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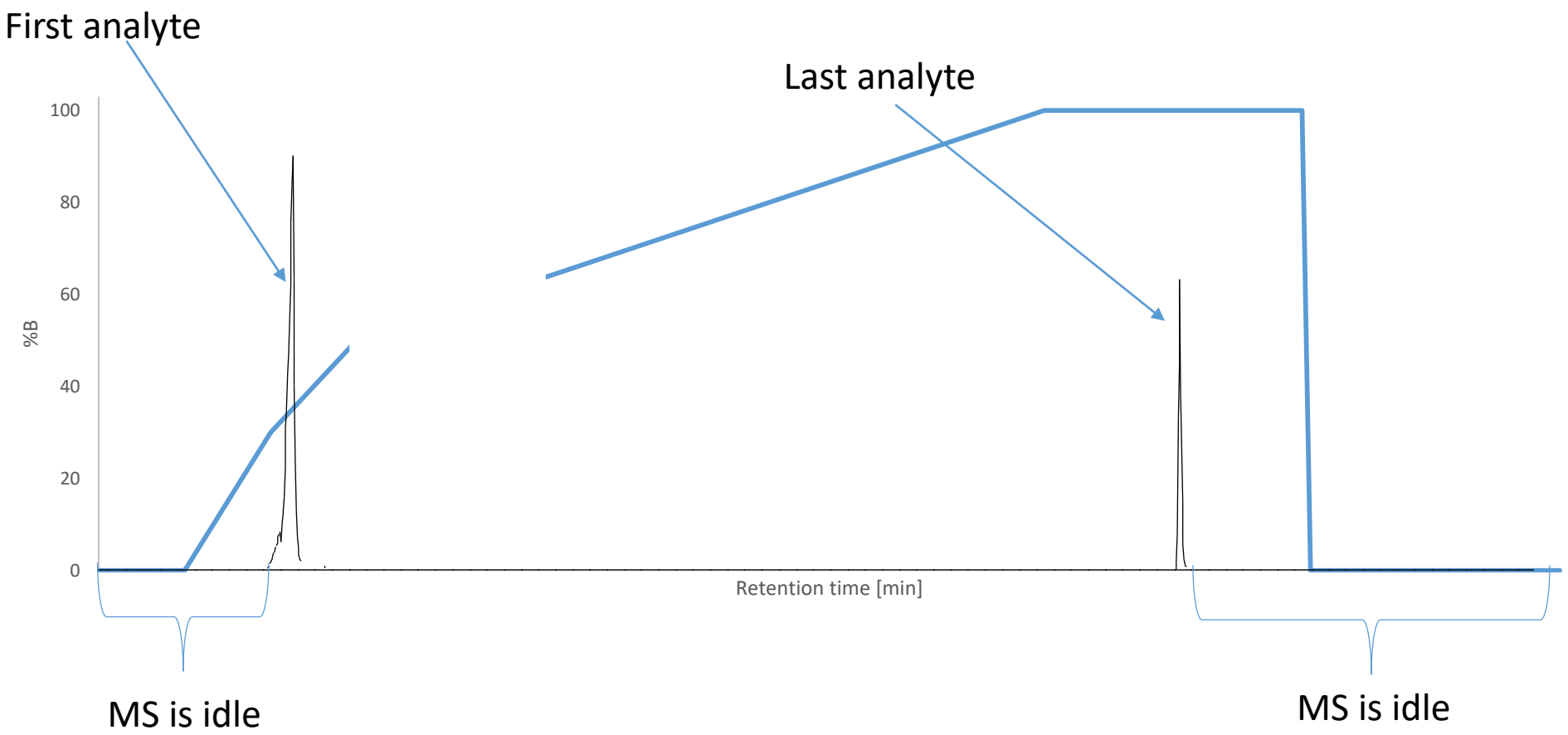
How to decrease the analysis time?

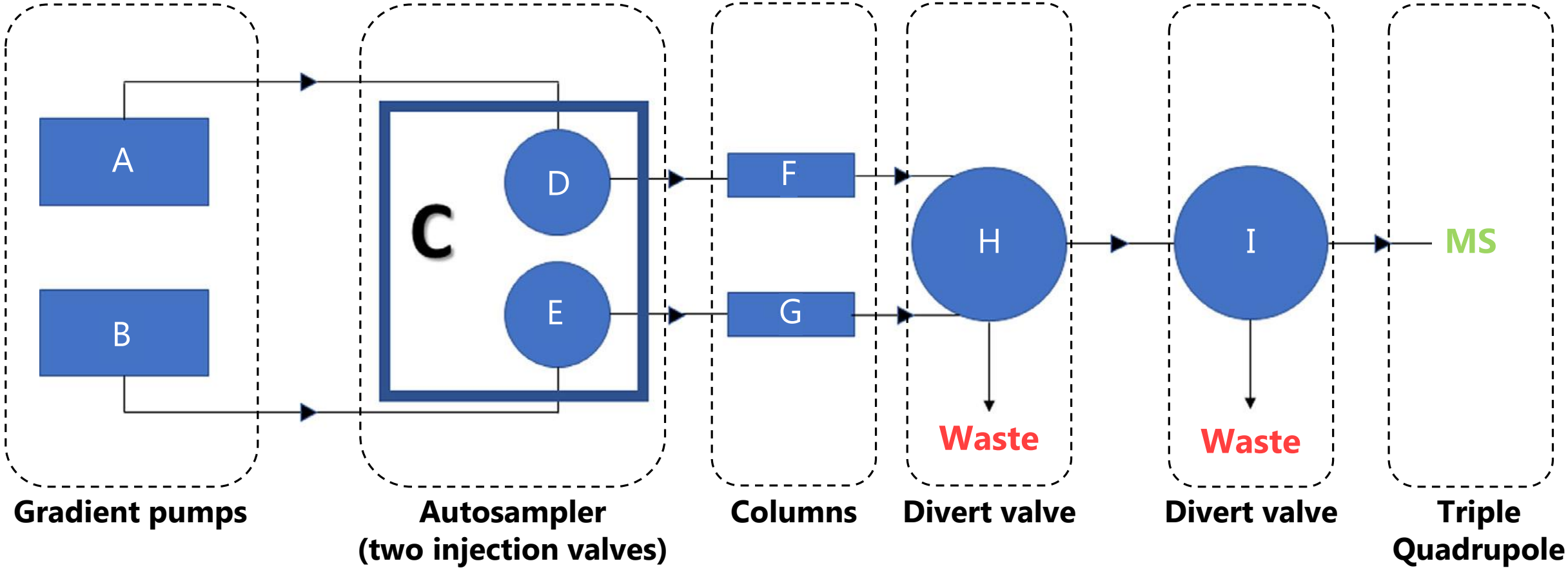
- Shorter column, steeper gradient, higher flow:
  - Compromised separation
    - More coeluting pesticides
      - Shorter dwell times -> lower sensitivity
      - Longer duty cycle -> Less data points per chromatographic peak -> worse peak area reproducibility
      - Common transitions
      - Possible cross-talk
    - More coeluting matrix (especially in “dirty matrices”)
      - Higher matrix effects -> lower sensitivity
      - Possible interferences

Another option to decrease the analysis time



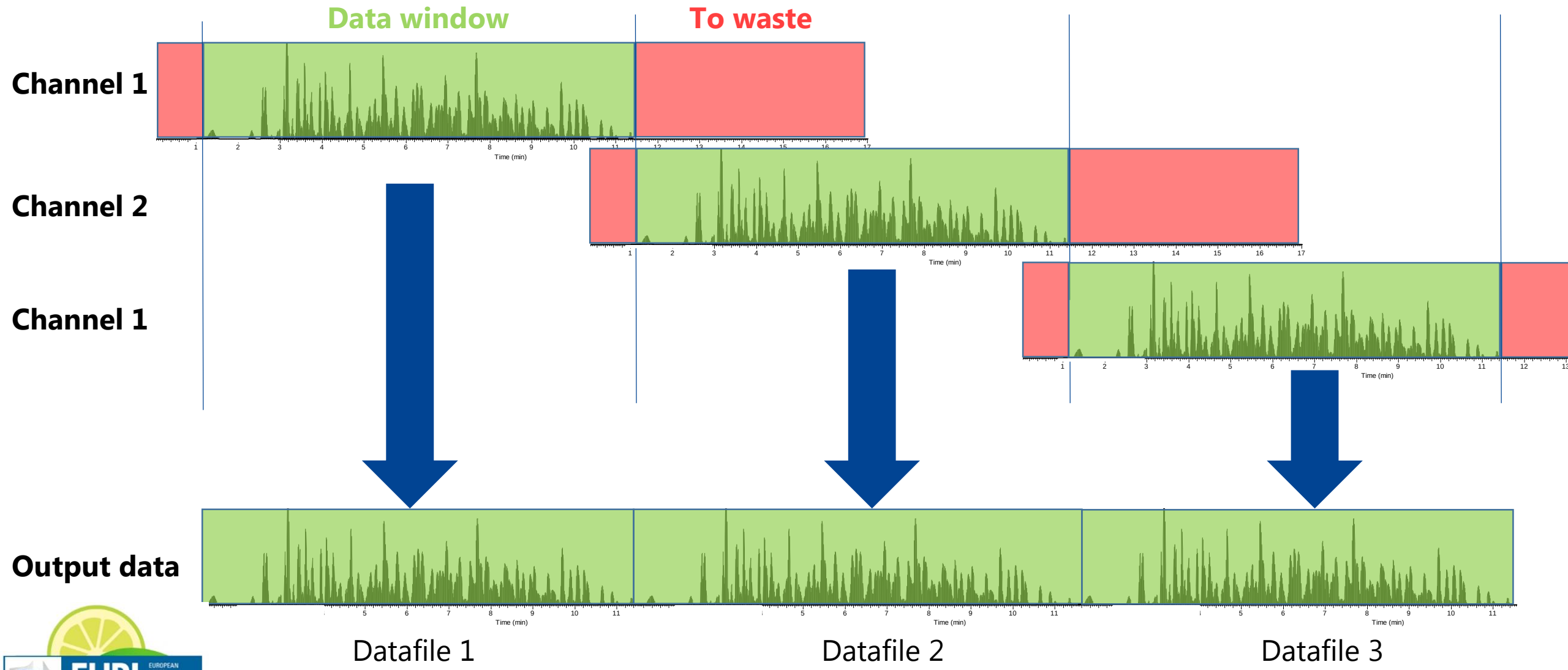
Analysis time can be decreased by the application of multi-channel chromatography and reduction of the idle time of the mass spectrometer

Dual-Channel LC-MS/MS: general diagram

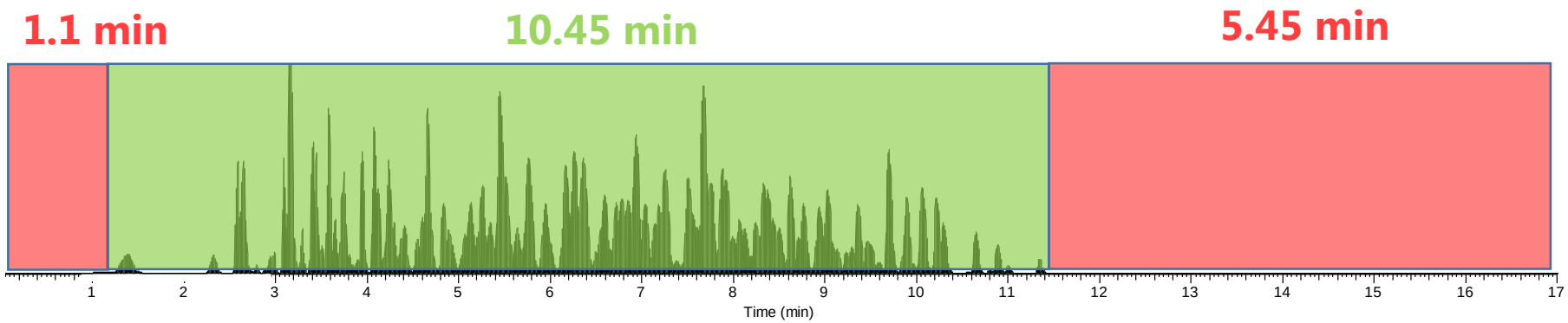


Thermo Scientific ™ Transcend™ Duo LX-2 UHPLC System

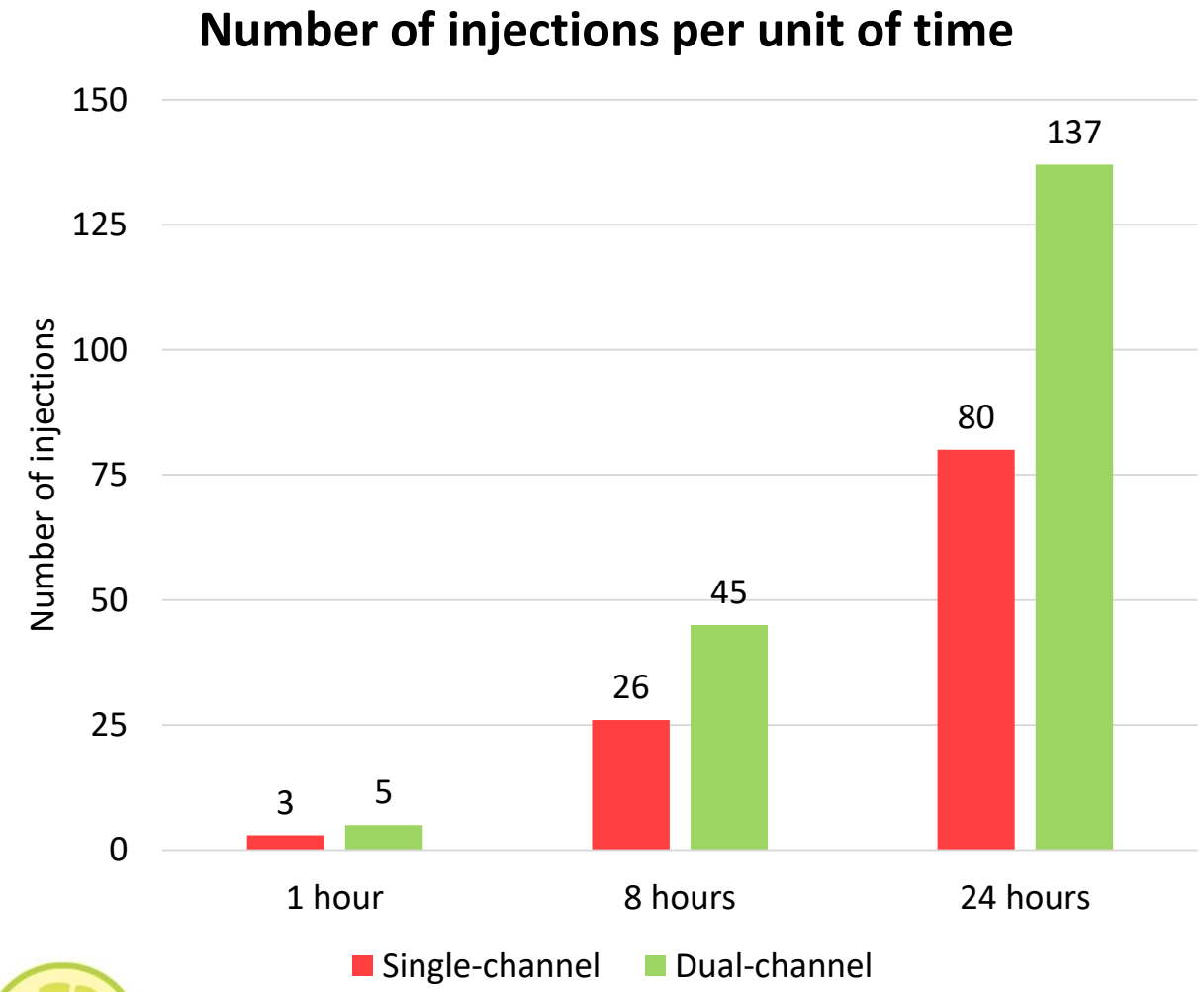
Dual-Channel LC-MS/MS: sample throughput



Dual-Channel LC-MS/MS: sample throughput



Dual-Channel LC-MS/MS: sample throughput



- With Dual-Channel chromatography, pre-acquisition and post-acquisition MS-idle times are removed
- Sample throughput is increased over 70 % (45 injections in an 8 hr period)

Benefits of a sensitive triple quadrupole MS

Thermo Scientific™ TSQ Altis™
Triple Quadrupole Mass Spectrometer

More sensitive triple quadrupole means:

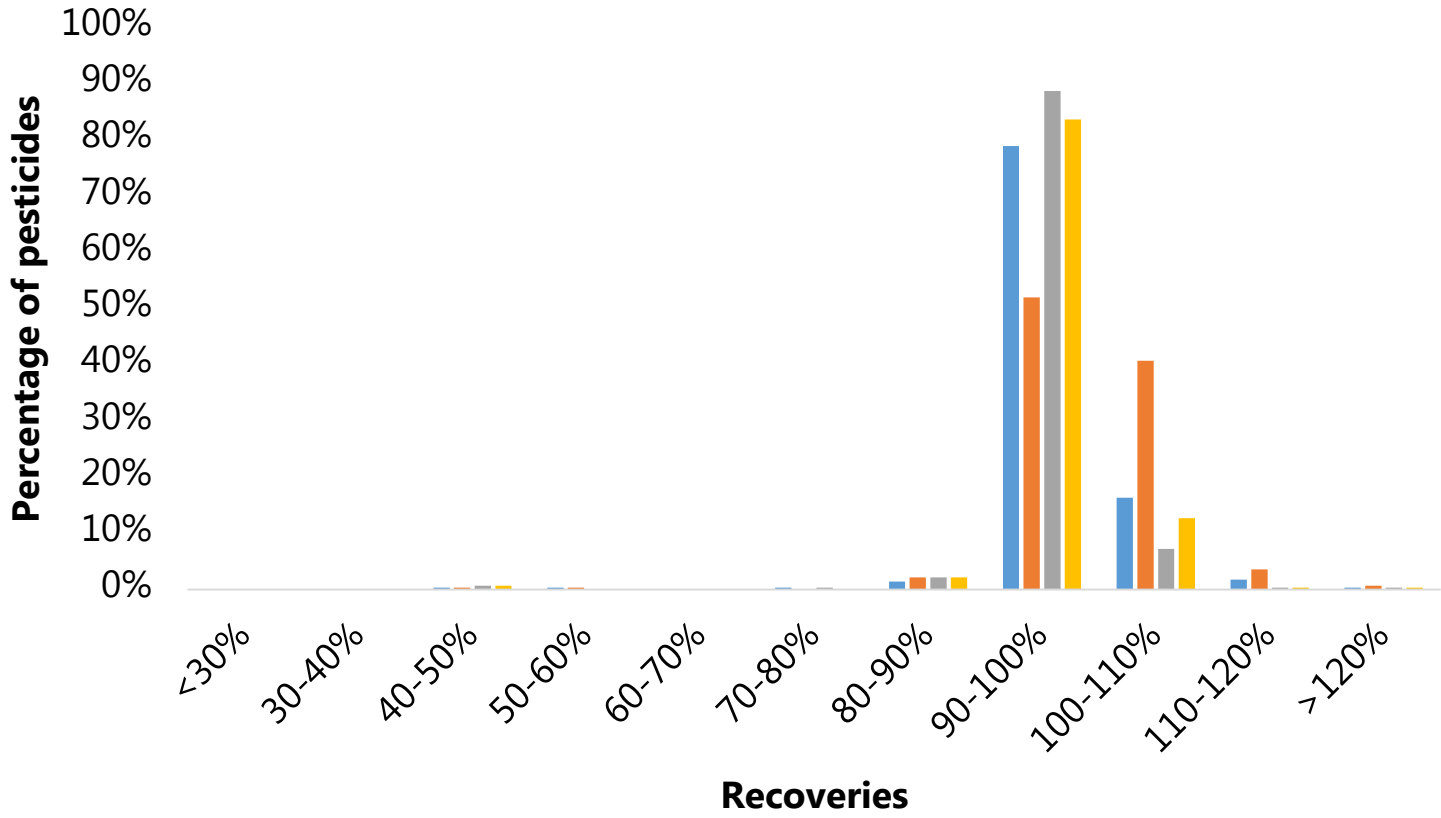
- Lower injection volume
  - Reduced maintenance
  - Better peak shape
  - Lower matrix effects
    - More accurate quantitation
- Shorter dwell times
  - More concurrent transitions possible
  - Shorter duty cycle

Single and Dual-Channel validation

- Validation experiments were performed employing **single channel** and **Dual-Channel**
- A total of **273 LC-amenable pesticide residues** were evaluated
- **Three matrices** belonging to two different commodity groups were studied
- Samples were extracted employing citrate-buffered QuEChERS method
- Validation criteria as per the Document Nº SANTE/12682/2019

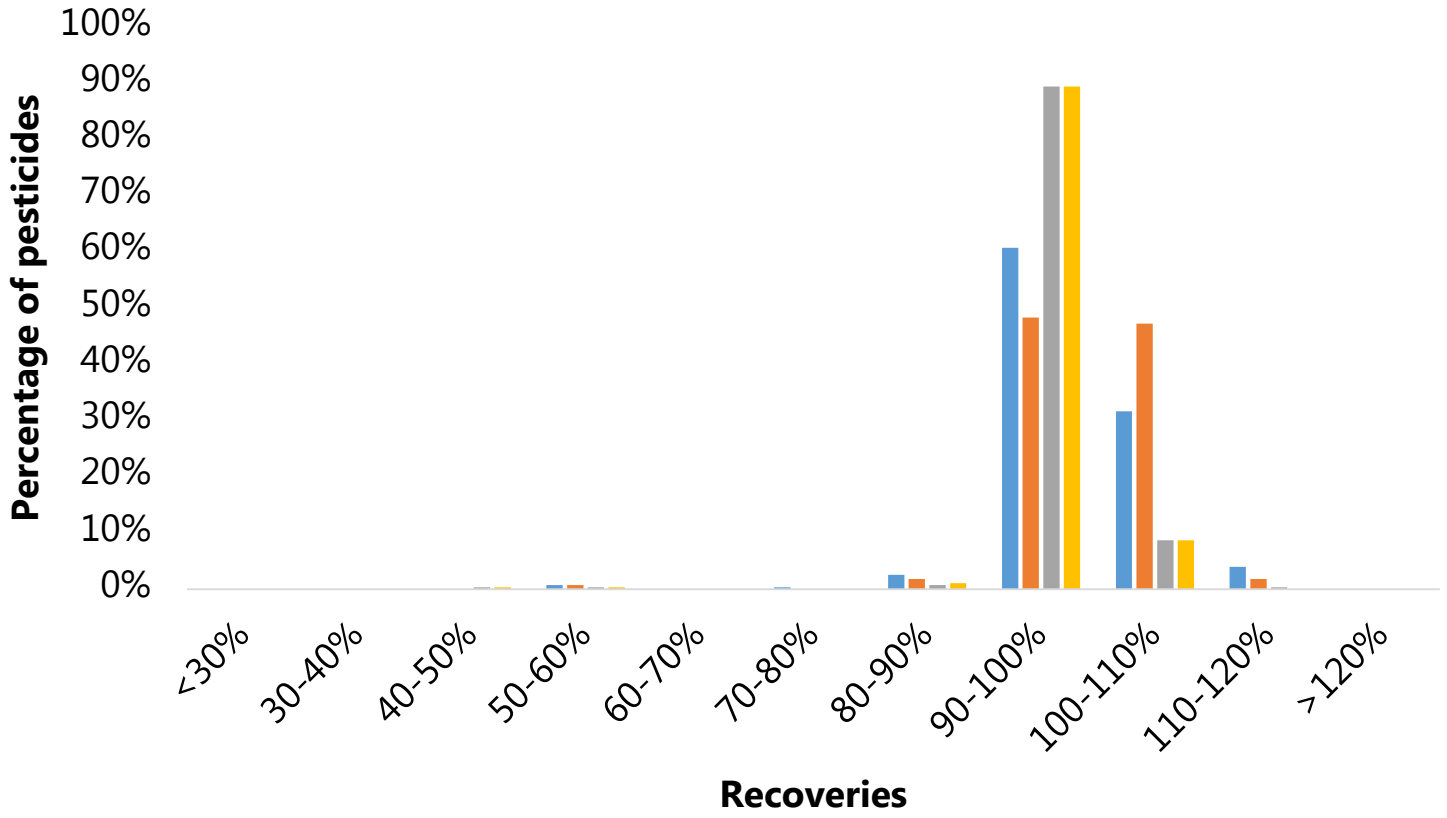
Single and Dual-Channel validation: apple

Technique	<70%	70-120%	>120%
Single channel 0.01 mg/kg	2	269	2
Dual-Channel 0.01 mg/kg	2	270	1
Single channel 0.1 mg/kg	2	270	1
Dual-Channel 0.1 mg/kg	2	270	1



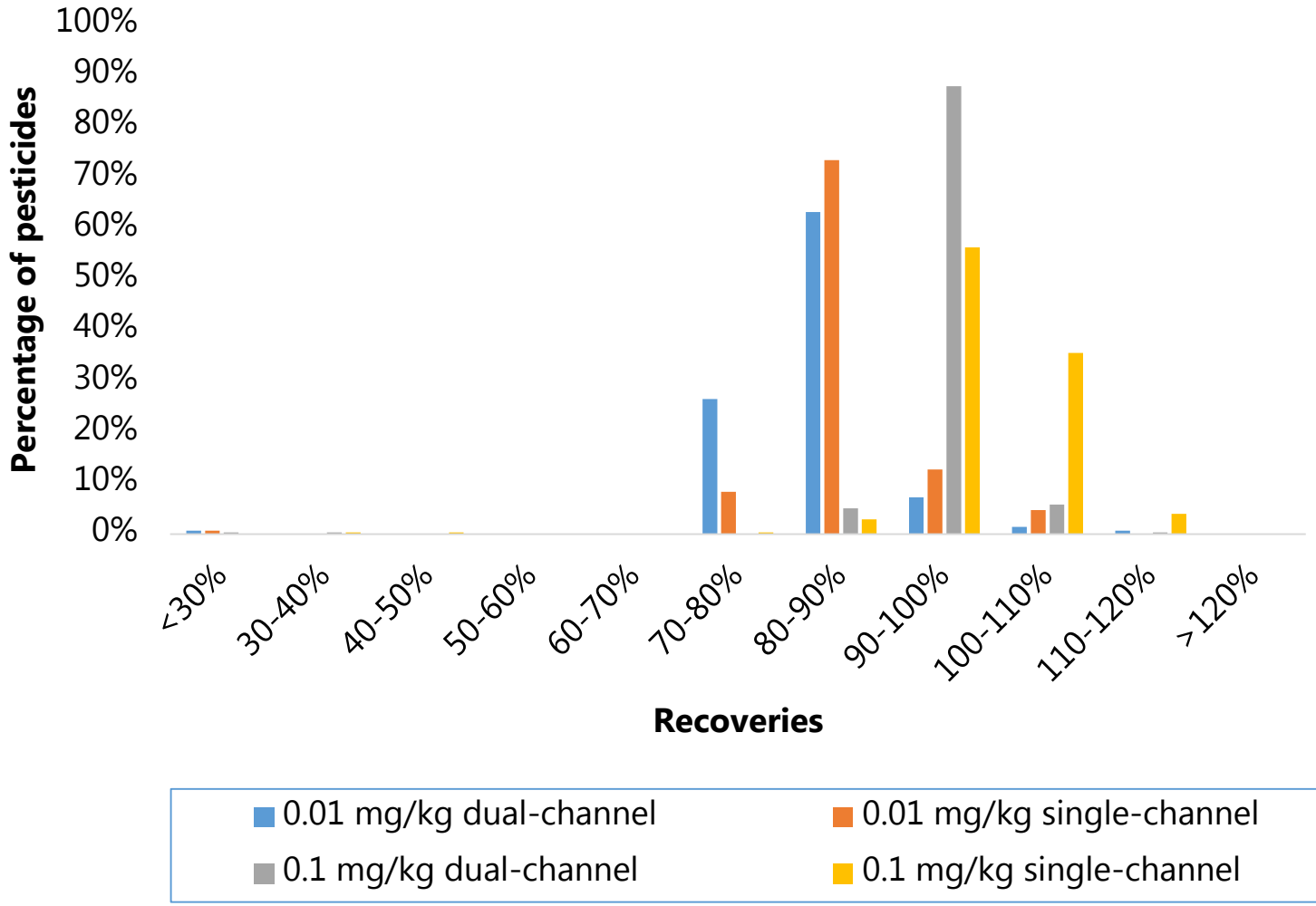
Single and Dual-Channel validation: bell pepper

Technique	<70%	70-120%	>120%
Single channel 0.01 mg/kg	2	271	-
Dual-Channel 0.01 mg/kg	2	271	-
Single channel 0.1 mg/kg	2	271	-
Dual-Channel 0.1 mg/kg	2	271	-



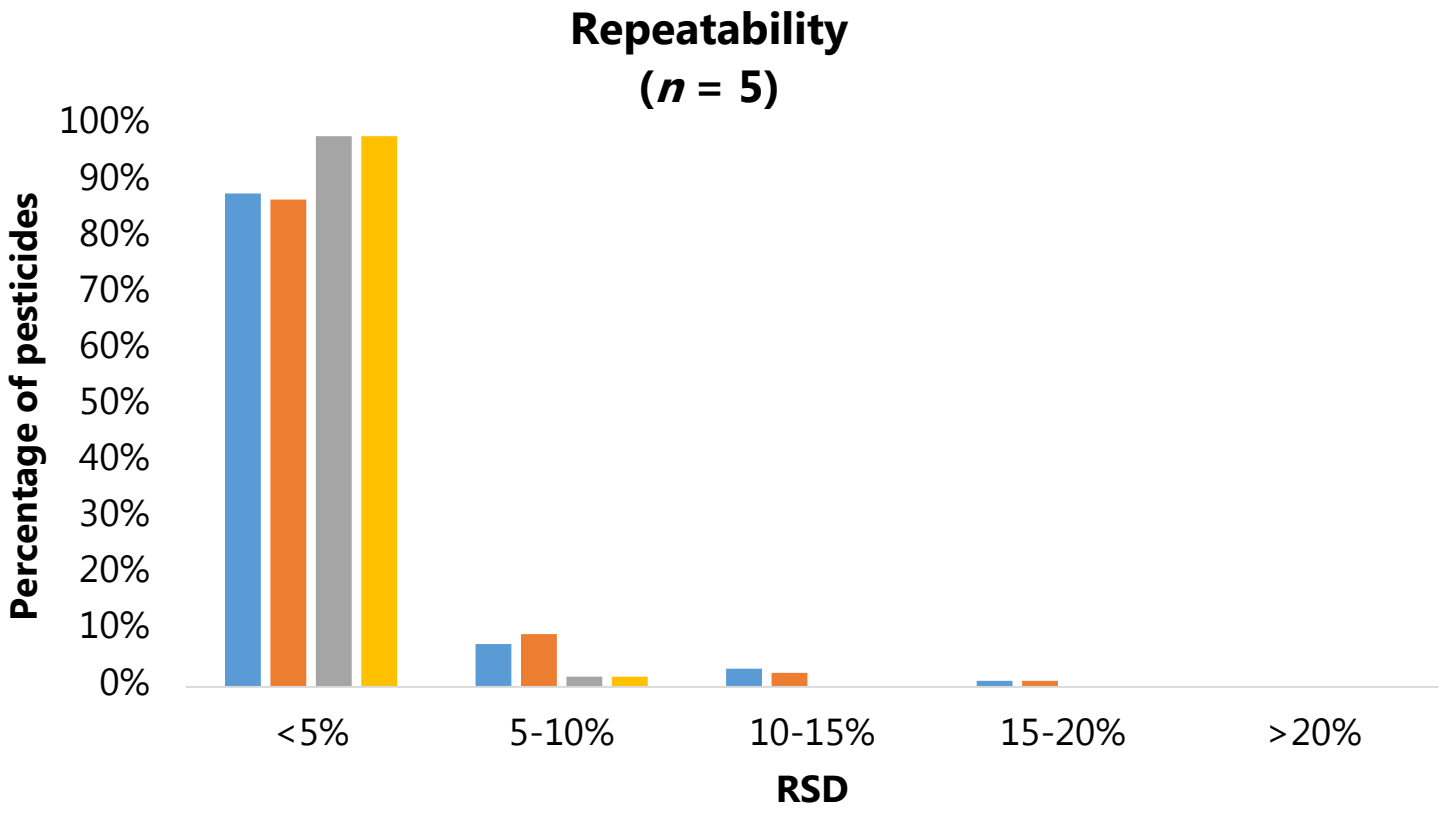
Single and Dual-Channel validation: orange

Technique	<70%	70-120%	>120%
Single channel 0.01 mg/kg	2	271	-
Dual-Channel 0.01 mg/kg	2	271	-
Single channel 0.1 mg/kg	2	271	-
Dual-Channel 0.1 mg/kg	2	271	-



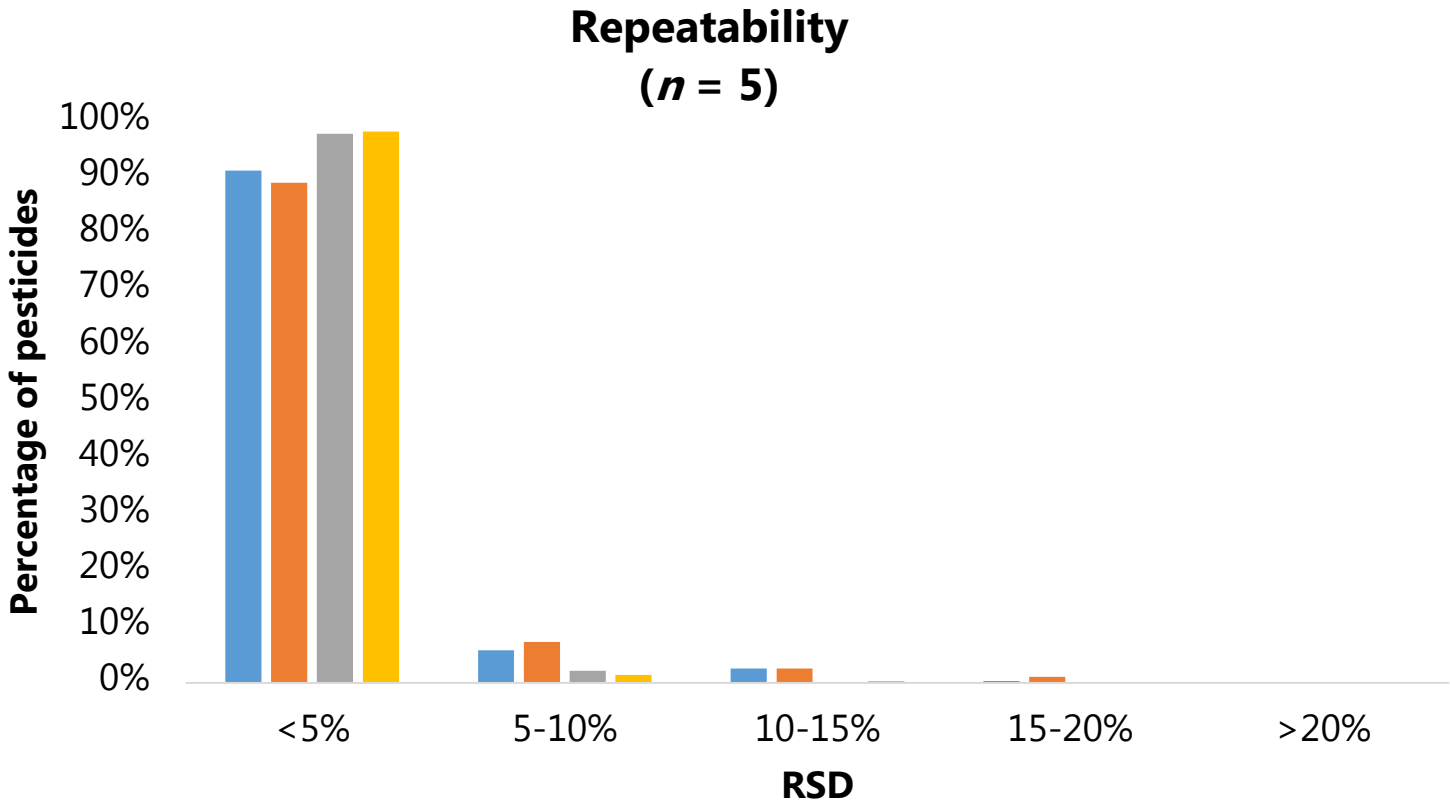
Single and Dual-Channel validation: apple

Technique	<5%	5-20%	>20%
Single channel 0.01 mg/kg	87%	13%	-
Dual-Channel 0.01 mg/kg	88%	12%	-
Single channel 0.1 mg/kg	98%	2%	-
Dual-Channel 0.1 mg/kg	98%	2%	-



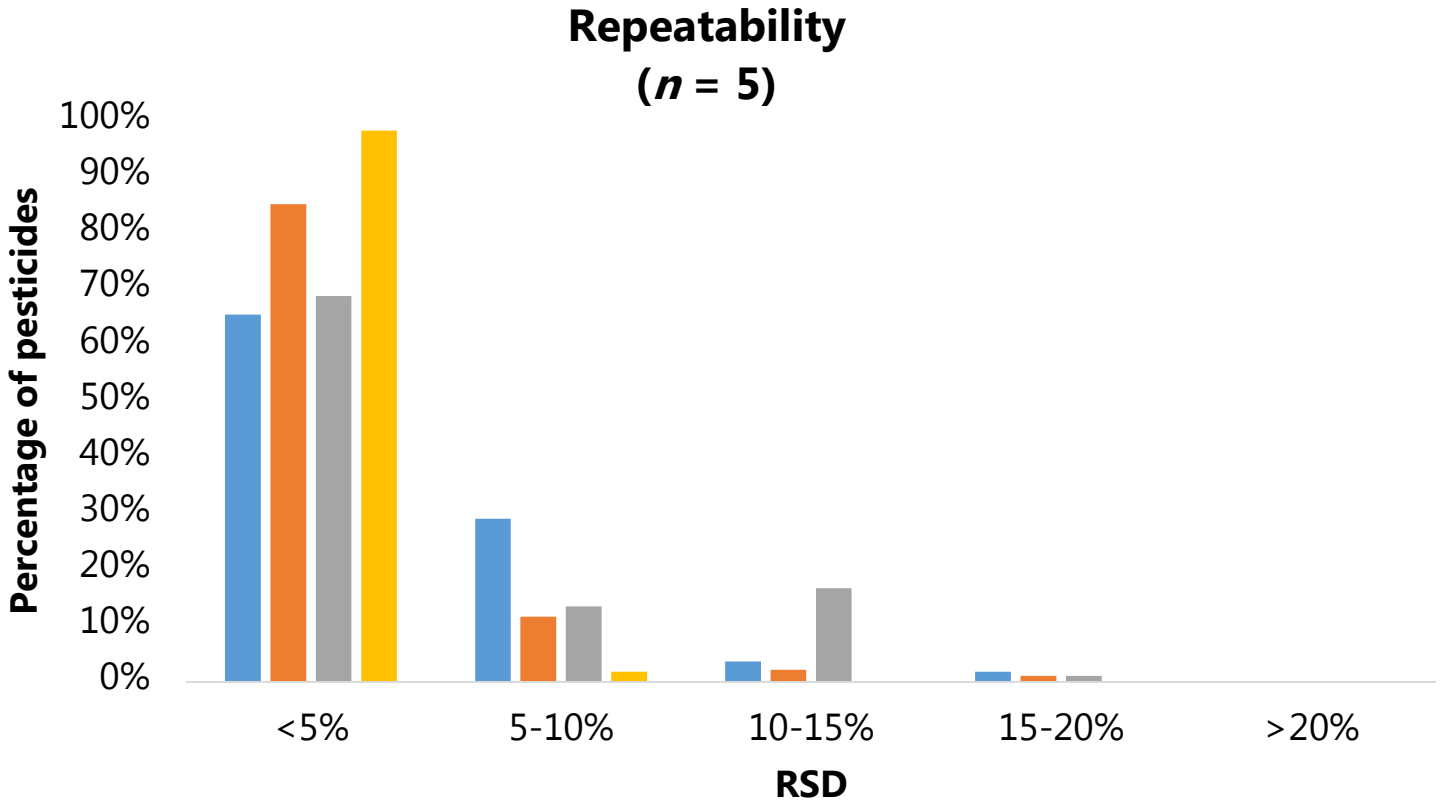
Single and Dual-Channel validation: bell pepper

Technique	<5%	5-20%	>20%
Single channel 0.01 mg/kg	89%	11%	-
Dual-Channel 0.01 mg/kg	91%	9%	-
Single channel 0.1 mg/kg	98%	2%	-
Dual-Channel 0.1 mg/kg	98%	2%	-



Single and Dual-Channel validation: orange

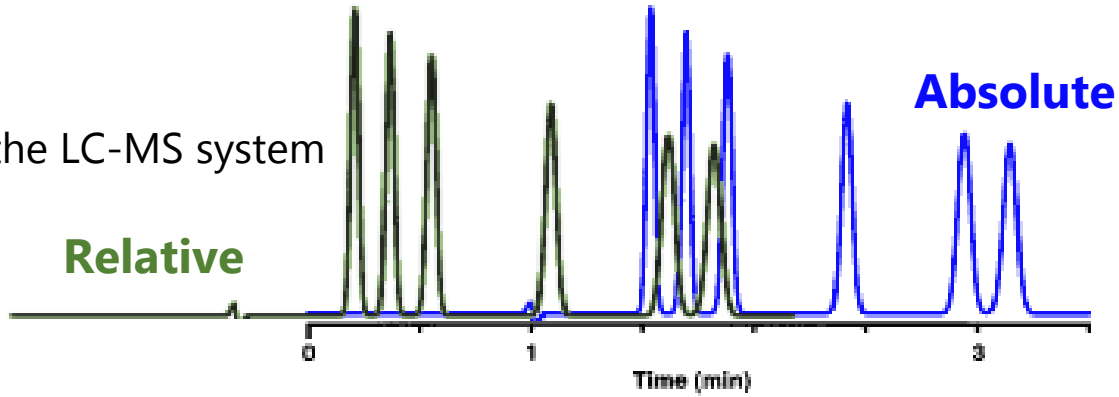
Technique	<5%	5-20%	>20%
Single channel 0.01 mg/kg	85%	15%	-
Dual-Channel 0.01 mg/kg	65%	35%	-
Single channel 0.1 mg/kg	98%	2%	-
Dual-Channel 0.1 mg/kg	69%	31%	-



Dual-Channel LC-MS/MS: retention time

- Retention time is **measured differently** in single channel compared to Dual-Channel

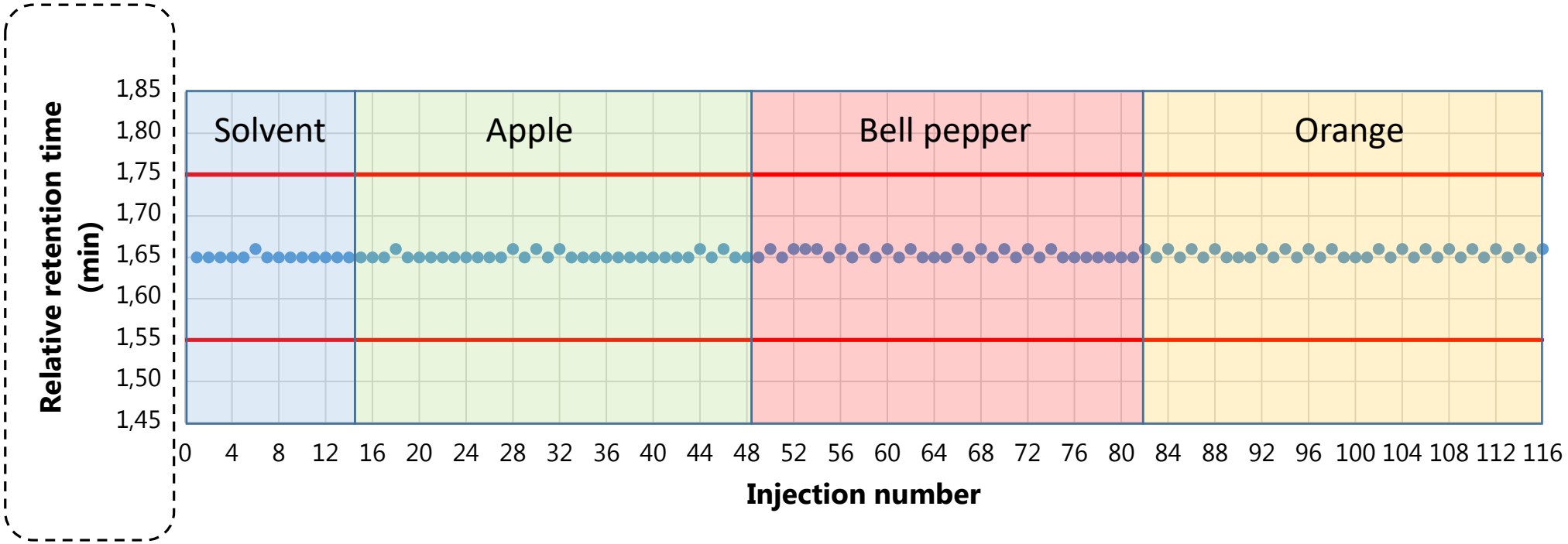
- **Single channel:**
  - Sample injection → 0.0 min
  - Data window beginning → 0.0 min
  - Retention time (absolute) → time an analyte spends on the LC-MS system



- **Dual-Channel**:
  - Sample injection → 0.0 min
  - Data window beginning → > 0.0 min
  - Retention time (relative) → time an analyte spends on the LC-MS system since the start of the data window

- The chromatographic process is the same in both cases

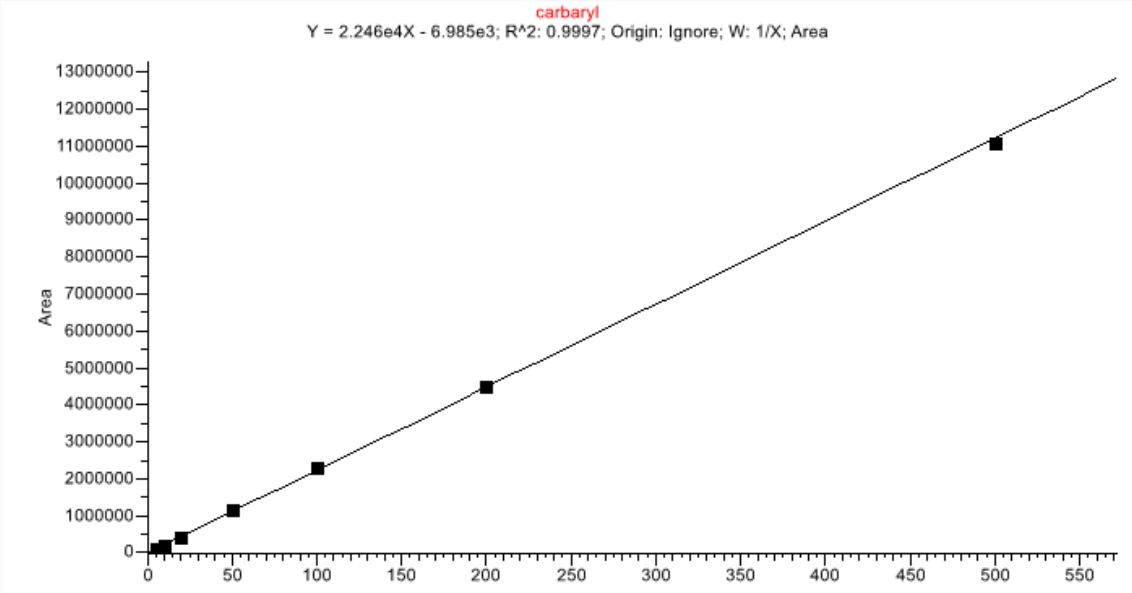
Dual-Channel LC-MS/MS: retention time stability



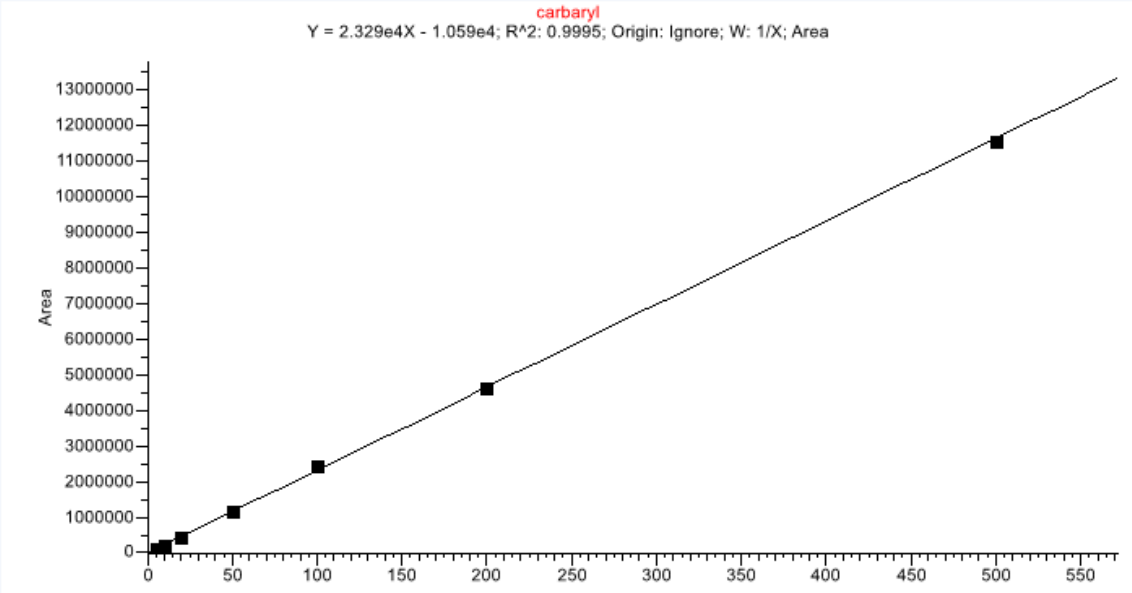
Retention time stability of pymetrozine. A sequence of 116 injections, alternate injections on channel 1 and channel 2. Red horizontal lines represent the ±0.1 min tolerance specified in the DG SANTE Document.

Dual-Channel LC-MS/MS: (cross-channel) calibration

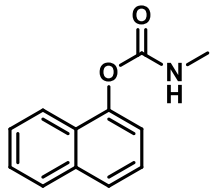
- Calibration standards can be injected using one channel, two channels, or either channel



Channel 1
R^2 = 0.9995



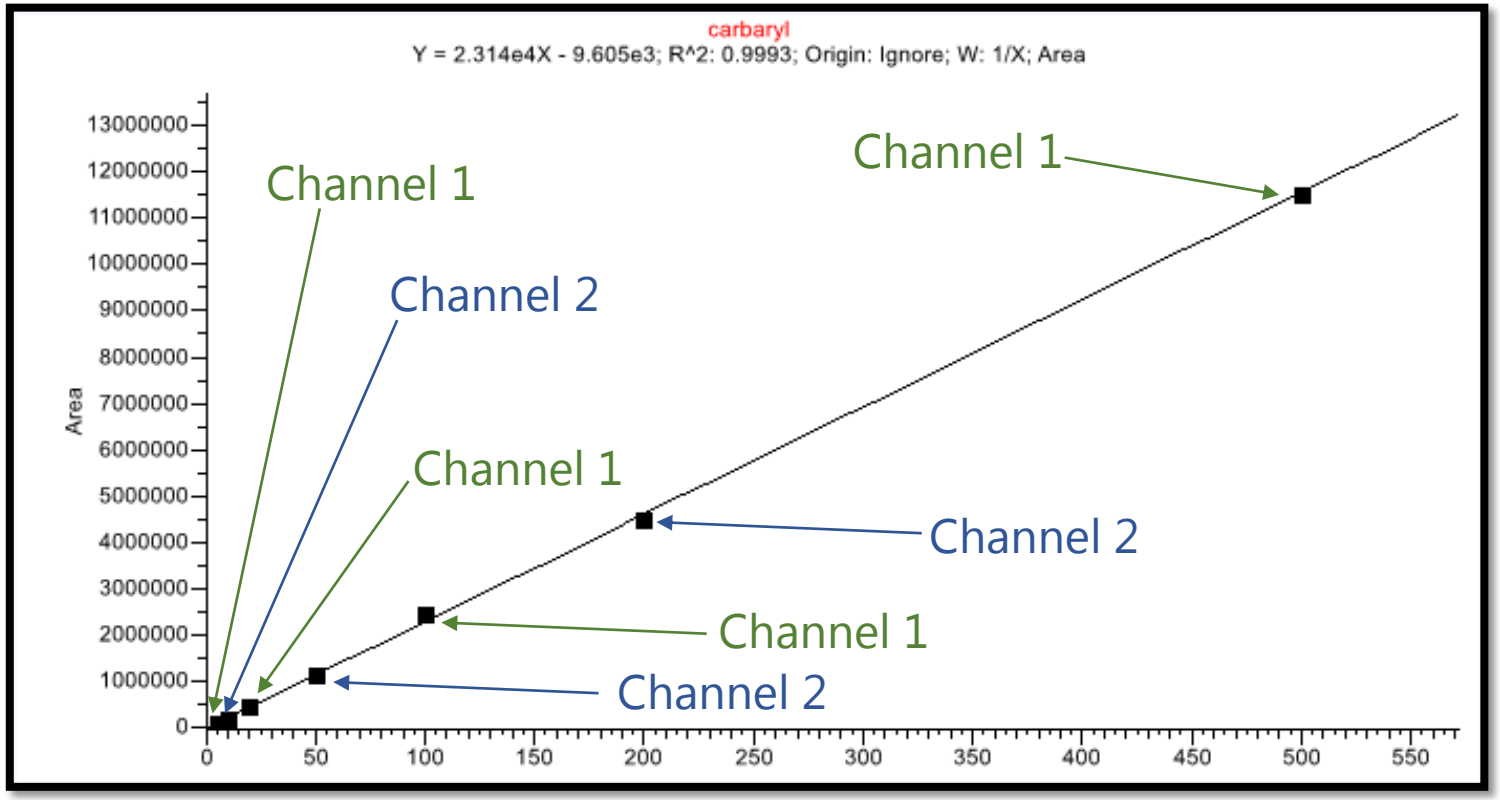
Channel 2
R^2 = 0.9997



Carbaryl

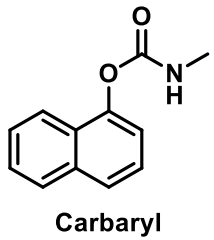
Dual-Channel LC-MS/MS: (cross-channel) calibration

- Calibration standards can be injected using one channel, two channels, or either channel



Channel 1 & 2

R^2 = 0.9993



Carbaryl

Dual-Channel LC-MS/MS: proficiency test samples

EUPT-FV 17 (broccoli)

Z-score

Compound	In-channel calibration/sample injected on channel 1	In-channel calibration/sample injected on channel 2	Cross-channel calibration/sample injected on channel 1	Cross-channel calibration/sample injected on channel 2
Bupirimate	0.2	0.1	0.2	0.2
Carbendazim	0.0	0.1	0.0	0.0
Diazinon	0.5	0.0	0.5	0.0
Difenoconazole	0.2	0.4	0.4	0.2
Diflubenzuron	0.2	0.2	0.1	0.3
Methoxyfenozide	0.7	1.0	0.8	0.9
Pendimethalin	0.5	0.1	0.6	0.1
Permethrin	0.7	0.7	0.6	1.0
Spinosad	0.6	0.6	0.1	0.0
Thiabendazole	0.5	0.4	0.5	0.4
Trifloxystrobin	0.0	0.2	0.3	0.1

Cal.: Channel 1 **Sample:** Channel 1

Cal.: Channel 2 **Sample:** Channel 2

Cal.: Cross-Channel **Sample:** Channel 1

Cal.: Cross-Channel **Sample:** Channel 2

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Dual-Channel LC-MS/MS: proficiency test samples

EUPT-FV 13 (mandarin)

Z-score

Compound	In-channel calibration/sample injected on channel 1	In-channel calibration/sample injected on channel 2	Cross-channel calibration/sample injected on channel 1	Cross-channel calibration/sample injected on channel 2
Carbendazim	0.7	0.7	0.7	0.6
Chlorpyrifos	0.5	0.6	0.4	0.5
Diazinon	0.6	0.7	0.6	0.7
EPN	0.1	0.2	0.0	0.3
Imazalil	0.1	0.1	0.1	0.1
Indoxacarb	0.7	0.5	0.7	0.5
Malathion	0.6	0.5	0.5	0.5
Methidathion	0.4	0.3	0.4	0.3
Methomyl	0.2	0.2	0.2	0.3
Oxamyl	1.3	1.6	1.4	1.6
Pendimethalin	0.2	0.3	0.2	0.3
Phosalone	0.7	0.8	0.6	0.7
Prochloraz	0.7	0.8	0.8	0.9
Pyriproxifen	0.5	0.4	0.4	0.3
Spinosad	0.7	0.6	0.8	0.6
Thiabendazole	0.1	0.2	0.1	0.3

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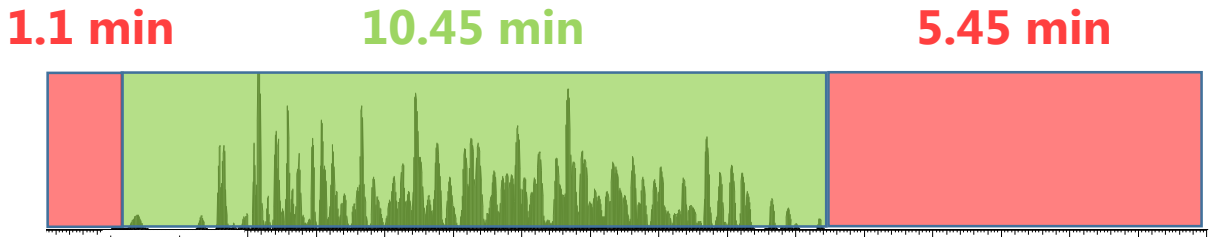
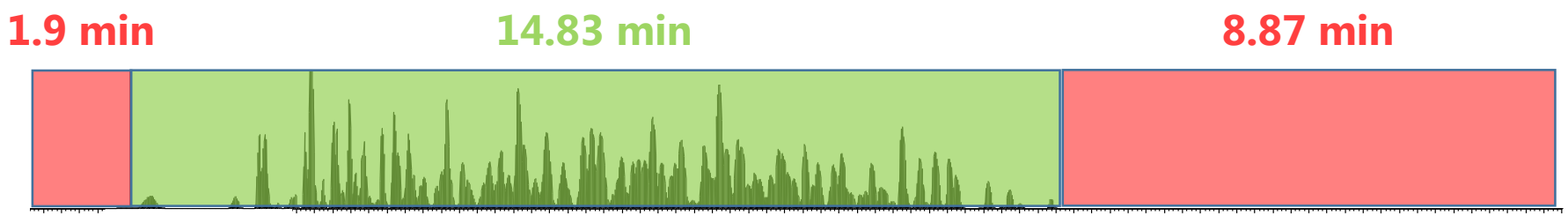
Dual-Channel LC-MS/MS: increased column length

- Chromatographic columns of **100 mm** and **150 mm** in length were compared
- **Remaining properties** were kept identical (porosity, particle size, type)
- 1.5x length → 1.5x increase in each **gradient** step
- **Elution time** also increased 1.5x, 14 min → 21 min
- **Data window** 14.83 min (TSQ Altis)
- **Longer analysis** time of longer columns compensated by Dual-Channel time savings

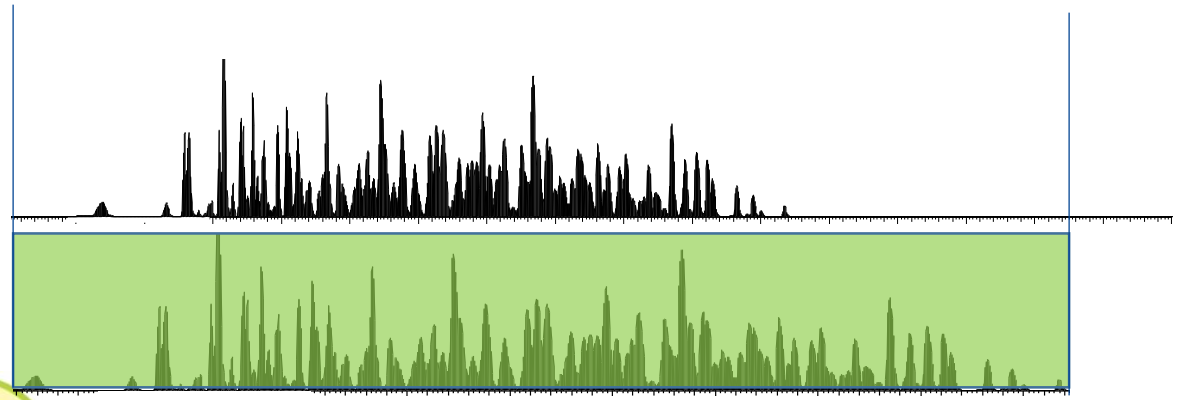
Dual-Channel LC-MS: increased column length



100 mm column



150 mm column



Using Dual-Channel chromatography and a 150 mm column results in shorter analysis times per sample compared to a single channel analysis on a 100 mm column

The use of a longer column results in improved separation, increasing selectivity and sensitivity without compromising analysis time

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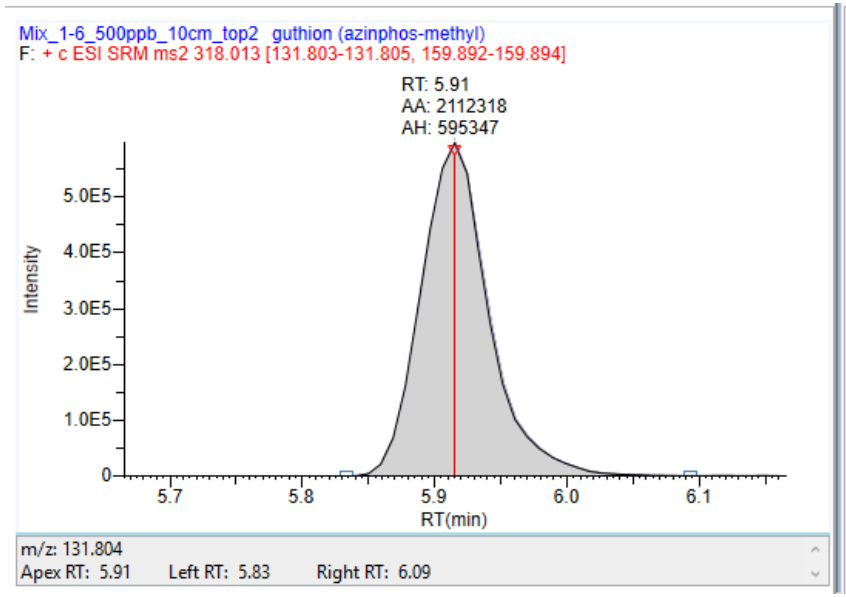
Dual-Channel LC-MS/MS: solving analyte coelution

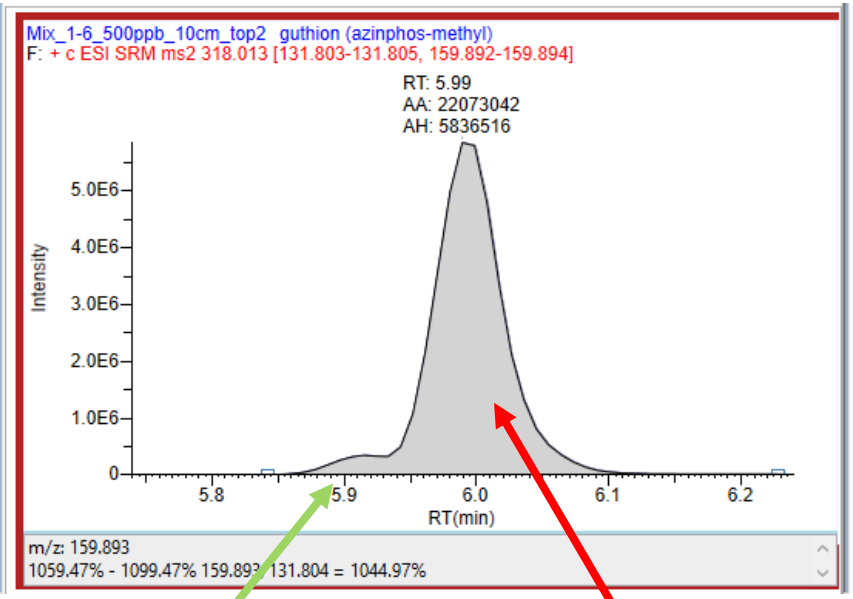
Azinphos methyl & phosmet coelution

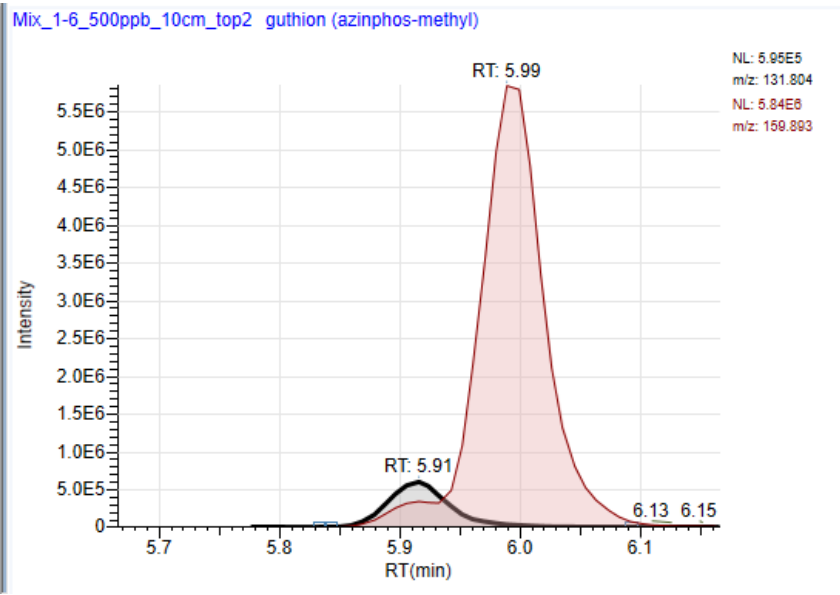
TSQ Altis
Triple quadrupole
100 mm column

***m/z* 318 -> 132**



***m/z* 318 -> 159**





Azinphos methyl

Interfering transition of phosmet

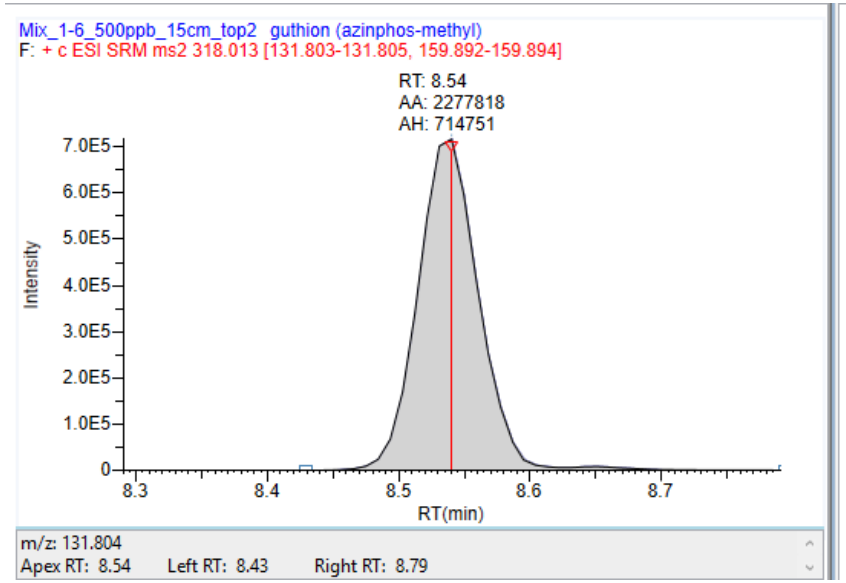
Dual-Channel LC-MS/MS: solving analyte coelution

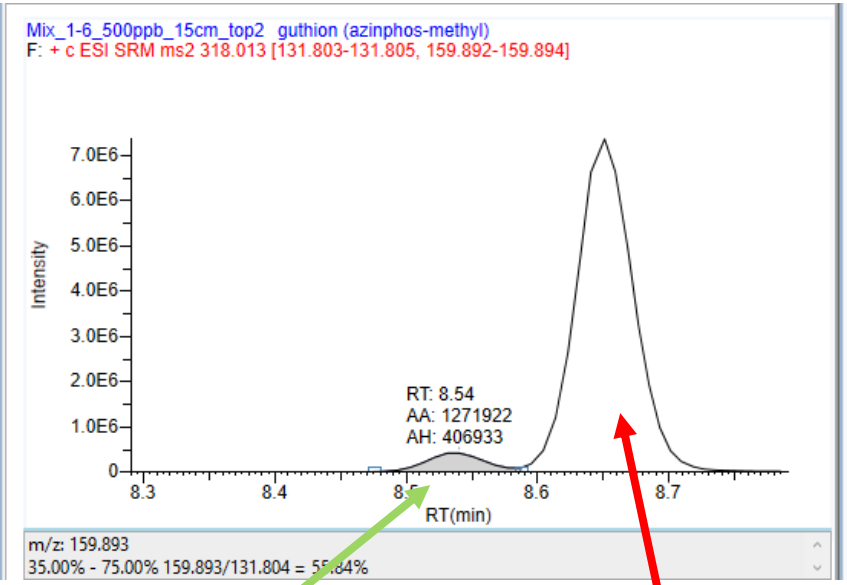
Azinphos methyl & phosmet coelution

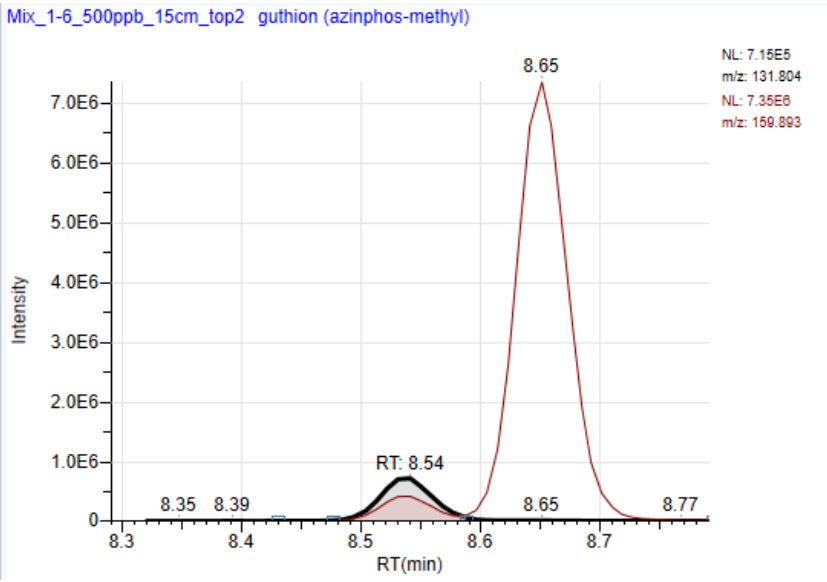
TSQ Altis
Triple quadrupole
150 mm column

***m/z* 318 -> 132**

***m/z* 318 -> 159**







Azinphos methyl

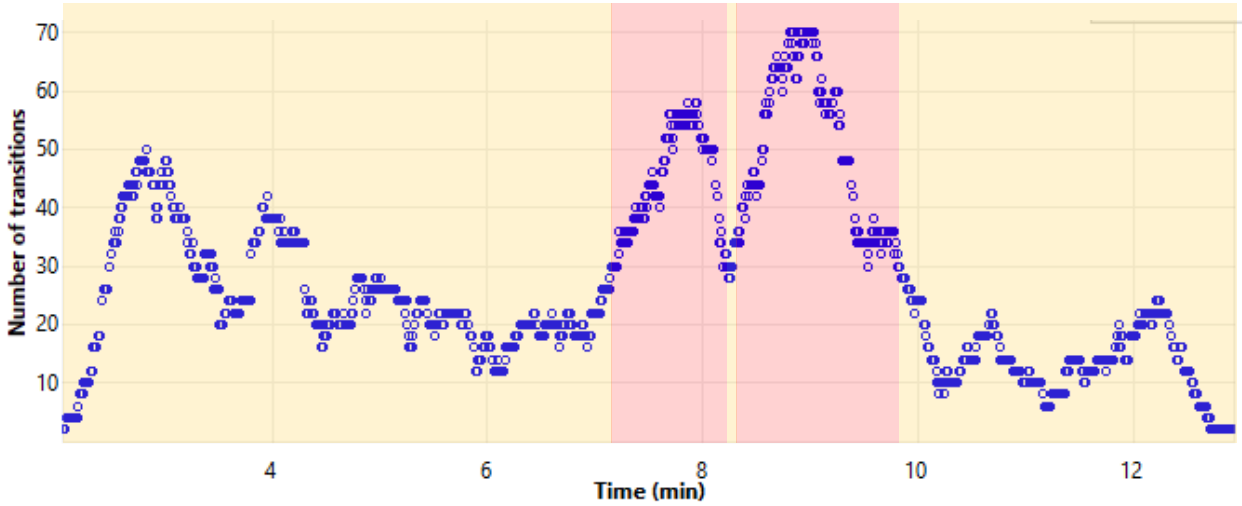
Phosmet is separated from azinphos methyl

Dual-Channel LC-MS/MS: increasing the sensitivity

300 pesticides / 600 transitions

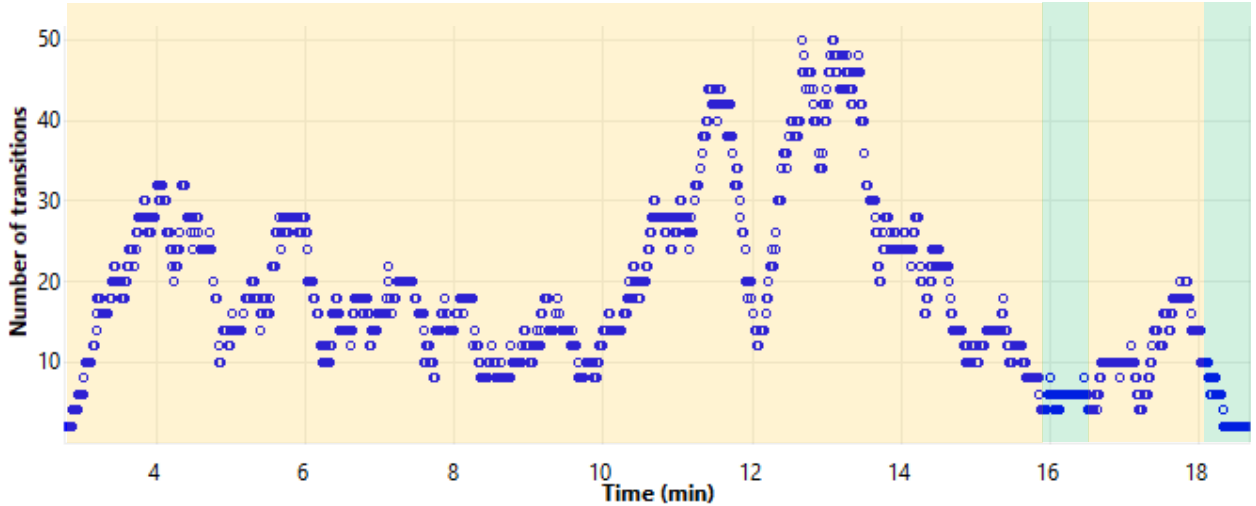
100 mm column

Number of transitions per cycle



150 mm column

Number of transitions per cycle



Dwell time < 10 ms

Dwell time 10 – 50 ms

Dwell time > 50 ms

A longer column separates better the analytes.
The dwell times can be increased without increasing the duty cycle.

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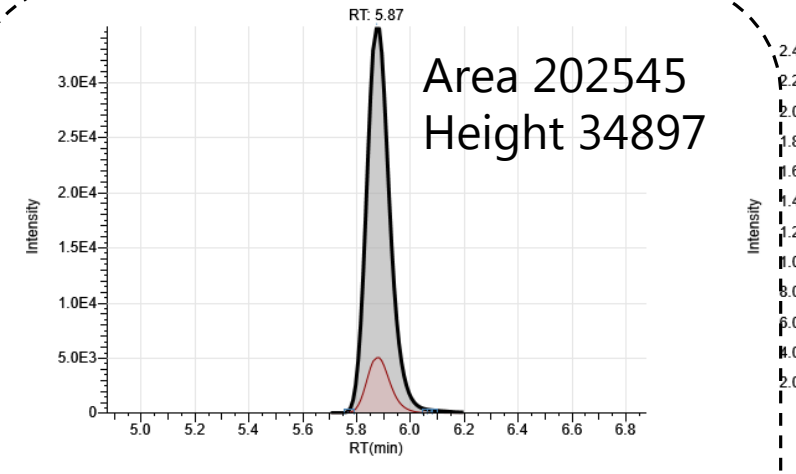
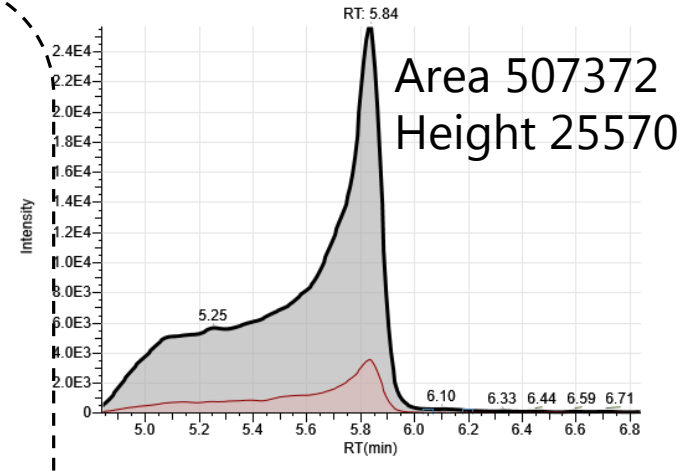
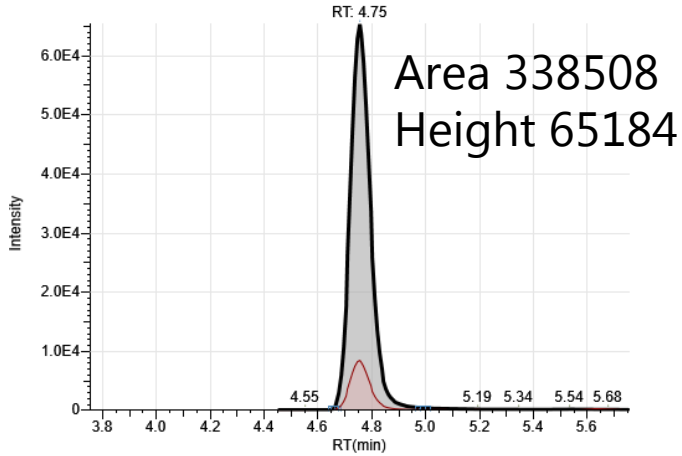
Dual-Channel LC-MS/MS: Mobile phase optimization- negative mode



Water/MeOH/formic acid/ammonium formate

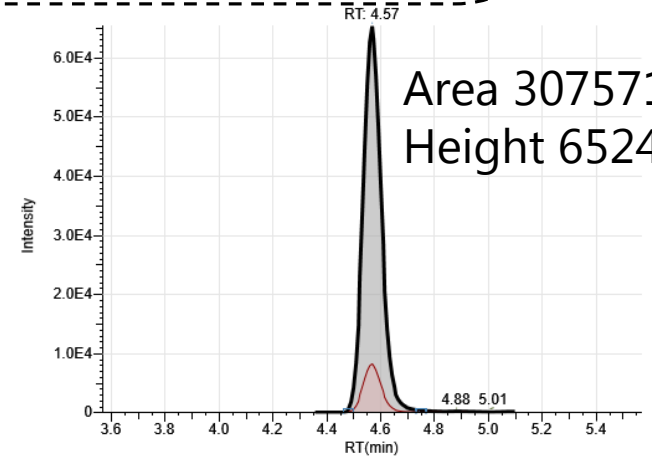


Water/AcN



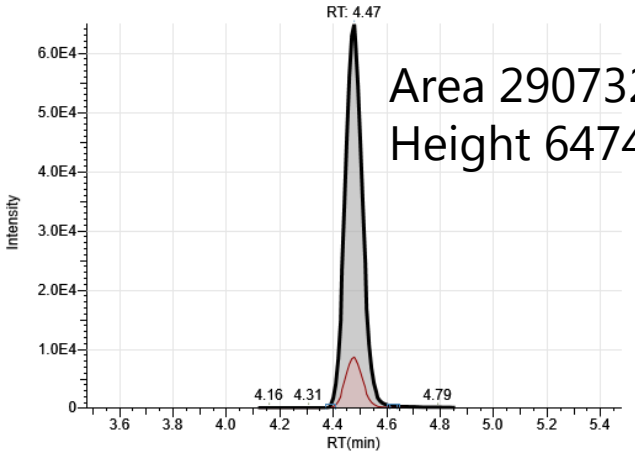
Water/AcN + 0.01 % acetic acid

Gradient 1



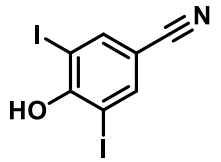
Water/AcN + 0.02 % acetic acid

Gradient 2



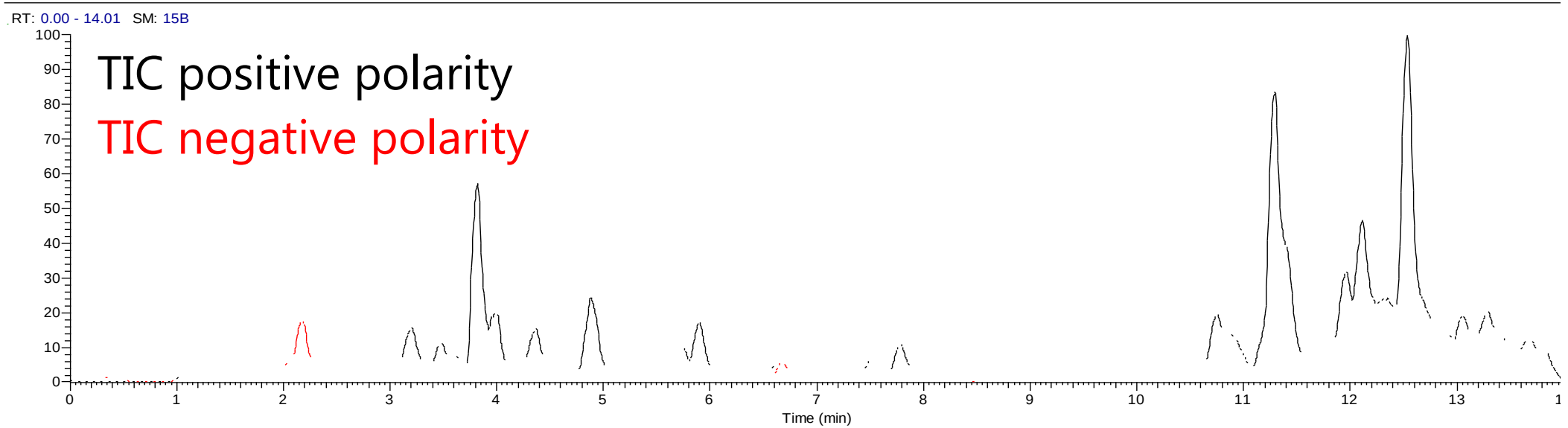
Water/AcN + 0.05 % acetic acid

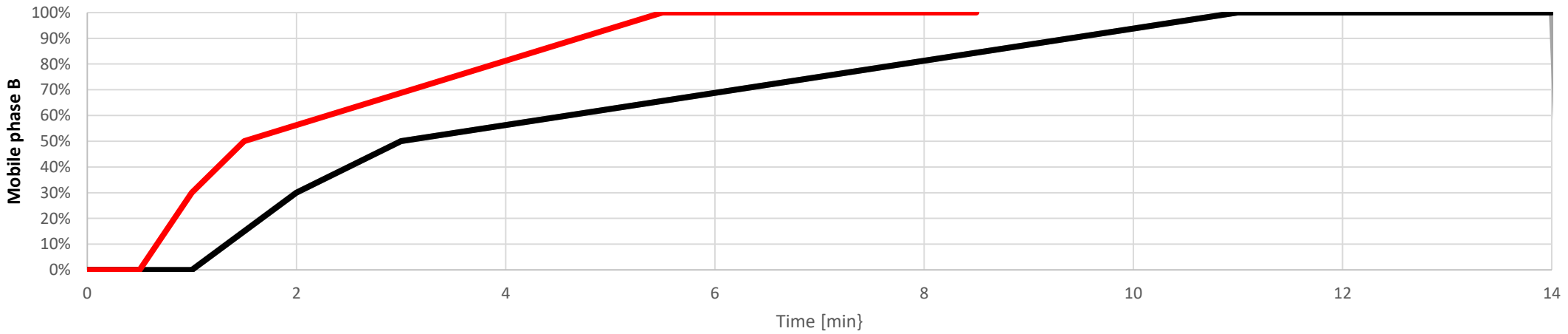
Ioxynil



Dual-Channel LC-MS/MS: total ion chromatograms

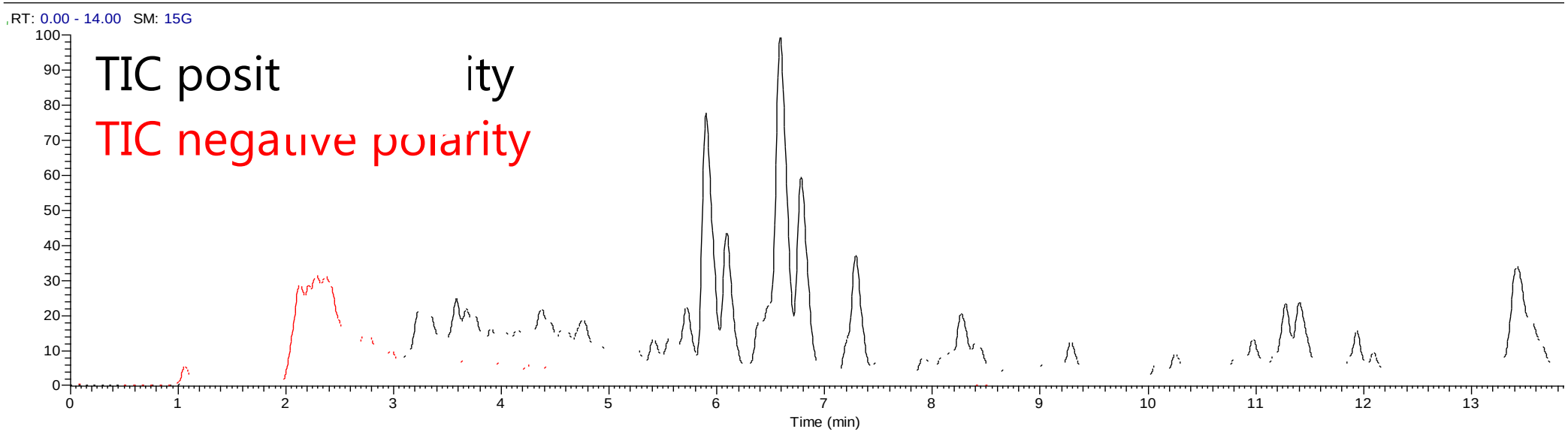
Tomato

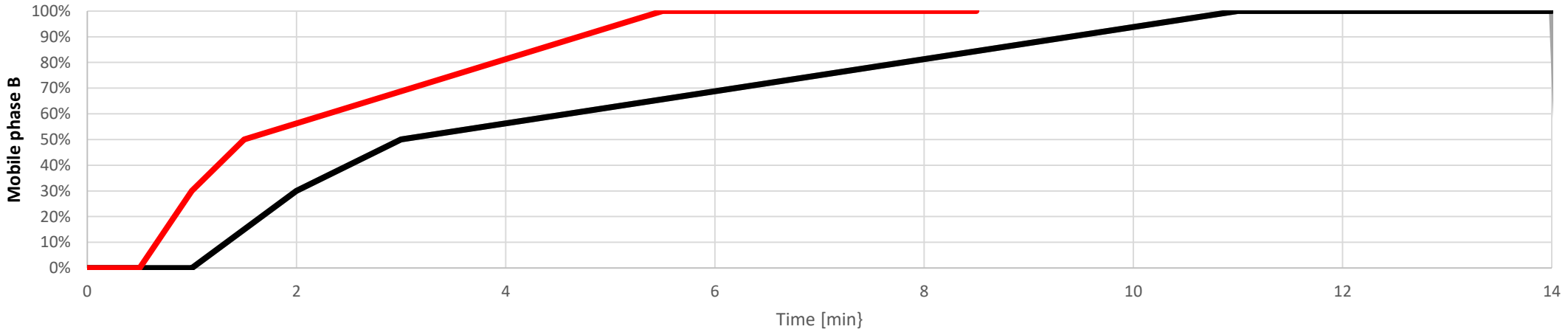




Dual-Channel LC-MS/MS: total ion chromatograms

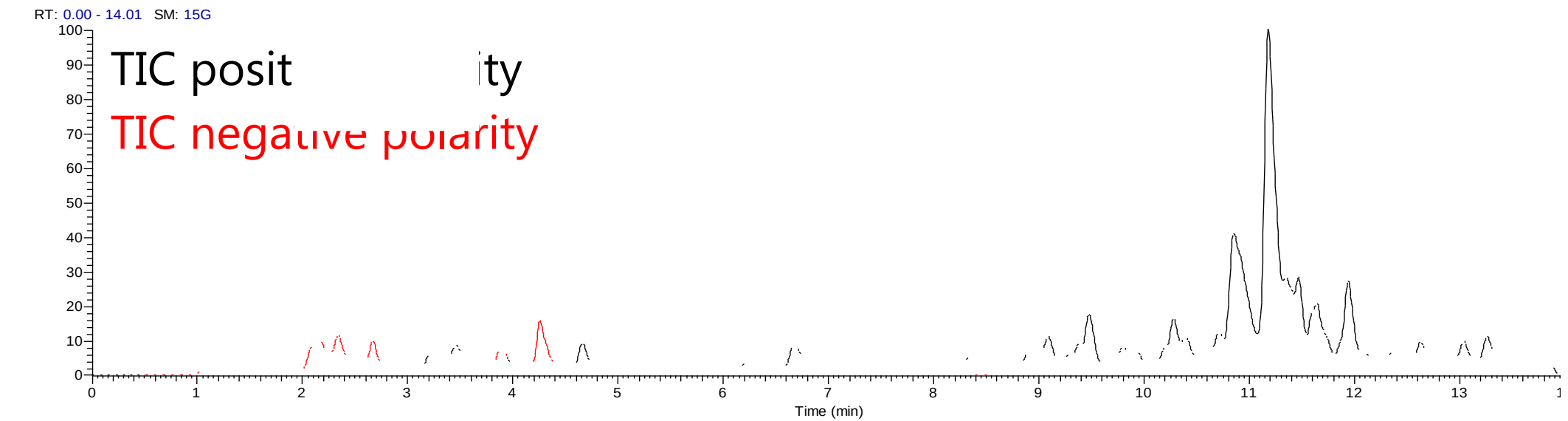
Orange

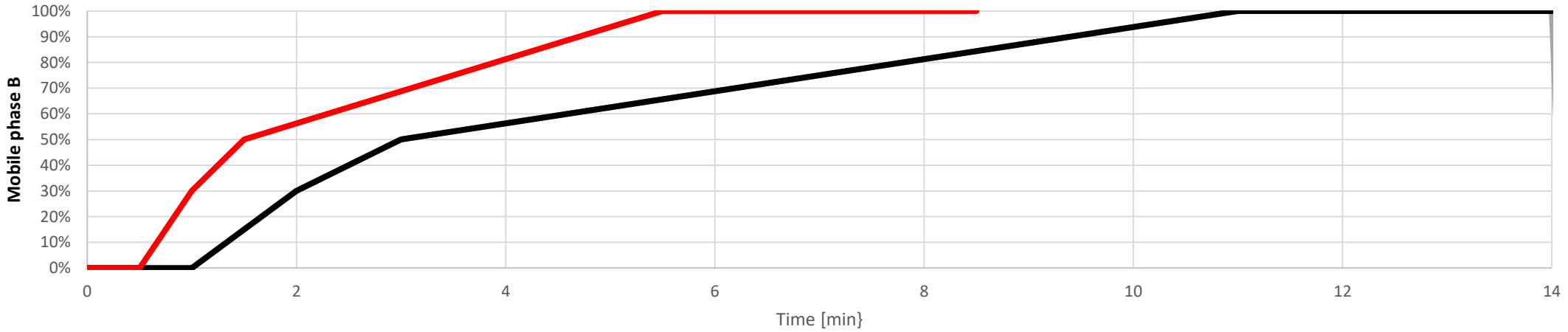




Dual-Channel LC-MS/MS: total ion chromatograms

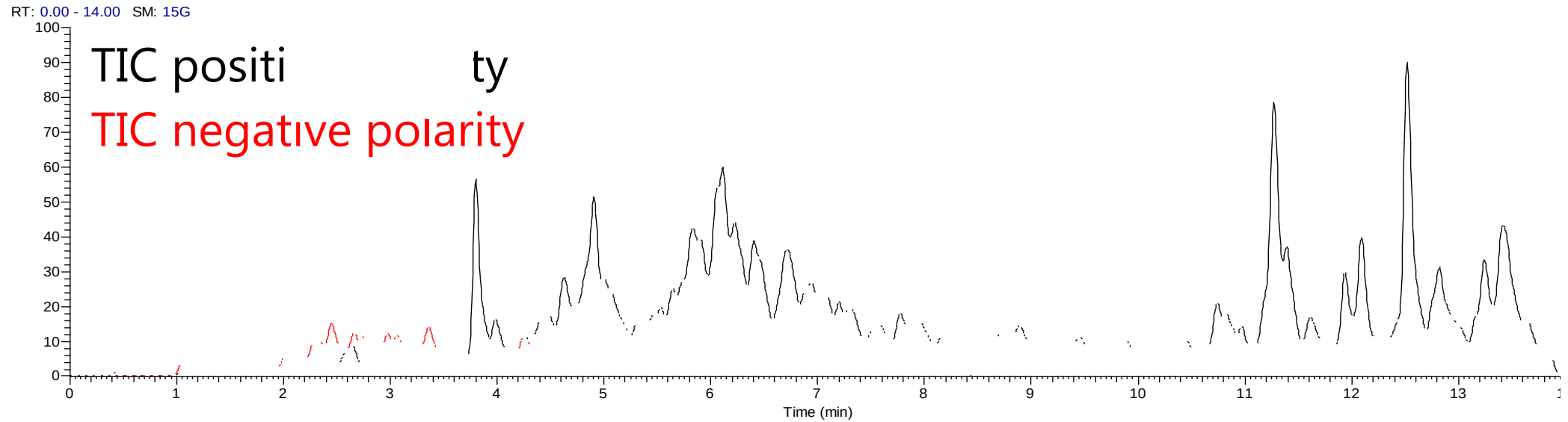
Avocado

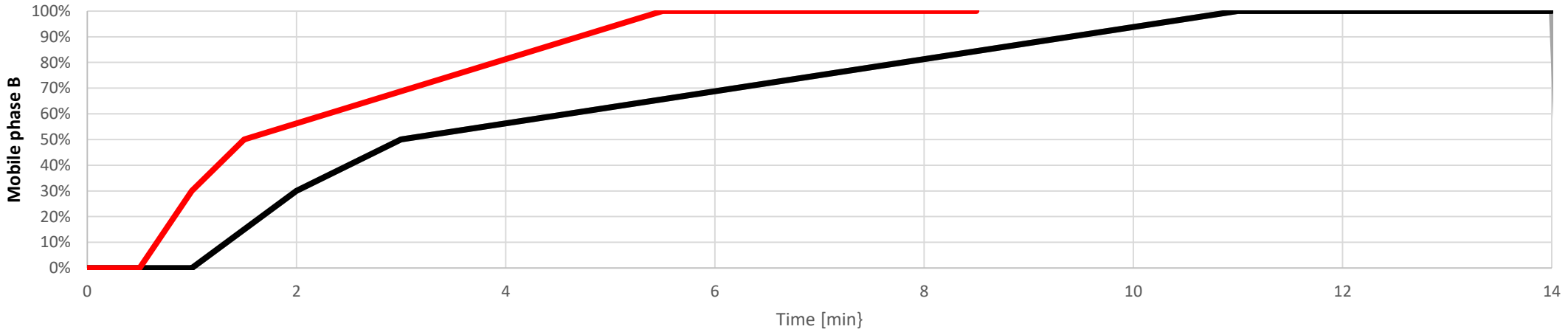




Dual-Channel LC-MS/MS: total ion chromatograms

Onion

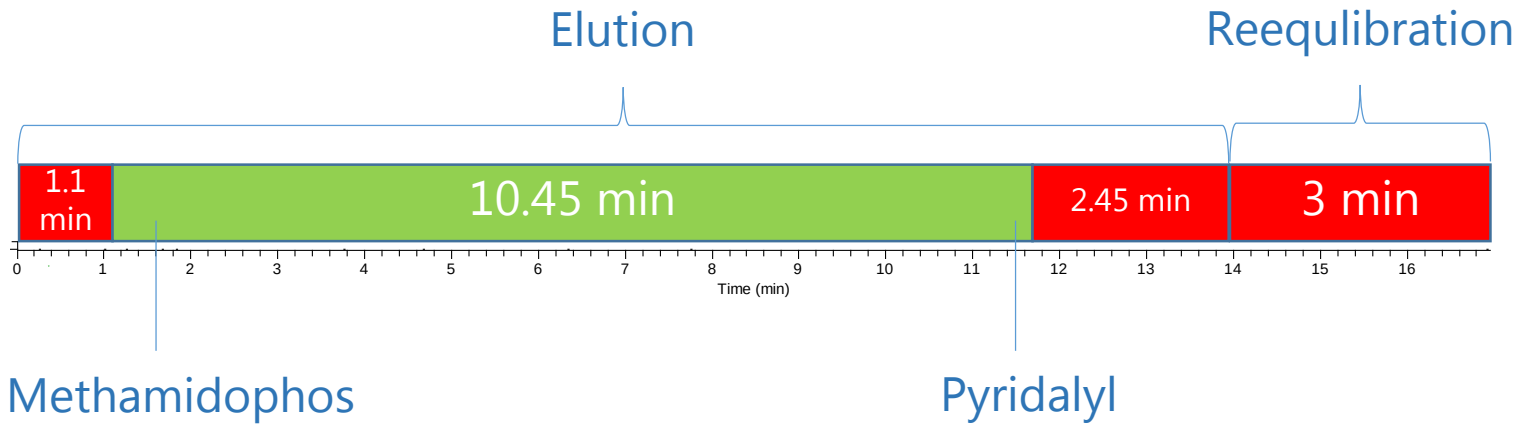




Dual-Channel LC-MS/MS: independent mobile phases

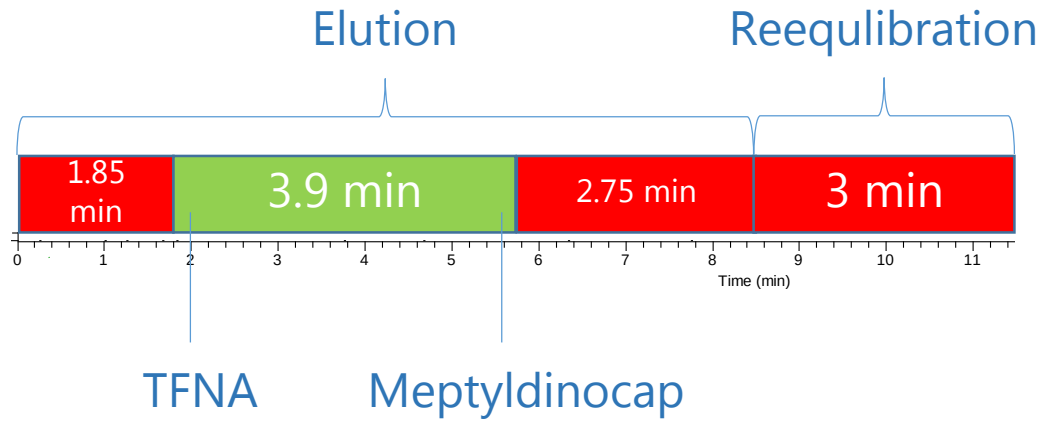
Gradient 1

Water:MeOH
Formic acid (0.1 %)
Ammonium formate (5 mM)

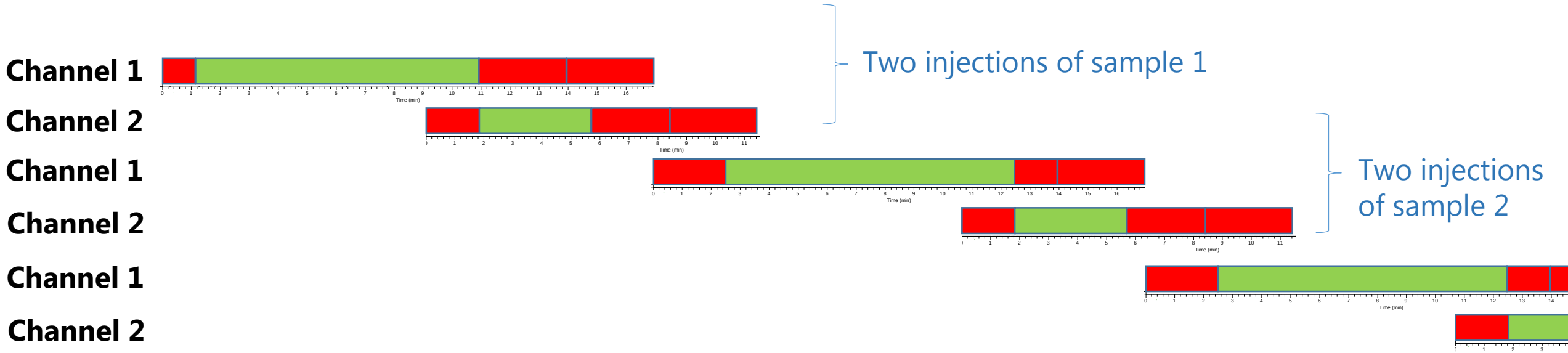


Gradient 2

Water:AcN
Acetic acid (0.05 %)



Dual-Channel LC-MS/MS: independent mobile phases



18.00 min 18.00 min 18.00 min

On a single channel instrument with polarity switching only one analysis in 18 min

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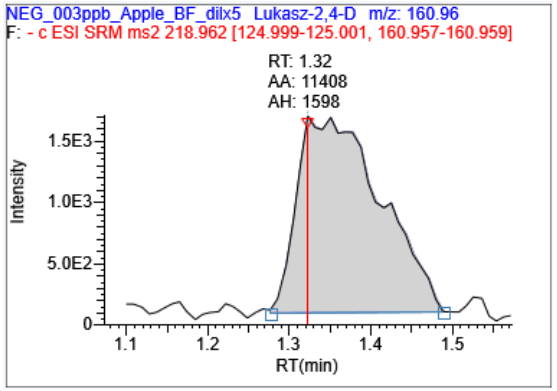
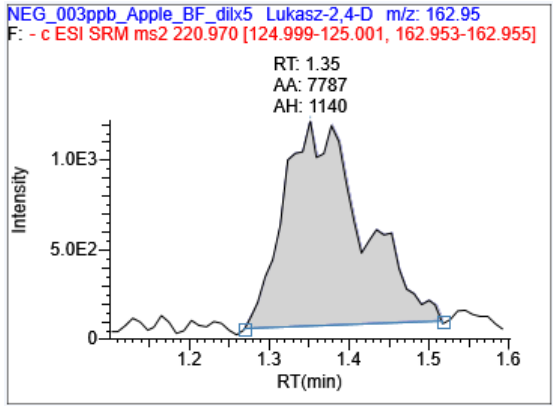
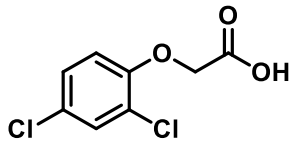
Dual-Channel LC-MS/MS: improved ionisation

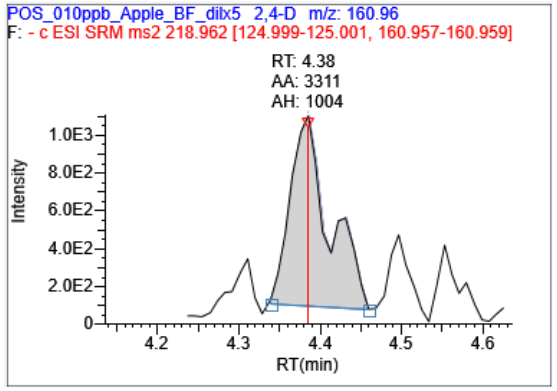


0.003 mg/kg

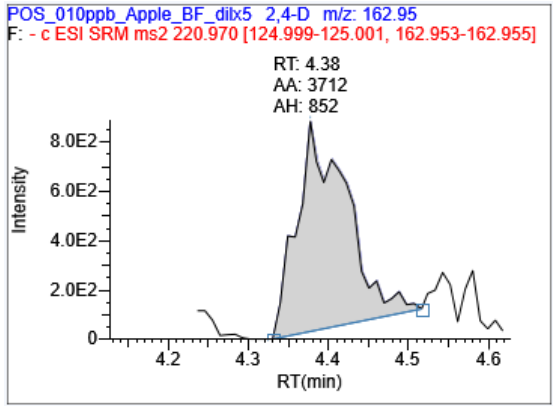


2,4-D





0.010 mg/kg



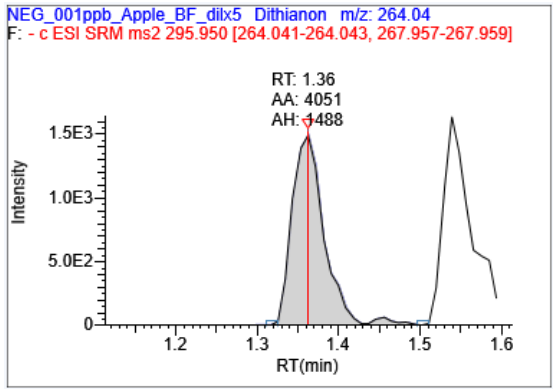
Gradient 2

Water:AcN
Acetic acid (0.05 %)

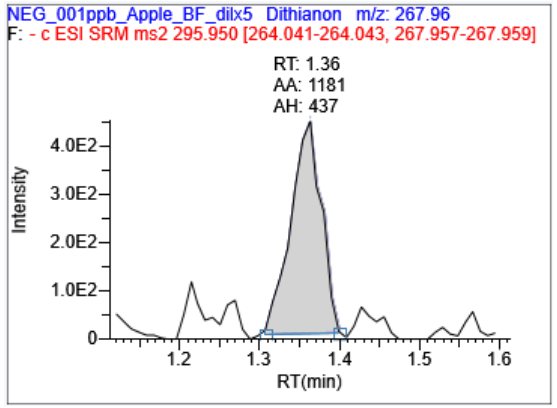
Gradient 1

Water:MeOH
Formic acid (0.1 %)
Ammonium formate (5 mM)

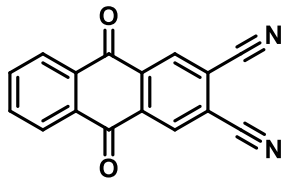
Dual-Channel LC-MS/MS: improved ionisation

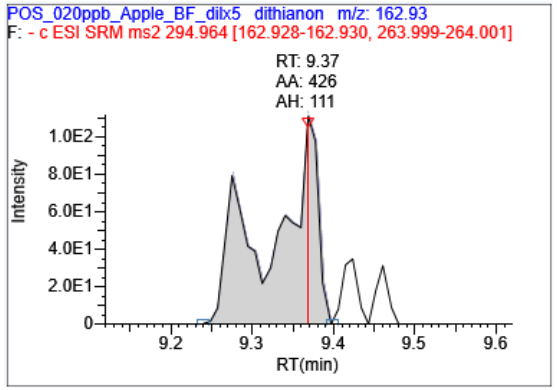


0.001 mg/kg

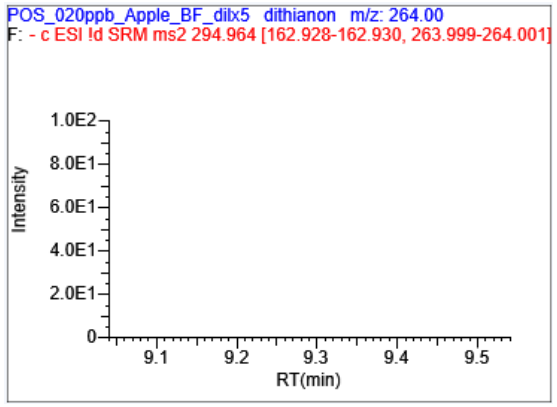


Dithianon





0.020 mg/kg



Gradient 2

Water:AcN
Acetic acid (0.05 %)

Gradient 1

Water:MeOH
Formic acid (0.1 %)
Ammonium formate (5 mM)

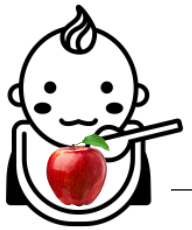
Dual-Channel LC-MS/MS: apple baby food validation

Gradient 1

Water:MeOH
Formic acid (0.1 %)
Ammonium formate (5 mM)

Commission Directive 2006/125/EC

Compound	Recoveries 0.003 mg/kg	RSD 0.003 mg/kg	Recoveries 0.006 mg/kg	RSD 0.006 mg/kg	Lowest calibration level (mg/kg)	Highest calibration level (mg/kg)
2,4-D	-	-	-	-	0.006	0.02
Bromacil	110 %	5 %	97 %	3 %	0.0005	0.02
Dithianon	-	-	-	-	-	-
Diuron	103 %	5 %	101 %	3 %	0.0005	0.02
Fensulfothion	102 %	5 %	104 %	3 %	0.0005	0.02
Fensulfothion-oxon-sulfone	104 %	5 %	95 %	4 %	0.0005	0.02
Fipronil	100 %	4 %	92 %	3 %	0.0005	0.02
Fipronil-desulfinyl	99 %	7 %	100 %	3 %	0.0005	0.02
Fipronil-sulfone	103 %	3 %	108 %	3 %	0.0005	0.02
Flubendiamide	25 %	224 %	98 %	14 %	0.003	0.02
Fludioxonil	93 %	6 %	102 %	6 %	0.0005	0.02
Haloxyfop	97 %	13 %	93 %	6 %	0.003	0.02
Hexaflumuron	-	-	106 %	11 %	0.003	0.02
Ioxynil	118 %	3 %	105 %	6 %	0.001	0.02
Lufenuron	83 %	22 %	75 %	30 %	0.003	0.02
MCPA	-	-	94 %	13 %	0.003	0.02
MCPB	-	-	-	-	-	-
Meptyldinocap	-	-	130 %	29 %	0.006	0.02
(*E*)-Metaflumizone	84 %	5 %	85 %	6 %	0.001	0.02
(*Z*)-Metaflumizone	109 %	3 %	102 %	5 %	0.001	0.02
Penthiopyrad	100 %	2 %	100 %	1 %	0.0005	0.02
Prothioconazole	107 %	12 %	110 %	11 %	0.003	0.02
Prothioconazole-desthio	106 %	8 %	94 %	5 %	0.0005	0.02
Teflubenzuron	100 %	9 %	105 %	2 %	0.001	0.02
TFNA	-	-	-	-	-	-
TFNG	26 %	224 %	47 %	93 %	-	-



Dual-Channel LC-MS/MS: apple baby food validation

Gradient 2

Water:AcN
Acetic acid (0.05 %)

Commission Directive 2006/125/EC

Compound	Recoveries 0.003 mg/kg	RSD 0.003 mg/kg	Recoveries 0.006 mg/kg	RSD 0.006 mg/kg	Lowest calibration level (mg/kg)	Highest calibration level (mg/kg)
2,4-D	97 %	11 %	109 %	6 %	0.001	0.02
Bromacil	101 %	6 %	104 %	4 %	0.0005	0.02
Dithianon	96 %	3 %	96 %	3 %	0.0005	0.02
Diuron	99 %	3 %	99 %	2 %	0.0005	0.02
Fensulfothion	99 %	3 %	100 %	3 %	0.0005	0.02
Fensulfothion-oxon-sulfone	100 %	4 %	103 %	2 %	0.0005	0.02
Fipronil	103 %	1 %	101 %	1 %	0.0005	0.02
Fipronil-desulfinyl	101 %	2 %	100 %	2 %	0.0005	0.02
Fipronil-sulfone	98 %	2 %	100 %	2 %	0.0005	0.02
Flubendiamide	104 %	1 %	97 %	2 %	0.0005	0.02
Fludioxonil	105 %	5 %	103 %	2 %	0.0005	0.02
Haloxyfop	96 %	5 %	101 %	3 %	0.003	0.02
Hexaflumuron	94 %	5 %	104 %	8 %	0.0005	0.02
Ioxynil	101 %	2 %	103 %	3 %	0.0005	0.02
Lufenuron	108 %	6 %	102 %	3 %	0.0005	0.02
MCPA	114 %	7 %	99 %	3 %	0.001	0.02
MCPB	-	-	115 %	10 %	0.006	0.02
Meptyldinocap	86 %	14 %	118 %	6 %	0.003	0.02
(*E*)-Metaflumizone	103 %	2 %	95 %	1 %	0.0005	0.02
(*Z*)-Metaflumizone	104 %	1 %	105 %	2 %	0.0005	0.02
Penthiopyrad	103 %	3 %	101 %	1 %	0.0005	0.02
Prothioconazole	106 %	3 %	90 %	5 %	0.0005	0.02
Prothioconazole-desthio	101 %	2 %	100 %	2 %	0.0005	0.02
Teflubenzuron	107 %	3 %	95 %	2 %	0.0005	0.02
TFNA	-	-	98 %	7 %	0.006	0.02
TFNG	103 %	8 %	101 %	5 %	0.003	0.02

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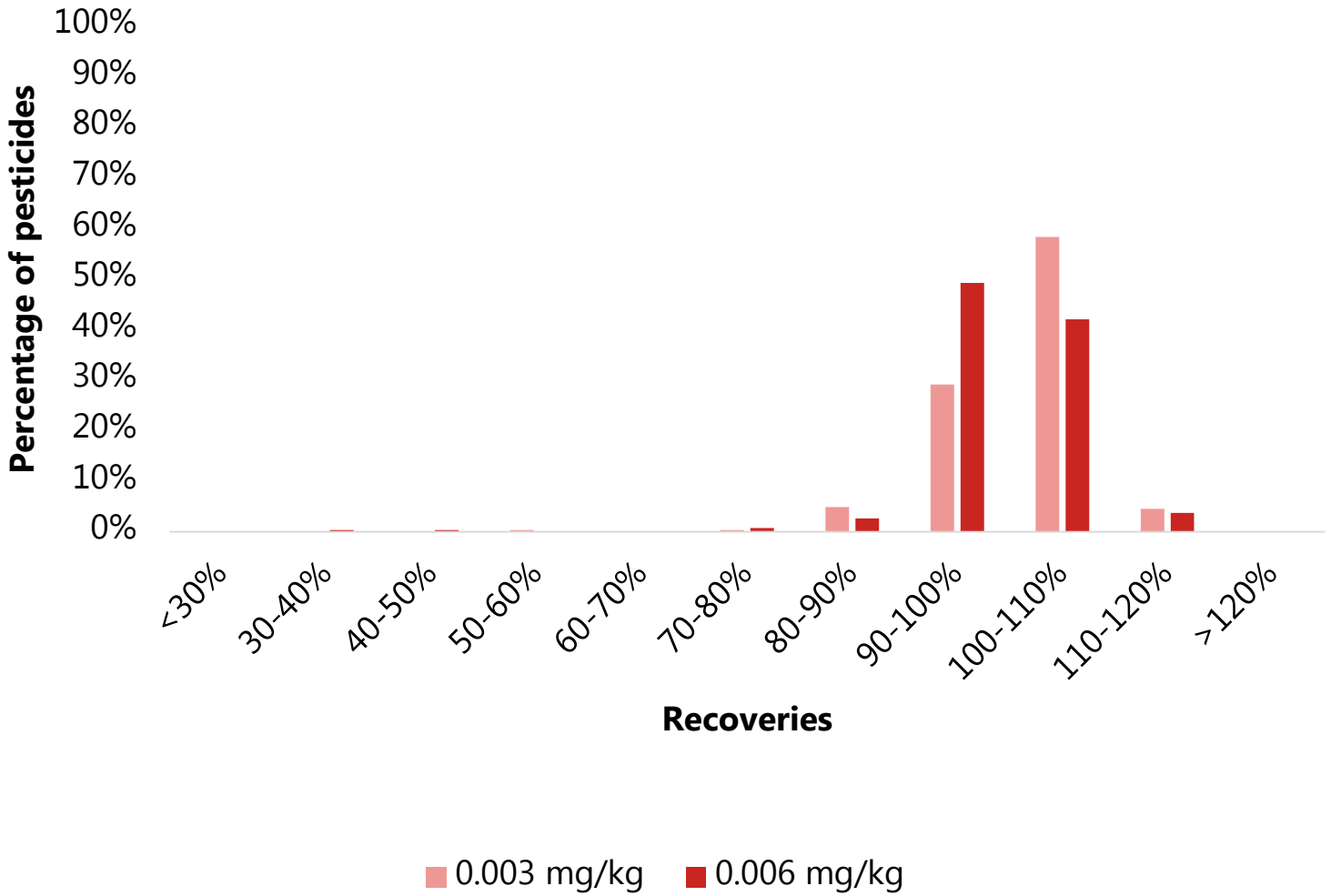
Dual-Channel LC-MS/MS: apple baby food validation

264 total pesticide residues (ESI+ and ESI-)

Technique	<70%	70-120%	>120%
Dual-Channel 0.003 mg/kg	1	257	-
Dual-Channel 0.006 mg/kg	2	260	-

256 pesticide residues validated at 0.003 mg/kg

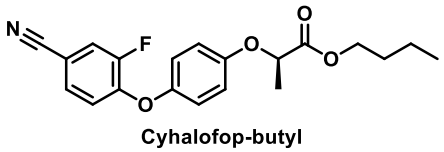
260 pesticide residues validated at 0.006 mg/kg



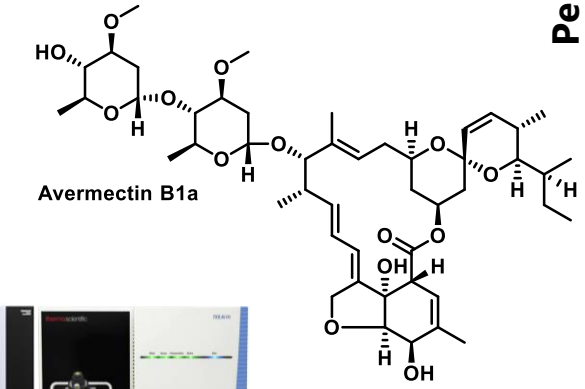
Dual-Channel LC-MS/MS: apple baby food validation

264 total pesticide residues (ESI+ and ESI-)

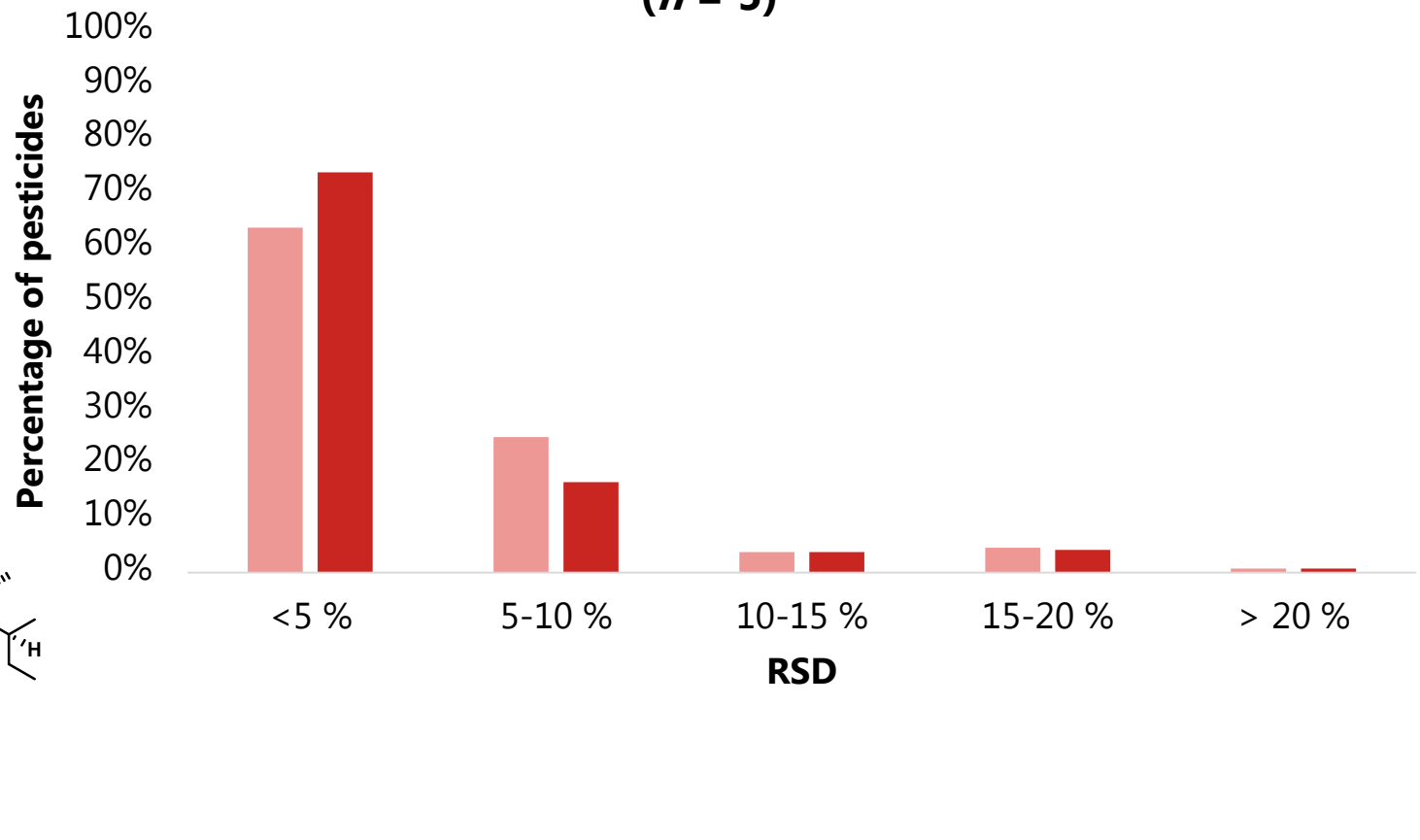
Technique	<5%	5-20%	>20%
Dual-Channel 0.003 mg/kg	64%	33%	1%
Dual-Channel 0.006 mg/kg	74%	25%	1%



Cyhalofop-butyl



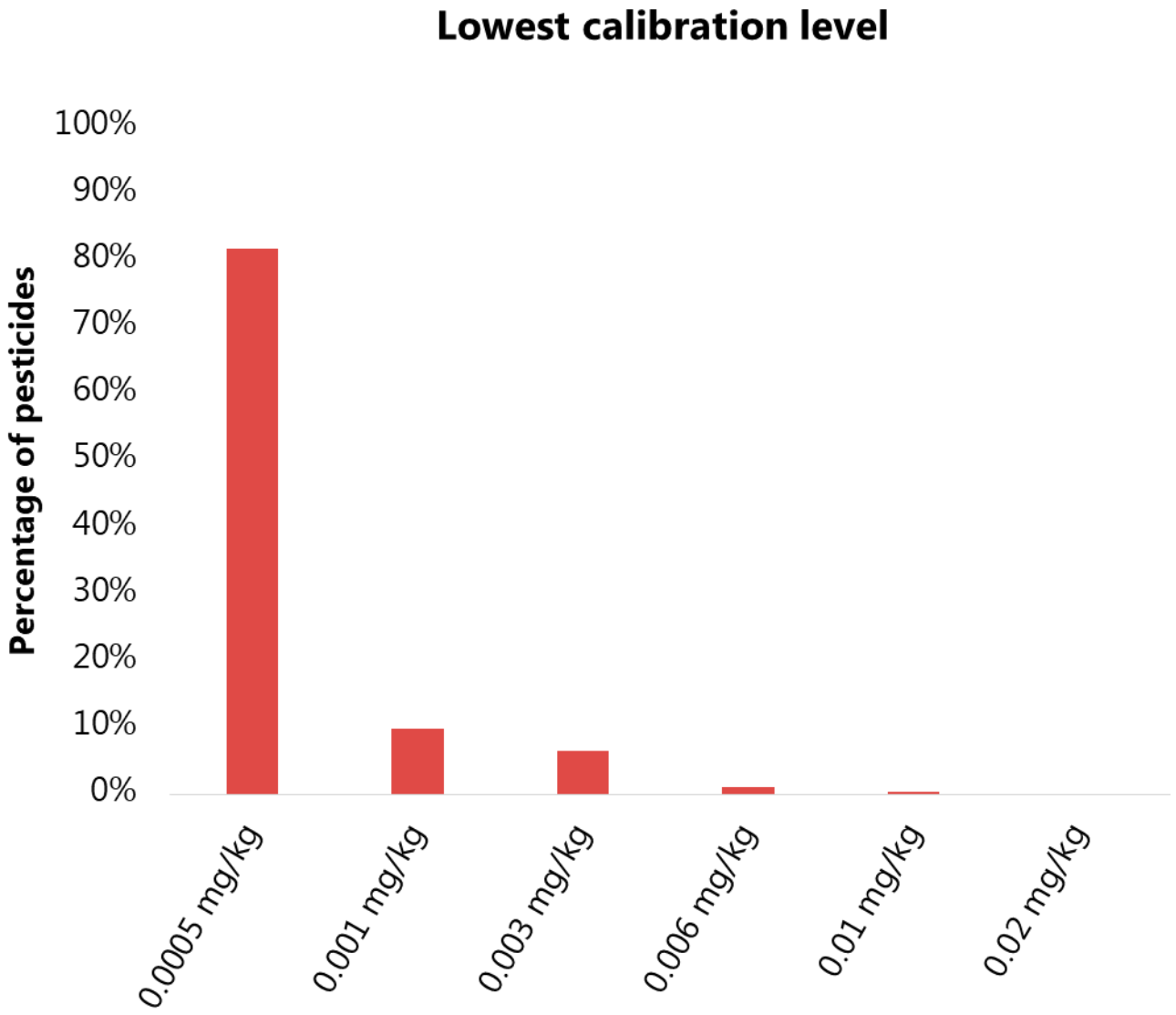
Avermectin B1a



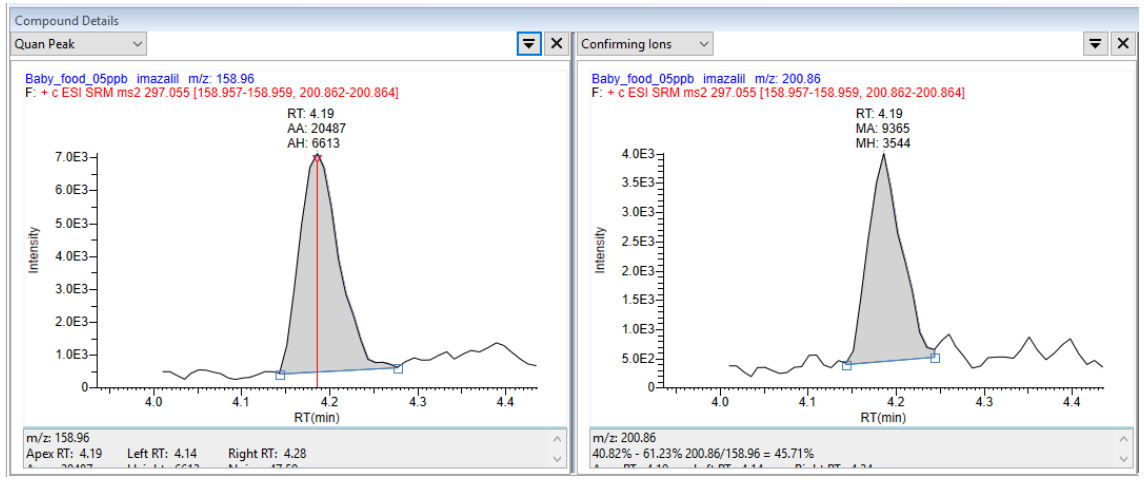
Dual-Channel LC-MS/MS: apple baby food validation

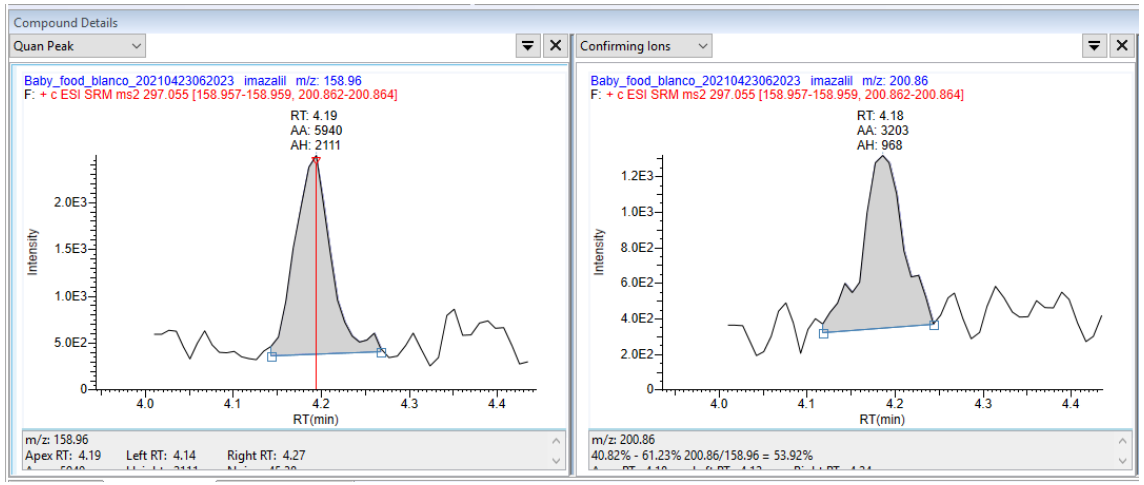
264 total pesticide residues (ESI+ and ESI-)

Calibration level (mg/kg)	Percentage of analytes
0.0005	82%
0.001	10%
0.003	6%
0.006	1%
0.010	1%
0.020	0%



Dual-Channel LC-MS/MS: carry over test

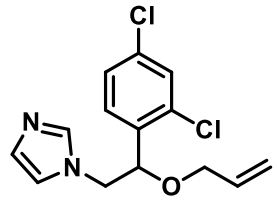




Imazalil

0.5 ppb in baby food

Quant ion peak area 2.0E4

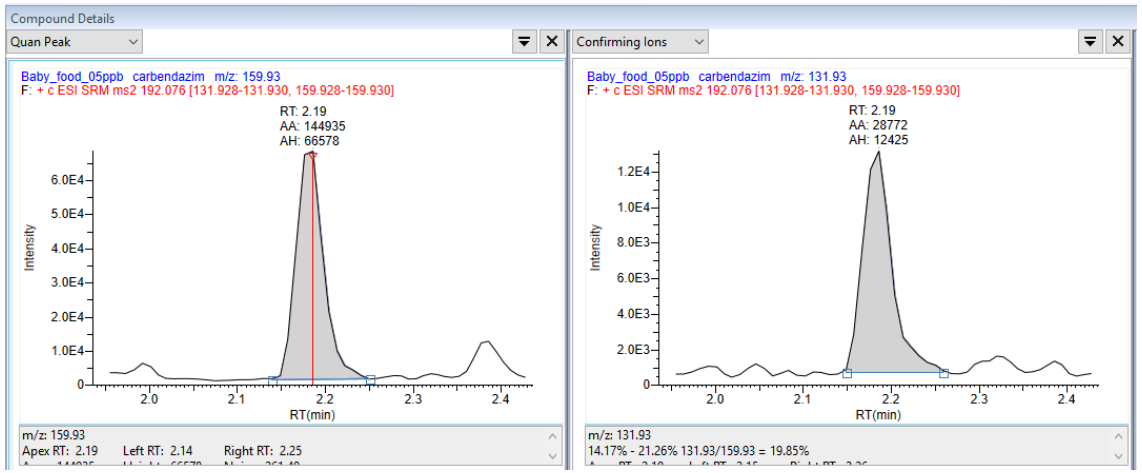


Imazalil

Blank baby food after 12 injections of 20 ppb standard

Quant ion peak area 6.0E3

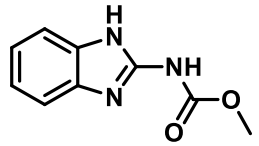
Dual-Channel LC-MS/MS: carry over test

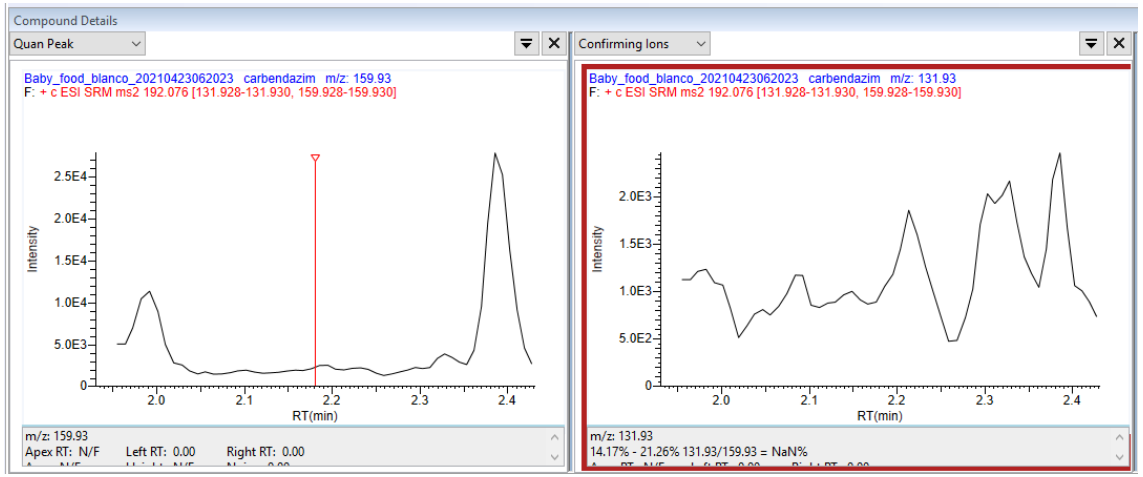


Carbendazim

<u>0.5 ppb in baby food</u>

Quant ion peak area 1.4E5





Carbendazim

<u>Blank baby food after 12 injections of 20 ppb standard</u>

Quant ion peak area 0.0E0

Conclusions

- Dual-Channel LC-MS can be used to increase **sample throughput** up to 70 %
- This technique can also be used to **improve selectivity** without sacrificing analysis time
- Furthermore, **two different mobile phases** can be employed simultaneously
- Most compounds could be **validated** on baby food at **0.003 mg/kg**, with minimum carry over
- In summary, Dual-Channel instrumentation provides laboratories advantages in **analysis time**, **selectivity**, and **sensitivity**

References

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Dual-channel chromatography a smart way to improve the analysis efficiency in liquid chromatography coupled to mass spectrometry

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Cutting-edge approach using dual-channel chromatography to overcome the sensitivity issues associated with polarity switching in pesticide residues analysis

Francisco José Díaz-Galiano , Łukasz Rajski , Carmen Ferrer , Piedad Parrilla Vázquez , Amadeo Rodríguez Fernández-Alba *

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Thank you!