

Algae Production and Their Potential Contribution to a Nutritional Sustainability

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Abstract

Sustainable diets are defined as those that present low impacts both on the environment and the biodiversity, contributing to food and nutrition security and to a healthy life for present and future generations. Algae (macroalgae and microalgae, including cyanobacteria) have recently taken an increased interest as valuable products, being used as ingredients or condiments in the modern diversifying occidental cuisine. Moreover, nutritional research has confirmed algae as rich sources of potentially valuable, health-promoting compounds in a scenario where consumers are increasingly aware of the relationship between diet, health and disease prevention. Combining both ideas, nutritional needs vs. health promotion and disease risk reduction, algae are shown as a very interesting source of functional ingredients for being considered as a component of our day-to-day diet and related food products.

Sustainability contribution of cultivation systems and techniques to biomass increasing in quality, security and control, so reducing effects on the environment and biodiversity, makes algae production a promising activity to be included in future developments toward a responsible and healthy way of living.

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Introduction

According to the world review by FAO, 2016, aquatic plants (mostly farmed seaweed species) contributed 2.73 million tonnes (dry weight) to the world aquaculture production, being *Kappaphycus* and *Eucheuma* the main genera, that are basically transformed by the hydrocolloids industry as carrageenan (E-407) producers, followed by other group of macroalgae mainly dedicated to the food industry (*Laminaria* > *Gracilaria* > *Undaria* > *Porphyra*).

Traditionally, some seaweed species have been used for human consumption, particularly in eastern countries (Japan, China and Korea). The development of open-sea cultivation systems, during the mid-20th century, for seaweed genera like phaeophytes (brown algae) such as *Laminaria/Saccharina* (kombu

– currently associated with the definition of the term *umami*, the fifth basic taste) and *Undaria* (wakame), the rhodophyte (red algae) *Porphyra/Pyropia* (nori) or the chlorophyte (green algae) *Ulva* (ao-nori) has increased their market in such a way that it is not difficult, nowadays, to find them at the occidental food stores. A market that increases proportionally with the curiosity that occidental consumers show to products labelled as healthy (some of them as organic produced according to the EC Commission Regulation No. 710/2009) and that might be easily introduced, as an ingredient or condiment, in the western manner of cooking (Mouritsen, et al., 2012), including benefits described for the Mediterranean diet.

In fact, new genera have been incorporated to the list of authorized/recognized seaweed for human consumption (Hafting, et al., 2012): browns as *Himanthalia* (sea-spaghetti), *Alaria*

(atlantic wakame) or *Hizikia* (hiziki), reds as *Palmaria* (dulse), *Chondrus* (Irish moss), *Gracilaria* (ogo-nori) or *Gigartina* and green as *Codium*, many of them naturally growing in Atlantic coasts of Europe and America and some included in the list of cultivated species.

These combined factors have allowed that new occidental innovative companies (i.e., Porto Muiños, Algamar or Suralgae in Spain, AlgaPlus in Portugal or Acadian Seaplants in Canada) develop products and market opportunities for cultured, harvested and processed biomass in different formats (fresh, dried, powders or flakes, salted, canned, liquid extracts or prepared foods) and distribute their products in a global world market, increasing the interest of restaurants, chefs and consumers towards these new food ingredients.

Coming back to FAO statistics (FAO, 2016), microalgae contribution to worldwide aquaculture numbers is poorly reflected and restricted to data for the cyanobacteria *Spirulina* (common name for most *Arthrospira* species), basically due to that only a few countries are able to report real biomass production values. Opposite to those occurring with macroalgae, the use of microalgae as food in the traditional cuisine is insignificant and its consumption have been mainly restricted to genera such as *Spirulina* and *Chlorella* in the form of dried powders and capsules for the dietetics market. However, as far as we increase our knowledge on the biodiversity, cultivation and processing possibilities for a higher number of species and their nutritional properties, biomass availability and new ideas to incorporate microalgae concentrated paste, fresh, powder or freeze-dried in dishes designed by *star chefs* is nowadays an authentic reality. As an example for mass media in Spain, Chef Angel León (*the chef of the sea*) from the restaurant Aponiente, in a research-development collaboration with the company Fitoplancton Marino (www.fitoplanctonmarino.com), creates an interesting variety of dishes phytoplankton-enriched (concentrated microalgae paste) with a great success. As a first important step, the cited company has obtained the European certification as “novel food” for the photobioreactor produced green microalgae *Tetraselmis chuii* that probably will open new opportunities for other alternative strains.

Added to this, microalgae production is not only limited to the possibility to obtain biofuels in a near future. Some microalgae strains, *Spirulina* and other green genera like *Chlorella*, *Dunaliella* or *Haematococcus*, are industrially cultivated for being used as protein and nutritional supplement (Enzing, et al., 2014), or additive sources for substances like antioxidants such as β -carotene, astaxanthin, polyphenols, vitamins or polyunsaturated fatty acids (Rasul Suleria, et al., 2015), included in the group of functional foods and nutraceuticals, those that taken in a regular basis contribute to reduce disease risks beyond the concept of conventional foods (Wong, et al., 2015; Gouveia, et al., 2010).

Nutritional composition

Generally speaking, chemical composition and therefore algal biomass properties are determined by environmental growth conditions. In the case of marine macroalgae, coastal zones where light, water movement, nutrients or pressure by herbivorous, have obligated these “marine plants” to develop different structural characteristics, and hence their chemical composition, that allow them to grow under these differential conditions. This is translated to a varied composition in pig-

ments, structural and storage carbohydrates, plant-based protein and many secondary metabolites, synthesized as responses to an oxidative environment (i.e. antioxidant substances) or predators repellent. This fact is also occurring in microalgae, which are also found in a higher environmental diversity, including those defined as extreme environments, where cells are adapted by modifying its metabolic composition.

In a nutritional context (Løvstad Holdt, et al., 2011), it can be stated that macroalgae are an important source of carbohydrates, polysaccharides and digestive fibres, both soluble and insoluble. Proteins are lower than carbohydrates, although working under intensive cultivation conditions algal metabolism might be re-directed to the accumulation of one or another (Gómez Pinchetti, et al., 1998). Lipid/fat contents are low and mineral composition is high (i.e., calcium, iron, phosphorus, sodium, potassium, or iodine).

In the case of microalgae (including cyanobacteria) considered in the food and feed industry, nutritional profiles change in a significant way (Enzing, et al., 2014; Freitas, et al., 2012). *Spirulina* and *Chlorella*, as typical examples, are generally a rich source of protein with a complete and varied amino acid profile. They present higher percentages in lipids, including polyunsaturated fatty acids ω -3 and ω -6, and generally, lower carbohydrate content than macroalgae.

Also, both macro- and microalgae show interesting natural vitamins profiles (A, C, D, E, vitamins of group B and folic acid) and other complementary substances such as phycobiliproteins, carotenoids (including β -carotene and astaxanthin among others) and polyphenols, generally showing high antioxidant activities. In general, energy values are low.

Different studies have correlated the effects that diet shows on some chronic diseases, therefore highlighting the enormous potential of traditional and alternative foods in the prevention and progression of chronic diseases beyond meeting basic nutritional needs (Freitas, et al., 2012). In the last years, nutritional research has confirmed also macro- and microalgae as rich sources of potentially valuable, health-promoting compounds in a scenario where consumers are increasingly aware of the relationship between diet, health and disease prevention (Freitas, et al., 2012; Hafting, et al., 2015). Combining both ideas, nutritional needs vs. health promotion and disease risk reduction, algae are shown as a very interesting source of functional ingredients for being considered as a component of our daily diet and related food products.

Sustainable cultivation processes

In the last 25 years, the highest percentages of algal biomass processed by the industry, both in eastern and western countries were mostly produced through cultivation activities^[1]. Previous overexploitation and, nowadays, control mechanisms in a scenario of climate change make natural populations difficult to exploit in a sustainable form. This fact is translated to the necessity to develop algae culture techniques based on the use of sunlight, seawater and non-arable land. Far to arise production levels reached in eastern countries where open-sea cultivation techniques have been improved for more than 50 years, occidental systems are focused on techniques and systems that allow increasing biomass yields at the same time than improving biomass quality (Hafting, et al., 2015): algae morphology and aspect, colour, nutritional composition, organoleptic properties or specific bioactive compounds yield.

At the Spanish Bank of Algae (ULPGC), control of intensive tank culture parameters have allowed us to obtain ball forming morphotypes of red macroalgae like *Hydropuntia cornea* or *Hypnea spinella* with red (original), green or yellow colours and increased total carbohydrate or protein contents. Also Acadian Seaplants Ltd., in Canada, produces seaweed for human consumption with green, yellow and pink colours under the commercial name Hana Tsunomata®. All these examples generate a great interest for the international food market.

An increasing number of species, both of macro- and microalgae, are being cultured in different systems, scales and control degrees: sophisticated closed photobioreactors, tanks, thin-layer cascades, ponds, raceways or open-sea farms. Production and processing of microalgae biomass appear to be technically more complex than macroalgae, mainly due to the work with cells with small size. However, under controlled conditions, developments on species and strains selection based on growth performance, sustainable yields, biomass quality and security or traceability can be carried out (Hafting, et al., 2015). In the last years, considering also the possibility of wastewater nutrients and CO₂ gases recycling have become key factors for the future success of industrial algae production, together with the concept of biorefinery (step-by-step biomass processing generating several final products of interest). As a recognized example, in the so-called “integrated multi-trophic aquaculture” systems (IMTA), through the photosynthetic process, algae are established as biofilters for dissolved nutrients (mainly N-nitrogen and P-phosphorus) generated by animals at higher trophic levels (fish or crustaceans) converting nutrients in biomass and O₂, instead of being diluted to the environment (Gómez Pinchetti, et al., 2011). Sustainable production of seaweed and seaweed-based products at AlgaPlus (<http://www.algaplus.pt>) are obtained under this IMTA concept, in a controlled environment and with organic certification, seeking a natural, but customized ingredient assured with quality, traceability, stability of supply and a small carbon-foot print that can help to differentiate their products.

Conclusions

Considerations stated at the Decalogue for sustainable food and nutrition in the community (Gran Canaria Declaration 2016), aims to improve food sustainability across the Earth planet as a major concern to a healthy life for present and future generations. Despite consumers being increasingly conscious of food safety, quality and health related issues; populations from the so-called developed countries still have much to work concerning strategies to fight modern age diseases (10). Algae, as a component of aquatic diversity, have been shown as rich sources of potentially valuable, health-promoting compounds for combining both ideas, nutritional needs vs. health promotion and disease risk decrease, being considered a very interesting source of functional ingredients as a main component of our day-to-day diet. Moreover, possibilities for sustainable cultivation systems and techniques to biomass increasing in quality, security and control, reducing effects on the environment and the biodiver-

sity, will make algae production a promising activity to be included in future developments toward a modern, responsible and healthy way of life.

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