Novel food production and diets for more sustainable food systems

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Recent Relevant Publications on Food System Sustainability

Articulating the effect of food systems innovation on the Sustainable Development Goals

Socio-Technical Innovation Bundles for Agri-Food Systems Transformation

Bundling innovations to transform agri-food systems

COVID-19 pandemic lessons for agri-food systems innovation

ETH zürich Alexander Mathys SFP
ETH Sustainable Food Processing Research

- **Novel Resources**
  - Microalgae
  - Algae Bioreactors

- **Primary Production**
  - Disintegration
  - Proteins & Lipids

- **Gentle Release**
  - Processing

- **Functional Ingredients**
  - Quality Foods

- **Structure + Safety**
  - Nutritive Foods

- **Consumption**

- **Biological Response**

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**Microbial Ecosystem Analysis and Control**

**Structure-Process Properties Interactions**

**Emerging processing (Structuring/Disintegration/Safety)**

**Cooperation with nutrition, medicine, and consumer science**

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**Insects**

**Rearing**

**Separation**

**Protein & Lipids**

**Processing**

**Quality Food/Feed**

**Nutritive Foods**

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Multi Indicator Sustainability Assessment - Method Development and Case Studies
Food system understanding by multi-indicator sustainability analysis of all three dimensions

Global food system sustainability performance
...a 5.65 trillion USD market

- Food Nutrient Adequacy (1)
- Ecosystem stability (2)
- Affordability and Availability (3)
- Sociocultural well-being (4)
- Resilience (5)
- Waste and loss reduction (7)
- Food safety (6)

Global food systems are at the heart of our 17 SDGs

(United Nations, 2015)

Chaudhary, Gustafson & Mathys 2018, Nature Communications. 9, 848
Multi-indicator approach quantifying the status of national food system performance

Table 1 Seven food system metrics, their indicators, and data sources

<table>
<thead>
<tr>
<th>Metric</th>
<th>Indicator</th>
<th>Median</th>
<th>Source</th>
<th>GDP correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Nutrient Adequacy</td>
<td>Shannon Diversity of Food Supply</td>
<td>61</td>
<td>Reams et al.33</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Non-Staple Food Energy</td>
<td>74</td>
<td>Reams et al.33</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Modified Functional Attribute Diversity</td>
<td>46</td>
<td>Reams et al.33</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>Population Share with Adequate Nutrients</td>
<td>76</td>
<td>This study</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>Nutrient Balance Score</td>
<td>75</td>
<td>This study</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>Disqualifying Nutrient Score</td>
<td>12</td>
<td>This study</td>
<td>– 0.74</td>
</tr>
<tr>
<td>Ecosystem Stability</td>
<td>Ecosystem Status</td>
<td>47</td>
<td>Hsu et al.34</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Per-Capita GHG Emissions</td>
<td>51</td>
<td>This study</td>
<td>– 0.79</td>
</tr>
<tr>
<td></td>
<td>Per-Capita blue water consumption</td>
<td>50</td>
<td>This study</td>
<td>– 0.75</td>
</tr>
<tr>
<td></td>
<td>Per-Capita Land Use</td>
<td>50</td>
<td>Alexander et al.35</td>
<td>– 0.09</td>
</tr>
<tr>
<td></td>
<td>Per-Capita Non-Renewable Energy Use</td>
<td>29</td>
<td>World Bank139</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Per-Capita Biodiversity Footprint</td>
<td>50</td>
<td>Chaudhary et al.38</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Chaudhary, Gustafsson & Mathys 2018, Nature Communications. 9, 848
ETH Sustainable Food Processing Research - Focus Insects

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**Multi Indicator Sustainability Assessment - Method Development and Case Studies**
Alternative animal proteins based on Black Soldier Fly waste utilization for more sustainable feeds

2) Aarts, Jansen, Jacobs, Mescher, Prenter, Mathys & De Moraes (2018). Processing of insect larvae. EU patent application. Application No 18175914.3-110
Environmental sustainability of most relevant protein sources in comparison
(Nutritional impacts are not included)

<table>
<thead>
<tr>
<th>Protein Source</th>
<th>DM %</th>
<th>Protein %</th>
<th>GWP, kg CO₂ eq. global warming potential</th>
<th>OD, mg CFC11 ozone depletion</th>
<th>AC, g SO₂ eq. acidification</th>
<th>EU, g N eq. eutrophication</th>
<th>ED, MJ energy demand</th>
<th>FD, m³ freshwater depletion</th>
<th>LU, m² land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean meal</td>
<td>67.5</td>
<td>49.1</td>
<td>0.34–0.72, 6.52*</td>
<td>0.2–3.3, 11.4</td>
<td>−1.2–3.1, 11.4</td>
<td>5.3⁰, 25.5³, 0.4³</td>
<td>3.2⁰</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapeseed cake</td>
<td>89⁴</td>
<td>34.8</td>
<td>0.37–0.57⁴</td>
<td>0.004–0.05⁴</td>
<td>6.8–7.5⁴</td>
<td>8–9.9¹⁴</td>
<td>3.3–3.8⁴, 0.001–0.03⁴, 1.5–1.6⁴</td>
<td>2.8⁴</td>
<td></td>
</tr>
<tr>
<td>Pea protein meal (pulses)</td>
<td>89⁴</td>
<td>0.4⁴</td>
<td>0.44–4.1⁴</td>
<td>0.05⁴</td>
<td>21.8⁴</td>
<td>7.4⁴</td>
<td>5.2⁴</td>
<td>0.5⁴</td>
<td>2.6⁴</td>
</tr>
<tr>
<td>Fishmeal</td>
<td>0.4¹</td>
<td>60.7²</td>
<td>0.12–0.58¹</td>
<td>0.016–0.073¹</td>
<td>0.128–7.1⁴, 3.1³</td>
<td>0.0002–1.17³</td>
<td>0.0005–0.05², 0.04⁴, 1.1³</td>
<td>0.05²</td>
<td></td>
</tr>
<tr>
<td>HM (this study)</td>
<td>96.6</td>
<td>56.4</td>
<td>5.3</td>
<td>0.43</td>
<td>21.3</td>
<td>17.9</td>
<td>84.1⁸</td>
<td>0.0028⁸</td>
<td>1.89</td>
</tr>
<tr>
<td>HP (this study)</td>
<td>30</td>
<td>17</td>
<td>1.16</td>
<td>0.091</td>
<td>5.3</td>
<td>4.6</td>
<td>17.9</td>
<td>0.0006⁸</td>
<td>0.48</td>
</tr>
<tr>
<td>Fresh meat (chicken)</td>
<td>25/30</td>
<td>22/24</td>
<td>1.62–3.12¹⁰</td>
<td>1.8¹⁰</td>
<td>44.25¹⁰</td>
<td>75⁰–8.05², 0.05g N₂O eq.³</td>
<td>18.65–60.3²</td>
<td>0.053–0.155²</td>
<td>19.3–31.3³</td>
</tr>
<tr>
<td>Whey concentrate</td>
<td>86/6</td>
<td>60/3</td>
<td>7.48</td>
<td>0.01</td>
<td>0.05</td>
<td>1.1⁴</td>
<td>58.1³</td>
<td>0.003–0.02⁵</td>
<td>0.26–0.4⁵</td>
</tr>
<tr>
<td>Egg protein concentrate</td>
<td>89/3</td>
<td>80/13²</td>
<td>0.87–7.4⁴</td>
<td>0.06³</td>
<td>1.5³</td>
<td>37.3⁴</td>
<td>83.3⁴</td>
<td>0.06⁴–2.7⁴</td>
<td>2.8⁴</td>
</tr>
<tr>
<td>Egg protein concentrate</td>
<td>85</td>
<td>80</td>
<td>2.3⁴</td>
<td>1.01</td>
<td>4900⁴</td>
<td>129³</td>
<td>182³</td>
<td>2.65⁴</td>
<td>40.1</td>
</tr>
<tr>
<td>Microalgae⁰</td>
<td>96/6</td>
<td>56/5</td>
<td>14.7–24.5¹</td>
<td>0.9–19.8</td>
<td>260.5–1407.5⁴</td>
<td>40.6–106.3³</td>
<td>217.1–418³</td>
<td>0.33–1.0⁴</td>
<td>1.7–5.4</td>
</tr>
</tbody>
</table>

**Sources:**
1. (Dulgaard et al., 2008); 2. (Kim et al., 2013); 3. Own calculations; 4. Danish LCA Food Database; 5. (Hall, 2011); 6. ecoinvent 3 and Agrifootprint databases; 7. (Smetana et al., 2010); 8. (Nikam et al., 2012); 9. (Smetana et al., 2017); 10. (Gonzalez-Garcia et al., 2014); 11. (Wiedermann et al., 2017); 12. (Bacetti et al., 2018); 13. (Papatryphon et al., 2004); 14. (Samuel-Fitt et al., 2013); 15. (Cashion et al., 2017); 16. (Smardon et al., 2017); 17. (Silva et al., 2017); 18. (Fréon et al., 2017); 19. Per kg protein. Note: HP = H. illuca puree (fresh insect production); HM = H. illuca meal (defatted protein concentrate); DM = dry mass; GWP = global warming potential; OD = ozone depletion; AC = acidification; EU = eutrophication; ED = energy demand; FD = freshwater depletion; LU = land use.

Different technology readiness level, the connected ecosystem and relevance of economies of scale

(Hensen et al., 2015)

ECONOMIES OF SCALE

www.fotolia.com
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Example for innovative microalgae upstream cultivation to increase efficiency and adapt final color to address consumer aspects

Changes in pigments: reduced green colour

Food, cosmetics and bio-based applications

O/W emulsions

Photoautotrophic
Mixotrophic
Heterotrophic

Chlorophyll
Carotenoids

Phot
Mix
Het

Effect of *Arthrospira* (Spirulina) protein purification on emulsification mechanism and efficiency

High moisture extrusion to produce bright algae-based meat analogs, with increase of nutritional value

Extruded meat analogues with enhanced nutritional value were produced by incorporating microalgae to its formulation. However, to achieve appropriate fibrillar structure, moisture contents were optimized.

Recommended daily intake (RDI) of the selected vitamins in 100 g of unprocessed microalgae (MA) powder, extrudate with 50% MA$_{DAW}$ before and after extrusion, and soy protein concentrate powder according to FDA (2016).
Different protein and lipid bioaccessibility in commercial biomass

Future outlook - How to integrate our R&D
Innovative Algae Biorefinery Concept based on emerging up- and downstream
Thank you very much
Our new Future Food lab at the Singapore ETH Center
Acknowledgement

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ETH Foundation Zürich

Whole IFNH

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Schweizerischer Nationalfonds
Fondo Nazionale Svizzero
Swiss National Science Foundation

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