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Electrotechnologies applied to microalgal biotechnology – Applications, techniques and future trends

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ABSTRACT

Electrotechnologies are based on the direct application of an external electric field through a given semi-conductive material. These technologies are part of a wide range of biotechnological processes, considered cost-effective and environmentally-friendly in view of the less intensive use of non-renewable resources and high levels of energetic efficiency. In this regard, electrotechnologies are a promising processing tool to overcome some of the microalgae's exploitation limitations. The application of electric field-based techniques can cover upstream (i.e. electroporation for genetic transformation, inactivation of culture contaminants, and improvement of growth kinetics) and downstream processes (e.g. harvesting and extraction methods). Pulsed electric fields (PEF) and moderate electric fields (MEF), targeted at microalgae cellular permeabilization and subsequent extraction of valuable compounds, count with a substantial body of fundamental research which puts them on the front row to become mainstream techniques in a near future. This review provides comprehensive knowledge systematization of the current status of the direct application of these techniques on microalgal biotechnology, as wells as future trends and challenges regarding developments in electrotechnologies to be applied to microalgae industrial exploitation.

1. Introduction

1.1. Microalgae and its applications

Microalgae are an extremely diverse group of microscopic organisms, representing one of the oldest forms of life on Earth [1]. These microorganisms are defined as primitive plants (thallophytes) – not presenting roots, stems and leaves – comprising unicellular plants (Chlorophyta), bacteria (Cyanobacteria), diatoms (Chromalveolata) and protists (Chromista) that can be found mostly in marine and freshwater environments [2–4]. In contrast with higher plants, microalgae do not need a vascular system for nutrient transport (absorbing nutrients directly), which confers a great advantage in terms of energy efficiency [5,6]. According to the nutritional requirements of microalgae, they can be classified as autotrophs or heterotrophs depending if the source of carbon used for growth is inorganic mineral ions or organic compounds, respectively [5] – Fig. 1. The great versatility displayed by microalgae allowed them to thrive on a wide range of environments across the globe including under extreme conditions of temperature, pH, light intensity and salinity [7].

Despite the limitless commercial potential of microalgae (see Fig. 1), these microorganisms remain greatly unexplored since several million of species are estimated to exist [8–10]. The starting point on microalgae use by humans occurred about 2000 years ago when the Chinese started using them as a food source.

In fact, due to their high nutritional value, especially in terms of proteins, lipids, and carbohydrates [15], microalgae are still extensively used as a source of food in Asiatic countries [16,17]. *Chlorella*, *Spirulina*, *Haematococcus* and *Dunaliella* represent the majority of the market, which can be commercialized in tablet, capsule, liquid and powder forms or added to pasta, snacks and drinks as nutritional supplements or natural dyes [4,16,18,19]. When ingested, the high-protein content microalga *Chlorella* was found to enhance the growth of intestinal *Lactobacillus*, while *Spirulina* sp. and *Dunaliella* sp. can act as potent anticancer agent due to their carotenoids content [20,21]. In spite of the significant efforts for leveraging microalgae as human food, linking

Abbreviations: AC, Alternating current; DC, Direct Current; DEP, Dielectrophoresis; DMSP, dimethylsulfoniopropionate; EC, Electrocoagulation; ECF, Electro-coagulation-flotation; ECH, Electrochemical harvesting; EF, Electric Field; HVED, High Voltage Electric Discharge; MEF, Moderate electric fields; OH, Ohmic heating; PEF, Pulsed Electric Fields; PUFA, Polyunsaturated fatty acid

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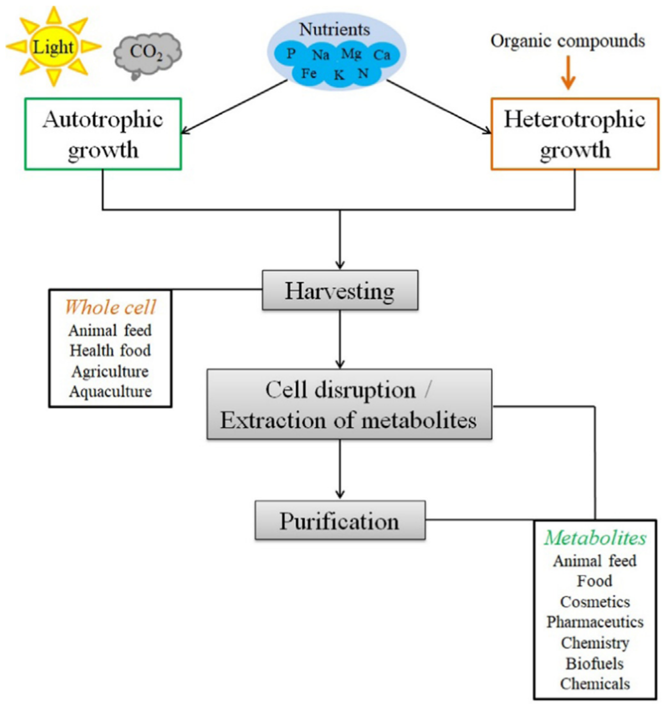

Fig. 1. Microalgae production steps and potential applications.

them to "healthy" food, the high production costs and the strict food safety regulations have shown to be restrictive to this mind-set shift. Consequently, microalgae cultures have been mostly used as feed additives in aquaculture food chain (e.g. larvae and juvenile molluscs, penaeid prawn, and crustaceans, as well as fish) improving immune system response, fertility and weight control in addition to promote a healthier skin (e.g. more colourful) and lustrous coat [9,22,23]. Besides aquaculture feeding, *Spirulina* and *Chlorella* are used in food diets of domestic animals [11]. As an example, eggs can be enriched in omega-3 fatty acids by feeding hens with microalgae containing high percentage of PUFAs [9,22]. Nowadays, besides food and feed applications, microalgae are utilized in chemical, biofuels, pharmaceutical, and cosmetics sectors, either in whole-cell form or through their functional compounds [12–14,22].

To reduce microalgae production costs and therefore stimulate its generalized commercialization, a strategy might be implemented combining algal growth in open or closed systems with CO_2 fixation (i.e. from exhaust gases originated by fossil fuel combustion) and/or wastewater treatment processes, supressing nutritional needs of microorganisms [5,12,14,24]. This will not only contribute to control issues involving greenhouse gases emissions (namely CO_2) and contaminants removal from wastewater, but also generate economic value utilizing wastes or by-products from other industrial processes [7]. Thus, besides ensuring environmental sustainability, such production scheme is also suitable to use microalgae cells as raw material to produce not only a wide range of biofuels (e.g. biodiesel, bioethanol), but also high added-value bioactive compounds (e.g. proteins, pigments, vitamins, antioxidants) [5,11,12,25,26]. Taking advantage of the ability of a number of microalgae for fixing atmospheric nitrogen, namely cyanobacteria species, these microorganisms are commonly utilized in agriculture as biofertilizers. By fixing nitrogen, microalgae improve soil fertility and its physico-chemical properties leading to higher plant growth yields. Moreover, the use of microalgae as biofertilizer entails another benefit for plants which consists on the production of several growth-promoting substances like vitamin B_{12} [4]. A different method for using microalgae as biofertilizers lies on subjecting them to a pyrolysis process resulting in the formation of solid charcoal residue (i.e. biochar) [22].

1.2. Metabolites with commercial interest

Depending on the type of microalgae used, numerous bioactive

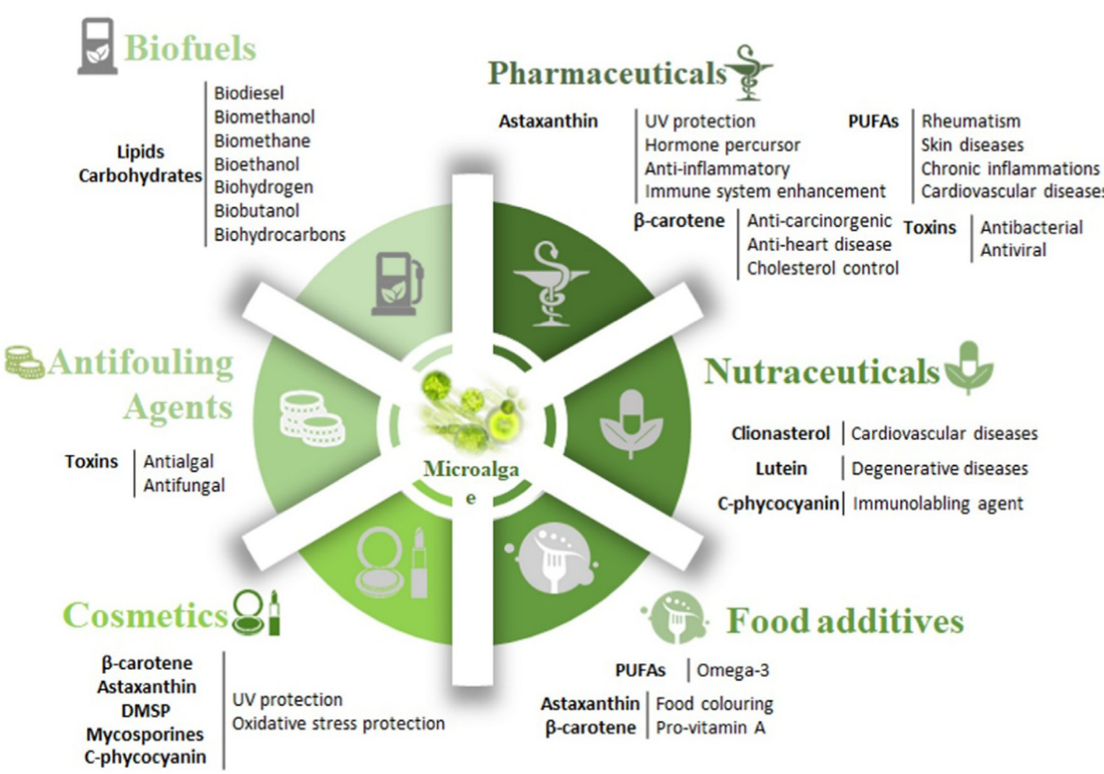

Fig. 2. Microalgae metabolites of interest and potential application areas.