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Viewpoint

Food and feed products from micro-algae: Market opportunities and challenges for the EU

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Micro-algae are a new and promising source of nutrients. The main products obtainable are dried algae with high nutrients content and high-value compounds such as fatty acids, pigments and anti-oxidants. This paper analyses the market and the economic opportunities of micro-algae-based food and feed sectors in the EU through an integrated methodology composed by literature search, interviews to experts and Delphi survey. Results show that the quantities produced and the market size of nutrients obtained from micro-algae are still significantly smaller in comparison to the ones derived from cereals and other commodity crops, but that the sector has seen an impressive and unique growth. Despite the challenges due to the climatic conditions together with the insufficient domestic demand and the complexity of the EU Novel Food regulation, the survey revealed that the EU can improve its market position in the next decade, thanks to its scientific and technological capacity and its dominant position in the global agri-food markets. New micro-algae-based products can be developed for foreign markets, and the improved global production share of European firms (presently of about 5%) may be the result of strategic acquisitions of foreign companies.

Introduction

In 2012, the European Union (EU) adopted a strategy entitled "Innovating for Sustainable Growth: A Bioeconomy for Europe" (EC, 2012). This strategy proposes a comprehensive approach to increase sustainable productions and limit the negative impacts on the environment. The EU is hence releasing large funding for improving the innovative and sustainable use of renewable resources, while continuing in satisfying the demand for food, energy and industrial products.

Marine resources are raising big expectations in the context of the EU bioeconomy, and micro-algae are particularly attractive as source of a wide variety of high-value molecules for diversified uses. The chemical, pharmaceutical, cosmetic and energy industries are exploring the potential of micro-algae, but it is the nutrition sector that seems to potentially benefit more from micro-algae technologies (Pulz & Gross, 2004).

Algae have been exploited for centuries as food and feed. Already in the 1950s, Burlew (1953) proposed the use of algae as candidates for alternative protein sources to face global food demand, and in the 1960s, Japan started the first industrial scale production of the micro-algae species *Chlorella* for human consumption. By the 1980s, large-scale algae production facilities were established in Asia, India, the US, Israel and Australia (Enzing, Ploeg, Barbosa, & Sijtsma, 2014). More recent technical improvements, like new design in production systems and developments in the field of micro-algae biotechnology, led to

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promising research programs that proved the possibility of obtaining different high-value nutrients from micro-algae, such as carotenoids, phycobilins, fatty acids, sterols, polyhydroxyalkonates and polysaccharides (Borowitzka, 2013).

These recent achievements renewed the interest in micro-algae as a sustainable source of food/feed commodities with enhanced nutritional and functional quality. Micro-algae have been promoted as having the potential of supplying a substantial portion of the EU food and feed market with a limited production surface (Draaisma *et al*., 2013), showing important implications for the reduction of world food insecurity (Ahsan, Habib, Parvin, Huntington, & Hasan, 2008; OECD, 2013).

The potential of micro-algae for the production of new compounds (not only nutrients but also bio-fuels, biochemicals and other bio-products) is being widely explored. The R&D scenario is very active in researching the options offered by biotechnology in micro-algae. In particular, genetic engineering can represent a relevant source of innovation in the field of algae and micro-algae, but the technology is still immature and far from commercial applications (Enzing *et al*., 2014).

Although the research activities on micro-algae-based nutrients are very promising, the products currently on the market are still limited. There are two main categories of food market products obtained from micro-algae (Enzing *et al*., 2014). The first category is dried algae (in particular the micro-algae species *Chlorella* and *Spirulina*) with high nutrients content, especially of vitamin B12, C and D2. These micro-algal products can be directly sold as dietary supplements and have the potential to be used in bulk commodities as sources of proteins and carbohydrates. The second type is specialty products isolated and extracted from the micro-algae that can be added to food and feed to improve their nutritional value. These high-value compounds are pigments (e.g. astaxanthin), anti-oxidants (e.g. ß-carotene), proteins (e.g. phycocyanin) and fatty acids (e.g. omega-3, docosahexaenoic acid - DHA and eicosapentaenoic acid – EPA).

A number of conditions are still to be met to exploit the production and commercial potential of micro-algae products in the EU. From a regulatory point of view, the European regulations on novel food and novel food ingredients, on food safety, and on nutrition and food health claims affect the marketing of micro-algae products. The safety of the products must be assessed before their launching on the markets, but restrictive regulatory requirements can delay the pace of commercialization. In particular, the EU food safety regulation requires the assessment of toxins, allergens or other harmful compounds potentially produced by the algae (EC, 2002). Hence, the correct and undoubtful identification of the algae strain is a fundamental step to ensure the safety of large-scale industrial productions of algae (Enzing *et al*., 2014).

The possibilities of increasing the production and commercialization of micro-algae high-value nutrients depend also on a series of market and economic factors, but the lack of public economic and market data make it difficult to evaluate their effective industrial potential for the support of funding and policy decisions. Data are mainly hold by private companies and are accessible at very high costs, usually not affordable by researchers.

The literature about the economic viability of these products and their markets is scarce. Some publications mainly review the high-value molecules of interest for food and feed that can be extracted from micro-algae (Chacón-Lee & González-Mariño, 2010; Draaisma *et al*., 2013; Dufossé *et al*., 2005), but without analyzing the market opportunities of these products. Other authors provide estimates of global production of specific molecules, such as carotenoids (Borowitzka, 2013; Milledge, 2012) and fatty acids (Ismail, 2010). The most relevant studies providing figures for a comprehensive range of micro-algae-based food products are Pulz and Gross (2004) and Spolaore, Joannis-Cassan, Duran, and Isambert (2006). All these authors provide global pictures of the micro-algae-based food applications, but none provides evidences on the development of this sector at EU level.

This paper discusses the main results of the European Commission (EC) project "Microalgae-based products for the food and feed sector: an outlook for Europe" (Enzing *et al*., 2014),[1] contributing to the existing literature in several ways. First of all, to overcome the problem of the scarcity of economic and market data, we designed a methodology that integrates literature review with primary information based on interviews and electronic (Delphi) survey to selected experts. Secondly, we examined all food and feed products derived from micro-algae (including nutrients) that are available on the market, considering both the global situation and the EU sectors, and taking into account the safety and regulatory issues. Thirdly, we analyzed the technical and non-technical factors affecting current and future production costs and determining the competitiveness of the EU sectors. Finally, the study aims to shed light on the industrial and market potential of micro-algae as a source of food/feed products and nutrients, going beyond the laboratory opportunities and discoveries, but exploring the development of the industrial sector.

Results from our research show that, although the market for micro-algae-based food and feed products has a

[1] The paper is not limited to presenting the results of Enzing *et al*. (2014), but includes additional details and research outcomes. In particular, Section 2 of the paper provides a full explanation of the Delphi methodology, presenting its pro and contra and motivating its application for the micro-algae sector; Section 3 contains the results of additional data search and discusses the constraints of the publicly available trade data; Fig. 1 has been originally elaborated for this article; in Section 4.2 we present in details the revision of the Novel Food regulation, discussing its implication for micro-algae products.