Biodegradation of polyethylene by macro-organisms such as mealworms and greater wax moth larvae: technological application potential

Pieter Billen, Sabrina Spatari, Serge Tavernier
Polyethylene bio-degradation by caterpillars of the wax moth Galleria mellonella

Paolo Bombelli 1, Christopher J. Howe 1, 2, Federica Bertocchini 2, 3, 8

The Guardian Tue 25 Apr 2017
## Experiments

<table>
<thead>
<tr>
<th>Format</th>
<th>Species</th>
<th>Substrate</th>
<th>Time</th>
<th>Experiment code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Live larvae</strong></td>
<td><strong>Galleria mellonella</strong></td>
<td><strong>Loosely folded cling film (LDPE)</strong></td>
<td>17 h</td>
<td>live$_{GWM}$-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Loosely folded cling film (LDPE)</strong></td>
<td>89 h</td>
<td>live$_{GWM}$-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Folded layers cling film (LDPE)</strong></td>
<td>96 h</td>
<td>live$_{GWM}$-3</td>
</tr>
<tr>
<td></td>
<td><strong>Tenebrio molitor</strong></td>
<td><strong>Loosely folded black bag (LDPE)</strong></td>
<td>216 h</td>
<td>live$_{GWM}$-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Loosely folded cling film (LDPE)</strong></td>
<td>38 days</td>
<td>live$_{MW}$-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Commercial fruit bag (LDPE)</strong></td>
<td>38 days</td>
<td>live$_{MW}$-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>None (blank)</strong></td>
<td>38 days</td>
<td>live$_{MW}$-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Bran</strong></td>
<td>38 days</td>
<td>live$_{MW}$-4</td>
</tr>
<tr>
<td><strong>Homogenate</strong></td>
<td><strong>Galleria mellonella</strong></td>
<td><strong>Cling film (LDPE)</strong></td>
<td>48 h</td>
<td>paste$_{GWM}$-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Cling film (LDPE) at 100 % RH</strong></td>
<td>20 h</td>
<td>paste$_{GWM}$-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Cling film (LDPE) and blank paste</strong></td>
<td>0 – 120 h</td>
<td>paste$_{GWM}$-3</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Liquid paraffin at 100 % RH</strong></td>
<td>14 days</td>
<td>paste$_{GWM}$-paraffin</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Polystyrene (PS) powder at 100 % RH</strong></td>
<td>14 days</td>
<td>paste$_{GWM}$-PS</td>
</tr>
<tr>
<td></td>
<td><strong>Tenebrio molitor</strong></td>
<td><strong>Liquid paraffin at 100 % RH</strong></td>
<td>14 days</td>
<td>paste$_{MW}$-paraffin</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Polystyrene (PS) powder at 100 % RH</strong></td>
<td>14 days</td>
<td>paste$_{MW}$-PS</td>
</tr>
</tbody>
</table>
Live larvae with polyethylene
Degradation by biomass paste?

No gravimetric changes

No glycol (confirming Weber et al. 2017)

How do they do it?

Food for thought...
Technology potential

Brandon et al. 2018
Mealworms of 75-85 mg each
0.05 to 0.35 mg per day

49% CO₂
51% PE in faeces

1 to 7.5 J per mealworm per day

42 MJ/kg

Microplastics?

Thévenot al. 2018
9.5 to 11 J per mealworm per day

0.35 mg PE per day (Brandon et al.)
to 0.45 mg (calculated, Thévenot et al.)

Technology potential

0.35 mg PE per day (Brandon et al.)
to 0.45 mg (calculated, Thévenot et al.)

Zheng et al. (2013):
mealworms in 76 days to 176 mg

Functional unit:
complete consumption of 1 tonne of PE film (without additional food) by 35-day old mealworms in an additional 32 days

5.5 to 7.1 tonnes of mealworms required

Oonincx & de Boer (2012):
55 mWh of grid electricity
240 mWh of natural gas
0.22 L of water per mealworm

Biomass growth?
Valorization of frass?
Revenue from biodiesel?

Electricity
Natural gas
290 EUR to 370 EUR
500 EUR to 642 EUR
790 EUR to 1112 EUR per tonne of PE treated

Oonincx, D.G.A.B., de Boer, I.J.M. PLOS One 7(12), e51145 (2012)
Yet... there may be value

$\text{paste}_{\text{GWM-paraffin}}$

wax moth larvae with paraffin

$\text{paste}_{\text{GWM-PS}}$

wax moth larvae with polystyrene

$\text{paste}_{\text{MW-paraffin}}$

mealworms with paraffin

$\text{paste}_{\text{MW-PS}}$

mealworms with polystyrene

<table>
<thead>
<tr>
<th>Graph 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{paste}_{\text{GWM-paraffin}}$</td>
</tr>
<tr>
<td>wax moth larvae with paraffin</td>
</tr>
<tr>
<td>$\text{paste}_{\text{GWM-PS}}$</td>
</tr>
<tr>
<td>wax moth larvae with polystyrene</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Graph 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{paste}_{\text{MW-paraffin}}$</td>
</tr>
<tr>
<td>mealworms with paraffin</td>
</tr>
<tr>
<td>$\text{paste}_{\text{MW-PS}}$</td>
</tr>
<tr>
<td>mealworms with polystyrene</td>
</tr>
</tbody>
</table>
Conclusions

• Destruction (degradation) of PE is not OK, especially not without energetic valorization
• No feasible remediation technology
  • Preference for other nutrition (even cannibalism)
  • Ubiquity and abundance issues
  • Microplastics
• Fundamental biological insights are interesting
• Indications of paraffin functionalization: promising for biochemical process?
Invitation for collaboration

Pieter Billen
BioGEM research group
University of Antwerp (Belgium)
pieter.billen@uantwerp.be

Sabrina Spatari
Civil and Environmental Engineering
Technion (Israel)
sabrinas@technion.ac.il

Serge Tavernier
BioGEM research group
University of Antwerp (Belgium)
serge.tavernier@uantwerp.be