Soybean and soy foods: benefits and limitations

- **Health and nutritional benefits**
  - Whole-bean products
  - Ingredients: wide food applications
  - Bioactives: health/nutraceutical industries

- **Environmental benefits**
  - Resource-efficient: low input/GHG emission, greater land-efficiency → highest protein/acre of farmland
  - Increasingly important in food security and combating metabolic conditions

- **Limitations**
  - Anti-nutritional factors
  - Lipoxygenases → sensory properties, acceptability and utilisation
World soybean production

- 350+ MMT, driven by increased consumption (animal industry) in China
- Dominated by GM soybean for oil and animal feed (over 80%)
- Food industry still demand non-GM
- Australia as a niche and value producer
Develop varieties with grain possessing enhanced functional and nutritional traits for culinary and feed uses

- Modified globulin contents of the major seed storage proteins for enhanced functionality (e.g. gelling in tofu making) and nutritional/health benefit (improved lipid and sugar profile)
- Lipoygenase (LOX) null to improve flavour, taste and acceptability → broaden applications
- Sucrose accumulators rather than raffinose and stachyose for improved acceptability
Grain proteins affect tofu quality

Highest protein (>40%): major functional components (gelling in tofu → texture, water holding capacity)
- Solubility
- Content and proportion of major storage proteins: 7S + 11S (65-80%), 11S/7S ratio
- Subunit composition of the globulins
- Lipoxygenases → beany/grassy/off-flavour
- Amino acid composition/sequence: nutrition

Silken tofu processing and gelation mechanism of proteins

Soak and grind with water ↓
Heat at 98-100°C ↓
Extract/Filter → Soy milk ↓
Add coagulant ↓
Curd formation at 85°C ↓
Store at 4°C → Silken tofu

Key step in extracting seed proteins into soymilk: protein solubility

(Kohyrma et al 1995)
Globulin subunit composition and processing conditions affect tofu properties

<table>
<thead>
<tr>
<th>Seed protein (%)</th>
<th>7Sα null (n=3)</th>
<th>7Sα' and 11SA4 null (n=3)</th>
<th>11SA4 null (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.98 b</td>
<td>41.49 b</td>
<td>42.55 a</td>
<td>41.37 b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Globulin subunit</th>
<th>7Sα'</th>
<th>11SA4</th>
<th>7S</th>
<th>11S</th>
<th>7S+11S</th>
<th>11S/7S</th>
</tr>
</thead>
<tbody>
<tr>
<td>7Sα</td>
<td>-</td>
<td>6.37 b</td>
<td>6.95 a</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11SA4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>44.7 b</td>
<td>46.5 a</td>
<td>43.1 b</td>
</tr>
<tr>
<td>7S</td>
<td>22.1 b</td>
<td>20.2 c</td>
<td>22.9 b</td>
<td>26.5 a</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11S</td>
<td>44.7 b</td>
<td>46.5 a</td>
<td>43.1 b</td>
<td>40.7 c</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7S+11S</td>
<td>66.8</td>
<td>66.7</td>
<td>66.0</td>
<td>67.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11S/7S</td>
<td>2.05 b</td>
<td>2.33 a</td>
<td>1.90 c</td>
<td>1.55 d</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tofu hardness (kg)</th>
<th>0.334 c</th>
<th>0.363 b</th>
<th>0.361 b</th>
<th>0.388 a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tofu water loss (%)</td>
<td>8.30 a</td>
<td>7.42 b</td>
<td>7.24 b</td>
<td>5.30 c</td>
</tr>
</tbody>
</table>

Yang and James 2013

Negative correlation between tofu texture and water loss

Yang and James 2013

Yang and James 2014
Protein content and 11SA4 null affect functional properties in soy foods

Practical significance: ↓ pressure for selecting for high protein which is negatively correlated with yield

Modified globulin profile for improved functionality and health benefit

Improved blood lipid profile

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Yang and James 2013
Yang and James 2014
James and Yang 2014
James and Yang 2016
Lipoxygenase (LOX) and sensory properties of soy foods

- Soybean oil (~20%) highly unsaturated (~50% 18:2, 10% 18:3)
- Richest source of LOX
- Developed lines without LOX (Lx1-2, Lx1-3)
- Soy foods evaluated by GC-MS and descriptive sensory panel

**Soybean oil characteristics**
- High unsaturation
- Significant source of LOX

**Soybean proteins**
- SDS-PAGE profile showing major proteins:
  - β-conglycinin (7S)
  - Glycinin (11S)
- Lipoxygenases (kDa 94-97)

**Soya foods evaluation**
- Developed lines without LOX:
  - Lx1-2
  - Lx1-3

**Sensory properties**
- Improved sweetness and bitterness
- Reduced rancidity and grassy aromas

**Control vs. LOX-free Soymilk**
- Chinese panel ("traditional soy users")
- Australian panel ("non-traditional soy users")
- Preference difference

**Rancidity/Grassy aroma**
- Soymilk: Control, Lx1-2, Lx1-3
- Tofu: Control, Lx1-2, Lx1-3

**Sweetness**
- Soymilk: Control, Lx1-2, Lx1-3
- Tofu: Control, Lx1-2, Lx1-3

**Bitterness**
- Soymilk: Control, Lx1-2, Lx1-3
- Tofu: Control, Lx1-2, Lx1-3

**Sensory preference**
- Difference in preference between a Western and a native Chinese for control and LOX-free soymilk (Yang et al. 2015)
Soybeans with improved sugar profile

- Proteins: content (40%+) and major storage proteins → functionality
  lipoxygenases → beany/grassy/off-flavour
- Lipids (20%) and its interaction with LOX → nutrition profile, stability
- **Carbohydrates: 30%**, < 20% soluble sugars
  sucrose > 50%, raffinose/stachyose up to 50%
  ↑ sucrose
  ↓ raffinose/stachyose
  ↑ improved taste
  nutrition
  acceptability

We have developed soybean genotypes

- With high (~45%) or low (~39%) protein content
- Null in 11SA4 and/or 7Sα’, 11S
- Lacking two (Lx1-2) or all three (Lx1-3) major isomer of lipoxygenases
- Containing greatly reduced raffinose (<0.5%) and stachyose (~2%) and increased sucrose (~94%)
Soybean genotypes with improved quality attributes

- Higher proteins content and 11SA4 deficiency consistently improved textural and water holding properties of tofu.
- Firmer silken tofu also had better water holding capacity - important for silken tofu manufacturers.
- 11SA4 null → compensatory accumulation of 7S globulins → similar 7S + 11S in soybeans.
- Soybeans lacking lipoxygenases → soy foods with decreased negative (grassy/rancid) and increased positive (sweet) aroma → more acceptable and broaden applications in foods.
- Currently assessing these novel genotypes as aqua feed.

Improved grain properties for better soy food quality

Superior functionality, nutrition, taste, acceptability

SDS-PAGE profile of soybean seed proteins containing all globulin subunits, lacking 7Sα and/or 11SA4, or lipoxygenase
Thank you!