COMPOSTABLE ADHESIVES
for PLU stickers

by Elizabeth Pegg, Erika Riffe, Jacob Huy Ngo, Jakob Dahl, Makayla Leonard, and Victoria Tovmasyan
The Impact of PLUs

Organization

Food Safety

Salmonella Outbreak Linked to Onions

- Illnesses: 892 (84 new)
- Hospitalizations: 183 (26 new)
- Deaths: 0
- States: 38 and Puerto Rico (1 new)
- Recall: Yes
- Investigation status: Active

CDC, 2021.

Price Look Up stickers

Fruitsticker.de, 2010

Persistence

Ban

→ no more labels shall be applied directly to fruits or vegetables, unless they are home compostable

> Article 80
Au plus tard le 1er janvier 2022, il est mis fin à l’apposition d’étiquettes directement sur les fruits ou les légumes, à l’exception des étiquettes compostables en compostage domestique et constituées en tout ou partie de matières biosourcées.


Approach

Strategy 1

Strategy 2

Strategy 3

Strategy 4

Preservatives

Discussion
Focus and Approach

Polymers:
- Polyacrylate
- Polyurethane

Tackifiers:
- Rosins, D-limonene

Preservatives:
- Formaldehyde

Biodegradable Solutions Necessary!

Chemical Replacement
Biodegradable Polymer with existing adhesive chemistry

Functional Replacement
Biodegradable Adhesive

Systemic Replacement
Biodegradable Labeling
Methods: Lasering, Sleeves

Formulation depends on polymer
Potential Solutions!
Wasteful or not universal

Introduction
Approach
Strategy 1
Strategy 2
Strategy 3
Strategy 4
Preservatives
Discussion
PSAs: Composition & Function

Pressure Sensitive Adhesive (PSA) = Polymer + Tackifier + ...

1. Pre-Contact
   - Surface
   - Pressure

2. Adhesion
   - Tack

3. Removal
   - Tension
   - Peel

Introduction
Approach
Strategy 1
Strategy 2
Strategy 3
Strategy 4
Preservatives
Discussion
Criteria for Success

- **Adhesive Properties**
  - Tack, Peel, Shear

- **Stable**
  - Shelf Life > 1 y, Humidity, Temperature

- **Biodegradable**
  - Home Compostable

- **Food Safe**
  - Non-toxic, Ingestible
**PROTEINS**

*nature’s glue*

---

**Gluten**
keeping your starch together in cereal germ cells

Feng et. al 2020

---

**Nb-1R Frog Glue**
sticking it to predators and prey on a frog’s back

[Image: Wikimedia Commons, 2008]

---

**Arabinogalactan Proteins (AGPs)**
driving ivy up the wall

Huang et. al 2016

---

Introduction  Approach  **Strategy 1**  Strategy 2  Strategy 3  Strategy 4  Preservatives  Discussion
Gluten + Glycerol: A Promising Biodegradable Formulation

Gliadin $+$ Glutenin $=$ Gluten

glycerol $+$ water $+$ salts for improved performance = effective, biodegradable PSA

Introduction

Approach

Strategy 1

Strategy 2

Strategy 3

Strategy 4

Preservatives

Discussion
Frog Glue: A Ribbiting Candidate

Notaden bennetti frog produces a tacky, elastic material on its back when provoked.

Dermal musculature is stimulated → Secretion is irrigated with a low pH buffer → Frog glue!
**Nb-1R: PSA-Type Properties**

- **Nb-1R is big!** Molecular mass ≈ 350-500 kDa
- **Glycine + proline + hydroxyproline (Hyp)**
- Noncovalent solidification driven by **hydrophobic protein-protein interactions**
- **Adheres to many surfaces** (wood, metal, plastics) in **wet or dry** conditions
- Tests suggest **shear thinning** behavior

---

**Nb-1R Amino Acid Composition**

- Gly, 14.50%
- Glx, 13.71%
- Pro, 9.91%
- Asx, 6.83%
- Val, 6.61%
- Hyp, 6.65%
- Leu, 6.60%
- Lys, 5.58%
- Thr
- Ile
- Arg
- Ser
- Phe
- Tyr
- Ala

---

**Flickr, 2011.**
Spherical nanoparticles adopt the tertiary structure of AGP.

Diameter ~ 70 - 110 nm

Low intrinsic viscosity means AGP nanoparticles have good flow.

AGPs: The OG Nanoparticle

Introduction

Approach

Strategy 1

Strategy 2

Strategy 3

Strategy 4

Preservatives

Discussion

Huang et. al 2016
AGPs: Adhesive Mechanism

AGPs can act as a **functional replacement** or inspiration for a **biomimetic solution**!
# Protein Technical Performance Values

<table>
<thead>
<tr>
<th>Property</th>
<th>Scotch Magic Tape</th>
<th>Gluten:Glycerol (1:1) at RH 58%</th>
<th>Gluten:Glycerol Ionized</th>
<th>Frog Glue Type I</th>
<th>Reconstructed AGP Nanoparticles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop Tack</td>
<td>1.4 N/cm(^{[25]})</td>
<td>0.16 - 0.2 N/cm(^{[1]})</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Peel Adhesion</td>
<td>1.7 - 2 N/cm(^{[25]})</td>
<td>0.16 - 0.2 N/cm(^{[1]})</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Lap-Joint Shear</td>
<td>—</td>
<td>—</td>
<td>0.0248 MPa (hog skin)</td>
<td>1.7 ± 0.3 MPa</td>
<td>0.53 ± 0.033 MPa (glass)(^{[19]})</td>
</tr>
<tr>
<td>Force of Adhesion</td>
<td>—</td>
<td>3 N (mango)</td>
<td>0.0168 MPa (plastic)</td>
<td>≥ 7.2 ± 2.3 nN,</td>
<td>298 ± 8.34 nN (pull-off force, max. 18.9 nN, measured by AFM)(^{[20]})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 N (porcine skin)</td>
<td>0.0283 MPa (glass)</td>
<td>max. 18.9 nN</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 N (apple peel)</td>
<td>0.0328 MPa (paper)</td>
<td>(nanomechanical)(^{[17]})</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 N (flatbread)(^{[1]})</td>
<td>0.0344 MPa (stainless steel)(^{[5]})</td>
<td>6.3 ± 0.3 kPa (PP)(^{[17]})</td>
<td></td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>89.6 kPa(^{[26]})</td>
<td>—</td>
<td>150 kPa(^{[5]})</td>
<td>300 kPa (clevis pins)(^{[19]})</td>
<td></td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>171 ± 40 kPa(^{[17]})</td>
<td>&gt; 1 × 10(^6) kPa(^{[20]})</td>
</tr>
</tbody>
</table>

*removed Dynamic Shear rows due to lack of values
These alternatives look promising, but we can’t make definitive statements.

<table>
<thead>
<tr>
<th>Endpoints of Interest</th>
<th>Bad Actors</th>
<th>Potential Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>monomer</td>
<td>polymer</td>
</tr>
<tr>
<td>Acrylates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluten</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Glycerol</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Nb-1R</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>AGPs</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Persistence</th>
<th>L</th>
<th>H-vH</th>
<th>None</th>
<th>None</th>
<th>None</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioaccumulation</td>
<td>L</td>
<td>H-vH</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Aquatic | M-vH | M-H | None | None | None | None |
| Terrestrial | M | M | None | None | None | None |
| Carcinogenicity | L-M | L-H | None | None | DG   | DG   |
| Single Exposure Toxicity | M-H | M-H | None* | L    | DG   | DG   |
| Skin, Eye, Respiratory Irritation / Sensitization | H | H | DG    | DG   | DG   | DG   |

* Assumes gluten will not pose any acute oral toxic effects to the average person; those with NCGS or CD are more susceptible to gluten. [Standardized using GHS and converted with GreenScreen Score]
POLYSACCHARIDES
sweet + sticky

Chitosan

Carrageenan

CRUSTACEANS

MOLLUSCS

INSECTS

CHITIN

CHITOSAN

Maddaloni et al. 2020

Introduction

Approach

Strategy 1

Strategy 2

Strategy 3

Strategy 4

Preservatives

Discussion

Wikimedia Commons Red Seaweed, Jamaican Irish Moss drink
Chitosan is a promising *polysaccharide* for biomedical adhesive applications!

- Amine group of chitosan becomes positively charged at $\text{pH} < 5 \rightarrow$ **electrostatic interaction**

- **Con:** low water resistance

- Adhesive properties and water resistance are dependant on **molecular weight** and **deacetylation degree (DD)**

**Introduction**

**Approach**

**Strategy 1**

**Strategy 2**

**Strategy 3**

**Strategy 4**

**Preservatives**

**Discussion**
Nanostructured Chitosan Adhesive

- Modify adhesive surface to improve bonding (van der Waals interactions)
- Laser-irradiated adhesive to *in vitro* calf intestine
  - Laser irradiation improves adhesion but is not required

---

**Introduction**

Approach

**Strategy 1**

**Strategy 2**

**Strategy 3**

**Strategy 4**

**Preservatives**

**Discussion**

---


---


---

van der Waals and electrostatic interactions

---

## Chitosan Formulation Technical Performance Values

<table>
<thead>
<tr>
<th>Property</th>
<th>Scotch Magic Tape</th>
<th>Chitosan A (≥75% DD*)</th>
<th>Chitosan B (90% DD*)</th>
<th>Chitosan (Flat)</th>
<th>Chitosan (Nanostructured)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tensile Shear</strong></td>
<td>—</td>
<td>1.11 - 14.75 MPa</td>
<td>2.15 - 13.72 MPa</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>Force of Adhesion</strong></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2.4 ± 0.7 nN (AFM)</td>
<td>5.5 ± 3.1 nN (AFM)</td>
</tr>
<tr>
<td><strong>Tensile Strength</strong></td>
<td>89.6 kPa</td>
<td>0.61 - 2.84 MPa</td>
<td>1.92 - 3.57 MPa</td>
<td>0.6 ± 0.5 kPa (no laser)</td>
<td>7.0 ± 3.2 kPa (no laser)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(double lap bond strength)</td>
<td>(double lap bond strength)</td>
<td>14.4 ± 4.0 kPa (laser)</td>
<td>20.8 ± 4.5 kPa (laser)</td>
</tr>
</tbody>
</table>

Abdelmoula et al. formulation: chitosan, 1% acetic acid, 1% glycerol
- Chitosan A - >75% DD
- Chitosan B - 90% DD

Chitosan 81% DD, acetic acid, and rose bengal (a biomedical dye)
- Flat
- Nanostructured

*DD = deacetylation degree
Carrageenan

1 $\text{SO}_3^-$

2 $\text{SO}_3^-$

3 $\text{SO}_3^-$

Introduction
Approach
Strategy 1
Strategy 2
Strategy 3
Strategy 4
Preservatives
Discussion

Modernist Pantry.

Magical Ingredients for the Modern Cook

https://doi.org/10.1016/j.colsurfa.2008.05.037

Iota Carrageenan

Kitchen Alchemy

Gelation

https://modernistpantry.com

https://modernistpantry.com
### Polysaccharide Technical Performance Values

<table>
<thead>
<tr>
<th>Property</th>
<th>Scotch Magic Tape</th>
<th>Chitosan Adhesive (Nanostructured)</th>
<th>Carrageenan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop Tack</td>
<td>1.4 N/cm</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Peel Adhesion</td>
<td>1.7 - 2 N/cm</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Force of Adhesion</td>
<td>—</td>
<td>5.5 ± 3.1 nN (AFM)</td>
<td>4 N/cm</td>
</tr>
</tbody>
</table>

*removed Lap-Joint Shear and Elastic Modulus rows due to lack of values*
# Polysaccharide Health and Environmental Performance

<table>
<thead>
<tr>
<th>Endpoints of Interest</th>
<th>Bad Actors</th>
<th>Potential Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>monomer</td>
<td>polymer</td>
</tr>
<tr>
<td>Acrylates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chitosan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrageenan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Persistence</td>
<td>L</td>
<td>H-vH</td>
</tr>
<tr>
<td>Bioaccumulation</td>
<td>L</td>
<td>H-vH</td>
</tr>
<tr>
<td>Aquatic Ecotoxicity</td>
<td>M-vH</td>
<td>M-H</td>
</tr>
<tr>
<td>Terrestrial Ecotoxicity</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Carcinogenicity</td>
<td>L-M</td>
<td>L-H</td>
</tr>
<tr>
<td>Single Exposure Toxicity</td>
<td>M-H</td>
<td>M-H</td>
</tr>
<tr>
<td>Skin, Eye, Respiratory Irritation / Sensitization</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

## Hazard Rating Legend
- Data Gap
- None
- Low (L)
- Medium (M)
- High (H)
- Very High (vH)

[Standardized using GHS and converted with GreenScreen Score]
BIOLIPIDS
this semester’s polyesters

PHAs
Plastix, 2013.

Soybean Oil
Calorie Secrets

Introduction  Approach  Strategy 1  Strategy 2  Strategy 3  Strategy 4  Preservatives  Discussion
**PHAs** (Polyhydroxyalkanoates)

- Microbes use PHA polyesters to store energy → **biodegradable**
- 150+ different PHA monomers
- Monomer blending → customizable material properties
- **Medium-chain-length (Mcl) PHA blends** → adhesive properties
- Mcl PHA adhesive can be **made from low-value waste**
- UV stable, low permeability, natural, biocompatible, no residue

Pereira et. al 2019
**Soybean oil** offers many reaction pathways + great performance

\[
\text{soybean oil} + \text{peroxide acid} \rightarrow \text{Epoxidized Soybean Oil (ESO)}
\]

**Curing agent pathways**

- **ESO** + UV + photoinitiator → **lactic acid**
- **ESO** + heat + catalyst → **acrylic rosin acid**

... and many more!

However, more work needs to be done to find a suitable home compostable reaction process.
# Biolipid Technical Performance Values

<table>
<thead>
<tr>
<th>Property</th>
<th>Scotch Magic Tape</th>
<th>mcl PHAs</th>
<th>OLA/ESO 3:1 w/ short chain OLAs</th>
<th>ESO/RA-copolyester 87.7:12.3, 10% RA cured 0.5 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop Tack</td>
<td>1.4 N/cm</td>
<td>—</td>
<td>8 N/cm</td>
<td>—</td>
</tr>
<tr>
<td>Peel Adhesion</td>
<td>1.7 - 2 N/cm</td>
<td>—</td>
<td>3.8 N/cm (stainless steel)</td>
<td>4.43 ± 1.25 N/cm (printer paper)</td>
</tr>
<tr>
<td>Shear Strength</td>
<td>—</td>
<td>12.7 ± 2.14 kPa (porcine skin)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>89.6 kPa</td>
<td>61.1 ± 20.6 kPa (porcine skin)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>—</td>
<td>0.6 - 0.9 MPa</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*removed Lap-Joint Shear and Force of Adhesion rows due to lack of values*
# Soybean oil seems to have higher concerns than PHAs

<table>
<thead>
<tr>
<th>Endpoints of Interest</th>
<th>Bad Actors</th>
<th>Potential Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>monomer</td>
<td>polymer</td>
</tr>
<tr>
<td>Acrylates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHAs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epoxidized Soybean Oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Persistence</td>
<td>L</td>
<td>H-vH</td>
</tr>
<tr>
<td>Bioaccumulation</td>
<td>L</td>
<td>H-vH</td>
</tr>
<tr>
<td>Ecotoxicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquatic</td>
<td>M-vH</td>
<td>M-H</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Carcinogenicity</td>
<td>L-M</td>
<td>L-H</td>
</tr>
<tr>
<td>Single Exposure Toxicity</td>
<td>M-H</td>
<td>M-H</td>
</tr>
<tr>
<td>Skin, Eye, Respiratory Irritation / Sensitization</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

*Copelops uptake scl-PHA microbeads, but no mortality was noted

**Generally non-toxic, yet downstream processes with mass generation may have hazardous terrestrial impacts

***Threshold levels are not found, yet pure soybean oil has no allergenic effects

<table>
<thead>
<tr>
<th>Hazard Rating Legend</th>
<th>Data Gap</th>
<th>None</th>
<th>Low (L)</th>
<th>Medium (M)</th>
<th>High (H)</th>
<th>Very High (vH)</th>
</tr>
</thead>
</table>

[Introduction] [Approach] [Strategy 1] [Strategy 2] [Strategy 3] [Strategy 4] [Preservatives] [Discussion]
Gecko Feet

Adhesive Soy Protein Film

Kamada et. al 2021
Factors influencing structural adhesives

Fill Area
(pillar area/total area)

Limit from fibres sticking to each other

Aspect Ratio
(height/width)

other materials properties

Desired Strength of Adhesion

Limit from fibres being too stiff to stick

“Goldilocks Area” for effective adhesion

Introduction  Approach  Strategy 1  Strategy 2  Strategy 3  Strategy 4  Preservatives  Discussion

Spolenak et. al 2005
Futuristic Solution: Adhesive Soy Protein Films

If aspect ratio could be increased from 2 to 4-6 and diameter decreased from 10 to 1-2 µm, this might work!
**Introduction**

**Approach**

**Strategy 1**

**Strategy 2**

**Strategy 3**

**Strategy 4**

**Preservatives**

**Discussion**

---

**Soy Protein Isolate has data gaps with potential discoveries**

<table>
<thead>
<tr>
<th>Endpoints of Interest</th>
<th>Bad Actors</th>
<th>Potential Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>monomer</td>
<td>polymer</td>
</tr>
<tr>
<td>Acrylates</td>
<td></td>
<td>Structured Protein</td>
</tr>
<tr>
<td>Bioaccumulation</td>
<td>L</td>
<td>H-vH</td>
</tr>
<tr>
<td>Soy Protein Isolate</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Persistence</td>
<td>L</td>
<td>H-vH</td>
</tr>
<tr>
<td>Single Exposure Toxicity</td>
<td>M-H</td>
<td>M-H</td>
</tr>
<tr>
<td>Carcinogenicity</td>
<td>L-M</td>
<td>L-H</td>
</tr>
<tr>
<td>Skin, Eye, Respiratory Irritation / Sensitization</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

**Hazard Rating Legend**

- Data Gap
- None
- Low (L)
- Medium (M)
- High (H)
- Very High (vH)

*Conflicting research study results → needs more specific research to address this*

[None]: assumed no/low hazard

[Standardized using GHS and converted with GreenScreen Score]
Safe Preservatives: three classes to fit any formulation

- **Organic Acids**
  - Effective in ≤ 5 pH systems (i.e. formulation pH ≤ pKa of acid)
  - Some options: Caprylhydroxamic Acid, Calcium Sorbate

- **Cationics**
  - Effective in positively charged systems (pH insensitive)
  - Some options: Chitosan, Polylysine

- **Phenols**
  - Effective in most systems (charge + pH insensitive)
  - Some options: Thymol, Propyl Gallate
## Wrap-Up Performance Table

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>Biodegradable</th>
<th>Home Compostable</th>
<th>Generally Safe</th>
<th>Good Technical Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current PLU PSA</td>
<td>✘</td>
<td>✘</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Gluten + Glycerol</td>
<td>✓</td>
<td>?</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Frog Glue (Nb-1R)</td>
<td>✓</td>
<td>?</td>
<td>~</td>
<td>✓</td>
</tr>
<tr>
<td>AGP Nanoparticles</td>
<td>✓</td>
<td>?</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Chitosan</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>~</td>
</tr>
<tr>
<td>Carrageenan</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PHAs</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Epoxidized Soybean Oil</td>
<td>✓</td>
<td>?</td>
<td>~</td>
<td>✓</td>
</tr>
<tr>
<td>Structurally Modified Adhesives</td>
<td>✓</td>
<td>?</td>
<td>?</td>
<td>~</td>
</tr>
</tbody>
</table>

- ✓: Yes
- ✘: No
- ~: Modifications Needed
- ?: Unsure
Remaining Questions

- What is the **scalability** of each of these candidates?
  - How/Where to source feedstock
  - Bacterial genetic engineering
- Would lab-replicated proteins have the same expected **mechanical properties**?
- How effective are these adhesives in **realistic conditions**?
  - Varying humidity
  - Varying temperature
  - On many different substrates
  - etc.
- What is the **lifetime** of each of these bio-alternative adhesives?
  - Can curing agents be developed to increase home compostability of ESOs?
- What is the **necessity of additives**?
  - Need to research potential additives... they can’t work as “drop-in” solutions.
- What are the **downstream environmental impacts** of these solutions? How can we mitigate these processes to be less harmful, even when the product is “environmentally friendly”?
Thank You!

We’d like to thank the BCGC Greener Solutions instructional team, our mentors, and the individuals/organizations that have supported us throughout this project.

Questions?

Dr. Ron Fearing, Dr. Robert Full
Dr. David Faulkner
William Hart-Cooper
Dr. Meg Schwarzman, Kim Hazard, Anna Kurianowicz
Scott Howarth


https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3564783/
Resources and Appendix (pg. 2)

Technical Content (Continued)

- https://www.jacionline.org/article/S0091-6749(96)70146-X/fulltext#bib43
- https://www.karger.com/article/Abstract/233858
- https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-128930_01-Jun-03.pdf
- https://doi.org/10.1016/j.colsurfa.2008.05.037

Slides

- This presentation template was created by Slidesgo, including icons, infographics & images by Freepik
Resources and Appendix (pg. 3)

Image Credit
- PLU sticker: http://fruitsticker.de/4images/data/media/19/big/37840.jpg
- Food Safety: https://www.cdc.gov/salmonella/oranienburg-09-21/index.html
- Ban: https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041553759/
- Gluten: adapted from https://doi.org/10.1016/j.gaost.2020.02.001
- Ivy: https://www.cosmeticsdesign.com/Article/2016/05/31/Nanoparticles-in-English-Ivy-could-lead-to-synthetic-cosmetic-adhesives
- AGP pic: adapted from https://doi.org/10.1073/pnas.1600406113
- Salt Shaker: PurePNG_Salt Shaker PNG Image - PurePNG | Free transparent CC0 PNG Image Library
- Notaden Bennetti: https://calphotos.berkeley.edu/cgi/img_query?enlarge=0000+0000+1211+0448
- Chitosan Inspiration: https://www.mdpi.com/2673-4079/1/3/22/htm
- Carrageenan Irish Moss Drink: https://commons.wikimedia.org/wiki/File:Jamaican_Irish_Moss_drink_-_in_can_and_over_ice.jpg
- Carrageenan Irish Moss Picture: https://commons.wikimedia.org/wiki/File:Red_seaweed,_South_East_Bay,_Three_Kings_Islands_PA111328.JPG
- Stamp: http://www.clipartpanda.com/clipart_images/postage-stamp-clip-art-68660246
- PHA in bacteria: https://matmatch.com/resources/blog/alternatives-to-pet-new-materials-for-a-food-packaging-revolution/
Resources and Appendix (pg. 4)

Image Credit

- Soybean Oil: https://www.caloriessecrets.net/is-soybean-oil-healthy/
- ARA: https://pubs.acs.org/doi/full/10.1021/acssuschemeng.0c03451
- Lactic Acid: https://commons.wikimedia.org/wiki/File:7_Milchsäure.svg
- Peroxide acid: https://commons.wikimedia.org/wiki/File:Peracid_Acid_General_Formulae_V.1.png
- Bacteria + PHAs: http://www.plastix.it/al-via-la-partnership-tra-gammarad-italia-e-bio-on/
- Soybean Oil: https://www.researchgate.net/publication/228664687_A_First_Law_Thermodynamic_Analysis_of_Biodiesel_Production_From_Soybean
- Carrageenan for Chefs: https://modernistpantry.com/products/iota-carrageenan.html
Appendix: Frog Glue Forms

Solid Type I

after dermal stimulation + low pH irrigation, emulsification settles and solids are collected

pH 4.5

Solid Type II

collected secretion on electrode after stimulation + pH 6.2 irrigation

Solid Type III

collected secretion on electrode after stimulation, no irrigation

Fresh Exudate

collected secretion in water after stimulation + irrigation
Appendix: Gluten formulations have knobs to turn

- Water
- Plasticizer
- Ions

Chemical structures and labels.
Amylose: Amylopectin ratio varies for crops

- Postage stamps: dextrin and Borax, re-moistening adhesive
- Most starch-based adhesives contain bad actors like formaldehyde
- Often < 10% starch in effective formulations
  - combined with acrylates

<table>
<thead>
<tr>
<th>Starch Source</th>
<th>Adhesive Strength</th>
<th>Peel Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Starch</td>
<td>—</td>
<td>1.34 N/cm</td>
</tr>
<tr>
<td>Potato Starch</td>
<td>376.57 N/cm²</td>
<td>—</td>
</tr>
<tr>
<td>Wheat Starch</td>
<td>400.3 N/cm²</td>
<td>—</td>
</tr>
<tr>
<td>Scotch Magic Tape</td>
<td>—</td>
<td>1.7 - 2 N/cm</td>
</tr>
</tbody>
</table>