Production of Bacteria derived Natural Bio-Polymers from Food Waste

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Main Focus of Current Research

Production of natural polymers using bacterial fermentation and their application in a range of different applications, especially medical applications. Other applications include packaging, adhesives, paints and chiral compounds for drug synthesis.

The natural polymers that I currently work on include:

- **Polyhydroxyalkanoates (PHAs)**
- $\gamma$-Polyglutamate ($\gamma$-PGA)
- Bacterial cellulose (BC)

With a major emphasis on PHAs
Polyhydroxyalkanoates are water-insoluble storage polymers which are polyesters of 3-, 4-, 5- and 6-hydroxyalkanoic acids produced by a variety of bacterial species under nutrient-limiting conditions. They are biodegradable and biocompatible, exhibit thermoplastic properties and can be produced from renewable carbon sources. Hence, there has been considerable interest in the commercial exploitation of these biodegradable polyesters.

Philip et al., 2007, JCTB, 82 (3):233-247
Akarayonye et al., 2010, JCTB, Volume 85 (6): 732-743
Keshavarz et al., 2010, Current Opinion in Microbiology 13 (3): pp. 321-326
The general structure of Polyhydroxyalkanoates

\[
\begin{array}{c}
\text{O} \\
\text{CH} \\
(\text{CH}_2)_x \\
\text{O} \\
\text{C} \\
\text{CH} \\
(\text{CH}_2)_x \\
\text{O} \\
\text{R}_1 \\
\text{R}_2 \\
\text{O} \\
\text{R}_1 \times \text{R}_2 \times \text{n} \\
\end{array}
\]

\[R_1 / R_2 = \text{alkyl groups (C}_1\text{C}_{13})\]
\[x = 1, 2, 3, 4\]
SCL and MCL Polyhydroxyalkanoates

Total Carbon chain length in monomer = 4-5; **SCL PHAs**

Total Carbon chain length in monomer = 6-14; **MCL PHAs**

**SCL-PHAs** - Thermoplastics

**MCL-PHAs** - Elastomeric
### Properties of SCL and MCL Polyhydroxyalkanoates

<table>
<thead>
<tr>
<th>Type of PHA</th>
<th>Melting Temp (°C)</th>
<th>Glass Transition Temp (°C)</th>
<th>Young’s Modulus (GPa)</th>
<th>Elongation at break (%)</th>
<th>Tensile strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(3HB)</td>
<td>171</td>
<td>2.7</td>
<td>3.5</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>P(3HB-co-20%3HV)</td>
<td>145</td>
<td>-1</td>
<td>1.2</td>
<td>3.84</td>
<td>32</td>
</tr>
<tr>
<td>P(4HB)</td>
<td>60</td>
<td>50</td>
<td>0.149</td>
<td>1000</td>
<td>104</td>
</tr>
<tr>
<td>P(3HB-co-16%4HB)</td>
<td>152</td>
<td>8</td>
<td>ND</td>
<td>444</td>
<td>26</td>
</tr>
<tr>
<td>P(3HO-co-18%3HHx)</td>
<td>61</td>
<td>35</td>
<td>0.008</td>
<td>400</td>
<td>9</td>
</tr>
<tr>
<td>P(3HB-co-3HHx)</td>
<td>120</td>
<td>-2</td>
<td>0.5</td>
<td>850</td>
<td>21</td>
</tr>
</tbody>
</table>
Polyhydroxyalkanoates as inclusions in bacteria

Large scale production of P(3HB) using fed batch fermentation in Kannan and Rehacek medium (Yield 38% dcw)

Valappil et al., 2007, Journal of Biotechnology, 132; 251-258
Large scale production of P(3HB) using cheap food related carbon source, molasses (Yield 67% dcw)

Akaraonye et al., 2012, Biotechnology Journal 7(2) 293-303
Large scale production of mcl-PHA using cheap food related carbon source, molasses (Yield 20% dcw)

MOLASSES as the main Carbon Source
Large scale production of P(3HB-co-3HO) using cheap food related carbon source, Corn Steep Liquor (Yield 21% dcw)

CORN STEEP LIQUOR as the main Carbon Source

An SCL-MCL POLYMER
Large scale production of P(3HB) using Food waste, rapeseed cake (Yield 48% dcw)

Rapeseed cake as the main Carbon Source
Material and Thermal Properties of the P(3HB) produced

<table>
<thead>
<tr>
<th>Type of PHA</th>
<th>Melting Temp (°C)</th>
<th>Glass Transition Temp (°C)</th>
<th>Young’s Modulus (GPa)</th>
<th>Elongation at break (%)</th>
<th>Tensile strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(3HB)</td>
<td>169</td>
<td>1.9</td>
<td>1.1</td>
<td>1</td>
<td>40</td>
</tr>
</tbody>
</table>
Material and Thermal Properties of the P(3HO) produced

<table>
<thead>
<tr>
<th>Type of PHA</th>
<th>Melting Temp (°C)</th>
<th>Glass Transition Temp (°C)</th>
<th>Young’s Modulus (GPa)</th>
<th>Elongation at break (%)</th>
<th>Tensile strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(3HO)</td>
<td>49</td>
<td>-36</td>
<td>1.4</td>
<td>276</td>
<td>9</td>
</tr>
</tbody>
</table>
Gamma-Polyglutamic acid

\( \gamma \text{-PGA} \)

Poly-\( \gamma \)-glutamate (\( \gamma \)-PGA) is a water soluble, hydrophilic anionic poly-peptide with unusual \( \gamma \)-amide linkages. It is produced extracellularly by *Bacillus subtilis*, is biodegradable, biocompatible, edible and highly water absorbent. \( \gamma \)-PGA has great potential in the food and cosmetics industry, in medicine and in water treatment. It can be used as a drug carrier, a sustained release material, thickener, biological adhesive and humectant.
Production of $\gamma$-PGA using Food waste, rapeseed cake

Rapeseed cake as the main Carbon Source
A proposed *Bacillus* based Biorefinery
Dual production of P(3HB) and $\gamma$-PGA

![Graph showing the production of P(3HB) and $\gamma$-PGA over time with data points for pH, gamma-PGA (g/L), and PHA yield (% dw)]
Production of Bacterial Cellulose from *Acetobacter xylinum*
Current on-going projects in the lab
Cardiac tissue engineering using P(3HO)

Cardiac patches

Total Grant amount: £2.5 million in collaboration with Imperial College London
Current FP7 project 1
REBIOSTENT
FP7-NMP-2013-SME-7

Reinforced Bioresorbable Biomaterials for Therapeutic Drug Eluting Stents

Grant amount: €548,000
Total Project Grant: £4.6 million
Current FP7 project 2
NEURIMP
FP7-NMP-2013-SME-7

Novel combination of biopolymers and manufacturing technologies for production of a peripheral nerve implant containing an internal aligned channels array

Grant amount: € 504,053.00
Total project Grant: £4.4 million
Possible contribution to the FoodWaste Net

Biopolymer production using Food Waste

Biopolymers are a highly sought after bio-products with a range of different applications including bulk applications such as packaging, paints, adhesives and medical applications such as tissue engineering, implants, chiral substrates for drug synthesis and drug delivery.

Various biopolymers including PHAs could be produced using food waste as the nutrient source. The resulting biopolymers would be much cheaper and hence more readily available for a variety of applications.
Key scientists:
Dr. S.P. Valappil  Ms. Hima Puttussery
Dr. Ranjana Rai  Ms. Barbara Lukasiewicz
Dr. Everest Akarayonye  Ms. Lorena Lizzaraga
Dr. Lydia Francis  Ms. Christy Thomas
Dr. DeCheng Meng  Ms. Prachi Dubey
Dr. Andrea Bagdadi  Ms. Bijal Panchal
Dr. Superb Misra  Dr. Rinat Nigmatullin
Dr. Pooja Basnett  Dr. Guneet Kaur

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My Group

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Thanks for your attention!