Microbes: Food for the Future

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Summary

The current food chain ensures a net excess of protein and calories, yet more than 800 million people are afflicted by food scarcity, more than 2 billion people suffer from malnutrition and the environmental costs of food production are no longer sustainable. We need to “rethink the whole agri-food system”. In particular, the consumption trend of animal products will be a key determinant to avoid further biodiversity losses, reduce adverse impacts on soil, water and atmosphere and to mitigate climate change, as the livestock sector appropriates 80% of agricultural land (4.0 out of 5.1 billion hectares) and accounts for a large share of the total agricultural water footprint, GHGs emissions and total nitrogen use. Disrupting technologies are urgently needed to improve the efficiency of the food production system and reduce the negative externalities of agriculture and particularly of meat production. Among these, the production of microbial protein (MP) in controlled and intensive systems called “bioreactors”, is receiving increasing interest from research and industry, since it does not require arable land, does not directly compete with crop-based food commodities and uses fertilizers with an almost 100% efficiency. Here we describe and briefly discuss the prospects and limitations of four MP sources (hydrogen oxidizing bacteria, methanotrophs, fungi and cyanobacteria) that are tested at pilot level by industry or already sold as food and food ingredients in niche markets.

Keywords: microbial protein, HOB, methanotrophs, cyanobacteria, *Quorn*

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1. INTRODUCTION

As concerns future food demand, most scientists, economists and politicians agree on the necessity to increase food production by more than 50% in the next three decades to satisfy the needs of the world growing population and income-dependent global dietary shift (e.g., increased consumption of animal protein). Most projections highlight the challenge of achieving such an increase and moving, at the same time, towards a sustainable global food system in the face of urbanization, scarcity of natural resources and climate change (Searchinger et al., 2014; FAO, 2017).

The current food chain ensures globally a net excess of protein (of more than 80%) and calories (of about 8%), yet more than 800 million people are afflicted by food scarcity, more than 2 billion suffer from malnutrition (lack of protein, vitamins, minerals, obesity) and the environmental costs of food production are no longer sustainable (FAO, 2018). We need to raise public awareness of the link between food choices and environmental sustainability of current agricultural production patterns and "rethink the whole agri-food system" (Berners-Lee et al., 2018).

If food were equally distributed and waste avoided, the current agricultural production could provide food (both in terms of calories and protein) to a population of about 10 billion. However, these objectives are unachievable in the short/mid-term and thus there is an urgent need to significantly increase food production. According to many analyses, an increase of food production of 50% with actual agricultural technologies will result in an 80% increase of greenhouse gases (GHGs) emissions (Berners-Lee et al., 2018; Tilman and Clark, 2014). In particular, the consumption trend of animal products will be a key determinant to avoid further biodiversity losses, reduce adverse impacts on soil, water and atmosphere and to mitigate climate change, as the livestock sector appropriates 80% of agricultural land (4.0 out of 5.1 billion hectares) and accounts for large shares (> 40%) of the total agricultural water footprint, GHGs emissions and total nitrogen use (D'Odorico et al., 2018). Despite this huge footprint, the livestock sector returns as edible food only a minor share of the protein and calories it consumes (Berners-Lee et al., 2018; Roser and Ritchie, 2019). Disrupting (innovative) technologies are urgently needed to improve the efficiency of the food production system and reduce the negative externalities of agriculture and particularly of meat production. The replacement of animal-based products, at least partially, with plant and novel protein sources (e.g., microorganisms and insects) cannot be postponed.

2. MICROBIAL PROTEIN (MP)

The term "microbial protein" (MP) relates to microbial biomass used as a source of food or feed. MP has a high protein content (up to 75% on dry biomass), contains all the essential amino acids and, generally, is rich in vitamins and minerals and various other nutritionally valuable substances (Matassa et al., 2016). MP can be produced in closed and intensive systems called "bioreactors", which differ in structure and functioning according to whether the organism is a phototroph or a chemotroph, an autotroph or a heterotroph. Producing biomass in a bioreactor is much more efficient than cultivating plants in an open field or raising animals, owing to the stability of growth parameters, efficient utilization of nutrients, which can be supplied to exactly match demand, low water and land footprint, no pesticide use (Pikaar et al., 2018, Tredici, 2018). MP production does not require arable land and does not directly compete with crop-based food commodities and can be located in industrial or metropolitan areas. In about thirty-five years from now urban areas will host more than two-thirds of the world population (FAO, 2017). Megacities pose the necessity and offer the opportunity, by means of MP production and vertical farming, to recover most of the nutrients and energy embedded in solid urban wastes or leaving the urban area via the sewage system, to be further recycled into sustainable protein sources (Matassa et al., 2016; Tredici, 2018).

One of the major environmental benefits associated with food production from microbial biomass lies in the efficient use of nitrogen, phosphorus and other nutrients. Conventional agriculture-based protein production converts a fraction of the supplied nitrogen into plant and animal protein (Pikaar et al., 2018), the remaining nitrogen is lost to the environment causing contamination of aquifers, eutrophication of surface waters, ocean acidification and GHGs emissions. In reactor-based MP production, almost all of the nitrogen (and of the other nutrients) supplied ends up as consumable protein with none or little impact on the environment. MP can be produced by exploiting the metabolic pathways of different microorganisms, such as hydrogen oxidizing bacteria (HOB), methanotrophs, fungi and cyanobacteria.

2.1. MP from H_2-oxidizing bacteria (HOB)

The use of HOB for food production is amongst the most challenging, yet promising, technologies of the future bio-economy (Matassa et al., 2016; Linder, 2019). HOB are mostly autotrophs, i.e., they need an inorganic carbon source (CO_2) to grow and produce biomass. Thus, MP production from HOB can be part of carbon capture and utilisation (CCU) strategies that exploit carbon dioxide emitted from industrial point sources (i.e., flue gases from power stations, incinerators, cement factories, steel plants), offering to large CO_2-emitting industries a tool to reduce their carbon footprint and produce, at the same time, feed or food (Pikaar et al., 2018; Tredici, 2018). Another key factor that characterizes MP from HOB is that their production can be decoupled from the use of fossil fuels. For example, H_2 and O_2, needed by HOB for cellular energy generation, can be obtained by water electrolysis driven by renewable electric energy. The production cost of HOB biomass, with a protein content of 70%, on H_2 obtained through water electrolysis at an electric energy cost of 0.045€ per kWh, has been estimated at ~2.5 €/kg (Pikaar et al., 2018), which compares favourably with that of animal protein. Solar Foods (Laskunet, Finland) has announced that will bring to market a food product from HOB by 2021 (Linder, 2019).

2.2. Methanotrophic bacteria as MP source

Methanotrophic bacteria (methanotrophs) use methane (CH_4) as energy and carbon source. In 2014 Unibio® (England, UK) has launched the EFPro (Environmentally Friendly Protein Production) project aimed to produce an MP (called Uniprotein®) from *Methylococcus capsulatus*. The product contains more than 70% protein with all the essential amino acids. Another company, CALYSTA (England, UK), produces several tonnes of MP from *M. capsulatus,* which is marketed under the name of *FeedKind*®. The company claims a production cost of about 1.5€/kg, which compares favourably with fishmeal. The advantage of using methane for MP production is that it can be attained, together with CO_2, from biomasses or waste streams (e.g., urban organic wastes, sewage sludge, food processing wastes, agricultural residues) through anaerobic digestion (Cumberlege et al., 2016; Linder, 2019).

2.3. Fungal MP

Mycoprotein from *Fusarium venenatum* has been sold in the UK since 1985 and is now marketed in the form of burgers and nuggets under the brand name of *Quorn*^{TM}. Mycoprotein, produced in large fermenters under sterile controlled conditions, is a source of protein (about 50% protein on dry weight) with a biological value similar to that of milk protein. Differently from MP from HOB and methanotrophs, the cultivation of fungi needs an organic carbon source (e.g. sugars) and hence is not decoupled from freshwater and arable land use. Despite this, mycoprotein production shows much higher sustainability than meat. A cradle-to-gate life cycle analysis (LCA) carried out by Carbon Trust (Finnigan et al., 2017) estimates for *Quorn* mince carbon, water and land footprints about ten times lower than that of beef. The global market value of *Quorn*, largely consumed in Northern Europe, is about 200 million euros and is prospected to increase by 15% annually in the coming years. *Quorn* is sold at a retail price of about 30€/kg.

2.4. MP from cyanobacteria

Many food and health-food products and ingredients are produced by cultivating cyanobacteria (mainly *Arthrospira* species), among these: beverages, yogurts, ice creams, cereal bars, instant soups, cakes, pastas and biscuits. The ability to use solar light, fix CO_2 and the high protein content (up to 70% on dry biomass) have been among the main reasons to consider cyanobacteria as sustainable sources of feed and food. Generally, the quality of most examined cyanobacterial proteins is similar, or superior, to that of conventional plant proteins. For example, spirulina (common term for *Arthrospira* species) contains 55-65% of highly digestible protein including all essential amino acids (Kim, 2015) and has shown many beneficial bioactivities in animals and humans (Bigagli et al., 2017). Besides, by varying the nutrient content of the growth medium and growth parameters, such as temperature and light spectrum and intensity, cyanobacterial metabolism can be manipulated to enrich the cell in desired micronutrients and vitamins (bio-fortification) and other useful compounds. Globally, production of *Arthrospira* biomass surpasses 5,000 tonnes/year with production costs ranging from 5 (in open ponds) to 50€/kg (in enclosed highly controlled photobioreactors) (Tredici, 2018)

3. CONCLUSIONS

Although the substitution of meat with MP will strongly reduce the use of arable land, consumption of freshwater, application of antibiotics, pesticides and fertilizers, biodiversity loss and GHGs emissions, there are still major barriers that hinder shifting away from a meat-based diet. MP, as insects, has still to meet the public acceptance and become competitive on the market. One of the main challenges will be to transform microbial biomass into a food commodity that, besides nutritional qualities, has pleasant taste and flavour, and is competitive in terms of cost with animal derived protein (milk, eggs, cheese, meat). Finally, before entering the market, novel MP needs to be authorized by the European Food Safety Authority (EFSA) since only few microorganisms are considered food or have today novel food status in Europe (European Union, Novel Food Catalogue).

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