Are microalgae a possible energy source for a sustainable world?

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ABSTRACT

In recent years, much scientific research has been directed to the search for viable alternatives to clean energy. One of the harshest criticisms of vegetables derived biofuels is the use of food producing agricultural land for biofuel production, whilst hunger still harms many countries. In such a scenery, the development of economically viable methodologies for microalgae derived bioproducts and biofuels would be very much appreciated. Energy generation is one of the most important microalgae applications in different forms, such as biodiesel, biohydrogen, and biogas. Additionally, many high valued substances of interest could be obtained, to the pharmaceutical and nutrition industries, such as carotenoids derivatives. Microalgae could be cultivated in compact photobioreactors (PBR), thus not competing with agricultural land. In this paper, the essential fundamentals for facing the challenges to be overcome to turn viable microalgae industrial utilization are presented.

Keywords: food supplements, biofuels, pharmaceuticals, compact photobioreactors

1 INTRODUCTION

The industry sector attention has been increasingly attracted to microalgae derived biofuel since it is ecologically correct and potentially more productive than oil crops. 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. In general, production systems are unsophisticated, with open-pit cultivation systems in land-bottomed tanks and with little or no control of environmental parameters. Recently photobiorrores (PBR) were developed for the cultivation of microalgae in which some control of growth parameters is possible.

The discussion includes the microalgae biological characteristics; possible direct and indirect applications; the search for genetic improvement; the use of the mathematical modeling and computational simulation tool for evaluating potential results; perspectives about the economic viability of clean energy use as a possible reality in the near future.

2 MICROALGAE

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 (Woese; Kandlert; Wheelis, 1990; Baldauf, 2008).

Microalgae should be photoautotrophic, but not all the time, being also heterotrophic or mixotrophic (Fig. 1). 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.

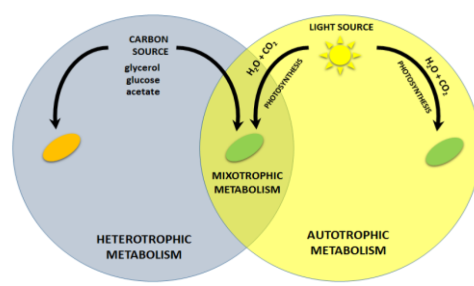

Figure 1 Microalgae metabolisms autotrophic, heterotrophic or mixotrophic.

At this point, it is important to recognize that the microalgae, initially the cyanobacteria and later of the eukaryotic microalgae, are among the first photosynthetic organisms to evolve on planet Earth about 3.5 billion years ago. Thus, these photosynthetic beings appeared in the Archean, and must have been responsible for the appearance of oxygen in the Earth's atmosphere.Thus, they indirectly created the basic conditions for the emergence of the human species and almost all kind of life on planet Earth.

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.

Many studies have been developed in the world seeking to make the industrial use of microalgae technically and economically feasible. By way of illustration, we can cite a self-sustaining energy plant for biomass of microalgae production, in PBRs at the Nucleus of Research and Development in Autosustainable Energy, NPDEAS, at the Federal University of Paraná, UFPR, in Curitiba, Brazil (Satyanarayana, Mariano; Vargas, 2011). In this 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 (Balen et al., 2015), using compact PBRs developed by this research group and shown in Fig. 2. The design of this PBR is innovative and the international patent has been required (Vargas et al., 2012).

Figure 2: Compact photobioreactor for microalgae cultivation built at UFPR

2.1 Microalgae and possibilities of direct use

Human consumption

One of the biggest problems that man will face in this century will be the production of food to meet the growing world population. The first record of the use of microalgae for human consumption has more than 2000 years, when the genus *Nostoc* was used by Chinese for their direct consumption, in a period of scarcity of other food sources. Still in antiquity, African populations incorporated the habit of consuming microalgae, especially the genus *Spirulina*. This same genus was used for consumption by the Aztecs in Mexico (Spolaore et al., 2006).

Fundamentally, the use of microalgae by humans at the present time is mainly as food or food supplement, like natural food colorant (Batista et al., 2006) and also in the pharmaceutical and cosmetics industries. The microalgae can be considered a functional food (Pulz; Gross, 2004), that is, they bring some benefit to the health, besides nourishing the individual that consumes them. Several products obtained from microalgae present therapeutic function, in addition to food, falling into the class of products called nutraceuticals, especially antitumor, anti-inflammatory, neuroprotective and antioxidant properties.

The lipids accumulated by microalgae are classified according to the number of carbon. 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) (Yen et al., 2013).

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 (Yen et al., 2013). 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.

The use of microalgae in cosmetics is partially related to their properties as natural dyes, but also involves other attributes, derived from the action of minerals, vitamins and other molecules present in the extracts. These extracts can be used mainly in skin products as sunscreens, in hair products, in the prevention of skin aging and the formation of stretch marks (Spolaore et al., 2006).

Animal nutrition

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 natural or added to feed (Balen et al., 2015). 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. However, microalgae may be considered as a good alternative for animal consumption, some metabolites produced by some species may have a toxic effect on some animals (Spolaore et al., 2006; Balen et al., 2015).

The use of microalgae in the supplementation of animal food has increased significantly in recent years also because in addition to the nutritional properties, effects such as improvement of the skin and the hair 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 (Spolaore et al., 2006).

Biofuels (biodiesel, biohydrogen, biomass)

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 the production of biofuels, particularly in Brazil, the United States of America and Europe (Eriksen, 2008). 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 (European Biodiesel Board - EBB, 2015). 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 110 kg of glycerine for each ton of biodiesel (Behr et al., 2008).

According to Chisti (2007) some microalgae have 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 Fig. 2 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, besides possessing a high energetic capacity.

Thus, it was to be expected that concrete technological and economic results for the use of these biofuels in the near future would be available. This raises the question of why this has not yet occurred. Stephens et al. (2010) present two arguments to try to answer this question: (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.

2.2 Microalgae and possibilities of indirect use

Carbon sequestration

To reduce the amount of carbon dioxide emitted into the atmosphere there are two possibilities: the first is the reduction of emissions and the second is the absorption of excess carbon dioxide, also referred to as carbon sequestration. Microalgae can collaborate to reduce these CO_2 emissions in the atmosphere, because CO_2 is a necessary contribution to the process of photosynthesis. This process, coupled with the direct diffusion of CO_2 into water, prevents even greater "greenhouse gas" accumulation. Recently an integrated system for the treatment of emissions and effluents was developed simultaneously (VARGAS et al., 2013).

Waste treatment

Another application of microalgae is in the treatment of wastewater. Microalgae provide O_2 to bacteria, making their biological degradation activity more efficient, removing nutrients such as nitrogen and phosphorus, which are responsible for the eutrophication processes of water resources, as well as removing some heavy metals and pathogenic microorganisms.

The production of animal protein leads to large production of waste due to the high density of the production units. Microalgae are able to efficiently treat the highly polluting pig farming residue as well as other agroindustrial wastes. The rapid growth of microalgae in crop systems allows the rapid utilization of the nutrients present, providing microalgae biomass and treated water at the end of the process (Taher, 2013).

2.3 Genetical improvement

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 the last 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. Basically, the DNA of interest should be cloned into vectors to be inserted into microalgae, followed by selective selection of transformants (Specht; Miyake-Stoner; Mayfield, 2010). A variety of transformation methods have been used to transfer DNA to microalgae cells, including electroporation, biobalistics, and *Agrobacterium tumefaciens*. The efficiency of the transformation is dependent on the species and the transformation method used for each microalga (Radakovits et al., 2010).

Some target genes have been identified and selected for genetic improvement (Dubini, Ghirardi, 2015), but other genes related to hydrogen production are still unknown (Toepel et al., 2013). 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.

2.4 Mathematical modeling and computational simulation

Generalizing, 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 (Xu; Boeing, 2014). As an example of recent progress, a mathematical model is presented by Kava-Cordeiro and Vargas (2015) to contemplate the possibility of genetic modification in microalgae to improve some aspect of interest (eg, increase of lipid content, biohydrogen production) .

3 CONCLUSIONS

Based on the arguments presented throughout this article, 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 CO_2 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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