Future Developments in Plant-Based Foods

Michael J. Leonard, PhD
Chief Technology Officer
mleonard@motiffoodworks.com
@mikeleonard
madewithmotif.com
Ingredient Innovation

Our Ambition:
To unleash the promise of plant-based foods
The world is hungry for better plant-based foods
Plant-Based Marketplaces are Getting Bigger

- $29 Billion
- 27% Meat-alt
- 73% Dairy-alt

Sources: 2020 Euromonitor, 2020 Statista, 2020 Market Watch Plant Based Meats
Plant-Based Segments are Outpacing their Animal-Based Counterparts

One Year Global Growth Rates
(Y/Y Average)

Meat: 15%
Dairy: 12%

Plant-Based Meats

Today, plant-based foods are NOT living up to expectations…

*there are still significant gaps in the performance of…*

plant-based foods vs. animal counterparts
Plant-based consumers are making big compromises

- **44%**
  - Consumers who don’t like how plant-based foods taste
  - *Yale Climate Change report*

- **67%**
  - Would eat plant-based over meat if products tasted better
  - *Yale Climate Change report*

- **31%**
  - Not interested in alternatives to animal products due to taste
  - *Health Focus International*

- **34%**
  - Name taste as a top reason for not wanting to eat plant-based foods
  - *Good Food Institute*
And therefore, velocity and repeat purchasing behavior significantly lags animal-based foods
Dairy and Meat Alternative Sensory Focus Groups

- Plant-based milk
- Plant-based yogurt
- Plant-based cheese
- Plant-based ice cream
- Plant-based meat
Taste is Very Much in the Mouth of the Beholder

“Taste”

Taste

Texture

Moisture

Color

Smell
Most Plant Substitutes are Limited in their Ability to Replace or Replicate Animal-Based Foods

<table>
<thead>
<tr>
<th>Soybean</th>
<th>Wheat Gluten</th>
<th>Pea</th>
<th>Mycoprotein</th>
<th>Almond</th>
<th>Cashew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common allergen</td>
<td>Common allergen</td>
<td>Green, beany off-notes</td>
<td>Limited application space</td>
<td>Nutty off-notes</td>
<td>Allergen</td>
</tr>
<tr>
<td>Green, beany off-notes</td>
<td>Limited application space</td>
<td></td>
<td>Chalky and powdery texture</td>
<td>Nutty off-notes</td>
<td>Nutty off-notes</td>
</tr>
<tr>
<td>Chalky and powdery texture</td>
<td>Low solubility</td>
<td></td>
<td>Limited gelling</td>
<td>Watery mouth coating</td>
<td>Off-notes from oxidation</td>
</tr>
<tr>
<td>Gray/brown color (alt. dairy)</td>
<td>Low protein digestibility (PDCAAS)</td>
<td>Gray/green color (alt. dairy)</td>
<td>Off-flavors</td>
<td>Grainy and powdery texture</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low protein digestibility (PDCAAS)</td>
<td>Off-white/gray color</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low protein digestibility (PDCAAS)</td>
<td></td>
</tr>
</tbody>
</table>
Success = Great Tasting, More Nutritious, Plant-Based Foods that People Crave
Target Applications for Novel Protein Sources

**Meat Alternatives**
- Ground applications
- Snacks & Jerky
- Whole Muscle

**Dairy Alternatives**
- Milk
- Yogurt
- Cheese
- Ice Cream

**Plant-Based Performance & Nutrition**
- Sports & Adult Nutrition
- Infant & Toddler Nutrition
- Snacks & Spreads
- Vegan Baking

**Applications**
- Milk
- Yogurt
- Ice Cream
- Infant & Toddler Nutrition
- Snacks & Spreads
- Vegan Baking
Standard

Modify & Mask
- Sensory Testing QDA
- Flavor Strategies
- Formulation Strategies
  - Gums Stabilizers
- Process Strategies

New

Fundamental Understanding
- Oral Processing Physics
- Cognitive Metrics
- Synthetic Biology
- Soft Matter Physics & Material Science
Novel Proteins and Ingredients Must Address Many Key Attributes

**Meat Alternatives**
- **Taste**
  - Rich, satisfying flavors and aromas
- **Appearance**
  - Tempting, mouth-watering color
- **Texture**
  - Meaty texture and juiciness
- **Nutrition**
  - Enhanced fat, salt and protein quality

**Dairy Alternatives**
- **Texture**
  - Rich and creamy with smooth mouthfeel
- **Stretch**
  - Stringy, stretchy options
- **Melt**
  - Consistent bubble and meltiness

**Plant-Based Performance & Nutrition**
- **Protein**
  - Enhanced nutrition
- **Texture**
  - Smooth and consistent mouthfeel
- **Appearance**
  - Color and surface attributes
It is Critical to Look at Food Design Through the Lens of Physics, Chemistry, and Materials Science

Proteins
UMASS AMHERST
GINKGO BIOWORKS™

Rheological properties
ILLINOIS
TEXAS TECH UNIVERSITY

Texture
THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Fat performance
UNIVERSITY OF GUELPH
coasun
Applying New Sciences to Food that Drive Breakthrough Discoveries

- Oral processing physics
- Rheology
- Neurobiology
Oral Processing is Dynamic

Transport properties

Bulk properties dominate
Surface properties dominate

Structure

Thickness, firmness, melting, breakdown
Creaminess, fattiness, smoothness, slipperiness
Astringency, roughness, afterfeel, homogeneity

Property

Dynamic

Oral Processing

Food transforms

Sensory

Mouthfeel Texture Wheel

Source: University of Queensland
Capturing the Physics in the “Stages” of Oral Processing

(i) First bite (mechanics)  (ii) Communion (chewing) (tribology)  (iii) Granulation  (iv) Bolus formation and processing  (v) Swallow  (vi) Residue

Rheology and Tribology

Temporal Dominance Profiling

Multiple deformation scales & food-transformation

Source: University of Queensland
Partnership with Ginkgo Bioworks

- Ginkgo can:
  - To engineer strains at scale using rational and unbiased approaches simultaneously
  - With gigabase-scale DNA synthesis capacity.
- And they have significant physical and digital economies of scale.
Biology is fundamentally programmable
Using Synthetic Biology to Produce Animal-Free Food Ingredients

1. **Sequencing**
   - Desired animal protein genes
   - DNA sequencer
   - Searchable sequence databases
   - Millions of gene sequences
   - Isolated genes

2. **Programming and Gene Assembly**
   - Nucleobases chemically synthesized from cane sugar derivatives
   - DNA Synthesizer "prints" small fragments of target sequence
   - Target gene is assembled and prepared for host
   - Enzymes

3. **Ingredient production**
   - New DNA incorporated into yeast cells
   - Engineered metabolic pathways
   - Fermentation process optimized for target
   - Yeast vector
   - Animal proteins produced without animals

SOT FDA Colloquia on Emerging Toxicological Science Challenges in Food and Ingredient Safety
The Cost of DNA Sequencing (Reading) and Synthesis (Writing) is Falling Dramatically
Gingko’s Foundry Produces Results

### 100x
More designs per batch

### 5x
Cheaper than conventional

<table>
<thead>
<tr>
<th></th>
<th>Foundry</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch size</td>
<td>2000</td>
<td>20</td>
</tr>
<tr>
<td>Foundry/Lab labor per batch (hours)</td>
<td>12.5</td>
<td>13</td>
</tr>
<tr>
<td>Design labor per enzyme (hours)</td>
<td>0.02</td>
<td>0.6</td>
</tr>
<tr>
<td>Equipment cost per sample</td>
<td>$1.53</td>
<td>$25.09</td>
</tr>
<tr>
<td>Labor cost per sample</td>
<td>$2.53</td>
<td>$104.88</td>
</tr>
<tr>
<td>Material cost per sample</td>
<td>$85.78</td>
<td>$322.33</td>
</tr>
<tr>
<td><strong>Cost per strain tested</strong></td>
<td><strong>$89.84</strong></td>
<td><strong>$452.29</strong></td>
</tr>
</tbody>
</table>
Synbio Case Study: Biodiversity for Better, More Functional Ovalbumin

Rapidly searching and screening thousands of potential ovalbumin proteins in bird eggs across the animal kingdom.
Screening for Proteins that Express Well in *P. Pastoris*

- Transglutaminase
- α-Lactalbumin
Entirely New Food Forms that Create New Categories
Entirely New Food Forms that Create New Categories
We can’t meet these challenges alone
Thank You

mleonard@motiffoodworks.com
@mikeleonard
madewithmotif.com