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Algae and Edible-Insect Proteins: Challenges and Opportunities for the Biofood Industry

Lucie Beaulieu, Ph.D. Université Laval-INAF

Alain Doyen, Ph.D. Université Laval-INAF

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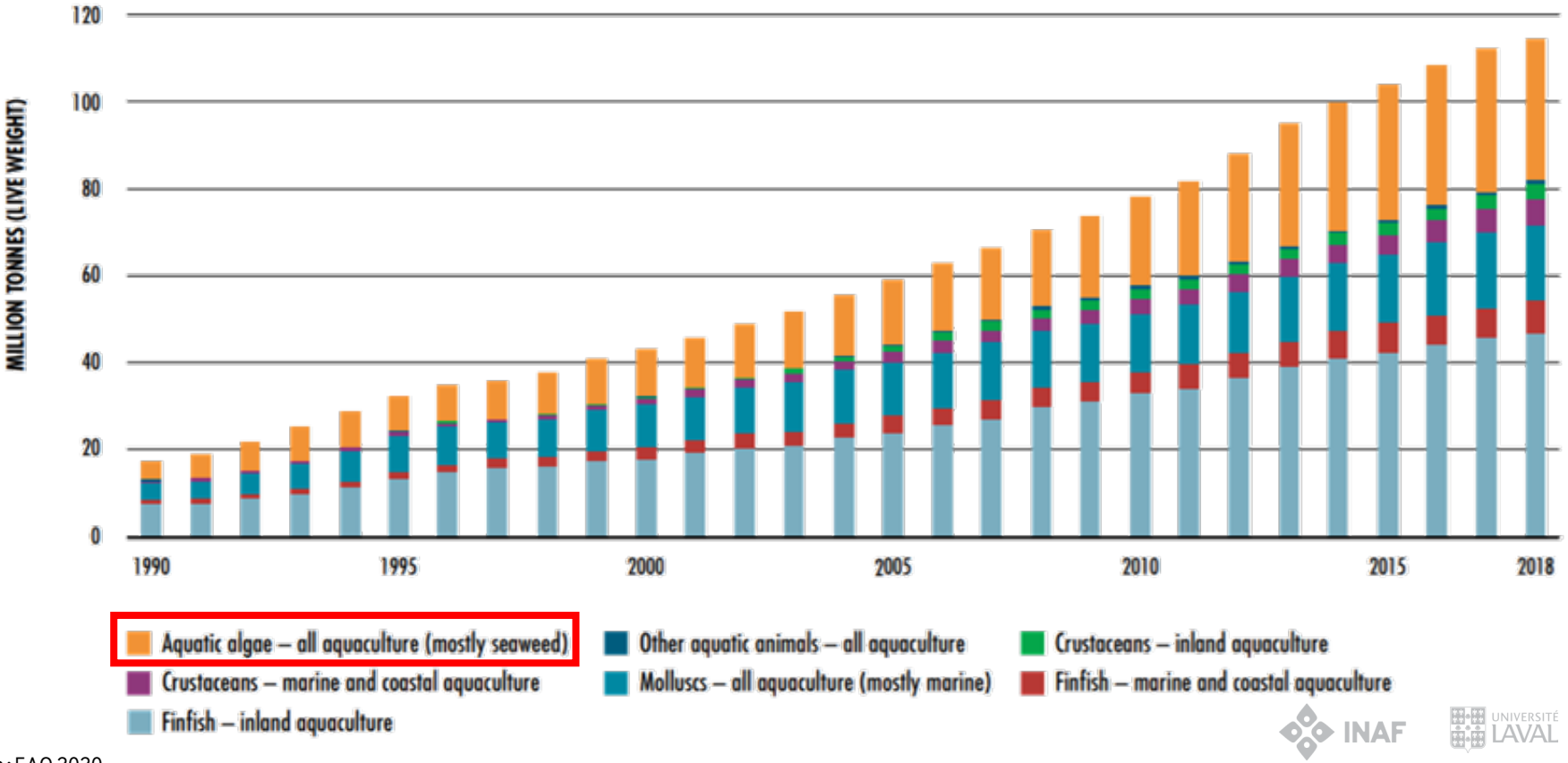
How to feed > 9.6 billion humans by 2050?

Edible algae (seaweed)

Figure 8

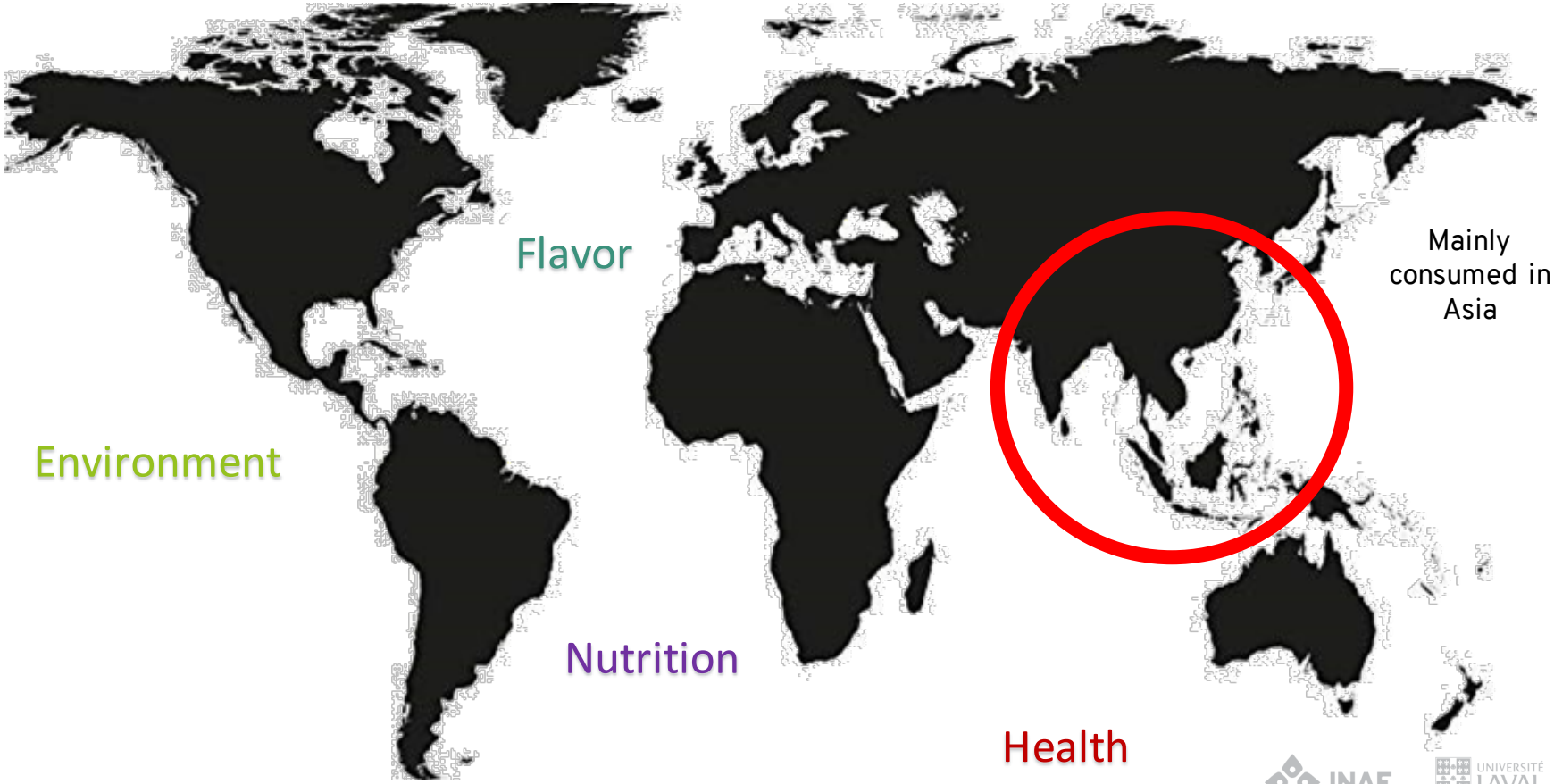
WORLD AQUACULTURE PRODUCTION OF AQUATIC ANIMALS AND ALGAE 1990-2018



Source : FAO 2020.

GLOBAL ALGAE PRODUCTION

35.1 million tonnes of aquatic algae (USD 16.5 billion)



Source: FAO 2022.

MORE SUSTAINABLE FOOD SOURCE

Seaweed cultivation

- Seaweed farming doesn't require fresh water, pesticides, or fertilizer.
- The low environmental footprint of farmed seaweed makes it an important ingredient of the future food supply.

Journal of Cleaner Production 307 (2021) 127301

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

2 scenarios resulted in a lower Global Warming Potential (GWP) and energy demand for seaweed protein than for soy protein.

Environmental impacts of protein-production from farmed seaweed: Comparison of possible scenarios in Norway

Matthias Koesling [a, *], Nina P. Kvadsheim [b], Jon Halfdanarson [b], Jan Emblemsvåg [b], Céline Rebours [b]

[a] NIBIO - Norwegian Institute of Bioeconomy Research, Department of Agricultural Technology and Systems Analysis, Gunnars Veg 6, 6630, Tingvoll, Norway
[b] Møreforsking AS, 6009, Ålesund, Norway

MACROALGAE AS A SOURCE OF PROTEIN

The protein composition of macroalgae varies depending on :

- Species
- Season
- Geographic distribution
- Cultivation parameters (nutrients, temperature, light, drought,…)
- Processing (drying, bleaching, freezing, fermentation,…)

Coastal areas with low level of industrial activity allow seaweed farming

- No problem associated with the accumulation of heavy metals or pathogenic microorganisms

Photo : Merinov

Source : Beaulieu et al. 2016; Lafeuille et al. 2023.

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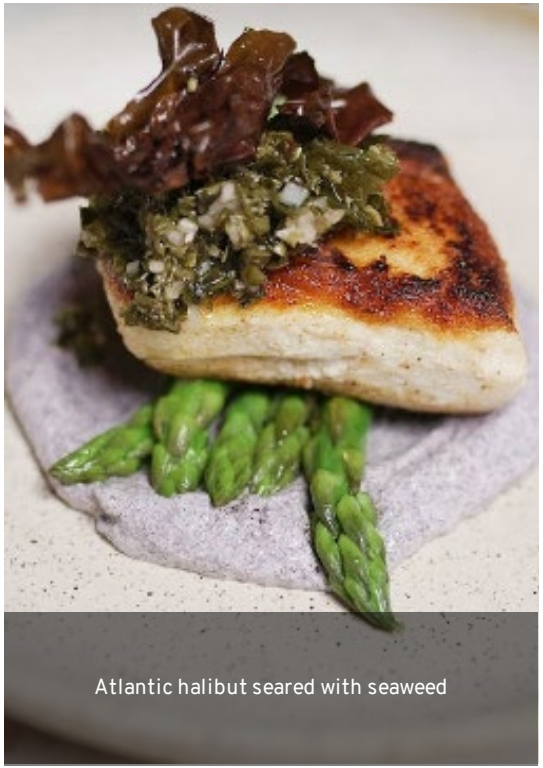
Are macroalgae good sources of protein?

Seaweed tartar



Atlantic halibut seared with seaweed

Seaweed salad with sesame

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EDIBLE MACROALGAE (SEAWEED)

Brown : (1-24% proteins)

Green : (4-44% proteins)

Red : (5-50% proteins)

% = dry weight

Nori

Source : Rioux et al. 2017.

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MACROALGAE: ALTERNATIVE SOURCES OF PROTEINS

Up to 50% proteins

Protein contents

- Comparison to
  - Soybean (37%)
  - Meat (43%)
  - Milk (26%)
  - Yeasts (39%)

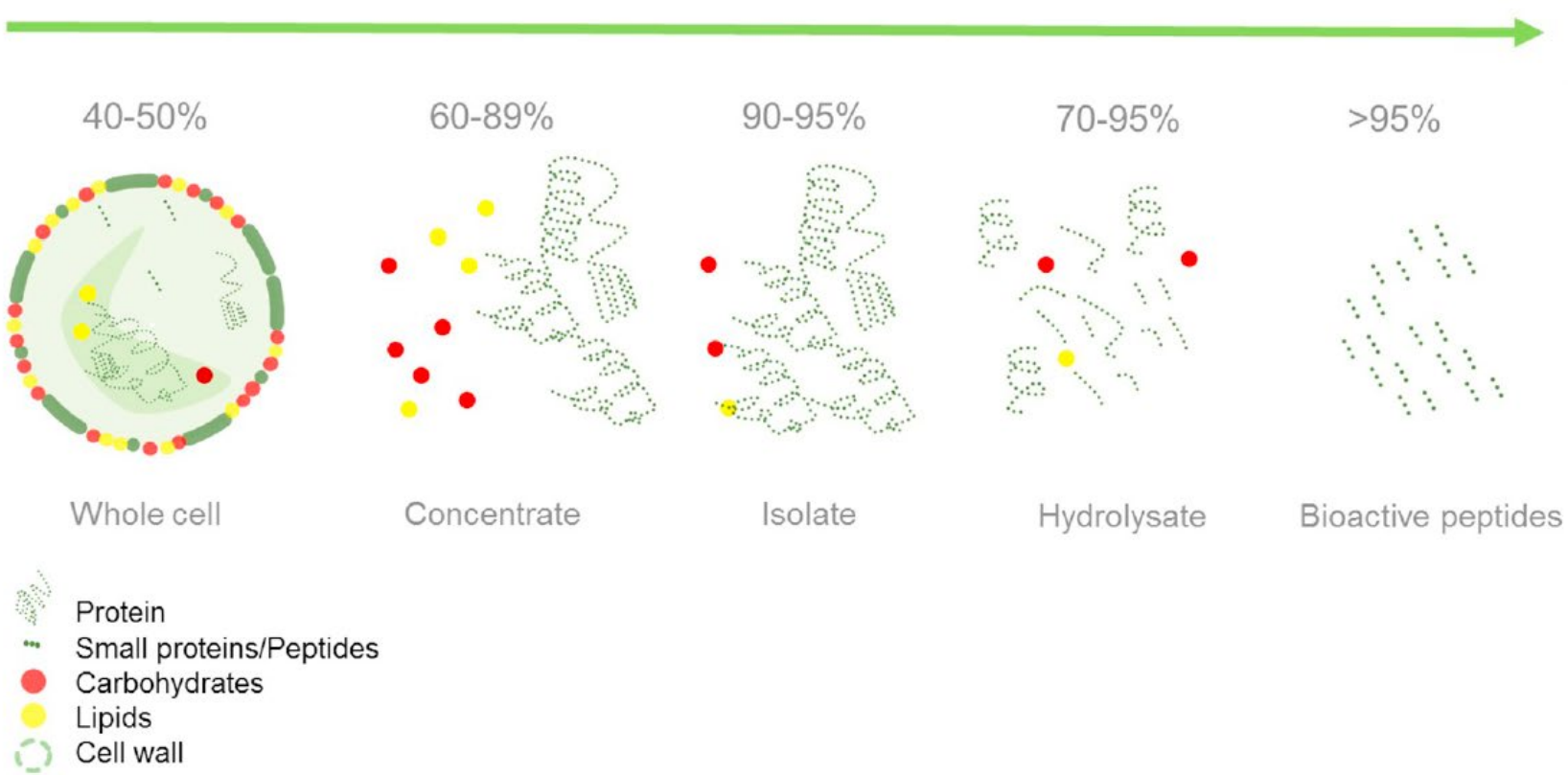
Essential amino acids

- Comparison to
  - Legumes & eggs
  - Aspartic & glutamic acids – **Umami**
  - Nutritive food ingredients with bioactive potential

% = dry weight

Sources : Pereira, 2011; Soto-Sierra et al. 2018; Wells et al. 2017.

ALGAE-BASED PROTEIN PRODUCTS



Source: Soto-Sierra et al. 2018.

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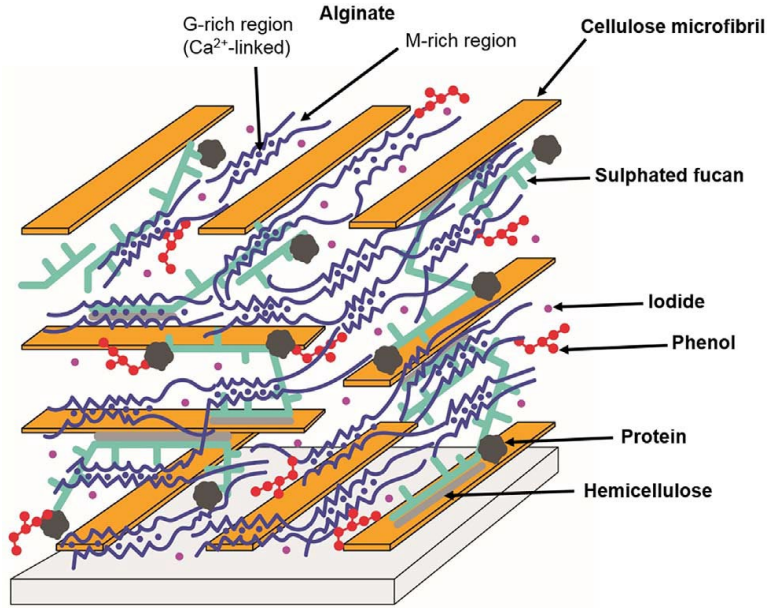
EXTRACTION OF MACROALGAE PROTEINS

Factors affecting protein extraction into the cell wall:

- Rigidity
- Polysaccharides (fibres)
- Polyphenols



Source: Charoensiddhi et al. 2017.

What about their digestibility and allergenicity?

Digestibility

Comparison to

- Cereals (69-84%)
- Legumes (72-92%)
- Fruits (72-92%)
- Vegetables (68-80%)

Antinutritional factors

- Polyphenols linked to proteins and digestive enzymes
- Protein-bound polysaccharides (fibres)

Species	In vitro digestibility*
Red	83% – 87%
Green	82% – 86%
Brown	79% – 82%

* Relative digestibility (%) compared to casein

Allergenicity

- Solely one case of food allergies to red (Nori) seaweed was reported.

Sources: Bikker et al. 2016; Charoensiddhi et al. 2017 ; Tibbetts et al. 2016; Thomas et al. 2019.

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HOW TO IMPROVE THE DIGESTIBILITY OF ALGAE PROTEINS?

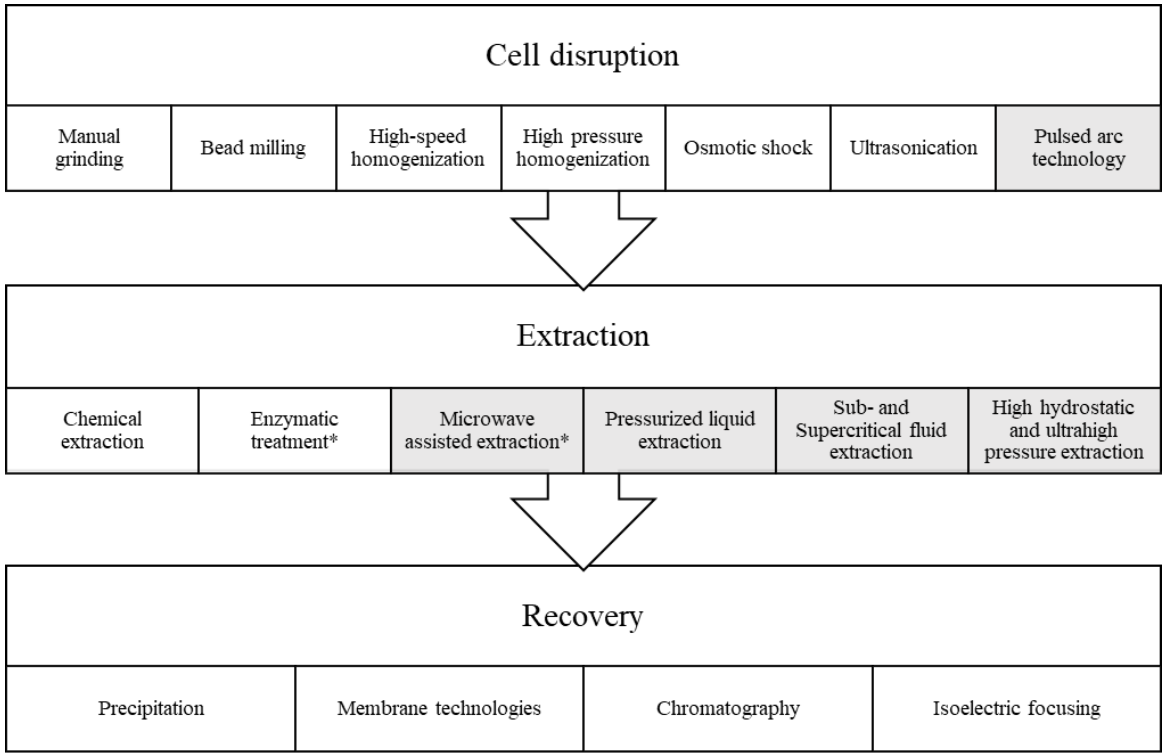


Figure 6.1. Overview of the conventional and emerging methods (highlighted in gray) for protein and peptide extraction from algae. * Both enzymatic treatment and microwave assisted extraction could be considered as cell disruption methods.

Source: Tremblay & Beaulieu, 2021.

How to incorporate macroalgae into your diet?

Figure 8. Différents produits alimentaires à base d'algues

Source : Côté-Laurin et coll., 2016; CRIBIQ, 2021

Source: Maillard et al. 2023. Fiche synthèse. CRAAQ – INAF – UL. 25 p.

AROMA WHEEL AND SENSORIAL ANALYSIS

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

pubs.acs.org/JAFC Review

Algae as a Source of Natural Flavors in Innovative Foods

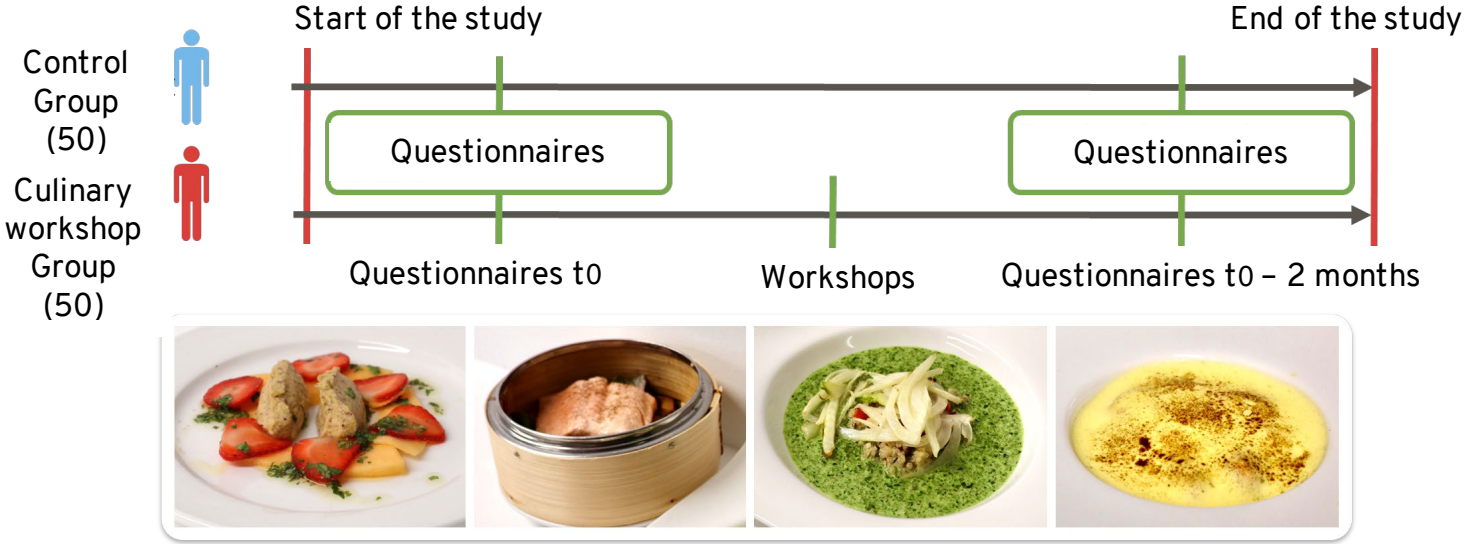
Nellie Francezon, Ariane Tremblay, Jean-Luc Mouget, Pamela Pasetto, and Lucie Beaulieu*

Cite This: https://doi.org/10.1021/acs.jafc.1c04409 Read Online

How consumers perceive macroalgae?

Increasing intention to eat seaweeds through culinary workshops with a chef : a randomized controlled study on Quebec consumers

Lafeuille, B., Turcotte, M., Tamigneaux, É., Berger, K., Beaulieu, L., Provencher, V. 2023. Food Quality and Preference. *Article in press.*

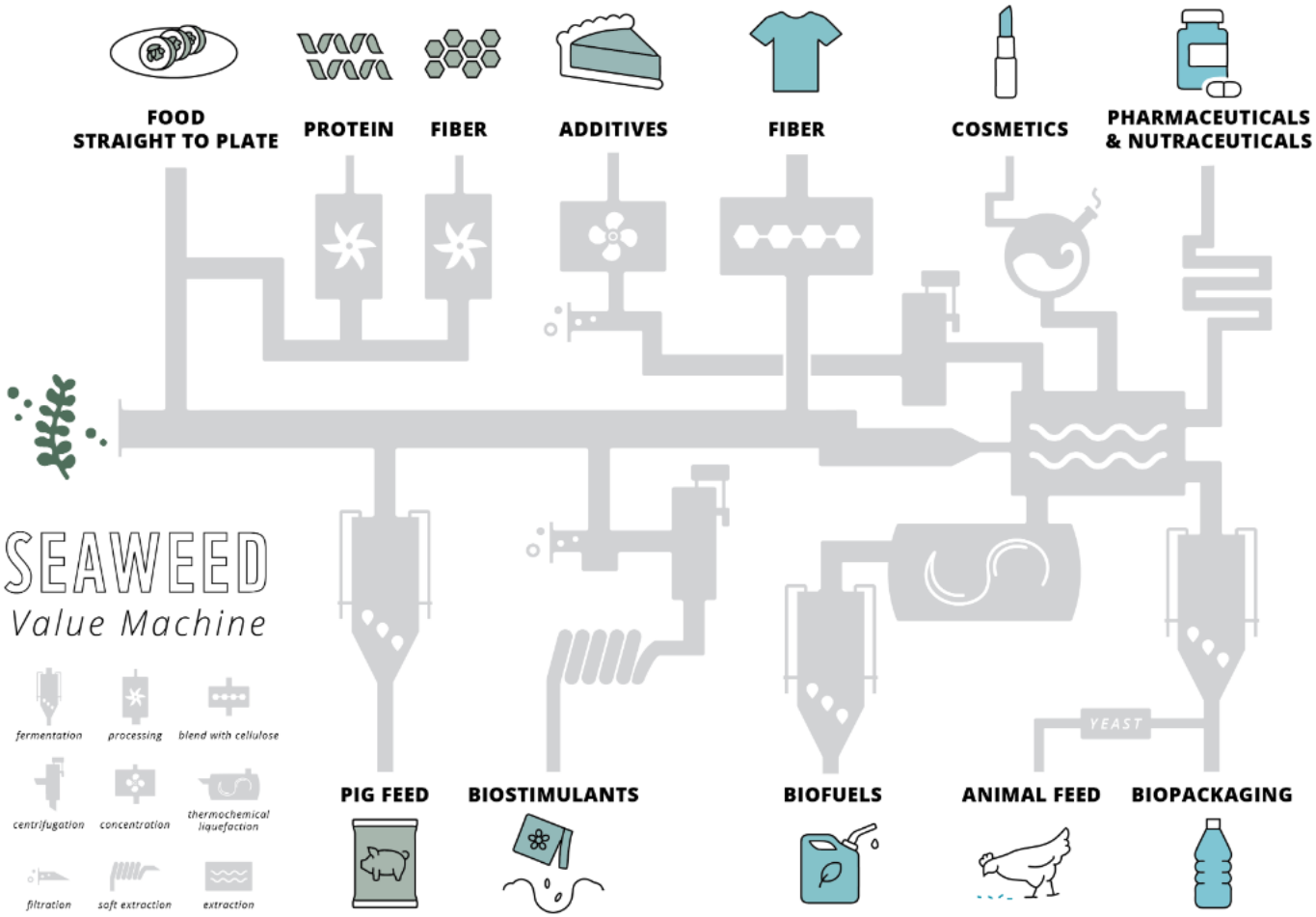


CONCLUSIONS AND OUTLOOK

Macroalgae in the spotlight

1. Macroalgae have a long tradition in Asian cuisine.
2. Asian producers are facing constraints related to pollution and availability of marine areas.
3. More interest in Occident: basic nutritional value, health benefits, specific flavors and textures to food.
4. Seaweed farming is possible with a low environmental footprint.
5. Algal protein content varies according to the species, origin, growth conditions and processing.
6. Algal protein-rich ingredients production is facing many challenges (technical, economic, high qualified personal ...).
7. Culinary innovation may be sustained by algae addition and consumer acceptance studies.

Photo : Seabiosis



©WWF-US / Katarina Jin with expertise from Oceanium

https://www.worldwildlife.org/industries/farmed-seaweed

Edible insects

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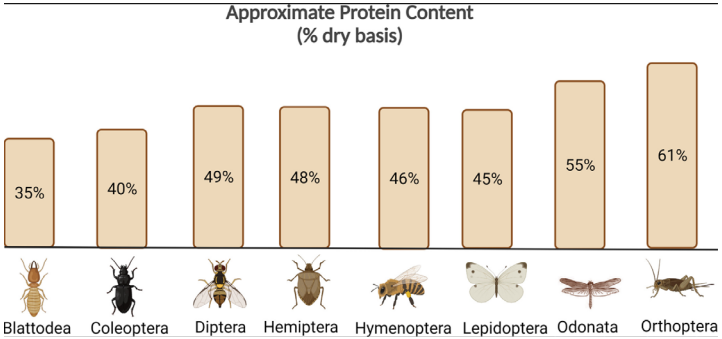
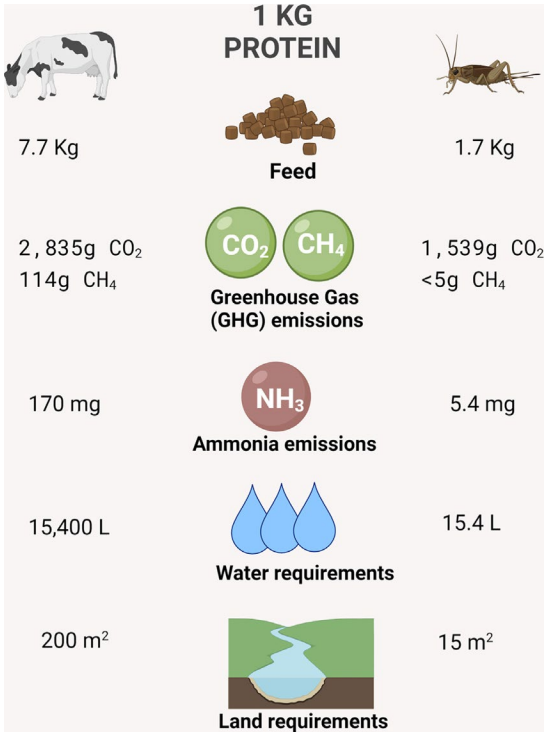


https://doi.org/10.1016/bs.afnr.2022.04.002



SDGs directly affected by edible insects	SDGs indirectly affected by edible insects	Other SDGs
2 ZERO HUNGER 6 CLEAN WATER AND SANITATION 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE 12 RESPONSIBLE CONSUMPTION AND PRODUCTION 13 CLIMATE ACTION 15 LIFE ON LAND 16 PEACE, JUSTICE AND STRONG INSTITUTIONS	1 NO POVERTY 3 GOOD HEALTH AND WELL-BEING 5 GENDER EQUALITY 7 AFFORDABLE AND CLEAN ENERGY 8 DECENT WORK AND ECONOMIC GROWTH 14 LIFE BELOW WATER	4 QUALITY EDUCATION 10 REDUCED INEQUALITIES 11 SUSTAINABLE CITIES AND COMMUNITIES
17 PARTNERSHIPS FOR THE GOALS		

https://doi.org/ 10.3390/insects12060557

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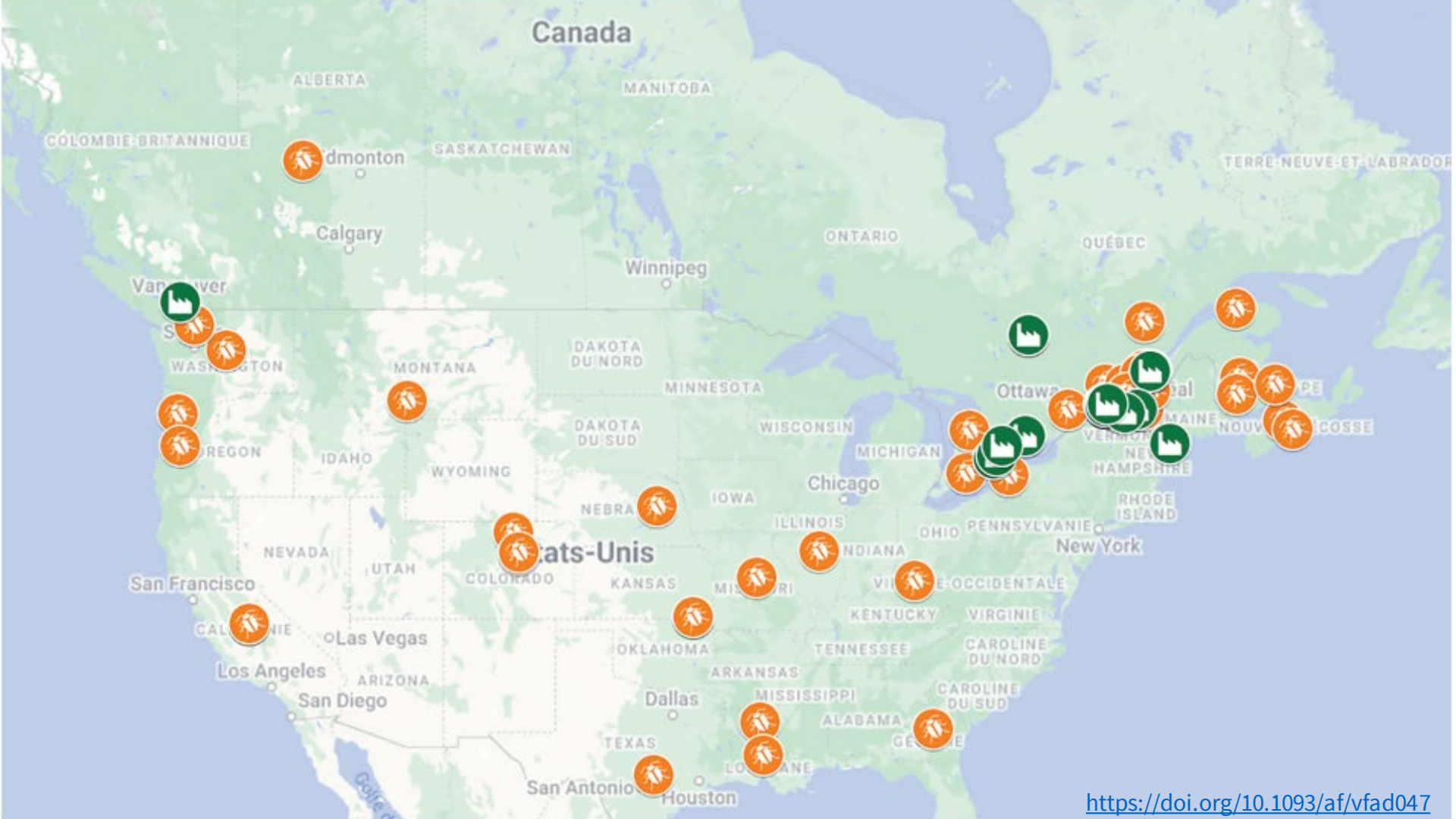
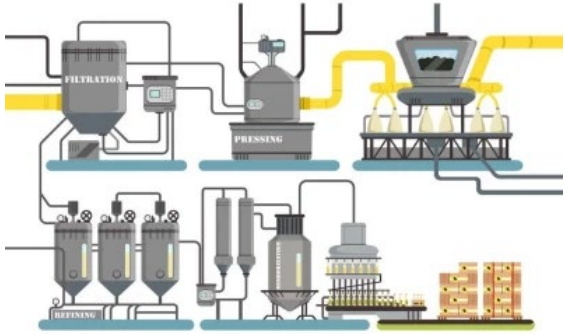
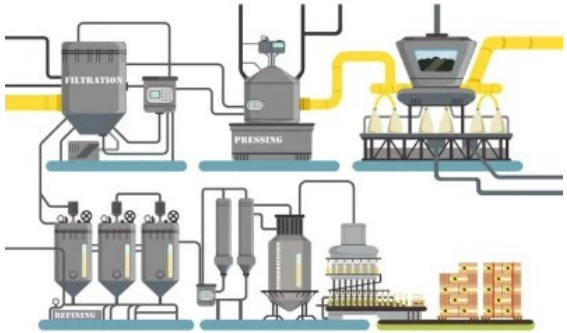


https://doi.org/10.1093/af/vfad047


FILTRATION
PRESSING
REFINING


Dairy
Gluten
Peanut
Egg
Nuts
Soy
Fish
Sesame
Crustaceans
Sulfites
Mustard
Celery
Shellfish
Lupine
FOOD ALLERGENS


Food Law



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Edible insect: the choice of food processes

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Table 2. Foodborne biological contaminants (bacteria and fungi) reported in edible insect species that pose a potential food safety risk. In the case only a genus name is mentioned, one or more species within that genus (other than a species that also may be listed) can be pathogenic.

Study	Insect species	Potential foodborne biological safety risks identified	
		Bacteria	Fungi
Garofalo *et al.* (2019)	*Alphitobius diaperinus* *Tenebrio molitor*	*Aeromonas, Bacillus, Pseudomonas* *Bacillus cereus* group, *Bacillus, Clostridium perfringens, Clostridium, Cronobacter, Escherichia coli, Listeria*[1], *Pseudomonas, Salmonella*[2], *Staphylococcus aureus, Staphylococcus, Vibrio, Yersinia*	*Aspergillus flavus, Aspergillus, Penicillium* *Penicillium*
	Acheta domesticus	*B. cereus* group, *Bacillus, C. perfringens, Clostridium, Listeria*[1], *Pseudomonas, Staphylococcus*	*Aspergillus*
	Locusta migratoria	*Bacillus, C. perfringens, Pseudomonas, Staphylococcus, Yersinia*	*Aspergillus*
Kooh *et al.* (2019)	*A. diaperinus* *T. molitor* *A. domesticus* *L. migratoria* Edible insects in general	 *B. cereus* group, *C. perfringens, Clostridium* *B. cereus* group, *C. perfringens* *C. perfringens* *Bacillus, B. cereus* group, *C. perfringens, S. aureus*	*A. flavus*
Murefu *et al.* (2019)	*A. diaperinus* *T. molitor* *A. domesticus* *L. migratoria*	*Bacillus, Clostridium* *Bacillus, B. cereus* group, *Clostridium, Escherichia, Listeria*[1], *Pseudomonas, Staphylococcus* *Bacillus, B. cereus* group, *Clostridium, Listeria*[1], *Staphylococcus* *Staphylococcus*	*A. flavus, Aspergillus, Penicillium* *Penicillium*
Cappelli *et al.* (2020)	*A. diaperinus* *T. molitor* *A. domesticus*	 *B. cereus* group, *Bacillus, C. perfringens, Clostridium, Listeria*[1], *Staphylococcus* *B. cereus* group, *Bacillus, C. perfringens, Clostridium, Listeria*[1], *Staphylococcus, Yersinia*	*Aspergillus*

[1] Only the genus *Listeria* was detected so far. The pathogenic species *Listeria monocytogenes* has never been detected in edible insect species.
[2] *Salmonella* spp. were only detected by means of DNA-based analyses. Viable cells have not been detected so far.

https://doi.org/10.1016/j.ese.2023.100287

Substrates used for insect rearing

Item	Rearing Substrates				
	SG	B	C	SG-C	B-C
No starvation					
Total viable aerobic counts	7.08	7.63	6.46	6.84	7.77
Enterobacteriaceae	6.31	6.44	6.33	5.87	6.30
Staphylococci	3.85 ^{c}	5.96 ^{a}	5.29 ^{ab}	4.38 ^{b}	5.19 ^{ab}
Yeast and molds	3.30 ^{b}	5.60 ^{a}	6.31 ^{a}	3.13 ^{b}	5.34 ^{ab}
Lactic acid bacteria	6.20	5.18	5.57	5.44	5.31
Bacterial endospores	0.00 ^{d}	4.44 ^{ab}	3.44 ^{b}	2.05 ^{c}	5.32 ^{a}

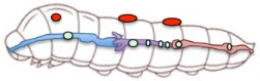
SG Spent grains

B Bread

C Cookies

10.3390/toxins11050282

Surface + gut microbiota



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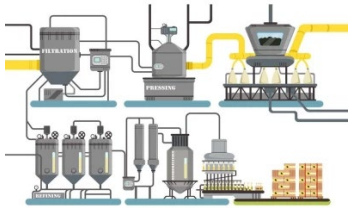


Thermal treatment: 90 à 100°C, <1 min to >5 min

Decrease of the initial contamination and inhibition of enzyme activities

Batch	Treatment	Microbial counts (log cfu/g)					
		Total aerobic count	Aerobic bacterial endospores	Entero-bacteriaceae	Lactic acid bacteria	Yeasts and molds	Psychrotrophic aerobic count
I	None (Initial count)	$7.9 \pm 0.3^{a, A}$	$2.6 \pm 0.3^{a, A}$	$7.3 \pm 0.5^{a, A}$	$7.4 \pm 0.2^{a, A}$	$3.8 \pm 0.5^{a, A}$	$7.2 \pm 0.4^{a,A}$
	10 s blanching	3.5 ± 0.8^{b}	2.8 ± 1.0^{a}	$<1.0 \pm 0.0^{b}$	$<1.0 \pm 0.0^{b}$	$<2.0 \pm 0.0^{b}$	$<1.0 \pm 0.0^{b}$
II	None (Initial count)	$8.2 \pm 0.7^{a, A}$	$2.8 \pm 0.4^{a, A}$	$7.5 \pm 0.6^{a, A}$	$7.0 \pm 0.1^{a, B}$	$3.5 \pm 0.2^{a, A}$	$6.0 \pm 0.2^{a, B}$
	20 s blanching	1.8 ± 0.4^{b}	4.7 ± 0.7^{b}	$<1.0 \pm 0.0^{b}$	$<1.0 \pm 0.0^{b}$	$<2.0 \pm 0.0^{b}$	$<1.0 \pm 0.0^{b}$
III	None (Initial count)	$7.6 \pm 0.4^{a, A}$	$3.1 \pm 0.1^{a, A}$	$7.1 \pm 0.9^{a, A}$	$6.9 \pm 0.2^{a, B}$	$3.5 \pm 0.4^{a, A}$	$6.5 \pm 0.6^{a, A, B}$
	40 s blanching	2.0 ± 0.4^{b}	2.3 ± 0.1^{a}	$<1.0 \pm 0.0^{b}$	1.5 ± 0.8^{b}	$<2.0 \pm 0.0^{b}$	$<1.0 \pm 0.0^{b}$

https://doi.org/10.1016/j.foodcont.2016.07.011

Specific bacteria and fungi encountered in processed insects ($n = 19$ isolates).

Species	Product	Findings
Acheta domesticus	Extruded	*Bacillus cereus*
Locusta migratoria	Dried	*Proteus* spp.[a], *Mucor* spp.[a]
Alphitobius diaperinus	Dried	*Penicillium* spp.
Tenebrio molitor	Dried	*Listeria ivanovii*, *Penicillium* spp., *Mucor* spp.
Apis mellifera	Pollen	Coliforms, *Serratia liquefaciens*, *Pseudomonas* spp.
Hermetia illucens	Fat	*Bacillus cereus*, *Aspergillus* spp., *Cryptococcus neoformans*
	Powder	*Bacillus cereus*[a]
	Dried	*Bacillus cereus*
Musca domestica	Dried	*Bacillus cereus*

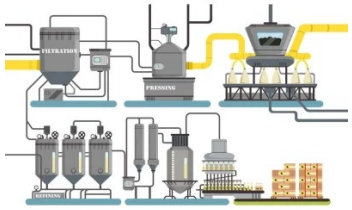
[a] Two samples positive, otherwise only one.

https://doi.org/10.1016/j.ijfoodmicro.2016.11.005

Thermal treatment: large decrease of the microbial load

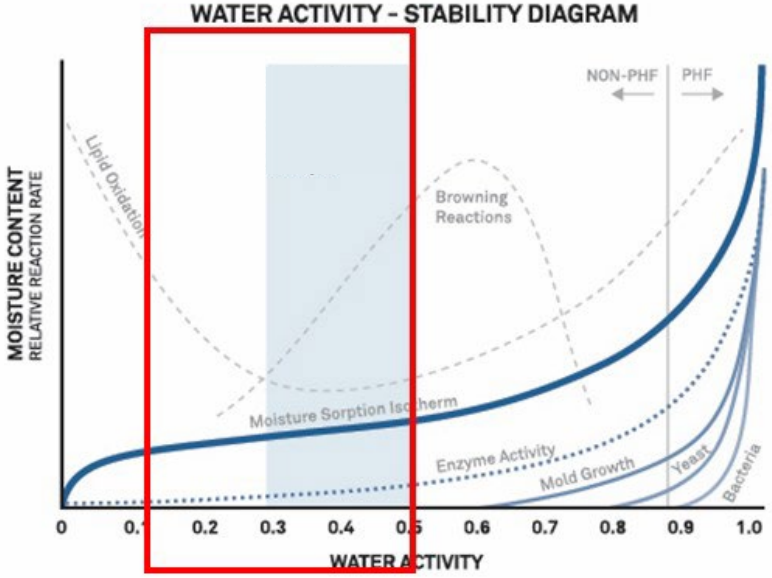
Persistence of foodborne and spoilage microorganisms

Necessary to optimize the process parameters



Drying processes

Treatment 	Water activity (–)
Fresh	0.95 ± 0.00[a]
Fluidized bed dried	0.54 ± 0.00[b]
Microwave dried	0.36 ± 0.01[c]
Freeze-dried	0.24 ± 0.00[d]
Vacuum dried	0.18 ± 0.01[e]
Rack oven dried	0.13 ± 0.00[e]



Stable products but potential autoxidation of unsaturated lipids

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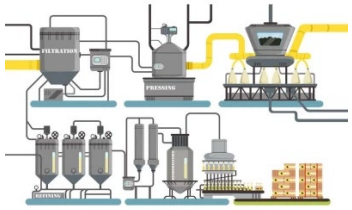
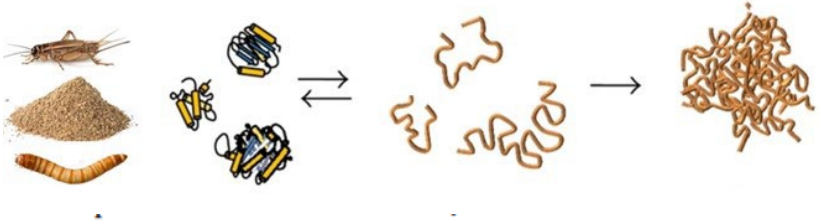


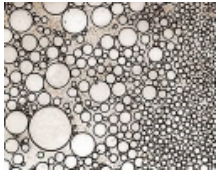
Thermal treatment

Drying

Grinding



Treatment	Protein solubility (%)
Fresh	53.24 ± 0.37[a]
Fluidized bed dried	19.25 ± 0.21[d]
Microwave dried	12.65 ± 0.06[f]
Freeze-dried	40.65 ± 0.21[c]
Vacuum dried	49.70 ± 0.12[b]
Rack oven dried	14.10 ± 0.27[e]



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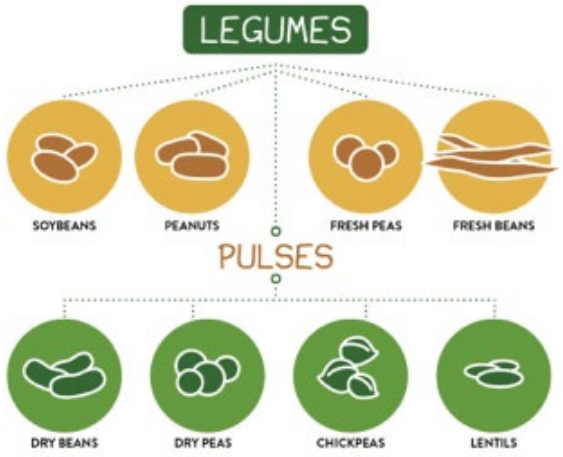
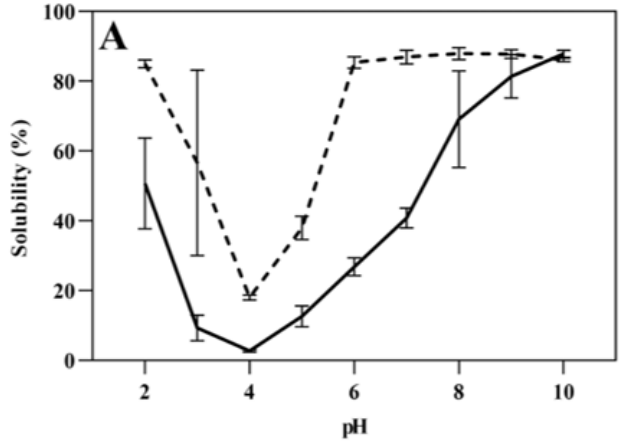
The development of high-added protein-rich ingredients



Edible insect protein concentrate and isolate (80-90% protein)

Protein concentrate and isolate



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Valorization of other insect components

Food Quality and Preference 79 (2020) 103755

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

Consumers' perception of bakery products with insect fat as partial butter replacement

Claudia Delicato[a,c], Joachim J. Schouteten[a,*], Koen Dewettinck[b], Xavier Gellynck[a], Daylan A. Tzompa-Sosa[b]

[a] Department of Agricultural Economics, Ghent University, Coupure Links 653, Gent 9000, Belgium
[b] Department of Food Technology, Safety and Health, Laboratory of Food Technology and Engineering, Ghent University, Coupure Links 653, Gent 9000, Belgium
[c] Department of Medical and Surgical Sciences, University of Foggia, Via A. Gramsci 89/91, Foggia 71122, Italy

Journal of Cleaner Production 264 (2020) 121670

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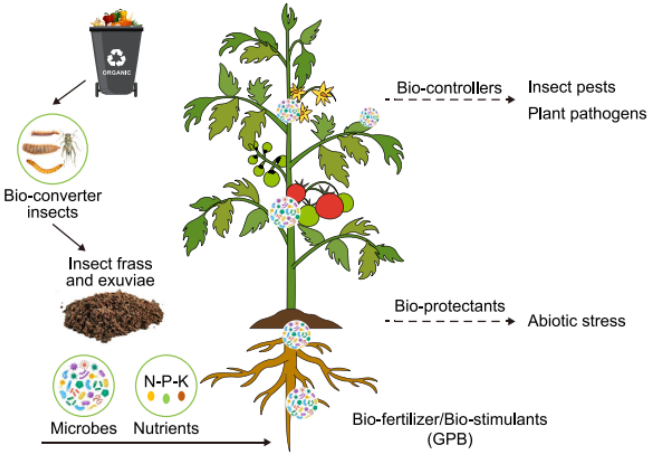
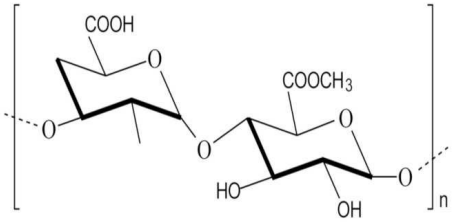
Insect margarine: Processing, sustainability and design

Sergiy Smetana [a, *], Lars Leonhardt [a], Saara-Maria Kauppi [b], Aleksandar Pajic [a], Volker Heinz [a]

[a] German Institute of Food Technologies – DIL e.V., Prof.-von-Klitzing-Str. 7, 49610, Quakenbrueck, Germany
[b] NTNU: Norwegian University of Science and Technology, NO-7491, Trondheim, Norway





Edible insects: the consumer acceptability

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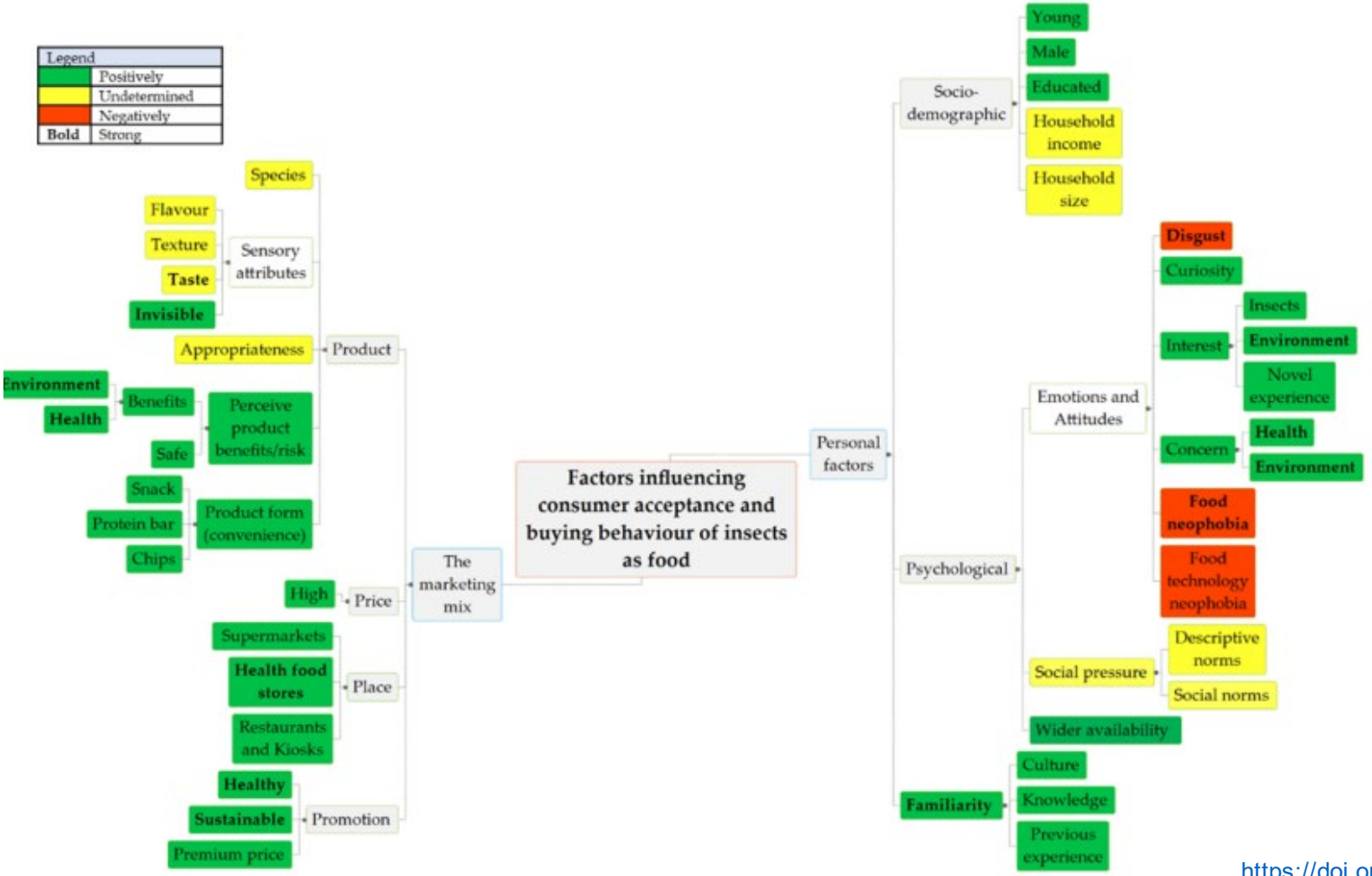

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Table 1. Interview questions asked before (Q1-7) and after (Q8) the offer to taste and respective answers (n=149 if not stated otherwise).

Questions	Yes (%)	No (%)
Q1 Have you ever eaten insects?	26.17 (n=39)	73.83 (n=110)
If yes, which species and where? (see also Figure 2)		
Q2 Do you like to try new things?	87.25 (n=130)	12.75 (n=19)
Q3 Can you imagine to eat insects?	78.52 (n=117)	21.48 (n=32)
Whole	17.45 (n=26)	
Processed e.g. in a protein bar	18.79 (n=28)	
Or both whole and processed?	42.28 n=63)	
Q4 Do you consider insects as food of the future? (n=145)	71.03 (n=103)	28.97 (n=42)
Q5 Are insects a sustainable alternative to meat? (n=148)	67.57 (n=100)	32.43 (n=48)
Q6 Would you buy whole insects in a supermarket?	36.24 (n=54)	63.76 (n=95)
Q7 Would you buy processed insects in a supermarket?	64.43 (n=96)	35.57 (n=53)
Q8 Did you like the taste of the sample? (n=112)[1]	71.43 (n=90)	17.86 (n=20)

[1] No answer was received by two interviewees.

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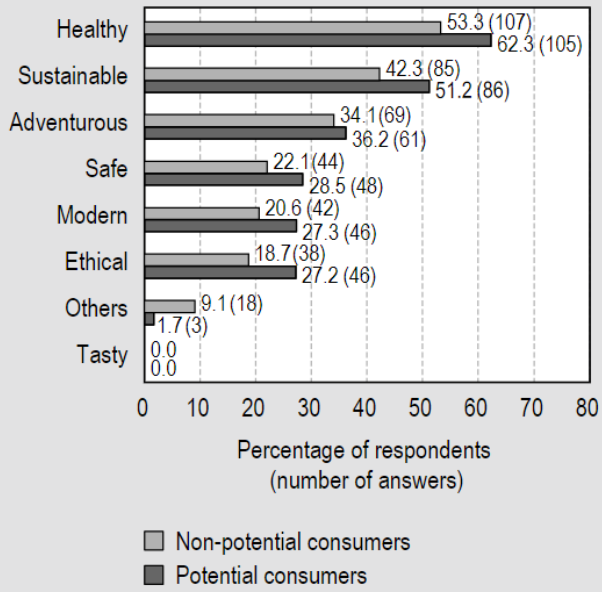

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Conclusion

Edible algae and insects: emerging protein sources = a lot of challenges but numerous benefits

Need to develop collaborative research on these matrices to popularize their use

Specific emphasis on consumer acceptability

- ❑ **Education**
- ❑ **Marketing**
- ❑ **Taste**

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THANK YOU FOR YOUR ATTENTION

Lucie Beaulieu
lucie.beaulieu@fsaa.ulaval.ca
Alain Doyen
alain.doyen@fsaa.ulaval.ca

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