Novel food production and diets for more sustainable food systems

Prof. Dr.-Ing. Alexander Mathys
ETH Zurich
16. November 2021

Recent Relevant Publications on Food System Sustainability

THE LANCET
Planetary Health

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

Mario Herrero, Philip K Thornton, Daniel Mason-D'Croz, Jeda Palmer, Benjamin L Bodirsky, Prajal Pradhan, Christopher B Barrett, Tim G Benton, Andrew Hall, Ilje Pikaar, Jessica R Bogard, Graham D Bonnett, Brett A Bryan, Bruce M Campbell, Svend Christensen, Michael Clark, Jessica Fanzo, Cecile M Godde, Andy Jarvis, Ana Maria Loboguerrero, Alexander Mathys, C Lynne McIntyre, Rosamond L Naylor, Rebecca Nelson, Michael Obersteiner, Alejandro Parodi, Alexander Popp, Katie Ricketts, Pete Smith, Hugo Valin, Sonja J Vermeulen, Joost Vervoort, Mark van Wijk, Hannah HE van Zanten, Paul C West, Stephen A Wood, Johan Rockström

nature sustainability

comment | Check for updates

Bundling innovations to transform agri-food systems

Christopher B. Barrett, Tim G. Benton, Karen A. Cooper, Jessica Fanzo, Rikin Gandhi, Mario Herrero, Steven James, Mark Kahn, Daniel Mason-D'Croz, Alexander Mathys, Rebecca J. Nelson, Jianbo Shen, Philip Thornton, Elizabeth Bageant, Shenggen Fan, Andrew G. Mude, Lindiwe M. Sibanda and Stephen Wood

ENVIRONMENTAL RESEARCH
LETTERS

PERSPECTIVE

COVID-19 pandemic lessons for agri-food systems innovation

Christopher B Barrett, Jessica Fanzo, Mario Herrero, Daniel Mason-D'Croz, Alexander Mathys, Philip Thornton, Stephen Wood, Tim G Benton, Shenggen Fan, Laté Lawson-Lartego, Rebecca Nelson, Jianbo Shen and Lindiwe Majele Sibanda

Socio-Technical Innovation Bundles for Agri-Food Systems Transformation

A Cornell Atkinson Center for Sustainability/
Nature Sustainability
Expert Panel Report

December 2020

nature sustainability

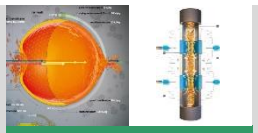
ETH Sustainable Food Processing Research

SFP Flagship Project

Novel Resources | Primary Production | Gentle Release | Functional Ingredients | Structure+Safety | Consumption | Biological Response


Microalgae


Algae Bioreactors

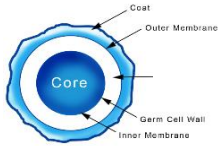

Disintegration


Proteins & Lipids

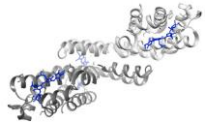

Processing

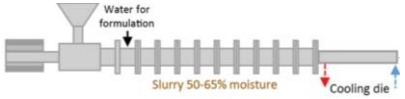

Quality Foods

?
Nutritive Foods



Microbial Ecosystem Analysis and Control


Structure-Process Properties Interactions



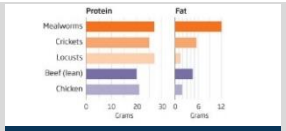
Emerging processing (Structuring/Disintegration/Safety)

Cooperation with nutrition, medicine, and consumer science


Insects


Rearing

Separation



Protein & Lipids

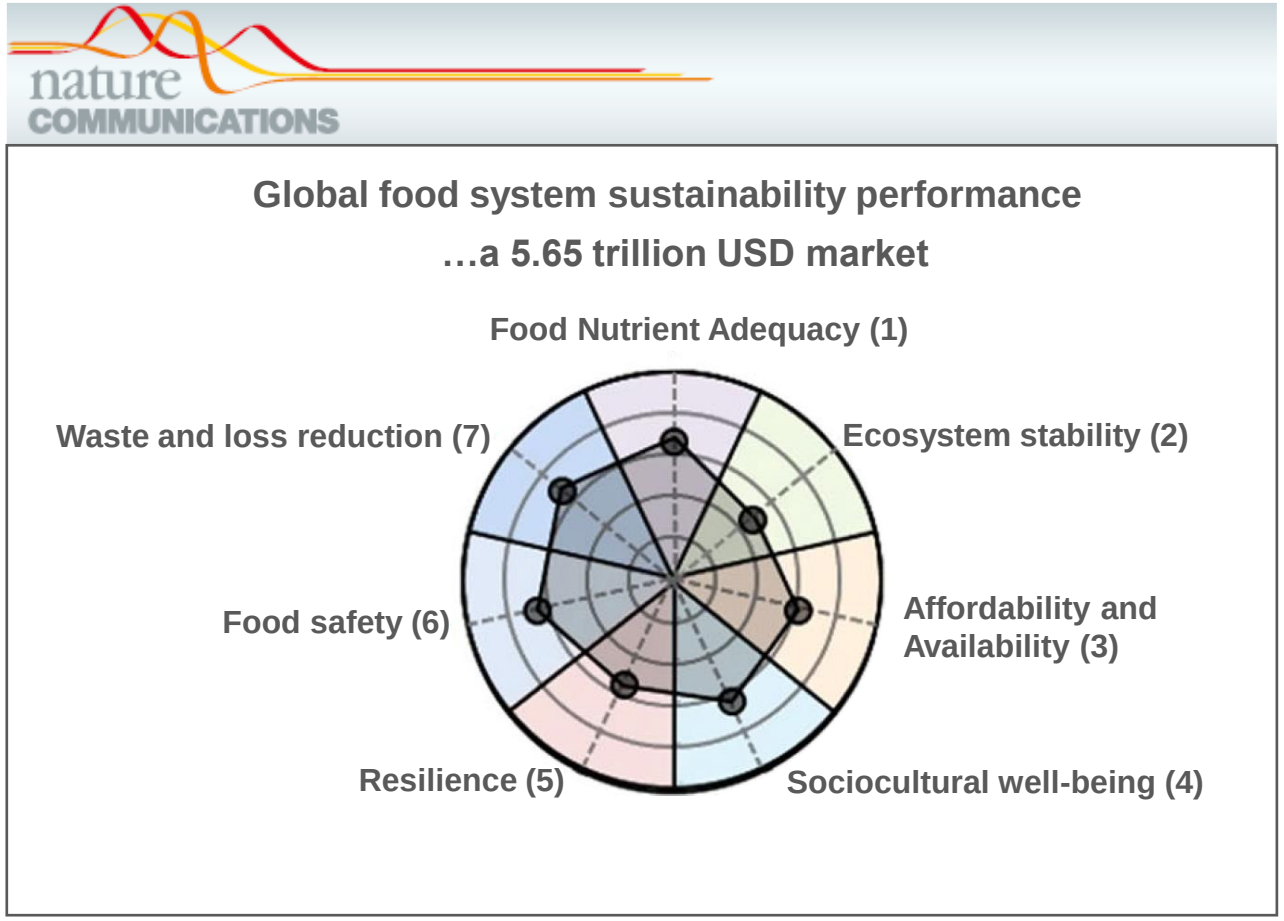

Processing

Quality Food/Feed

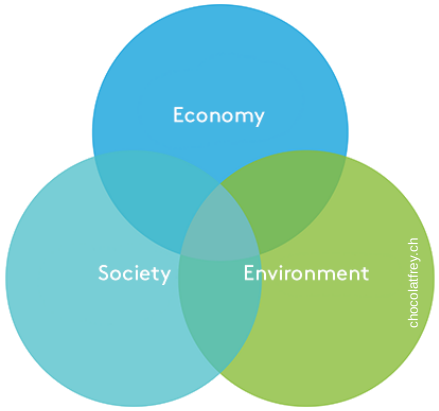
?
Nutritive Foods

Multi Indicator Sustainability Assessment - Method Development and Case Studies

Food system understanding by multi-indicator sustainability analysis of all three dimensions



Chaudhary, Gustafson & Mathys 2018, Nature Communications. 9, 848



FNSNF
73 NRP Sustainable Economy
National Research Programme

Global food systems are at the heart of our 17 SDGs

(United Nations, 2015)

Multi-indicator approach quantifying the status of national food system performance

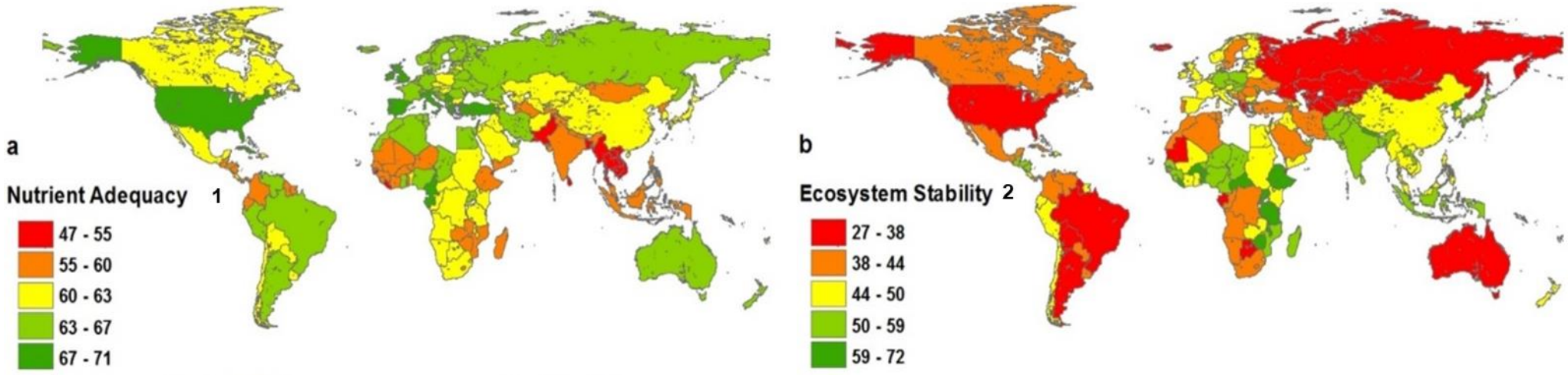


Table 1 Seven food system metrics, their indicators, and data sources

Metric	Indicator	Median	Source	GDP correlation
Food Nutrient Adequacy		**61**		0.53
	Shannon Diversity of Food Supply	74	Remans et al.[33]	0.42
	Non-Staple Food Energy	46	Remans et al.[33]	0.72
	Modified Functional Attribute Diversity	77	Remans et al.[33]	0.70
	Population Share with Adequate Nutrients	76	This study	0.64
	Nutrient Balance Score	75	This study	0.46
	Disqualifying Nutrient Score	12	This study	− 0.74
Ecosystem Stability		**47**		− 0.36
	Ecosystem Status	43	Hsu et al.[34]	0.51
	Per-Capita GHG Emissions	51	This study	− 0.79
	Per-Capita blue water consumption	50	This study	− 0.75
	Per-Capita Land Use	50	Alexander et al.[9]	− 0.09
	Per-Capita Non-Renewable Energy Use	28	World Bank[59]	0.00
	Per-Capita Biodiversity Footprint	50	Chaudhary et al.[28]	0.02

Chaudhary, Gustafson & Mathys 2018, Nature Communications. 9, 848

ETH Sustainable Food Processing Research-Focus Insects

Novel Resources | Primary Production | Gentle Release | Functional Ingredients | Structure+Safety | Consumption | Biological Response

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Algae Bioreactors

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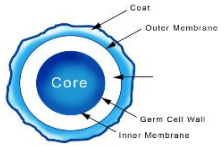
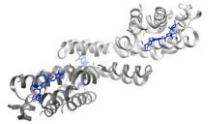
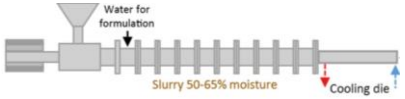


Microbial Ecosystem Analysis and Control


Structure-Process Properties Interactions



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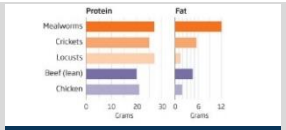

Protein & Lipids


Processing

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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

(Stefan Diener, Black Soldier Fly Biowaste Processing Manual, Sandec 2017; ETH Zurich SFP and Eawag facility in Dübendorf, CH)

1) Gold,Tomberlin, Diener, Zurbrügg, & Mathys (2018). Waste Management. 82, 302-318.
2) Aarts, Jansen, Jacobs, Mescher, Prenter, Mathys & De Moraes (2018). Processing of insect larvae. EU patent application. Application No 18175914.3-110
3) Gold, Cassar, Zurbrügg, Kreuzer, Bolus, Diener & Mathys (2019). Waste Management. 102, 319-329.
4) Gold, Egger, Scheidegger., Zurbrügg, Bruno, Bonelli, Tettamanti, Casartelli, Schmitt, Kerkaert, De Smet, van Campenhout & Mathys (2020). Waste Management. 112, 40-51.
5) Gold et al. (2020). Journal of Insect Science, 20: 3, 21ff.
6) Gold, von Allmen, Zhang, Zurbrügg & Mathys (2020). Frontiers in Microbiology, 11: 582867.
7) Gold, Fowles, Fernandez-Bayo, Palma Miner, Zurbrügg, Nansen, Bischel & Mathys (2021). Journal of Insects as Food and Feed. accepted

Environmental sustainability of most relevant protein sources in comparison (Nutritional impacts are not included)

Environmental impact comparison of main protein sources used for feed and food (per 1 kg of product)

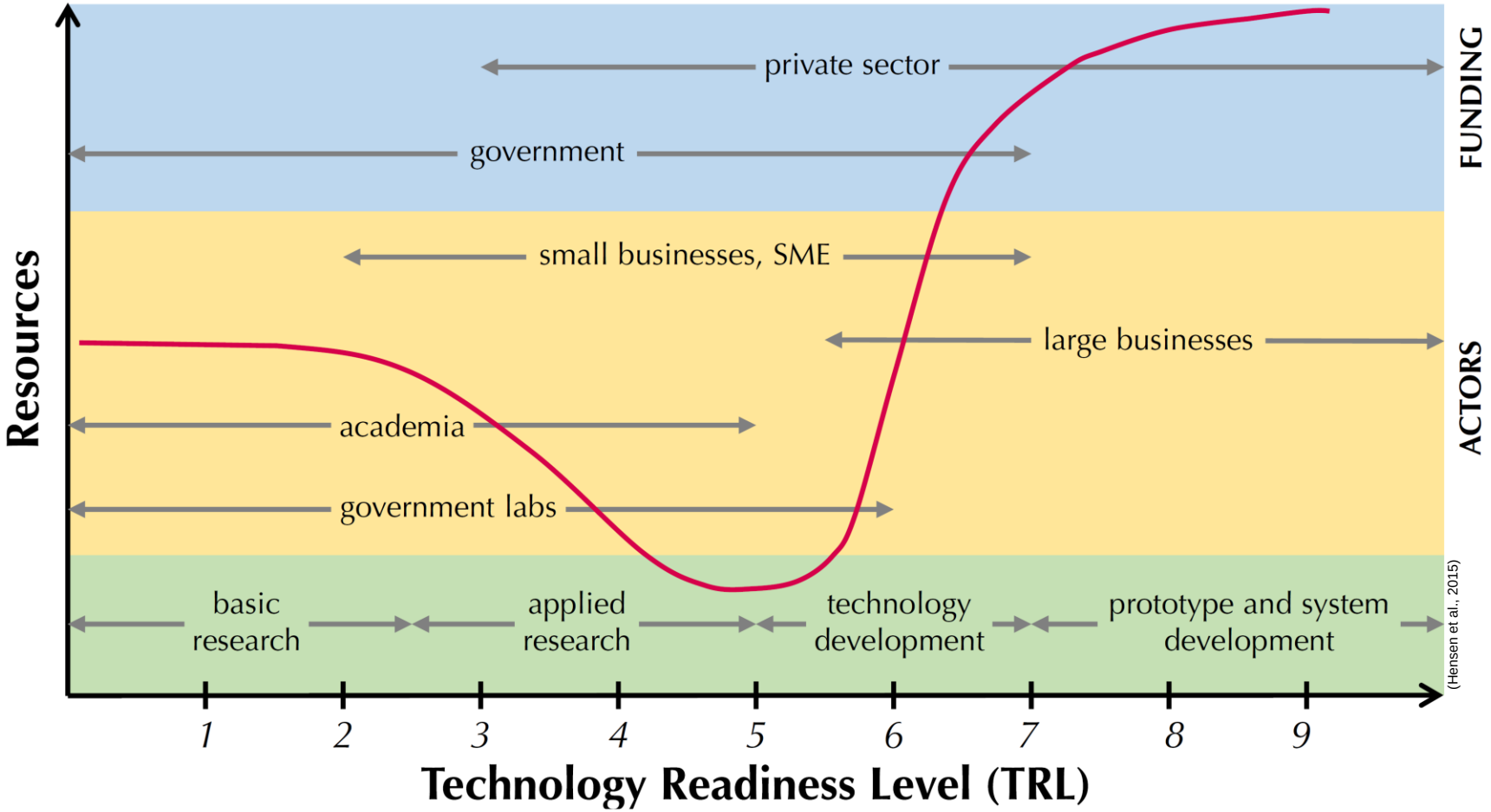
	DM %	Protein, %	GWP, kg CO_2 eq. global warming potential	OD, mg CFC11 ozone depletion	AC, g SO_2 eq. acidification	EU, g N eq. eutrophication	ED, MJ energy demand	FD, m^3 freshwater depletion	LU, m^2a land use
Soybean meal	87.5[1]	49.1[1]	0.34-0.72[1] 6.52[19]	0.2-0.3[1,17]	−1.2 – 3.1[1] 11.4[17]	−81-2[1] (g NO_3 eq.)	5.37[6] 25.5[19]	0.04[6]	3.26[6]
Rapeseed cake	89[1]	34.8[1]	0.37-0.57[6]	0.004-0.05[6]	6.8-7.5[6]	8.9-9.1[6]	3.3-3.8[6]	0.001-0.03[6]	1.5-1.6[6]
Pea protein meal	n/a	n/a	0.44[6] 4-10[8] (pulses)	0.057[6]	21.8[6]	7.94[6]	5.25[6]	0.03[6]	2.85[6]
Fishmeal	90[4]	60-72[5]	0.12-0.58[18] 0.65-1.8[14,3,4,13] 0.48-5.6[15,16] 5.37[17]	0.016-0.073[18] 0.83[3] 0.947-1.03[17,4]	0.12-8.7 [14,18] 7.0[13] 15.9-18.0[4.16] 56.7-62.6[19,3]	−16[4] 0.4-0.87 [3.18]	2.13-17.1[18,4,3] 21[13] 79.8[17] 120[16]	0.0002-0.0016[18] 0.0036[3] 0.347[4]	0.0005-0.0052[1] [8,3] 0.6-1.1[14]
HM (this study)	96.6	56	5.3	0.43	21.3	17.9	84.18	0.0028	1.89
HP (this study)	30	17	1.16	0.091	5.3	4.6	17.9	0.0006	0.48
Fresh meat (chicken)	25-30	23-24	1.62-3.12[10]	1.8[10]	44.25[10]	75[10] (g NO_3 eq.)	18.5-65[10]	0.053-0.155[11]	19.5-31.3[11]
Whey concentrate	86-89[3]	60[3,7] 80[11,kp]	7.48[7] 0.8-7.4[6] 12.1[2] 28–43[8,kp] 40.6[11,kp]	0.01-0.06[9] 3.33[7] 3.8[11,kp]	0.05-1.5[6] 56.6[7]	1.14[6] 37.3[2] 3.59-101[9] 229.3[11,kp]	58.1[2] 83.3[7] 10.7-39.4[6]	0.003-0.066[6] 1.45[2] 9.58[7]	0.26-8.27[6]
Egg protein concentrate[9]	85	80	23.4	1.01	4000	139	183	2.65	40.1
Microalgae[9]	96	55	14.7-245.1	0.9-19.8	260.5-1407.5	40.6-105.3	217.1-4181.3	0.3-3.9	1.7-5.4

HM-Insect meal (defatted protein concentrate)
HP-Insect puree (fresh insect production)

Sources: [1] – (Dalgaard 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., 2016); [8] - (Nijdam et al., 2012); [9] – (Smetana et al., 2017); [10] – (González-García et al., 2014; Weidema et al., 2008); [11] – (Wiedemann et al., 2017); [12] – (Bacenetti et al., 2018); [13] – (Papatryphon et al., 2004); [14] – (Samuel-Fitwi et al., 2013); [15] – (Cashion et al., 2017); [16] – (Smárason et al., 2017); [17] – (Silva et al., 2017); [18] – (Fréon et al., 2017); [kp] – per kg protein. Note: HP – *H. illucens* puree (fresh insect production); HM – *H. illucens* 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.

Smetana, Schmitt & Mathys (2019). Resources, Conservation & Recycling. 144, 285–296.

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



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ECONOMIES OF SCALE

ETH Sustainable Food Processing Research-Focus Microalgae

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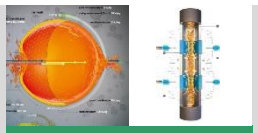
Microalgae


Algae Bioreactors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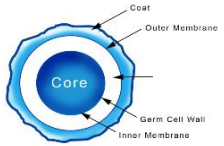

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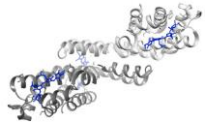
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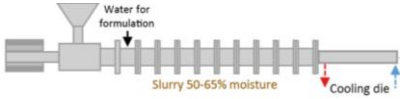

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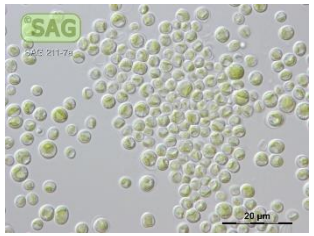
Multi Indicator Sustainability Assessment - Method Development and Case Studies

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



Auxenochlorella protothecoides

Changes in pigments: reduced green colour → Food, cosmetics and bio-based applications

Photoautotrophic
Mixotrophic
Heterotrophic

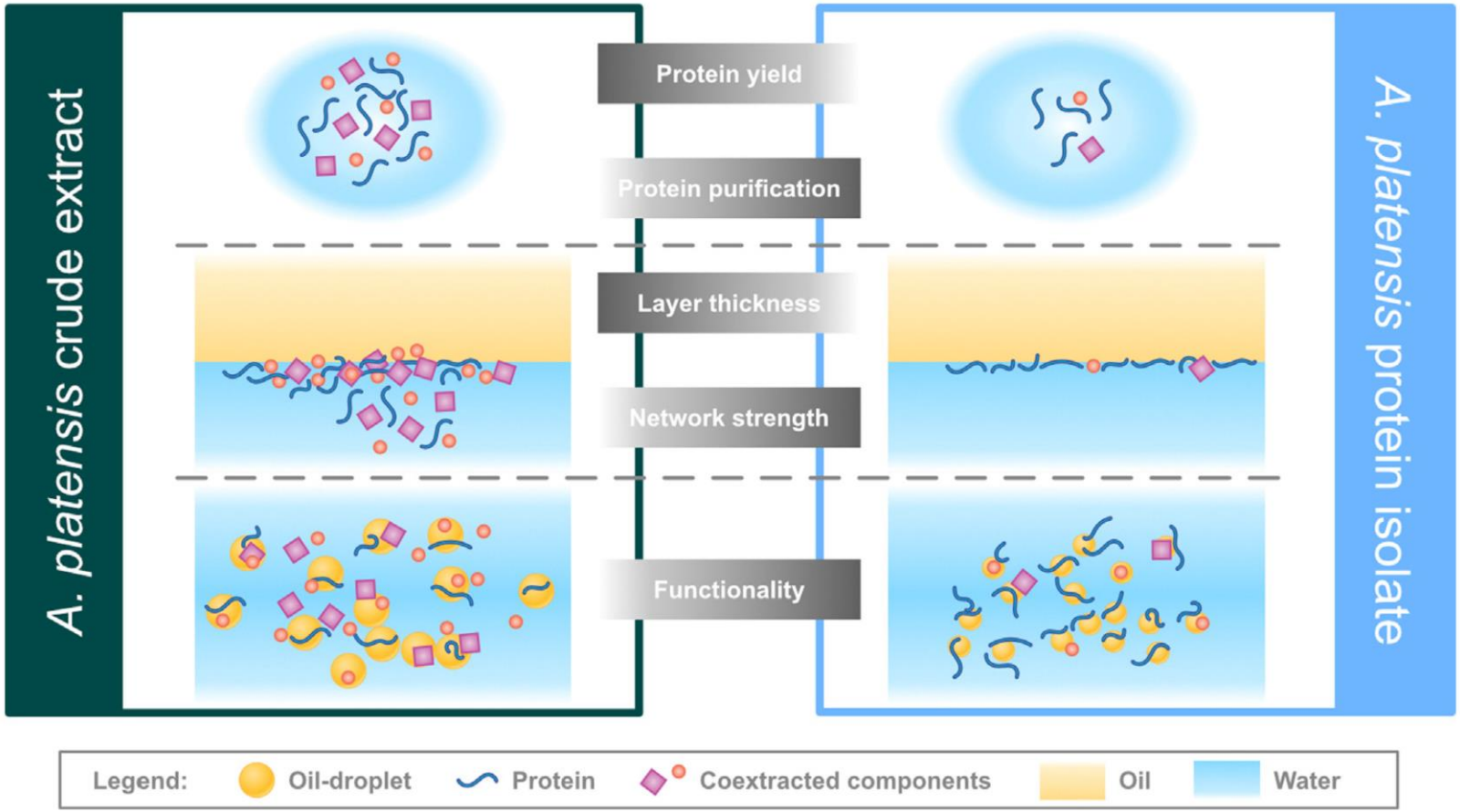
→ Chlorophyll ↓
Carotenoids ↑

→ O/W emulsions

Phot
Mix
Het

Caporgno, Haberkorn, Böcker & Mathys (2019). Bioresource Technology, 288, 121476.

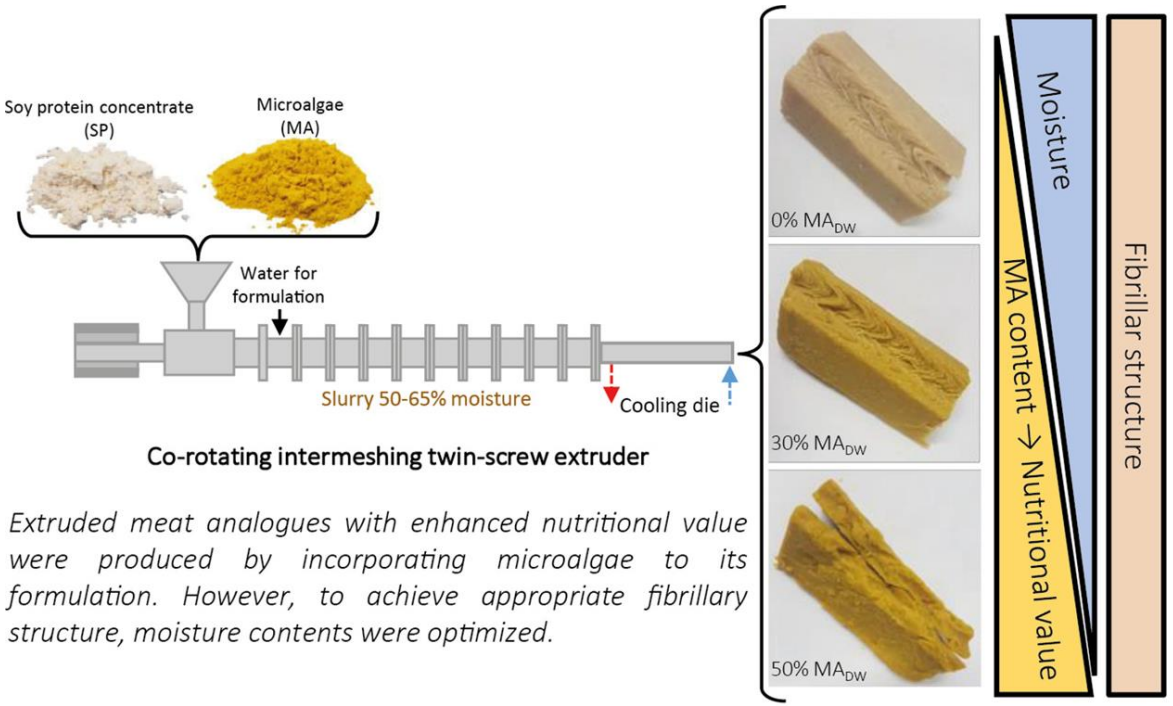
Effect of *Arthrospira* (Spirulina) protein purification on emulsification mechanism and efficiency



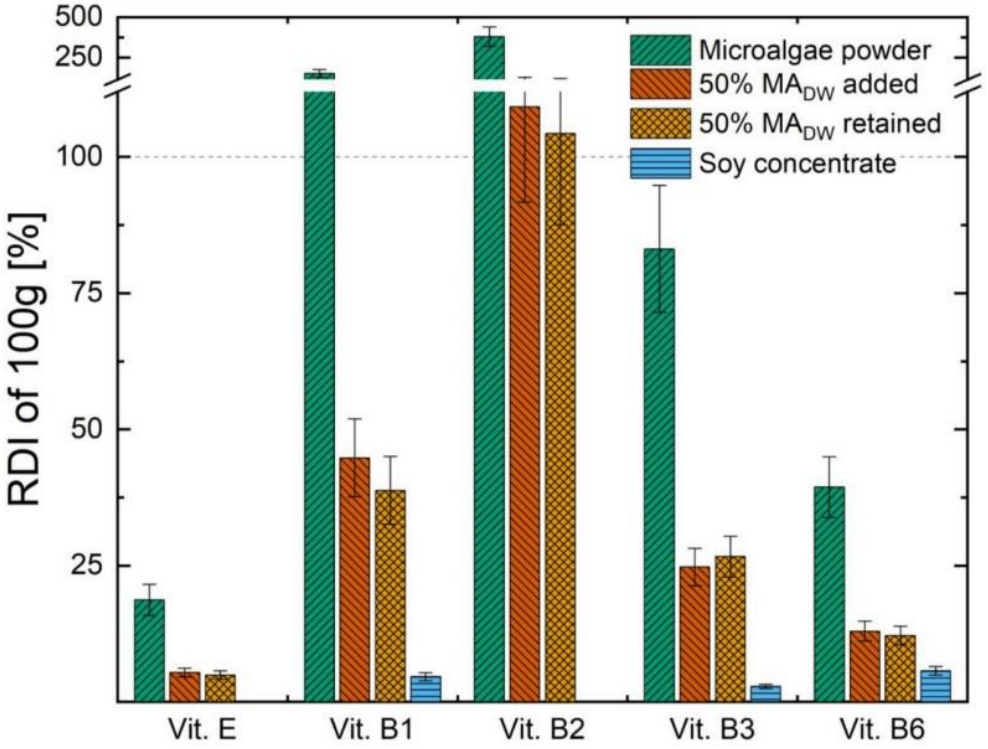
Böcker, Bertsch, Wenner, Teixeira, Bergfreund, Eder, Fischer & Mathys (2021) Journal of Colloid and Interface Science. 584, 344-353.

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

planted.



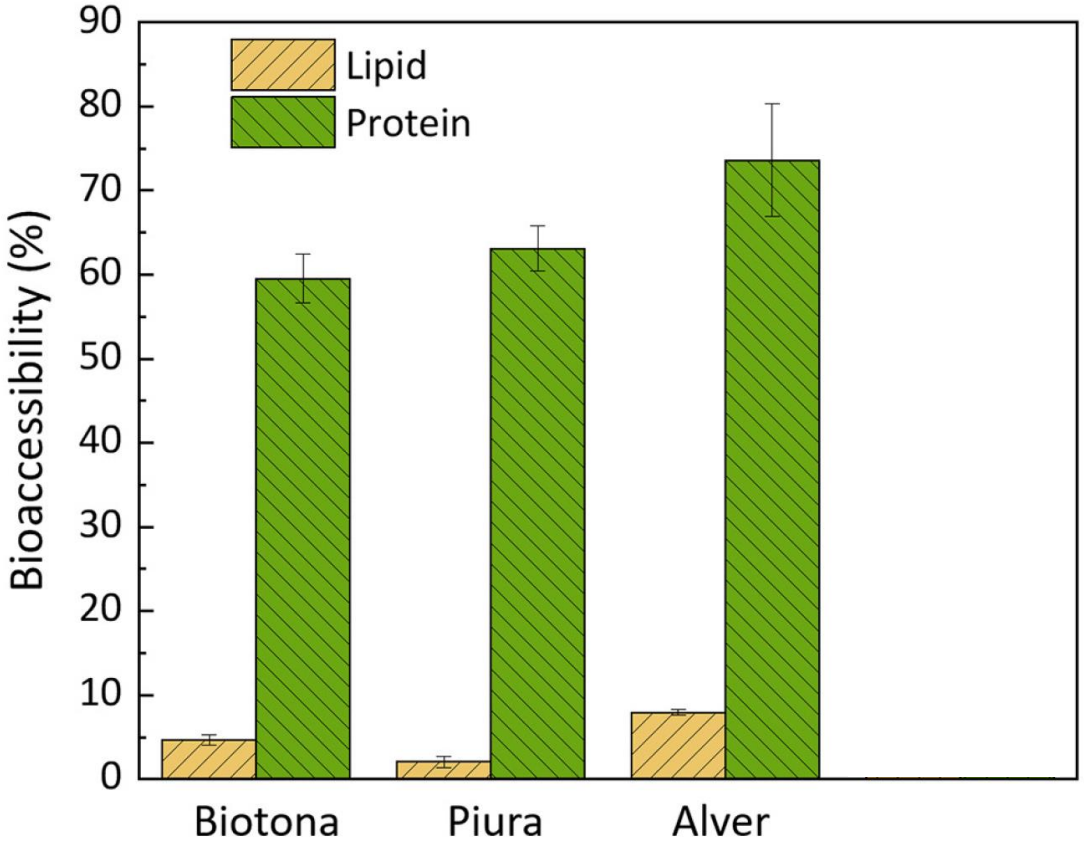
Extruded meat analogues with enhanced nutritional value were produced by incorporating microalgae to its formulation. However, to achieve appropriate fibrillary structure, moisture contents were optimized.



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

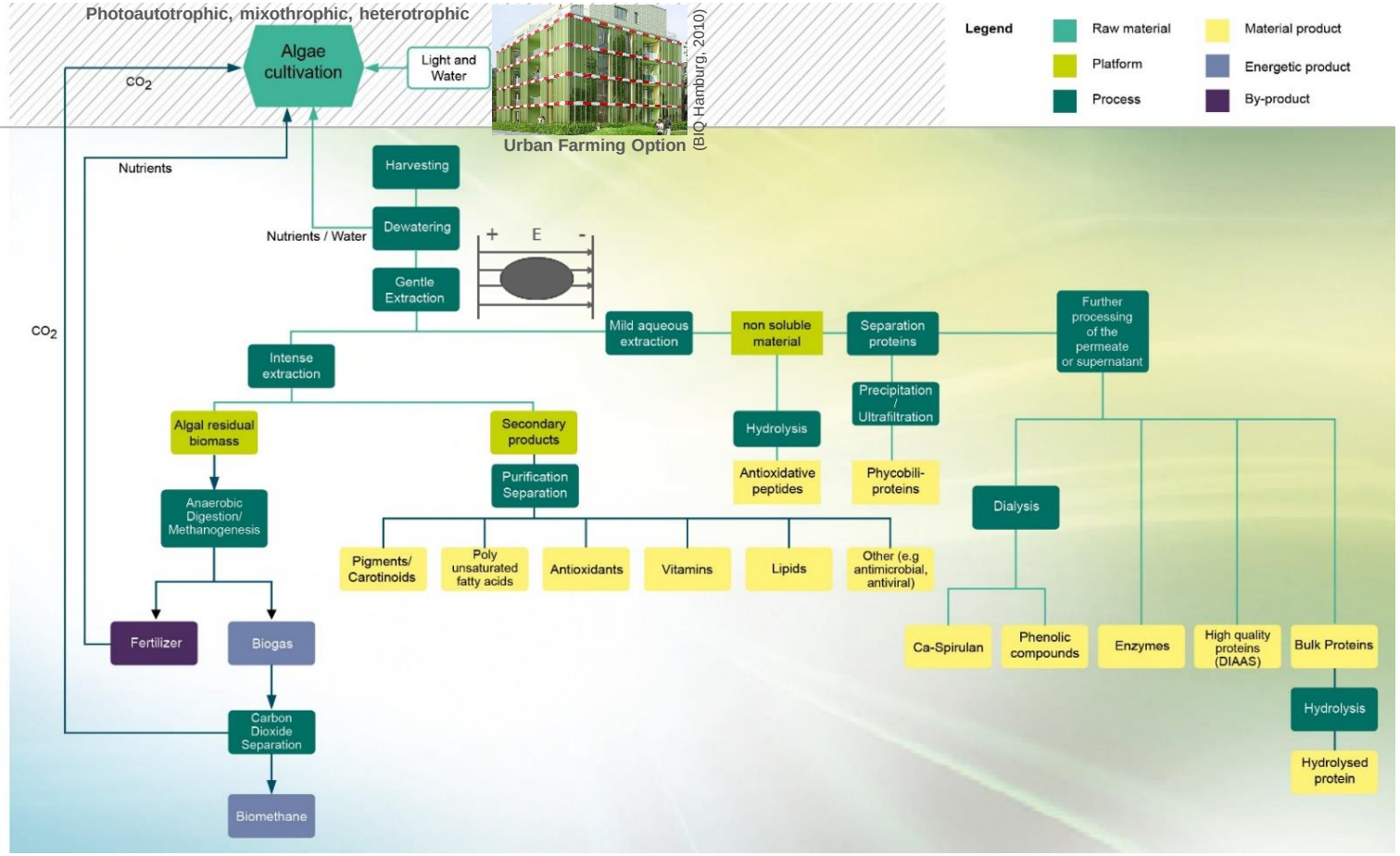
Caporgno, Böcker*, Müssner, Stirnemann, Haberkorn, Adelmann, Handschin, Windhab & Mathys (2020). Innovative Food Science and Emerging Technologies, vol. 59, pp. 102275*

Different protein and lipid bioaccessibility in commercial biomass



Canelli, Tarnutzer, Carpine, Neutsch, Bolten, Dionisi and Mathys (2020).Front. Nutr. 7:565996.

Future outlook-How to integrate our R&D
Innovative Algae Biorefinery Concept based on emerging up- and downstream



Multi Indicator Sustainability Assessment

ETH zürich (SEC) SINGAPORE-ETH CENTRE World Food System Center

1) Buchmann, Bloch & Mathys, 2018
2) Buchmann, Böcker, Frey, Haberkorn, Nyffeler & Mathys, 2018
3) Caporgno & Mathys, 2018; Mathys, 2018
4) Böcker, Ortmann, Surber, Leeb, Reineke & Mathys, 2019
5) Buchmann, Bertsch, Böcker, Krähenmann, Fischer & Mathys, 2019
6) Buchmann, Brändle, Haberkorn, Hiestand & Mathys, 2019
7) Buchmann, Frey, Gusbeth, Ravaynia & Mathys, 2019
8) Buchmann & Mathys, 2019
9) Caporgno, Haberkorn, Böcker & Mathys, 2019
10) Haberkorn, Buchmann, Hiestand & Mathys, 2019
11) Smetana, Schmitt & Mathys, 2019
12) Böcker, Hostettler, Diener, Eder, Demuth, …Mathys, 2020
13) Canelli, Neutsch, Carpine, Tevere, Giuffrida, …Mathys, 2020
14) Canelli, Tarnutzer, Carpine, Neutsch, Bolten, Dionisi ...Mathys, 2020
15) Caporgno, Böcker, Müssner, Stirnemann, Haberkorn, …Mathys, 2020
16) Haberkorn, Walser, Helisch, Böcker, Belz, Schuppler …Mathys, 2020
17) Bertsch, Böcker, Mathys & Fischer, 2021
18) Böcker, Bertsch, Wenner, Teixeira, Bergfreund, Eder …Mathys, 2021
19) Canelli, Murciano Martínez, Austin, Ambühl, Dionisi, …Mathys, 2021
20) Canelli, Murciano Martínez, Maude Hauser, …Mathys, 2021
21) Haberkorn, Buchmann, Häusermann & Mathys, 2021
22) Haberkorn, Off, Besmer, Buchmann & Mathys, 2021
23) Haberkorn, Siegenthaler, Buchmann, Neutsch & Mathys, 2021

Thank you very much

Our new Future Food lab at the Singapore ETH Center

(SEC) SINGAPORE-ETH CENTRE

CREATE Tower. *Credit:Photography by Tim Griffith*

Acknowledgement

Whole IFNH

Donors Buhler AG & Migros Industry Support

Partners

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