DART-MS: Strategies for Rapid Screening & Quantitation of Pesticides

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Evolving Open Air Ionization

DART-SVP Ionization Source

DART TECHNOLOGY
Key DART Source Parameters

- **Source Parameters:**
  - Ionization gases
    - N₂ (Standby)
    - He (Run Mode)
  - Temperature of ionization gas
  - Sample introduction speed

- **Ions typically observed in DART–MS mass spectra:**
  - \([M+H]^+\), \([M-H]^-\)
  - \(M^+\), \(M^-\) (ionic compounds)
  - Use of dopants to promote ionization:
    - \([M+\text{NH}_4]^+\) (ammonia)
    - \([M+\text{Cl}]^-\) (e.g. \(\text{CH}_2\text{Cl}_2\))
    - \([M+\text{CF}_3\text{COO}]^-\) (trifluoroacetic acid)

Figure courtesy of Prof. Jana Hajšlová
ICT Prague, Czech Republic
DART-SVP: Experiments Overview

- **Pesticide Screening**
  - FDA swab screening method

- **Quantitative Pesticide Analysis in Orange Juice**
  - 1-D Transmission Experiment Module
    - Fast liquid analysis – Carbendazim in orange juices
  - **Sample Concentration**
    - Stir-bar sorptive concentration followed by DART-MS
  - **X-Z scanner Experiment Module**
    - Higher throughput option for liquid sample analysis – up to 96 samples per run

- **Mycotoxin Screening**
  - HR-AM screening with DART-SVP
Pesticide Screening and Quantitation
Surface swabbing technique for the rapid screening for pesticides using ambient pressure desorption ionization with high-resolution mass spectrometry

Practical considerations for the rapid screening for pesticides using ambient pressure desorption ionisation with high-resolution mass spectrometry

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A rapid screening method for pesticides has been developed to streamline the processing of produce entering the United States. Foam swabs were used to recover multi-class mixtures of 240, 140, 132 and 60 pesticides from the surfaces of apples, kiwis, peaches and tomatoes. The mixtures were selected to span a large range of chemical classes, polarities, solubilities and sizes to provide a broad look at how this technique will perform for a variety of analytes. The swabs were analysed using direct analysis in real-time (DART) ionisation coupled with a high-resolution Exactive Orbitrap™ mass spectrometer. This study expands the types of commodities analysed using...
Spiking

- Each piece of produce was weighed to determine the pesticide dosing volume based on the determined spiking levels.
Transmission DART
Using Polyurethane Swabs

- Concentrate trace amount of analytes on a sponge type swab for DART analysis.
- Scan up to 10 swabs in one run using the temperature ramp method with user defined sampling time and heater temperatures.
- The heated DART gas passes through the swab and into MS inlet.
Utility of High Resolution for Very Rapid Analysis of Complex Mixtures

Pesticide Mixture

DART Heater Temperature Quickly Ramped from 95 – 350° C

Fenpropimorph

Clofentezine

Cyanazine

Total Run Time 1.8 minutes
Typical Results

- 114 of the 132 pesticides were detected (86%), (some were isobaric compounds)
- 88% of the analytes had a mass error of $< 1$ ppm, 97% of the analytes had a mass error of $< 2$ ppm


Transmission DART
Quantitation - Carbendazim
Unapproved Fungicide for Citrus Fruits in US

1. Objectives:
   - Generate standard curve data for carbendazim in orange juice ranging from 1 ppb – 2000 ppb.
   - Screen for carbendazim in a variety of orange juices from the EU, India and the USA.
     - European maximum residue limit* (MRL) is set at 200 ppb for oranges and carbendazim is not approved for use on citrus fruits in the US. The US FDA has set an action limit of 10 ppb.

2. Analysis Overview:
   - No sample preparation – liquid from consumer juice beverages directly analyzed by transmission mode direct analysis in real time (DART) source coupled with Q Exactive.
   - Positive ion mode - carbendazim targeted MS² experiment.
     - m/z 192.07675 → 160.05032

Stainless steel mesh screens: Used as the sampling surface for *juice samples*

3 µL of liquid sample pipetted onto stainless steel mesh screen and allowed to completely dry before DART analysis

*Juice is directly applied to the mesh*
**$m/z \ 192.07675 \rightarrow 160.05032$**

**RT: 1.15 - 5.66**

- **NL: 5.18E4**
- **m/z= 160.04952-160.05112**
- **F: FTMS +**
- **p NSI Full ms2 192.08@hcd50.00**
- **[50.00-215.00] MS**

**XIC generated with +/- 5 ppm window around 160.05032**

- **20 ppb ; 7 % CV**
  - RT: 4.00
  - SN: 164
  - RT: 4.43
  - SN: 162
  - RT: 4.84
  - SN: 114
  - RMS

- **10 ppb ; 16 % CV**
  - RT: 3.54
  - SN: 91

- **5 ppb ; 9 % CV**
  - RT: 2.70
  - SN: 64
  - RT: 3.16
  - SN: 69
  - RT: 3.54
  - SN: 91
  - RMS

- **RT: 1.48**
  - SN: 35
  - RMS
  - RT: 1.97
  - SN: 35
  - RMS
  - RT: 2.39
  - SN: 31
  - RMS

- **20 ppb ; 7 % CV**

- **5 ppb ; 9 % CV**

- **10 ppb ; 16 % CV**

- **RT: 4.00**
  - SN: 164
  - RT: 4.43
  - SN: 162
  - RT: 4.84
  - SN: 114
  - RMS

- **RT: 1.15 - 5.66**

- **Time (min)**
  - 0
  - 10
  - 20
  - 30
  - 40
  - 50
  - 60
  - 70
  - 80
  - 90
  - 100

- **Relative Abundance**

- **m/z 192.07675 → 160.05032**

- **20 ppb ; 7 % CV**

- **5 ppb ; 9 % CV**

- **10 ppb ; 16 % CV**

- **XIC generated with +/- 5 ppm window around 160.05032**
Carbendazim: Major Fragment

Carbendazim fragment
\([C_8H_6N_3O]^+\) spectral simulation

Carbendazim product ion
δ mass accuracy: -0.9 ppm

Interference ion at
\(m/z\) 161.05955

A+1 isotope completely resolved from + 37 ppm interference at
\(m/z\) 161.05955 (140,000 FWHM)

NL:
1.06E5

\(C_8H_6O_1N_3: \quad C_8H_6O_1N_3\)
\(p\) (gss, s/p:8) Chrg 1
R: 140000 Res .Pwr. @FWHM

160.05054
161.05390
162.05725

5,10,20ngmL_Carbendazim_Nantucket
NectOJ_140K_tMS2_02_20120514#34
2-366 RT: 3.10-3.32 AV: 25 F: FTMS
+ p NSI Full ms2 192.08@hcd50.00 [50.00-215.00]

10 ppb Carbendazim spiked in orange juice
Carbendazim Curve in OJ: Q Exactive  tMS²

$y = 24684x - 412957$

$R^2 = 0.9987$

$n = 3$ per conc.
Screening for Carbendazim in OJ: Q Exactive tMS² m/z 192.07675 → 160.05032

ND = Not Detected

Orange Juice Consumer Beverages

USA OJ 1  NL OJ 1  PL OJ 1  PL OJ 2  DE OJ 1  IT OJ 1  IN OJ 1  IN OJ 2  IN OJ Bev 1  IN OJ Bev 2

n = 3; except n = 9 for German OJ
1. Objectives:

- Generate **standard curve** data for carbendazim in orange juice ranging from \(1 \text{ ppb} - 5000 \text{ ppb}\).
- **Screen for carbendazim** in a variety of **orange juices** from the EU (2 countries) and the USA.
  
  - **European maximum residue limit**\(^*\) (MRL) is set at **200 ppb** for oranges and carbendazim is **not approved** for use on citrus fruits in the US. The **US FDA** has set an **action limit** of **10 ppb**.

2. Analysis Overview:

- **No sample preparation** – liquid from consumer **juice** beverages **directly analyzed** by **transmission mode** direct analysis in real time (**DART**) source coupled with triple quad.
- Positive ion mode; carbendazim transition \(m/z \ 192.2 \rightarrow 160.2\).

API 4000 QTRAP with DART-SVP

MRM Settings

- **Scan Parameters:**
  - Positive Ion Mode
  - Resolution: Unit
  - Fragmentation: carbendazim major transition monitored
    \[ m/z \ 192.2 \rightarrow 160.2 \]
    - DP 56 V
    - CE 27 V
  - Dwell Time: 100 ms

DART-SVP Settings

- **DART Source:**
  - Positive Ion Mode
  - Heater Temperature: 250° C

- **Motorized Linear Rail:**
  - Sample Introduction Speed: 0.5 mm/s
Carbendazim Levels: API 4000 QTRAP
MRM m/z 192.1 → 160.1

ND = Not Detected

Fruit Juice Consumer Beverage

n = 8; except n = 16 for German OJs
Twister was spun overnight in orange juice with 50 ppb level of 10 pesticides
## 10 Pesticide Mix

<table>
<thead>
<tr>
<th>10 Pesticide Mix</th>
<th>[Exact Mass + H] (^+)</th>
<th>Log (K_{ow})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl</td>
<td>202.08626</td>
<td>2.4</td>
</tr>
<tr>
<td>Metalaxyl</td>
<td>280.15433</td>
<td>1.7</td>
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<tr>
<td>Spiroxamine</td>
<td>298.27406</td>
<td>Unknown</td>
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<tr>
<td>Fenhexamid</td>
<td>302.07091</td>
<td>3.5</td>
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<tr>
<td>Diazinon</td>
<td>305.10833</td>
<td>3.8</td>
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<tr>
<td>Pyriproxyfen</td>
<td>322.14377</td>
<td>5.6</td>
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<tr>
<td>Pyridaben</td>
<td>365.14489</td>
<td>5.5</td>
</tr>
<tr>
<td>Dimethomorph</td>
<td>388.13101</td>
<td>2.7</td>
</tr>
<tr>
<td>Azoxystrobin</td>
<td>404.12410</td>
<td>2.5</td>
</tr>
<tr>
<td>Difenoconazole</td>
<td>406.07197</td>
<td>4.2</td>
</tr>
</tbody>
</table>
10 Pesticides Concentrated onto Twister:
50 ppb in orange juice spun overnight → DART/MS

Twister Blank
Spun in Blank OJ

Twister Spun in Spiked OJ

NL: 4.23E4
m/z= 202.08512-202.08714  MS
120424-01_Twister19&20_OSCranLt_Blank&50ppbSpin
NL: 4.23E4
m/z= 202.08512-202.08714  MS
120424-01_Twister19&20_OSCranLt_Blank&50ppbSpin
NL: 2.20E5
m/z= 280.15286-280.15567  MS
120424-01_Twister19&20_OSCranLt_Blank&50ppbSpin
NL: 6.78E4
m/z= 302.06818-302.07120  MS
120424-01_Twister19&20_OSCranLt_Blank&50ppbSpin
NL: 1.88E6
m/z= 305.10634-305.10939  MS
120424-01_Twister19&20_OSCranLt_Blank&50ppbSpin
NL: 2.62E6
m/z= 322.14134-322.14456  MS
120424-01_Twister19&20_OSCranLt_Blank&50ppbSpin
NL: 9.00E5
m/z= 365.14233-365.14598  MS
120424-01_Twister19&20_OSCranLt_Blank&50ppbSpin
NL: 1.71E5
m/z= 388.12772-388.13161  MS
120424-01_Twister19&20_OSCranLt_Blank&50ppbSpin

Exactive XICs generated with +/- 5 ppm m/z window.

50 ppb level mixture of pesticides were well concentrated onto the Twister and were then directly desorbed from the Twister sorptive material for direct exact mass analysis with DART.
Direct Twister DART-MS Analysis

10 Pesticide Mix (50 ppb) in orange juice
DART Heater 325° C; linear rail movement 0.2 mm/s
Summary

• There is a very good concentration effect on the Gerstel Twister for direct screening for low levels (50 ppb) of pesticides with ambient ionization DART source.

• Long lasting signal from the Twister experiments indicates that a large amount of material is collected on the Twister surface.
  • A temperature ramp of the DART heater would yield thermal separation and long lasting signal would be beneficial for MS/MS experiments.

API 5500 QTRAP Settings

- MRM Parameters for Pesticide A:
  - Positive Ion Mode
  - Q1: 382.1 ; 382.1
  - Q3: 342 ; 314
  - Dwell Time: 150 ms/transition
  - DP: 16 ; 16
  - EP: 10 ; 10
  - CE: 31 ; 35
  - CXP: 28 ; 24

DART-SVP ion source with X-Z Scanner Experiment Module for Transmission Mode DART-MS/MS
1. Spot 5 µL aliquots of liquid sample onto the mesh surface

2. Let sample spots dry

3. Insert the mesh plate into the slot on the X-Z scanner module

4. Set up the desired X-Z scanner method in the DART software to run up to 96 samples/run
USDA Mycotoxin Screening
- Aflatoxin B1 (AFB1)
  Detection off of Corn Kernels

Major area for future work...
Questions?