Products from microalgae: 
The formulators perspective

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Outline

D-Factory products in formulations

Formulated products
The role of the formulator
Products from microalgae biorefineries in formulations - Why?

Example 1: Delivery systems for carotenoid-rich extracts

Example 2: Properties of algal starch and its use as Pickering emulsifier

Example 3: Polar lipids as clean-label emulsifiers
Formulated products are typically a complex, micro-heterogeneous mixture of substances fulfilling a specific set of requirements and addressing the needs of industry and/or consumer. They are also formulated with 3-100 times higher value than the value of ingredients. The global emerging market for formulated products is in the order of €1,400 billion.
The role of the formulator
Let’s take mayonnaise as an example...

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Processing</th>
<th>Final product</th>
</tr>
</thead>
<tbody>
<tr>
<td>What?</td>
<td>How?</td>
<td>Right properties?</td>
</tr>
<tr>
<td>How much?</td>
<td>Order of addition?</td>
<td>Storage?</td>
</tr>
<tr>
<td>Why?</td>
<td>Why?</td>
<td>Why?</td>
</tr>
</tbody>
</table>

- Sustainable?
- Yardsticks?
- Energy efficient?
- Resource efficient?
- Recycling?
- Longer shelf-life?

- Healthy
- Eco
- Clean label
- Organic
- All Natural
Products from microalgae biorefinaries in formulations- Why?

Biorefinery products → heterogeneity, purity and variability challenges

Demonstrating use in prototype formulated products:

✓ Early identification of limitations.

✓ Early assessment of technical value, performance, competitive edge.

✓ Early engagement of potential stakeholders.
D-Factory products → Formulated products

Cultivation

Harvesting

Water treatment

Stabilisation

Dry

Bag

Fractionation & Formulation

scCO2

HPCCC

Solvents

HPLC

Memb

1: Glycerol
2: Enzymes
3: Polar lipids
4: Powder

5: Carotenoid extract
6: Defatted powder
7: Lutein
8: Zeaxanthin
9: Polar lipids
10: Chlorophyll
11: All-trans β-carotene
12: Non-polar lipids
13: 9-cis β-carotene
14: α-carotene
Delivery systems for carotenoid-rich extracts

- Carotenoids - organic pigments
- Widely used in food supplements and colourants
- Many associated health benefits
- Products: Drinks, supplements, skin creams

- Low solubilities in most common oils
- Prone to chemical degradation /oxidation

- Effect on solubility in carrier oils?
- Effect on chemical stability of caroteneoids?
- Effect of physical stability of formulations?

Carotenoid-rich extract
≥ 25-30% carotenoids + chlorophylls, + tri- and diglycerides
Solubility in carrier oils

Carotenoid-rich extract

- Higher solubility in oils than the high purity compounds
- Lutein and β-carotene (0.05% in grapeseed oil)

<table>
<thead>
<tr>
<th>OILS</th>
<th>Carotenoid-rich Extract [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grapeseed oil</td>
<td>4</td>
</tr>
<tr>
<td>Oleic acid</td>
<td>2.4</td>
</tr>
<tr>
<td>Rapeseed oil</td>
<td>2.1</td>
</tr>
<tr>
<td>Olive oil</td>
<td>1.5</td>
</tr>
<tr>
<td>Medium Chain Tryglic.</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Sesame oil</td>
<td>0.2</td>
</tr>
<tr>
<td>Glycerol Monooleate</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Steady of carotenoid extract in nano-carriers

Carotenoid-rich extract

Stearic acid nano dispersion

Carnuba wax nano dispersion

MC Triglyceride nano emulsion

10% lipid/oil
2500 mg/L extract (0.025%)
Emulsifier: Soy Lyso Lecithin
Starch from defatted powder

- 38% of starch in defatted algal powder
- 73% isolated through separation process

Thermogram of starch upon heating from 20 to 100°C (starch/water 1:3).

Melting onset, 57°C
Melting onset, 47°C
Starch from defatted powder

Use as Pickering emulsifier

Drop size distribution (% V) of algal starch and oil in water Pickering emulsions

- Algal Starch
- Modified starch
- Natural starch
- Oil in water Pickering emulsions

Particles (granules)
O/w emulsion
Water
Major components of polar lipid fractions isolated from algal biomass

- Glycolipids
  - (e.g. DiGalactosyl-DiacylGlycerol)
- Phosphoinositol-phospholipid
- Phosphatidylcholine (PC)
- Phosphatidylserine (PS)

Trigger natural appetite control mechanism (‘ileal brake’).
Polar lipids as clean-label emulsifiers

Reference emulsifier

<table>
<thead>
<tr>
<th>Oil</th>
<th>Soybean Lecithin</th>
<th>PL-NBT Acetone</th>
<th>PL-NBT MeOH</th>
<th>Required HLB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloroform</td>
<td>o/w Unstable!</td>
<td>x</td>
<td>x</td>
<td>&gt; 15</td>
</tr>
<tr>
<td>Castor oil</td>
<td>x Unstable!</td>
<td>x</td>
<td>x</td>
<td>14</td>
</tr>
<tr>
<td>Kerosene</td>
<td>o/w Unstable!</td>
<td>x</td>
<td>x</td>
<td>14</td>
</tr>
<tr>
<td>Sunflower oil</td>
<td>o/w Unstable!</td>
<td></td>
<td>o/w Stable!</td>
<td>7</td>
</tr>
<tr>
<td>Dimethicone</td>
<td>o/w Stable!</td>
<td>o/w Stable!</td>
<td>x</td>
<td>5</td>
</tr>
</tbody>
</table>

Algal polar lipids with different polarity
The take-home messages:

• Formulation industries are an interesting target for microalgae biorefinery products.

• Worth investing time in identifying and addressing technical challenges.

• Identified and tested suitable nano carrier systems for carotenoid-rich extracts.

• Demonstrated use of algal starch as novel Pickering emulsifier.

• Demonstrated emulsification properties of algal polar lipids.
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and to you for your attention!