



Mini Review

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Microalgae and Sustainability



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Abstract

The evolution of aerobic metabolism and complex life on Earth was made possible by microalgae, that absorb carbon dioxide and release oxygen as a result of photosynthesis. Such organisms have conducted the process for more than 3 billion years, and currently are considered responsible for up to 60% of the global oxygen production. Furthermore, microalgae have been indicated as the most promising source of sustainable energy for the future. Energy generation from microalgae can occur in different ways, after biomass processing into biofuels (e.g., biodiesel, biohydrogen, biogas). Alternatively, many high valued compounds of interest can be obtained, such as food supplements to humans and animals, pharmaceutical and nutraceutical products, carotenoids derivatives, and even fertilizers. Microalgae cultivation does not compete with food crops for agricultural land, since they can be cultivated in compact photobioreactors (PBR) that can grow vertically, and use arid lands, requiring sunlight, water, and nutrients that could be supplied from effluents of the biodegradation of animal manure. In this mini review, some of the main applications of microalgae are presented, as well as some challenges that shall be overcome to make microalgae industrial utilization a possible future reality.

Keywords: Energy; Food supplements; Biorremediation; Biofuels; Pharmaceuticals; Compact photobioreactors

Introduction

Microalgae can be classified as a large group of microorganisms with a high degree of biological diversity, composed of prokaryotic organisms (cyanobacteria) and eukaryotic photoautotrophic protists [1]. However, divergences still prevail in the taxonomic classification of algae [2]. Thus, they are organized into groups, based on the composition of pigments, product storage profile and structural characteristics [3]. The industry sector attention has been increasingly attracted to microalgae derived biofuel since it is ecologically correct and potentially more productive than oil crops [4]. Microalgae can be grown in different systems, in volumes ranging from a few liters to billions of liters. In order to make possible any large-scale microalgae cultivation process, the need for a system with high productivity per occupied area, low cost of installation and operation is highlighted. The biodiversity of these organisms represents an important technological feature, allowing the cultivation of different species in a wide range of operational conditions. By way of illustration, we can cite a self-sustaining energy plant for biomass of microalgae production, in PBRs at the Self-sustainable Energy Research & Development Center, NPDEAS, at the Federal University of Paraná, UFPR, in Curitiba, Brazil [5]. In that project, it was decided to study and

develop the pilot-scale fish feed production process, from the microalgae residue that was previously used to produce biodiesel as the primary material [6], using compact PBRs developed by this research group and shown in Fig. 1. The design of this PBR is innovative and two patents have been submitted [7,8].

In that scenario, the development of economically viable methodologies for microalgae derived bioproducts and biofuels would be very much appreciated. The discussion includes the microalgae biological characteristics and possible direct and indirect applications. To make the industrial use of microalgae technically and economically feasible, some possibilities as genetic improvement; the use of mathematical modeling and computational simulation tool for evaluating potential results are presented.

Microalgae Utilization

Microalgae are a group of organisms with a polyphyletic origin. To be identified as a microalgae, the organism must be small, unicellular or colonial, with little or no cellular differentiation, must have color, due to the presence of pigments, and occur mainly in water. In this way, microalgae are an artificial group, since it includes the so-called cyanobacteria, which belong

to the Bacteria domain, but most species of microalgae belong to the Eukarya domain [9,10].

Microalgae should be photoautotrophic, but not all the time, being also heterotrophic or mixotrophic. In the first, the functions are governed by photosynthesis, and in the heterotrophic cultivation, nutrients are made available for the metabolism to occur in the absence of light. And finally, in the mixotrophic culture both metabolisms mentioned above occur.

The exact number of species of microalgae is still unknown, and citations are found that there may be between 200,000 and a few million representatives of this group. This diversity makes microalgae a source of a wide range of chemicals with applications in the food, nutraceuticals, pharmaceuticals and cosmetics industries. The lipids accumulated by microalgae are classified according to the number of carbon atoms. Fatty acids with a chain of 14-20 carbons are used in the production of biodiesel, while those with larger chains are used as food supplements, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) [11]. In addition to lipids, microalgae have other value-added metabolites, such as carbohydrates, proteins and pigments that can be refined and marketed with different applications. Carbohydrates are one of the most important microalgae compounds [11]. These compounds have high added value, with several applications. Some examples are the marketing of dietary supplements based on *Chlorella* and *Spirulina*, β - carotene, phycobiliproteins, astaxanthin, oil rich in docosahexaenoic acid, among others. In this way, one must explore all the potentiality provided by microalgae biomass.

Microalgae are the main food of various species of fish, molluscs and crustaceans in natural environments. Because they are the primary marine producers, microalgae are essential for structuring almost all coastal and ocean ecosystems. The main use of microalgae in aquaculture is as a nutritional source, and can be used *in natura* or added to feed [6]. Protein content is the main component evaluated in the selection of microalgae for animal feed. However, when selected for *in natura* consumption, especially in the larval stage of aquatic organisms, they should have adequate size and shape to be ingested. Also, microalgae may be considered as a good alternative for animal consumption, but some metabolites produced by some species may have a toxic effect on some animals [6,12]. On the other hand, the improvement of the skin and fur of pets have been reported. In the case of feed for farmed animals, 5 to 10% of protein source may be microalgae, with no adverse consequences for the animals [12].

Both animal feeds and biofuels have as their main raw material agricultural products. This is one of the main aspects on which critics of the use of biofuels are based, i.e. the competition for agricultural land that should be primarily intended to produce human food. The increase in the global demand for fuels from renewable sources has leveraged many initiatives in the private and federal sectors, aiming at the production of

biofuels, particularly in Brazil, the United States of America and Europe [13]. Globally, European biodiesel accounted for 43% of world production in 2011, being the world's largest producer of biodiesel, according to the United States Department of Energy. Total biodiesel production in Europe in 2013 was 10,367,000 tonnes [14]. It is interesting to highlight other advantages that result from the use of biodiesel, such as increased employment and useful coproducts obtained during the processing of this new fuel such as about 110kg of glycerine for each ton of biodiesel [15].

According to Chisti [4] some microalgae may have up to 70% of lipids in their structure and are capable of producing more than 30 times the amount of oil per area of land, when compared to oilseed crops. The microalgae biomass doubling over a very short period of time, the use of a smaller physical space, the ability to grow in areas not suitable for agriculture and the least waste generation make this biofuel a promise of a clean energy source. The great challenge is to purify the lipid portion with the right properties for use as biodiesel. This process still requires a higher energy cost than the generated energy. In order to obtain a higher yield aiming at the economic viability of a microalgae-based energy system, hydrogen generation from photobioreactors such as those shown in Figure 1 can be included. It should be remembered that hydrogen is considered the fuel of the future, because it is renewable, its source is inexhaustible and does not generate any pollutant, and have the highest lower heating value (per unit of mass) among all known fuels possessing a high energetic capacity [16].

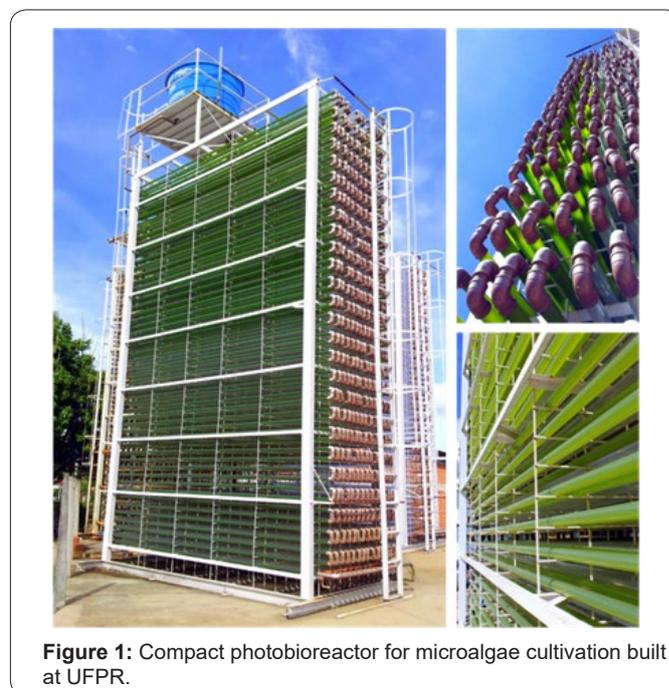


Figure 1: Compact photobioreactor for microalgae cultivation built at UFPR.

Feasibility of microalgae derived biofuel industrial use

Based on the positive aspects raised so far, it was to be expected that concrete technological and economic results for

the use of microalgae as source of biofuels in the near future would be available. Stephens et al. [17] present two arguments that can explain why this has not yet occurred: (i) the pilot and demonstration plants are still below the economic feasibility scale, and ii) there was not enough time for the industry to evolve through the injection of recent capital into large-scale commercial production. In addition, another very important point regarding biofuels is the cost of oil. Whenever the price of the barrel is low, the economic advantages of renewable fuels decrease.

Once the optimum microalgae cultivation conditions have been reached, increasing the productivity of biofuels, biomass or any other bio-product can only be achieved with the genetic improvement of these organisms. The potential for genetic improvement of microalgae is enormous, there are many efforts in this regard, and in recent decades many advances have been achieved.

The genetic engineering tools have been adapted for microalgae. Strategies including increasing the number of copies of a gene, increasing or decreasing the expression of one or more genes, and still the expression of heterologous genes, selected from other species, are possible for several species of microalgae [18]. A variety of transformation methods have been used to transfer DNA to microalgae cells, including electroporation, biobalistics, and *Agrobacterium tumefaciens*, and the efficiency of the transformation is dependent on the species and the method used [19]. Some target genes have been identified and selected for genetic improvement, mainly after the publication of the genome of some species like *Chlamydomonas reinhardtii* [20-22]. Genetic modifications are now considered the great promise that could lead to an economically viable scenario for the production of clean energy and bio-products by microalgae. New technologies like genome edition using CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) are being applied with good results in microalgae, and with the advantage that the resulting mutants are not considered genetically modified organisms (GMOs), with less restrictions than GMOs regarding their use [23,24].

The prediction of cultivation techniques results, even with microalgae wild or mutants species, is possible using mathematical modeling and computational simulation. In general, a mathematical model is designed to simulate the response or behavior of a real system in a computer, which allows to calculate the spatial and temporal distribution of any physical quantity within the physical system under study. These distributions are determined by the external environment conditions, fluid flow, physical system geometry, and internal system generation terms. Many mathematical models to predict the growth of microalgae in photobioreactors have been proposed [25,26]. As an example of recent progress, a mathematical model was presented by Kava-Cordeiro & Vargas [27] to contemplate the possibility of genetic modification in microalgae to improve some aspect of

interest (e.g., increase of lipid content, biohydrogen production).

Conclusion

Based on the arguments presented throughout this mini-review, at the current moment of possible future shortage of energy and food resources to maintain human society's living standards, it is reasonable to think that microalgae could bring a possible solution to a sustainable world. In short, they were the organisms that transformed the inhospitable conditions of our planet into a life-friendly environment as we know it today. In fact, microalgae reproduce rapidly, they are the largest CO₂ fixers on the planet, and they are at the bottom of the food chain. They generate huge amounts of biomass, so they are the largest known bioenergy store and have the potential to supply the energy needed to maintain a sustainable human society in an environmentally sound way, because it is renewable energy. With the presence of multi-generator and environmental remediation systems coupled with microalgae cultivation, it is expected to be possible to perform superior microalgae use in comparison with terrestrial cultures from all points of view, as well as to make microalgae commercially competitive in the production of biofuels and other products with high added value. However, it is not an easy goal to achieve. There are major technological challenges to be overcome in order to make possible the industrial use of microalgae with all the resources that can be obtained from these small but versatile organisms.

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Conflict of Interest

The authors declare that any economic interest or any conflict of interest do not exist.

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