Potato peel as a product for environmentally protective management of potato cyst nematodes

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Potato cyst nematodes (PCN)

- Potato: 4th most important crop worldwide. Most important non-cereal crop.
- PCN: most important pest of potato (€500 million damage p.a. in EU)
- Two related species: *Globodera pallida, G. rostochiensis*
- Microscopic soil-borne eelworms
Conventional PCN control

Control:
• Nematicicides
• Resistant potato cultivars
• Crop rotation

Effectiveness:
• Better control of *G. rostochiensis* than *G. pallida*

Result: *G. pallida* is becoming the major pest in Europe
Achilles heel of PCN

- PCN: specialist soil-borne pest
- Hatches in response to hatching factors (HFs) from host only

HF:
- sesquiterpenoids
- glycoalkaloids (GCAs, present in tuber peel)
PCN control using induced hatch

HFs in absence of potatoes

Nematodes hatch

No food plant - die

HFs in presence of potatoes

Nematodes hatch early

+ nematicide

More nematodes die
Evaluation of potato peel in PCN management

1. Does peel affect PCN?

2. Optimising the peel formulation

3. Ecotoxicology

4. Field trials
1. Does peel affect PCN survival?

- *In vitro* hatch response of PCN to GCAs
- *In vivo* response of PCN to peel
In vitro hatch of *G. rostochiensis* (left) and *G. pallida* (right) in response to alpha-solanine

Main points:

- both PCN species produced bimodal hatch response to both major glycoalkaloids (solanine > chaconine)
- *G. rostochiensis* responded better to GCAs than *G. pallida*
- Maximum hatch was 92% of that achieved by potato root leachate
**In vivo** effect of potato peel incorporation into soil on *Globodera rostochiensis* population

<table>
<thead>
<tr>
<th>Peel (mg/kg soil)</th>
<th>Hatch + parasitism</th>
<th>Parasitism</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>59%</td>
<td>15%</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
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**Total control**

74%
2. Optimisation of peel formulation

a. Maximise GCA content of peel
b. Optimise GCA release from peel
c. Optimise peel application method
a. Maximise GCA content of peel

- Peeling
- White light levels (24 h)
- Light quality (24 h)

1. Dark
2. White light
3. Red light
4. Blue light
5. UVB light
b. Optimise GCA release from peel

Globodera rostochiensis

Globodera pallida
c. Optimise peel application method

- Aim: peel to be incorporated (0.5 t/ha) into planting furrow – inter-ridge distance is approximately 60-80 cm
- Needed – some mobility (>70% hatch at 30 cm horizontal, >70% hatch at 20 cm vertical) to ensure contact with most of PCN population
- Needed - not enough mobility to pose a threat to groundwater
In-soil movement of hatching activity from peel (after 2 weeks) at 12°C

Greater vertical than horizontal mobility of hatching activity
72% hatch at 20 cm (vertical)
32% hatch at 30 cm (horizontal)
Similar behaviour in most soils, except organic soils (less movement). Similar response from both PCN species
In-soil mobility of % hatch from directed and broadcast application

<table>
<thead>
<tr>
<th>% hatch</th>
<th>Directed</th>
<th>Broadcast</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm horizontal spread</td>
<td>32</td>
<td>53</td>
</tr>
<tr>
<td>20 cm vertical spread</td>
<td>72</td>
<td>77</td>
</tr>
</tbody>
</table>
Effect of encasement of pulverised peel in alginate beads on PCN hatch

- Produce alginate beads 2 mm diameter
- Mill to produce 1 and 0.5 mm diameter beads
- Smallest beads – more rapid disintegration
- Optimum size profile for maximum hatch:
  - 3 small: 4 medium: 1 large
- % hatch at 20 cm depth: 78%
- % hatch at 30 cm spread: 60%
- But: beads reduced parasitism of PCN
3. Ecotoxicology: effects of peel soil amendment on non-target organisms

Behaviour of GCAs in soil:
- Persistence
- Mobility

Effect on non-target organisms:
- Crop plants
- Soil microbiota (bacteria, fungi)
Recovery of GCA from soil

Red: alpha-solanine  Blue: alpha-chaconine
GCA half-life

- Very short: 6.2 days for solanine, 7.7 days for chaconine at 12°C
- Causes of loss:
  - microbial degradation
  - irreversible binding to soil particles
- Effect of soil type
  - shortest half-life on organic soils
Effects of peel on economic yield of barley (blue) and oilseed rape (red)
Effects on soil microbiota

Soil containing peel compared to soil:

• 1.8-fold increase in bacteria (Biolog plate)
• 1.4-fold increase in fungi (ergosterol)
• Quantitative increase in bacterial biodiversity (up to 500 mg peel/kg soil)
• No qualitative change in bacterial functional biodiversity (up to 250 mg peel/kg soil)
Biolog plate system: Community Level Physiological Profiling
Principal component analysis of bacterial diversity in absence (green triangles) and presence of different rates of peel
PCN control using induced hatch

HFs in absence of potatoes

- Nematodes hatch
- No food
- Plant - die

HFs in presence of potatoes

- Nematodes hatch early
  + Nematicide
- More nematodes die
Field trial results: effect of peel on reduction in PCN population in absence of potato

<table>
<thead>
<tr>
<th></th>
<th>Control (% reduction in population size)</th>
<th>Plus peel (% reduction in population size)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>G. rostochiensis</strong></td>
<td>17 b</td>
<td>73 b</td>
</tr>
<tr>
<td><strong>G. pallida</strong></td>
<td>8 a</td>
<td>59 a</td>
</tr>
</tbody>
</table>

Any two samples with a common letter are not significantly different (P>0.05)
Field trial results: effect of peel on nematicidal control of multiplication of PCN in presence of potato

<table>
<thead>
<tr>
<th></th>
<th>Control (PCN, potato, no peel, no nematicide)</th>
<th>Treatment 1 (PCN, potato, nematicide)</th>
<th>Treatment 2 (PCN, potato, peel, nematicide)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>G. rostochiensis</em></td>
<td>4.7 d</td>
<td>0.3 ab</td>
<td>0.2 a</td>
</tr>
<tr>
<td><em>G. pallida</em></td>
<td>4.3 d</td>
<td>1.5 c</td>
<td>0.8 b</td>
</tr>
</tbody>
</table>

Any two samples with a common letter are not significantly different (P>0.05)
Conclusions

• Application of peel to *G.pallida*-infested soil in the absence of a potato crop could shorten the crop rotation period for potato farmers

• Application of peel to *G.pallida*-infested soil in the presence of a potato crop increased the effectiveness of the nematicide oxamyl in controlling PCN
Further research

• Further optimisation needed
• Lower peel dosage rates needed (currently 1 t/ha)
Reducing, re-using and re-cycling waste from a potato processing plant: a desk study

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Crisp manufacture

- Highly integrated, automated process
- Several waste streams: peel, wastewater (starch, protein)
- Heavy use of water, power
Cleaning And Peeling — Selecting — Slicing Or Strip — Fulling And Burning — Dehydrating

Packing — Packing — Cooling — Seasoning — Degreasing Oil — Frying
Crisp manufacture: annual requirements (moderate scale operation)

- 20,000 t potatoes
- 90,000 m³ water
- 2 M kW energy (processing: heating, etc.; plant maintenance)
Crisp manufacture: waste streams

- Wastewater
- Peel
- Starch granules
- Suspended solids
- Soluble proteins
Crisp manufacture: peel waste stream

- Collect peel by settling
- Microbial spoilage is rapid, high water content.
- Collected for use in stockfeed (8% protein – can constitute 5-15% feed ration)
- Reduce water content by 40% using screw press
Peel

Fibre
(lignocellulose)

- Baked products

Chlorogenic acid,
catechin

- Anti-oxidants, preservatives

Glycoalkaloids

- Pharmaceuticals

- Agriculture
Wastewater

Centrifugation

Flocculation

Reverse osmosis

Moderate-to high-quality water

Starch granules

Protein

Treatment, discharge
Uses of products from wastewater

- **Starch**: on-site – biofuel, soil amendment; off-site – biodegradable plastics, lactic acid, etc.
- **Protein**: high quantity (30%), quality – use as stockfeed supplement
Biofuel from waste streams

hydrolysis  fermentation
• \textbf{Starch} $\rightarrow$ sugars $\rightarrow$ \textbf{bioethanol}

esterification
• \textbf{Waste cooking oil} $\rightarrow$ \textbf{biodiesel}
Wastewater treatment using hybrid vertical-horizontal flow sub-surface flow constructed wetlands
Composting of potato waste

- Aerobic $\rightarrow$ compost (soil amendment; garden product, €1-300/tonne)
- Anaerobic $\rightarrow$ biogas + digestate
Biogas by anaerobic digestion

- Small- to large-scale sealed tanks
- **Services**: waste disposal and biogas production
- **Products**: biogas (methane) and digestate (fertiliser, biostimulant, peat-free compost)
- Biogas from potato waste: potential for generation of 25% of the electricity requirement of the processing plants
Additional opportunities for large-scale operations

• **Starch**: for manufacture of biodegradable crisp packets
• **Heat**: captured using heat exchangers
• **Water**: recovered by condensor pipes from steam released during frying
Biorefinery model

- Environmentally protective and economically viable
- Bottom-up: expansion of existing facility
- Top-down: design of purpose-built facility
Conclusions

Significant opportunities for:
• Reducing waste disposal
• More sustainable use of resources, e.g. water
• Reduced costs (electricity, water)
• Generation of additional income streams from waste