Pectin gel: a promising edible ink for the 3D printing of food with desired properties

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Promotors: Pr. Bart Nicolaï
Pr. Jeroen Lammertyn
Research on interactions between biological systems and physical processes.
Objective

Development of new methods for the 3-D printing of pectin-based food with customizable properties

- Formulation of edible ink
- Design particular structure
- Deposition strategy
Extrusion printing

CNC Machine

Controller software
WinPC-NC USB

Syringe pump

Dispensing part

KU LEUVEN
Characterization

**Texture properties**
- Compression test
  - Young modulus ($E$)
  - Rupture stress ($RS$)

**Structure properties**
- Micro-tomography
  - Porosity ($\varepsilon$)
  - Pore size ($d_{eq}$)

![Texture analyser](image1)

![Graph](image2)

![Horizontal slice](image3)

![Pore space image](image4)
Formulation and 3D printing of pectin-based food

**Gel**
- Low-methoxylated pectin
- Calcium Chloride

**Additives**
- Sugar Syrup
- Bovine serum albumin

**Post-treatment**
- Incubation in CaCl$_2$ solution

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Image Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 g/L pectin 12.5 mM Ca$^{2+}$</td>
<td>Photographic image</td>
</tr>
<tr>
<td>15 g/L pectin 12.5 mM Ca$^{2+}$ 50% (v/v) sugar 5 g/L BSA</td>
<td>X-ray CT image horizontal slice</td>
</tr>
<tr>
<td>55 g/L pectin 17.5 mM Ca$^{2+}$ 5 g/L BSA</td>
<td>3-D X-ray CT pore space image</td>
</tr>
</tbody>
</table>
Prediction model of printed object properties

Mechanical properties
- Pectin
- Sugar syrup

<table>
<thead>
<tr>
<th>[pectin]</th>
<th>Low</th>
<th>Middle</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$ (kPa)</td>
<td>15-140</td>
<td>160-480</td>
<td>340-720</td>
</tr>
<tr>
<td>$RS$ (kPa)</td>
<td>1-60</td>
<td>60-130</td>
<td>60-300</td>
</tr>
</tbody>
</table>

Structure property
- BSA

<table>
<thead>
<tr>
<th>[BSA]</th>
<th>Low</th>
<th>Middle</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon$</td>
<td>0-5%</td>
<td>10-20%</td>
<td>10-30%</td>
</tr>
</tbody>
</table>
Structure design

- Honeycomb structure
  - 4 cell sizes
- Printing strategy

Not good
Structure design

- Honeycomb structure
  - 4 cell sizes

- Printing strategy

Not good

Good 😊
Young's modulus vs porosity

\[ y = -0.63x + 31.2 \quad R^2 = 0.92 \]

\[ y = -1.3x + 65.9 \quad R^2 = 0.96 \]

\[ y = -2.1x + 108.3 \quad R^2 = 0.98 \]

15 g/L pectin
25 g/L pectin
35 g/L pectin
Deposition strategy: Co-axial extrusion

- Design of co-axial printhead
  - Inner flow = pectin ink
  - Outer flow = Ca²⁺ crosslinker
- No post-treatment
- Optimization of printing setting

Not good  Good 😊
Effects of printing settings

[Pectin] = 15 g/L
[CaCl$_2$]$_{out}$ and $Q_{out}(\text{CaCl}_2)$ = constant

![Bar charts showing the effects of printing settings on $E$ and volume.](attachment:barCharts.png)
Effects of printing settings

\[
\text{[Pectin]} = 15 \text{ g/L} \\
\text{[CaCl}_2\text{]_{out} \text{ and } Q_{out}(\text{CaCl}_2) = \text{constant}}
\]

<table>
<thead>
<tr>
<th>Porosity</th>
<th>Z085_fill75%</th>
<th>Z085_fill85%</th>
<th>Z095_fill75%</th>
<th>Z095_fill85%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.9 ± 1 %</td>
<td>2.0 ± 0.9 %</td>
<td>8.2 ± 1.7 %</td>
<td>6.3 ± 0.5 %</td>
</tr>
</tbody>
</table>
Effects of outer flow settings

[Pectin] = 15 g/L
Height and infill = constant
Effects of outer flow settings

[Pectin] = 15 g/L
Height and infill = constant

<table>
<thead>
<tr>
<th>[CaCl$<em>2$]$</em>{\text{out}}$</th>
<th>$Q_{\text{out}}$</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 mM</td>
<td>0.1 mL/min</td>
<td>1.2 ± 0.09 %</td>
</tr>
<tr>
<td>30 mM</td>
<td>0.5 mL/min</td>
<td>1.6 ± 0.3 %</td>
</tr>
<tr>
<td>150 mM</td>
<td>0.1 mL/min</td>
<td>2 ± 0.9 %</td>
</tr>
<tr>
<td>150 mM</td>
<td>0.5 mL/min</td>
<td>1.4 ± 0.1 %</td>
</tr>
</tbody>
</table>
Perspective

3D printing by simple deposition = 3D printing by coaxial deposition
Conclusions

3-D printing of pectin edible ink
• Printable gel
• Variable sweetness
• Particular porosity

Characterization protocol
• Compression test
  • Firmness
• Micro-computed tomography
  • Printing accuracy
  • Porosity

Property control using 3-D printing
• Porous design
  • Good printing accuracy
• Co-axial extrusion
  • Dependant on parameter settings
Thank you
questions?