Mechanistic investigation into the uptake and translocation of weathered persistent organic pollutants from soil by *Cucurbita* species

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Why look at Persistent Organic Pollutants?

• They persist for decades
• Likely mutagenic, estrogenic, carcinogenic effects
• Bioaccumulation, biomagnification
• Other remediation strategies are ineffective due to high degree of sequestration; plants should not accumulate them
Uptake and translocation of chlordane from soil by zucchini and cucumber

![Graph showing chlordane uptake and translocation in different parts of plants](graph_image_url)

- **Soil**: 24000 ng/g
- **Zucchini**:
  - Roots: 21000 ng/g
  - Stems: 8000 ng/g
  - Leaves: 2000 ng/g
  - Fruit: 1000 ng/g
- **Cucumber**:
  - Roots: 3000 ng/g
  - Stems: 6000 ng/g
  - Leaves: 5000 ng/g
  - Fruit: 4000 ng/g
Uptake and translocation of weathered $p,p'$-DDE by selected plant species

Cucurbita pepo ssp pepo

$p,p'$-DDE (ng/g)
Uptake and translocation of weathered PCBs from soil (105 μg/g) by 4 plant species

- Zucchini
- Summer squash
- Cucumber
- White lupin

The diagram shows the uptake and translocation of PCBs in different parts of the plants: Roots, Stems, Leaves, and Fruit, with specific values for each plant species.
Average PAH content (ng/g) in roots and stems of 3 cucurbits grown in an MGP soil (37 µg/g)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Species</th>
<th>3 Ring</th>
<th>4 Ring</th>
<th>5 Ring</th>
<th>6 Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roots</td>
<td>Zucchini</td>
<td>1800 A</td>
<td>5200 A</td>
<td>3000 A</td>
<td>4100 A</td>
</tr>
<tr>
<td></td>
<td>Cucumber</td>
<td>350 B</td>
<td>970 B</td>
<td>540 B</td>
<td>640 B</td>
</tr>
<tr>
<td></td>
<td>S. Squash</td>
<td>230 AB</td>
<td>520 B</td>
<td>51 C</td>
<td>0.00 B</td>
</tr>
<tr>
<td>Stems</td>
<td>Zucchini</td>
<td>560 A</td>
<td>1000 A</td>
<td>59 A</td>
<td>34 A</td>
</tr>
<tr>
<td></td>
<td>Cucumber</td>
<td>18 A</td>
<td>18 A</td>
<td>0.00 A</td>
<td>0.00 A</td>
</tr>
<tr>
<td></td>
<td>S. Squash</td>
<td>230 A</td>
<td>140 A</td>
<td>0.00 A</td>
<td>0.00 A</td>
</tr>
</tbody>
</table>
The *C. pepo* ssp *pepo* system

- *C. pepo* ssp *pepo* is unique in 2 areas-
  1. *Ex planta* - Release and uptake of a highly sequestered residue from soil to roots
  2. *In planta* - Translocation of a hydrophobic residue from roots to shoots
- For 1., root exudate-mediated soil matrix deconstruction
- Low molecular weight organic acids that scavenge nutrients inadvertently increase the bioavailability of weathered POPs
- For 2., ?????
<table>
<thead>
<tr>
<th>Plant</th>
<th>Treatment</th>
<th>Citric (μM)</th>
<th>Total LMWOA (μM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cucumber</td>
<td>Full</td>
<td>&lt;0.017</td>
<td>3.3</td>
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<tr>
<td></td>
<td>-P</td>
<td>0.12</td>
<td>2.7</td>
</tr>
<tr>
<td>Zucchini</td>
<td>Full</td>
<td>&lt;0.017</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>-P</td>
<td>0.29</td>
<td>16</td>
</tr>
</tbody>
</table>
Schematic of DDE supply system

Aluminum trough

Solution reservoir

Particle filter

Solution

TENAX

Stirrer

Mixing chamber

Frit filter

Peristaltic pump
DDE accumulation in cucurbits under hydroponic conditions. Plants were supplied DDE at 2ng/ml at a rate of 2.6 ml/min

<table>
<thead>
<tr>
<th>Species</th>
<th>Days of exposure</th>
<th>Root (ng/g)</th>
<th>Stem (ng/g)</th>
<th>Petiole (ng/g)</th>
<th>Leaf (ng/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cucumber</td>
<td>8</td>
<td>39,800</td>
<td>100</td>
<td>ND</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>72,400</td>
<td>200</td>
<td>ND</td>
<td>200</td>
</tr>
<tr>
<td>Zucchini</td>
<td>8</td>
<td>23,900</td>
<td>1,000</td>
<td>500</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>30,900</td>
<td>2,000</td>
<td>1,000</td>
<td>400</td>
</tr>
</tbody>
</table>
Rhizotron studies: *in situ* analysis of root exudates and rhizosphere pore water
We can collect root exudates directly from the root or from the rhizosphere
Organic acids on quartz fiber filters in contact with the roots of 3 cucurbit species and in non-vegetated soil.

Organic acids summed are citric, malic, succinic, tartaric, and malonic.

- **Zucchini**: High concentration of organic acids (8000 picomoles).
- **Squash**: Moderate concentration of organic acids (4000 picomoles).
- **Cucumber**: Lower concentration of organic acids (3000 picomoles).
- **Control**: Lowest concentration of organic acids (0 picomoles).
Organic acids in rhizosphere pore water of 3 cucurbit species and in non-vegetated soil.

Organic acids summed are citric, malic, succinic, tartaric, malonic.
Amount of chlordane in the rhizosphere pore water of 3 cucurbits and in non-vegetated soil

![Bar graph showing the amount of chlordane in the rhizosphere pore water of 3 cucurbits and in non-vegetated soil.](Image)
Concentration of select elements in the pore water of 3 cucurbits and of non-vegetated controls

- **Zucchini**
- **Squash**
- **Cucumber**

**Pore water concentration** (mg/L)

- **Control**
- **Mg**
- **Mn**
- **P**
Collection of Xylem Sap

-- Sever plant stem > 1 cm above soil surface

-- Allow sap to bleed for 1-2 minutes, wipe cut surface

-- Collect sap via capillary action

-- Keep sap cooled throughout timed collection

-- Extract POPs from aqueous sap via SPME

-- Desorb SPME onto chiral GC column interfaced to ITD
Concentration in of DDT and metabolites in the xylem sap of 3 cucurbits

**Xylem sap Concentration (ng/mL)**

- **DDE**
  - Zucchini
  - Squash
  - Cucumber

- **DDT**
  - Zucchini
  - Squash
  - Cucumber

- **DDD**
  - Zucchini
  - Squash
  - Cucumber
Concentration of other POPs in the xylem sap of 3 cucurbits

Xylem sap Concentration (ng/mL)

- Chlordane
- Phenanthrene
- Pyrene

Varieties:
- Zucchini
- Squash
- Cucumber
Rate of DDE Flow in the Xylem Sap of 3 Cucurbits

- **Zucchini**
- **Cucumber**
- **Squash**

**DDE Flow (ng/h)**

**Root mass (g, dry weight)**
Rate of Chlordane Flow in the Xylem Sap of 3 Cucurbitas

- **Zucchini**
- **Cucumber**
- **Squash**
Concentration of elements in xylem sap of 3 cucurbits

<table>
<thead>
<tr>
<th>Plant</th>
<th>Cd (ppb)</th>
<th>P (ppm)</th>
<th>Zn (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zucchini</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squash</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucumber</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The graph shows the concentration of Cd, P, and Zn in the xylem sap of Zucchini, Squash, and Cucumber.
Conclusions

• *C. pepo* ssp *pepo* uniquely phytoextracts significant quantities of weathered POPs

• The mechanisms are somewhat non-specific, as widely different contaminants are accumulated to varying extents, including DDE, chlordane, PAHs, PCBs, and dioxins

• This is not a specifically evolved ability; POPs are entering on pre-existing physiological systems, unique patterns of nutrient acquisition via LMWOA exudation being one likely candidate

• The mechanism of intra-plant translocation of hydrophobic organic compounds is under investigation

• Elucidating these mechanisms is of interest on several fronts, including development of a novel phytoremediation system
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