

# Alternative Proteins

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Alternative Proteins include cultured meat, plant-based meat, insect protein and single-cell protein. Here, the technological, safety and environmental aspects of these protein sources are described.

alternative proteins

cultured meat

plant-based meat

edible insects

single-cell protein

novel food

environmental issues

food safety

## 1. Introduction

Global population is projected to reach 9.8 billion in the year 2050 [1]. This population growth entails a projected livestock production of 455 million tons in 2050 [2], which is 40% higher than the reported number in 2019 [3]. Currently, livestock production contributes to 14.5% of anthropogenic greenhouse gas (GHG) emission [4]. In particular, livestock production releases methane and nitrous oxide gases, which have higher global warming potential than carbon dioxide [5]. To avoid potential catastrophic events, global temperature increase should be maintained within 1.5 °C of the pre-industrial levels [6]. Considerable requirements for water and land further contribute to the environmental footprints of livestock production [7][8].

Mitigation efforts include improved feeding practices for better forage digestibility, manure management and diversification of crop and animal varieties [9][10]. Nevertheless, climate issues are a matter of great urgency and more radical solutions may be necessary to ensure food availability in an environmentally sustainable manner. Thus, the concept of alternative protein arises as an attempt to substitute conventional meats with other protein sources that require less intensive production means.

Several examples of novel protein sources are cultured meat, plant-based meat, insect protein and single-cell protein, which have gained interests from researchers and the food industry in the past few years.

## 2. Technological Aspect

Cultured meat, also known as in vitro, lab-grown or cell-based meat, is derived from animal stem cells that are cultivated in controlled settings. Currently, the two main stem cells considered to be the most suitable for culturing meat are embryonic stem cells or satellite cells [11]. The main steps involved in the production of cultured meat include the isolation of stem cells from an animal biopsy, followed by the proliferation and differentiation of these isolated stem cells into desired tissues (for example, skeletal muscles) in a cell culture medium [11][12]. In the

process, the growing cells can be attached to scaffolding materials, such as collagen-like gel polymers, which serve as a support network for the tissue development [11][12] —potential polymers to be used as scaffolds are listed elsewhere [13]. Recapitulation of complex meat structures via tissue engineering needs to include skeletal muscles (myogenesis), extracellular matrix (fibrogenesis), microvascular networks (vascularization) and intramuscular fats (adipogenesis) [14]. Thus, there are practical advantages of using pluripotent stem cells, especially the induced pluripotent stem cells (iPSC) derived from adult cells [15][16].

Texturized vegetable proteins (TVP) can be used as a potential replacement of conventional meat and are commonly derived from soy proteins [17], or to a lesser extent, from wheat glutens [18][19] and legume proteins (for example, pea and chickpea) [20][21]. Currently, plant-based meats are mainly produced through thermoplastic extrusion [19][20][22][23][24]. This process can be categorized based upon the amount of water added, i.e., low moisture (20–35%) or high moisture (50–70%) [25]. Both product types are made in three main steps: (1) preconditioning of the raw materials outside of the extruder; (2) heating and compression inside of the extruder; (3) cooling of the die and processing of the final product (for example, cutting to desired pieces) [26]. Shear technology has also been used to structure vegetable proteins [27].

Insects have been a part of the human diet for centuries, particularly in Asia and Africa [87]. According to the Food and Agriculture Organization of the United Nations (FAO), there are over 1900 insect species consumed around the world [28]. This practice of eating insects, also known as entomophagy, is sustainable due to the high amounts of protein and polyunsaturated fatty acid contained in edible insects, although there are variations across species [29][30][31][32]. Insects are also more effective in converting feed into edible body mass than farm animals [33]. These have made them an attractive option for expanded production to improve global food security. Most edible insects are harvested from the wild, but they can also be semi-domesticated through habitat manipulation or reared in farms for a mass-scale production [28][34]. Similar to other animals, insects require macronutrients (lipids, proteins and carbohydrates) and micronutrients (essential sterols and vitamins), which can be derived from animals, plants and yeast [35]. In particular, polyunsaturated acids, essential amino acids and sterols must be supplied in the feeds, given that insects lack the ability to synthesize these compounds in sufficient amounts [36]. In addition to adequate nourishments, rearing conditions (for example, temperature, humidity and population density) need to be optimized [37].

Single-cell proteins, also known as microbial proteins, are commonly derived from microalgae, fungi or bacteria. In their review article, Ritala et al. summarized available studies on potential fungal, microalgal and bacterial species for application in the production of single-cell proteins, including patents from the years 2001 to 2016 [38]. These include green algae (*Chlorella vulgaris*), *Haemotococcus pluvialis*, *Dunaliella salina* and spirulina (*Arthrosphaera maxima* or *Arthrosphaera platensis*) [39], *Fusarium venenatum* A3/5 (previously known as *Fusarium graminearum* A3/5) [40] and *Methylcoccus capsulatus* [41][42].

### 3. Safety Concerns

Briefly, cultured meat grown in fetal bovine serum-based media can be exposed to viruses or infectious prion, in addition to other safety risks associated with the use of genetic engineering. Plant-based meat may contain allergens, anti-nutrients and thermally induced carcinogens. Microbiological risks and allergens are the primary concerns associated with insect protein. Single-cell protein sources are divided into microalgae, fungi and bacteria, all of which have specific food safety risks that include toxins, allergens and high ribonucleic acid (RNA) contents. The environmental impacts of these alternative proteins can mainly be attributed to the production of growth substrates or during cultivation. Legislations related to novel food or genetic modification are the relevant regulatory framework to ensure the safety of alternative proteins. Detail explanations are provided in the original version of this article.

## 4. Environmental Impact

The environmental impact of cultured meat may vary depending on the growth medium used (Table 1). Regardless, current data suggest that the theoretical greenhouse gas emission, water use, eutrophication and land use in culturing meat are lower than conventional meat production, although cultured meat is still more energy intensive [43][44]. Similar to cultured meat, the environmental impact of insect-based food production depends on the type of feed used [45][46][47], with nutritious waste-based feeds being the most environmentally friendly [46].

**Table 1.** Life cycle analyses (LCA) of alternative proteins.

| Protein Type   | Energy Use (MJ/kg) | GHG Emission (kg CO <sub>2</sub> -eq/kg Product) | Water Use or Eutrophication <sup>a</sup>                            | Land Use (m <sup>2</sup> a/kg) <sup>b</sup> | Reference |
|--|--------------------|--|---|---|-----------|
| <b>Cultured meat</b>                                     |                    |  |   |   |           |
| Minced beef <sup>1</sup>                                 | 26–33              | 1.90–2.24  | 0.36–0.52 m <sup>3</sup> /kg meat (W)                               | 0.19–0.23                                   | [43]      |
| CHO <sup>2</sup>   | 106                | 7.5  | 7.9 g PO <sub>4</sub> -eq/kg meat (E)                               | 5.5   | [44]      |
| <b>Plant-based meat</b>                                  |                    |  |   |   |           |
| Beyond Burger <sup>®</sup>                               | 54.15              | 3.35   | 28.84 m <sup>3</sup> /kg meat (W)                                   | 3.97  | [48]      |
| Impossible Burger <sup>®</sup>                           | NA                 | 3.5  | 0.11 m <sup>3</sup> /kg meat (W); 1.3 g PO <sub>4</sub> -eq/kg meat | 2.5   | [49]      |
| <b>Insect protein</b>                                    |                    |  |   |   |           |
| Mealworm ( <i>T. molitor</i> and <i>Zophobas morio</i> ) | 33.68              | 2.65   | NA  | 3.56  | [45]      |

| Protein Type  | Energy Use (MJ/kg) | GHG Emission (kg CO <sub>2</sub> -eq/kg Product) | Water Use or Eutrophication <sup>a</sup>  | Land Use (m <sup>2</sup> a/kg) <sup>b</sup> | Reference |
|---|--------------------|--|---|---|-----------|
| Black soldier fly ( <i>H. illucens</i> )                    | 21.20–99.60        | 1.36–15.10                                       | NA  | 0.032–7.03                                  | [46]      |
| Cricket ( <i>G. bimaculatans</i> and <i>A. domesticus</i> ) | NA                 | 2.29   | 0.43 m <sup>3</sup> /kg cricket (W); 0.00047 kg P-eq and 0.020 kg N-eq/kg cricket (E)         | NA  | [47]      |
| <b>Single-cell protein</b>                                  |                    |  |   |   |           |
| Spirulina tablets ( <i>A. platensis</i> )                   | 7.88–12.7          | 5.05–7.71  | 0.015–0.022 kg N-eq/kg tablet (E)   | NA  | [50]      |
| Micoalgal protein ( <i>A. platensis</i> )                   | 1225.6–3338.3      | 78.1–196.3                                       | 3.2–3.3 m <sup>3</sup> /kg protein meal (W); 49.2–85.3 kg N-eq/kg protein meal (E)            | 1.7–4.3                                     | [51]      |
| Microalgal protein ( <i>C. vulgaris</i> )                   | 217.1–4181.3       | 14.7–245.1                                       | 0.3–3.9 m <sup>3</sup> /kg protein meal (W); 40.6–105.3 kg N-eq/kg protein meal (E)           | 1.9–5.4                                     | [51]      |
| Mycoprotein   | 60.07–76.8         | 5.55–6.15  | NA  | 0.79–0.84                                   | [52]      |
| Bacterial protein ( <i>Cupriavidus necator</i> )            | NA                 | 0.81–1   | 0.0001–0.0038 m <sup>3</sup> /kg protein (W); 0.00033 kg P-eq/kg protein (E)                  | 0.029–0.085                                 | [53]      |
| Bacterial protein (hydrogen-oxidizing bacteria)             | 200                | 8  | 2.5 m <sup>3</sup> /kg protein (W); 0.0025 kg P-eq/kg protein and 0.00035 N-eq/kg protein (E) | 0.8   | [54]      |

GHG, greenhouse gas; NA, not available. <sup>a</sup> Water use (W) is expressed in volumetric unit (m<sup>3</sup> or L/weight of product), whereas eutrophication (E) is a measure of the amount of contaminants released into freshwater or marine environments (g contaminant/weight of product). <sup>b</sup> Land use is expressed in annual area occupation (m<sup>2</sup>a).

<sup>1</sup> Cyanobacterial hydrolysate was assumed as the growth medium. <sup>2</sup> LCA was conducted based on the proliferation of Chinese hamster ovary (CHO) in a growth medium mainly comprising basal medium and soy hydrolysate.

Available life cycle analyses on two commercial plant-based meats—namely, Beyond Burger® and Impossible Burger®—suggest that these products are more environmentally sustainable than conventional meats, as measured by their energy use, carbon emission, land use, water use and eutrophication. The environmental impact of these plant-based meats mainly occurs during the raw ingredient production [48][49].

Hydrogen-oxidizing autotrophic bacteria, such *C. necator*, can be turned into a sustainable protein source with a lower environmental impact than animal-based meat, including beef, fish and poultry [54]. As electricity consumption is the main driver of bacterial protein production, energy sources should be optimized for a mass-scale production [53][54]. Similarly, the cultivation of microalgae is the most energy intensive stage, and thus it contributes towards the majority of the environmental footprints associated with microalgal protein production [50], particularly when an open raceway pond is used [51].

Smetana et al. conducted a comparative study of different alternative proteins and found that cultured meat had the highest environmental impact (carbon emission and water use), as compared with mycoprotein and insect-based protein, including when caloric and protein contents were considered. However, the production of insect-based protein required the largest amount of land occupation, relative to mycoprotein and cultured meat [52]. Consistent with our data (Table 1), another study by Smetana et al. reported that microalgal proteins were more energy intensive, and thus had a higher carbon emission than other protein sources, including cultured meat, insect, yeast and bacteria [55]. Interestingly, the data collated in this review also indicate that cultured and plant-based meats have lower eutrophication potential than insect and single cell proteins (Table 1). To our knowledge, the two reports by Smetana et al. [52][55] are the only studies that directly compared the environmental impacts of these alternative proteins, and thus more research is required to establish a firm scientific framework for this issue. It is noteworthy that as functionalities of different food types can vary (for example, protein content or nutrient availability), direct comparison of the environmental impacts of different alternative proteins should be conducted with prudence.

## 5. Future Outlook

Alternative proteins are a growing industry, and thus the global food sector should initiate collaborative efforts to ensure the safety of foods in this category. The main focus of these efforts should be to maintain food safety in a mass-scale production, including aspects related to allergens, pathogens, chemical contaminants and the environmental implications during production scale-ups.

There is a lack of research on the safety of cultured meat, with most studies focusing on technological improvements for better production means. Infectious prion and viruses are potentially the main hazards related to cultured meat production using serum-based media. Thus, future developments of methods for removing these contaminants are warranted, such as the use of hollow fiber anion-exchange membrane chromatography to remove prion from large volumes of cell culture media [56]. Concerns about the introduction of foreign genes, such as during the conversion of somatic cells into iPSC, may be circumvented by the use of small molecules as an alternative cell reprogramming system [57]. In the current literature, it appears that antibiotics are not used in the production of cultured meat, primarily based upon the notion that this alternative protein is produced in a highly controlled and closely monitored environment [58][59]. However, to our knowledge, there have not been any studies addressing this issue using verifiable data, and thus we encourage the scientific community to investigate this issue further, including through the provision of assessments of the safety measures used to control biological contaminants in cultured meat without antibiotics.

Available data suggest that plant-based meat may contain allergens, anti-nutrients or traces of glyphosate, although activities of these compounds may be reduced by heat treatments. In the future, there is also a need for discussion of the health implications of extensive processing (i.e., ultraprocessed) involved in the production of plant-based meat, including potential development of carcinogens during the thermal treatments.

Allergens are one of the primary safety issues associated with the consumption of insects, but the clinical significance of this is yet to be established. Future research can aim at identifying the types of allergen present in different edible insect species, and subsequently assessing their health effects across demographics, i.e., by age, allergy status, ethnicity, etc. Microbiological content of insects also varies with species, and future mass-scale production of edible insects would require careful selection of those species harboring bacteria communities that are less pathogenic to humans.

Toxins pose a health risk related to single-cell protein. In microalgae, this is primarily due to environmental cross-contamination, which indicates the importance of choosing appropriate cultivation reservoirs. For mycoprotein, allergens are the main hazard, and future research is necessary to identify the risk factors associated with mycoprotein allergies. When bacteria are used as single-cell protein, careful selection of non-pathogenic bacterial strains is paramount.

In the current literature, the regulatory framework for novel foods has been described based upon food standards in Europe and the USA. As alternative proteins are a global strategy to mitigate climate and environmental issues, the scientific community should expand the scope of the discussion to include food standards in other parts of the world. For example, Australia-New Zealand Food Standard Code Standard 1.5.1 describes the pre-market assessment criteria for novel foods intended for sale in Australia and New Zealand [60], or Schedule 25 lists the approved novel food products, including several that are derived from microalgae [61]. Soy leghemoglobin has also been approved in these two countries [62].

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## References

1. United Nations Department of Economic and Social Affairs. World Population Projected to Reach 9.8 Billion in 2050, and 11.2 Billion in 2100. Available online: (accessed on 30 March 2021).
2. Alexandratos, N.; Bruinsma, J. World Agriculture Towards 2030/2050: The 2012 Revision; FAO: Rome, Italy, 2012.
3. Organization for Economic Co-operation and Development/Food and Agricultural Organization. OECD-FAO Agricultural Outlook 2020–2029; OECD Publishing, Paris/Food and Agriculture Organization of the United Nations: Rome, Italy, 2020.
4. Gerber, P.J.; Steinfeld, H.; Henderson, B.; Mottet, A.; Opio, C.; Dijkman, J.; Falcucci, A.; Tempio, G. Tackling Climate Change through Livestock—A Global Assessment of Emissions and Mitigation Opportunities; FAO: Rome, Italy, 2013.

5. Gerber, P.J.; Hristov, A.N.; Henderson, B.; Makkar, H.; Oh, J.; Lee, C.; Meinen, R.; Montes, F.; Ott, T.; Firkins, J.; et al. Technical Options for the Mitigation of Direct Methane and Nitrous Oxide Emissions from Livestock: A Review. *Animal* **2013**, *7*, 220–234.
6. Intergovernmental Panel on Climate Change. Special Report on Global Warming 1.5 °C. Available online: (accessed on 30 March 2021).
7. Steinfeld, H.; Gerber, P.; Wassenaar, T.; Castel, V.; Rosales, M.; de Haan, C. *Livestock's Long Shadow: Environmental Issues and Options*; FAO: Rome, Italy, 2006.
8. Phelps, L.N.; Kaplan, J.O. Land Use for Animal Production in Global Change Studies: Defining and Characterizing a Framework. *Glob. Chang. Biol.* **2017**, *23*, 4457–4471.
9. Hristov, A.N.; Oh, J.; Lee, C.; Meinen, R.; Montes, F.; Ott, T.; Firkins, J.; Rotz, A.; Dell, C.; Adesogan, A.; et al. Mitigation of Greenhouse Gas Emissions in Livestock Production: A Review of Technical Options for Non-CO<sub>2</sub> Emissions; FAO: Rome, Italy, 2013.
10. Rojas-Downing, M.M.; Nejadhashemi, A.P.; Harrigan, T.; Woznicki, S.A. Climate Change and Livestock: Impacts, Adaptation, and Mitigation. *Clim. Risk Manag.* **2017**, *16*, 145–163.
11. I. Datar; M. Betti; Possibilities for an in vitro meat production system. *Innovative Food Science & Emerging Technologies* **2010**, *11*, 13-22, 10.1016/j.ifset.2009.10.007.
12. Mark J. Post; Cultured meat from stem cells: Challenges and prospects. *Meat Science* **2012**, *92*, 297-301, 10.1016/j.meatsci.2012.04.008.
13. Mark J. Post; Shulamit Levenberg; David L. Kaplan; Nicholas Genovese; Jianan Fu; Christopher Bryant; Nicole Negowetti; Karin Verzijden; Panagiota Moutsatsou; Scientific, sustainability and regulatory challenges of cultured meat. *Nature Food* **2020**, *1*, 403-415, 10.1038/s43016-020-0112-z.
14. Tom Ben-Arye; Shulamit Levenberg; Tissue Engineering for Clean Meat Production. *Frontiers in Sustainable Food Systems* **2019**, *3*, 46, 10.3389/fsufs.2019.00046.
15. Kazutoshi Takahashi; Shinya Yamanaka; Induction of Pluripotent Stem Cells from Mouse Embryonic and Adult Fibroblast Cultures by Defined Factors. *Cell* **2006**, *126*, 663-676, 10.1016/j.cell.2006.07.024.
16. Nicholas J. Genovese; Timothy L. Domeier; Bhanu Prakash V. L. Telugu; R. Michael Roberts; Enhanced Development of Skeletal Myotubes from Porcine Induced Pluripotent Stem Cells. *Scientific Reports* **2017**, *7*, 41833, 10.1038/srep41833.
17. O. P. Malav; S. Talukder; P. Gokulakrishnan; S. Chand; Meat Analog: A Review. *Critical Reviews in Food Science and Nutrition* **2013**, *55*, 1241-1245, 10.1080/10408398.2012.689381.
18. Orcutt, M.W.; McMindes, M.K.; Chu, H.; Mueller, I.N.; Bater, B.; Orcutt, A.L. Soy Applications in Food; Riaz, M.N., Eds.; CRC Press: New York, 2006; pp. 155–184.

19. Valerie L. Pietsch; M. Azad Emin; Heike P. Schuchmann; Process conditions influencing wheat gluten polymerization during high moisture extrusion of meat analog products. *Journal of Food Engineering* **2017**, *198*, 28-35, 10.1016/j.jfoodeng.2016.10.027.

20. Raffael Osen; Simone Toelstede; Florian Wild; Peter Eisner; Ute Schweiggert-Weisz; High moisture extrusion cooking of pea protein isolates: Raw material characteristics, extruder responses, and texture properties. *Journal of Food Engineering* **2014**, *127*, 67-74, 10.1016/j.jfoodeng.2013.11.023.

21. Sharima-Abdullah, N.; Hassan, C.Z.; Arifin, N.; Huda-Faujan, N.; Physicochemical Properties and Consumer Preference of Imitation Chicken Nuggets Produced from Chickpea Flour and Textured Vegetable Protein. *Int. Food Res.* **2018**, *25*, 1016-1025.

22. Ajami, D.; Anderson, D.; Dill, J.; Geistlinger, T.; Mayoral, K.; Ngo, H.B.; Noriega, T.; Ryan, D.A.; Suarez-Trujillo, D.; Timmons, M.; et al. Meat-Like Food Products. US 2017/0105438 A1, 20 April 2017.

23. Anderson, D.; Fuller, J.; Geistlinger, T. Nutrient Dense Meat Structured Protein Products. US 9526267 B2, 27 December 2016.

24. Geistlinger, T. Plant Based Meat Structured Protein Products. US 2015/0296834 A1, 22 October 2015.

25. Fellows, P.J.. Food Processing Technology; Woodhead Publishing Limited: Cambridge, 2017; pp. 753-780.

26. Riaz, M.N.. Proteins in Food Processing; Yada, R.Y., Eds.; Woodhead Publishing Limited: Cambridge, 2004; pp. 517–558.

27. Kyriakopoulou, K.; Dekkers, B.; van der Goot, A.J. . Sustainable Meat Production and Processing; Galanakis, C.M., Eds.; Elsevier: Amsterdam, 2018; pp. 103–126.

28. van Huis, A.; van Itterbeeck, J.; Klunder, H.; Mertens, E.; Halloran, A.; Muir, G.; Vantomme, P. Edible Insects: Future Prospects for Food and Feed Security (No. 171); Food and Agriculture Organization of the United Nations: Rome, Italy, 2013.

29. Raksakantong, P.; Meeso, N.; Kubola, J.; Siriamornpun, S. Fatty Acids and Proximate Composition of Eight Thai Edible Terricolous Insects. *Food Res. Int.* **2010**, *43*, 350–355.

30. Ghosh, S.; Lee, S.M.; Jung, C.; Meyer-Rochow, V.B. Nutritional Composition of Five Commercial Edible Insects in South Korea. *J. Asia. Pac. Entomol.* **2017**, *20*, 686–694.

31. Kouřimská, L.; Adámková, A. Nutritional and Sensory Quality of Edible Insects. *NFS J.* **2016**, *4*, 22–26.

32. Pieterse, E.; Pretorius, Q. Nutritional Evaluation of Dried Larvae and Pupae Meal of the Housefly (*Musca domestica*) Using Chemical-and Broiler-Based Biological Assays. *Anim. Prod. Sci.* **2014**,

54, 347–355.

33. Arnold Van Huis; Potential of Insects as Food and Feed in Assuring Food Security. *Annual Review of Entomology* **2013**, *58*, 563-583, 10.1146/annurev-ento-120811-153704.

34. A.L. Yen; Insects as food and feed in the Asia Pacific region: current perspectives and future directions. *Journal of Insects as Food and Feed* **2015**, *1*, 33-55, 10.3920/jiff2014.0017.

35. Cortes Ortiz, J.A.; Ruiz, A.T.; Morales-Ramos, J.A.; Thomas, M.; Rojas, M.G.; Tomberlin, J.K.; Yi, L.; Han, R.; Giroud, L.; Jullien, R.L. . Insects as Sustainable Food Ingredients; Dossey, A.T., Rojas, M.G., Morales-Ramos, J.A., Eds.; Academic Press: Cambridge, 2016; pp. 153-201.

36. Morales-Ramos, J.A.; Rojas, M.G.; Coudron, T.A.. Mass Production of Beneficial Organisms: Invertebrates and Entomopathogens; Morales-Ramos, J.A., Rojas, M.G., Shapiro-Ilan, D.I., Eds.; Academic Press: San Diego, 2013; pp. 203-240.

37. Kerensa J. Hawkey; Carlos Lopez-Viso; John M. Brameld; Tim Parr; Andrew M. Salter; Insects: A Potential Source of Protein and Other Nutrients for Feed and Food. *Annual Review of Animal Biosciences* **2021**, *9*, 333-354, 10.1146/annurev-animal-021419-083930.

38. Anneli Ritala; Sivi Häkkinen; Mervi Toivari; Marilyn G. Wiebe; Single Cell Protein—State-of-the-Art, Industrial Landscape and Patents 2001–2016. *Frontiers in Microbiology* **2017**, *8*, 2009, 10.3389/fmicb.2017.02009.

39. Gouveia, L.; Batista, A.P.; Sousa, I.; Raymundo, A.; Bandarra, N.M.. Food Chemistry Research Developments; Papadopoulos, K.N., Eds.; Nova Science Publishers: New York, 2008; pp. 75-112.

40. Whittaker, J.A.; Johnson, R.I.; Finnigan, T.J.A.; Avery, S.V.; Dyer, P.S. The Biotechnology of Quorn Mycoprotein: Past, Present and Future Challenges. In *Grand Challenges in Fungal Biotechnology*; Nevalainen, H., Ed.; Springer: Cham, Germany, 2020; pp. 59–79.

41. Margareth Øverland; Anne-Helene Tauson; Karl Shearer; Anders Skrede; Evaluation of methane-utilising bacteria products as feed ingredients for monogastric animals. *Archives of Animal Nutrition* **2010**, *64*, 171-189, 10.1080/17450391003691534.

42. Charlotte R. Kleiveland; Lene T. Olsen Hult; Signe Spetalen; Magne Kaldhusdal; Trine Eker Christoffersen; Oskar Bengtsson; Odd Helge Romarheim; Morten Jacobsen; Tor Lea; The Noncommensal Bacterium *Methylococcus capsulatus* (Bath) Ameliorates Dextran Sulfate (Sodium Salt)-Induced Ulcerative Colitis by Influencing Mechanisms Essential for Maintenance of the Colonic Barrier Function. *Applied and Environmental Microbiology* **2012**, *79*, 48-56, 10.1128/aem.02464-12.

43. Tuomisto, H.L.; De Mattos, M.J.T. Environmental Impacts of Cultured Meat Production. *Environ. Sci. Technol.* **2011**, *45*, 6117–6123.

44. Mattick, C.S.; Landis, A.E.; Allenby, B.R.; Genovese, N.J. Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States. *Environ. Sci. Technol.* 2015, 49, 11941–11949.

45. Oonincx, D.G.A.B.; de Boer, I.J.M. Environmental Impact of the Production of Mealworms as a Protein Source for Humans—A Life Cycle Assessment. *PLoS ONE* 2012, 7, e51145.

46. Smetana, S.; Palanisamy, M.; Mathys, A.; Heinz, V. Sustainability of Insect Use for Feed and Food: Life Cycle Assessment Perspective. *J. Clean. Prod.* 2016, 137, 741–751.

47. Halloran, A.; Hanboonsong, Y.; Roos, N.; Bruun, S. Life Cycle Assessment of Cricket Farming in North-Eastern Thailand. *J. Clean. Prod.* 2017, 156, 83–94.

48. Heller, M.C.; Keoleian, G.A. Beyond Meat's Beyond Burger Life Cycle Assessment: A Detailed Comparison between a Plant-Based and an Animal-Based Protein Source; University of Michigan: Ann Arbor, MI, USA, 2017.

49. Khan, S.; Dettling, J.; Loyola, C.; Hester, J.; Moses, R. Environmental Life Cycle Analysis: Impossible Burger 2.0; Quantis: Boston, MA, USA, 2019.

50. Ye, C.; Mu, D.; Horowitz, N.; Xue, Z.; Chen, J.; Xue, M.; Zhou, Y.; Klutts, M.; Zhou, W. Life Cycle Assessment of Industrial Scale Production of Spirulina Tablets. *Algal Res.* 2018, 34, 154–163.

51. Smetana, S.; Sandmann, M.; Rohn, S.; Pleissner, D.; Heinz, V. Autotrophic and Heterotrophic Microalgae and Cyanobacteria Cultivation for Food and Feed: Life Cycle Assessment. *Bioresour. Technol.* 2017, 245, 162–170.

52. Smetana, S.; Mathys, A.; Knoch, A.; Heinz, V. Meat Alternatives: Life Cycle Assessment of Most Known Meat Substitutes. *Int. J. Life Cycle Assess.* 2015, 20, 1254–1267.

53. Sillman, J.; Uusitalo, V.; Ruuskanen, V.; Ojala, L.; Kahiluoto, H.; Soukka, R.; Ahola, J. A Life Cycle Environmental Sustainability Analysis of Microbial Protein Production via Power-to-Food Approaches. *Int. J. Life Cycle Assess.* 2020, 25, 2190–2203.

54. Järviö, N.; Maljanen, N.-L.; Kobayashi, Y.; Ryyränen, T.; Tuomisto, H.L. An Attributional Life Cycle Assessment of Microbial Protein Production: A Case Study on Using Hydrogen-Oxidizing Bacteria. *Sci. Total Environ.* 2021, 776, 145764.

55. Smetana, S.; Aganovic, K.; Irmscher, S.; Heinz, V. Agri-Food Waste Streams Utilization for Development of More Sustainable Food Substitutes. In *Designing Sustainable Technologies, Products and Policies*; Springer: Cham, Germany, 2018; pp. 145–155.

56. Chou, M.L.; Bailey, A.; Avory, T.; Tanimoto, J.; Burnouf, T. Removal of Transmissible Spongiform Encephalopathy Prion from Large Volumes of Cell Culture Media Supplemented with Fetal Bovine Serum by Using Hollow Fiber Anion-Exchange Membrane Chromatography. *PLoS ONE* 2015, 10, e0122300.

57. Qin, H.; Zhao, A.; Fu, X. Small Molecules for Reprogramming and Transdifferentiation. *Cell. Mol. Life Sci.* 2017, 74, 3553–3575.
58. Post, M.J.; Levenberg, S.; Kaplan, D.L.; Genovese, N.; Fu, J.; Bryant, C.J.; Negowetti, N.; Verzijden, K.; Moutsatsou, P. Scientific, Sustainability and Regulatory Challenges of Cultured Meat. *Nat. Food* 2020, 1, 403–415.
59. Chriki, S.; Hocquette, J.F. The Myth of Cultured Meat: A Review. *Front. Nutr.* 2020, 7, 7.
60. Food Standards Australia New Zealand. Australia New Zealand Food Standards Code—Standard 1.5.1—Novel Foods. Available online: (accessed on 29 March 2021).
61. Food Standards Australia New Zealand. Australia New Zealand Food Standards Code—Schedule 25—Permitted Novel Foods. Available online: (accessed on 29 March 2021).
62. Food Standards Australia New Zealand. A1186—Soy Leghemoglobin in Meat Analogue Products. Available online: (accessed on 29 March 2021).

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