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Magnetic Field Application to Increase Yield of Microalgal Biomass in Biofuel Production

Lucielen Oliveira Santos, Pedro Garcia Pereira Silva, Sharlene Silva Costa and Taiiele Blumberg Machado

Abstract

Use of fuels from non-renewable sources has currently been considered unsustainable due to the exhaustion of supplies and environmental impacts caused by them. Climate change has concerned and triggered environmental policies that favor research on clean and renewable energy sources. Thus, production of third generation biofuels is a promising path in the biofuel industry. To yield this type of biofuels, microalgae should be highlighted because this raw material contains important biomolecules, such as carbohydrates and lipids. Technological approaches have been developed to improve microalgal cultivation under ecological conditions, such as light intensity, temperature, pH and concentrations of micro and macronutrients. Thus, magnetic field application to microalgal cultivation has become a viable alternative to obtain high yields of biomass concentration and accumulation of carbohydrates and lipids.

Keywords: magnetic effect, bioenergy, third generation biofuel, *Chlorella*, *Spirulina*, carbohydrates, lipids

1. Introduction

Due to exponential growth of the population and consequent increase in the demand for energy, the energy crisis has worsened globally. Various current energy sources are non-renewable fossil fuels, such as diesel, gasoline, coal, natural gas and oil [1]. Those that have been used in electricity, transportation and heating industries have the disadvantages of releasing toxic and harmful gases into the atmosphere and of polluting the environment [2]. Greenhouse Gas (GHG) levels in the environment have increased by a staggering 25% in the post-industrialization [1]. As a result, changes in climatic conditions have occurred and replacing fossil fuels by other sources that can benefit the environment has become an alternative [3].

Thus, biofuels derived from plant material have emerged as a promising solution to reduce supply of fossil fuels in recent decades [4]. Biofuels have advantages, such as the ability to reduce GHG emissions, continuous supply of raw material and ease of cultivation, harvesting, and transportation [5]. According to the Global Trends Report (GTR), 133.7 billion liters of ethanol and 47.4 billion liters of biodiesel were produced in 2019 worldwide; the three largest producers were the United States, Brazil and Indonesia. The increase was 7.8 billion liters, by comparison with 2018 [6].

Biofuels are classified into three generations, depending on their sources. The first generation is derived from plant sources; the second ones comes from agro-industrial waste and wood waste, while the third one comes from microalgae. The fact that first- and second-generation raw material are limited by competition with food production and arable land emphasizes the importance of using alternatives, such as microalgae, which are attractive options [7].

Microalgae, which are photosynthetic microorganisms with simple growth needs, adapt to a wide range of variations in the culture medium. Depending on the conditions, they can produce large amounts of compounds, such as carbohydrates and lipids that can be processed into bioethanol and biodiesel, respectively [8].

Magnetic Fields (MF) are capable of causing effects on biological systems and, therefore, application of this technique has attracted attention in biotechnology and bioenergy to increase production of biomolecules of interest [9]. MF correspond to the region in which magnetic forces act [10]. MF can be generated either by magnets composed of conductive material with characteristic magnetic intensity, such as ferrite and neodymium or by an electric current that results from straight conductors, circular loop, flat circular coil, electromagnets and solenoids [11]. Since magnetic forces can act differently on microorganisms due to distinct biochemical and physiological constitutions, their biological effects can be inhibitory, null or stimulating [9, 12].

Studies have reported that some changes that can affect production of compounds are electro activation of some enzymatic systems and metabolic routes [13], oxidative stress, changes in enzyme and protein activity, gene expression, electron and ion movements [14, 15], cell growth [16–19] and high activity of photosystem II [20]. However, different strains of microalgae, application time and MF intensity can give different responses. Therefore, previous studies of MF, applied at different exposure times and intensities during cultivation, should be investigated to evaluate their effects [21].

2. Biofuels

The world population has currently faced a major challenge, i. e., to associate economic development with sustainable practices [22]. The amount of fossil fuel consumed by the population and, consequently the number of environmental problems, such as excess of CO₂ in the atmosphere and global warming, increased significantly [1].

Biofuels are promising for the replacement of fossil fuels since they can reduce environmental impacts and meet the global demand for energy consumption [23]. The first generation biofuels, such as biodiesel is produced from oleaginous crops. It has currently been questioned due to the large amount of water it consumes, the use of agricultural land and its competition with food production [24].

Third generation bioethanol and biodiesel are biofuels that use microalgal biomass as raw material which has become an alternative for this generation of sustainable and renewable biofuels. Adequate cultivation conditions are necessary to obtain high biomass yields, desirable carbohydrate accumulation for bioethanol production [25, 26] and essential lipid levels for biodiesel production [27, 28].

Global interest in renewable energy sources, such as biofuel production has been continuously growing. Thus, microalgal biomass is an excellent alternative for bioethanol production, not only because it decreases the use of traditional energy sources, but also because of the large carbohydrate accumulation in biomass. Regarding the third-generation bioethanol production, three countries, i. e., the USA, Brazil and China, produced 14,806, 7093 and 813 million gallons, respectively, in 2015 [26, 29].

According to Costa and Morais [30] biomass production is significantly positive for biodiesel production. Estimated average annual productivity of microalgal biomass in a tropical country, such as Brazil is $1.53 \text{ kg m}^3 \text{ day}^{-1}$ with an average of 30% of extracted lipid and the biodiesel yield from microalga of $98.4 \text{ m}^3 \text{ ha}^{-1}$. Microalgae have the ability to use nitrogen and phosphorus from culture medium in their photosynthetic process and synthesize lipids [31]. Thus, microalgae can produce 58.700 L ha^{-1} of algal oil and $121.104 \text{ L ha}^{-1}$ of biodiesels. The Renewable Fuels Standard (RFS) estimated that microalga-based fuel production will obtain 36 billion gallons by 2022 [26].

3. Microalgae

Microalgae are photoautotrophic microorganisms that grow fast under relatively simple nutritional conditions. Therefore, they are considered promising organisms for biomass production due to their high-value biomolecules for commercial application [32, 33]. Due to the diversity of biomolecules, several studies have investigated the use of microalgae for biofuel production. Both genera *Chlorella* and *Spirulina* have great potential for this purpose, since they have high concentrations of composites of interest, such as carbohydrates and lipids [33, 34].

Microalgae can be cultivated in three forms: photoautotrophic, heterotrophic and mixotrophic cultivation. The mixotrophic one is a variant of the heterotrophic culture, where CO_2 and organic carbon are assimilated by the respiratory and photosynthetic metabolism with high growth rate and biomass productivity [35]. In this type of cultivation, an organic source of carbon, such as molasses, glycerol and glucose is added [36, 37]. The capacity for assimilating high concentrations of available carbon by microalgae tends to accumulate more carbohydrates and lipids [36], macromolecules of interest in biofuel production.

Production of metabolites by microalgae is determined by several factors, such as species, agitation, pH, nutrient composition, CO_2 concentration, light intensity and temperature [38, 39]. According to Khan et al. [26], light intensity and temperature are the main limiting factors in microalgal cultivation, since these physical stress factors directly influence biochemical processes, such as photosynthesis and biomass production yield.

4. MF application to increase biomass and carbohydrate production

New strategies of culture technologies with high yield of biomass concentration are necessary to enable biofuel production by microalgae [40]. Thus, MF application has been considered a new low-cost technological approach to stimulate cell growth and increased carbohydrate content in microalgal biomass. These outcomes may be achieved by the complex biochemical system in microalga cells, which may cause changes in their defense mechanism and activate proteins, some enzymatic systems and free radicals [21, 41].

Small et al. [42] evaluated the cultivation of *Chlorella kessleri* in a raceway bioreactor with Blue-Green Medium (BG-11) with static MF from 5 to 15 mT, generated by a water-cooled solenoid for 13 d. Cultivation with 10 mT had significant increase of 50% in biomass production while the carbohydrate content reached 42.2% at the end of cultivation. Bauer et al. [16] investigated the influence of 30 mT on *Chlorella kessleri* cultivation in BG-11 medium for 10 d. In relation to the control assay (without MF application), biomass concentration increased 23.5%; its carbohydrate content reached 21.4% with MF applied throughout cultivation (**Table 1**).

Microalga species	Intensity (mT)	Time of exposure (h d ⁻¹)	Increased biomass content (%)	Carbohydrate content (%)	References
<i>Chlorella kessleri</i> UTEX 398	10	0.3	50	42.2	[42]
<i>Chlorella fusca</i> LEB 111	60	24	21.4	31.4	[17]
<i>Spirulina</i> sp. LEB 18	30	24	40	30.3	[43]
<i>Chlorella kessleri</i> LEB 113	30	24	23.5	21.4	[16]
<i>Spirulina platensis</i> sp	30	6	30.4	12.8	[44]
<i>Chlorella minutissima</i> sp	30	24	30	60.5	[19]

Table 1.
Magnetic effect on biomass and carbohydrate contents of different species of microalga.

Deamici et al. [43] investigated physiological changes in *Spirulina* sp. cultivated in Zarrouk medium under the influence of 30 mT in different periods of MF application (24 h d⁻¹ and 1 h d⁻¹) for 15 d. When the microalga was exposed to the permanent condition, biomass concentration increased 40% and reached the highest carbohydrate content of 30.3%, it was 133.2% higher than the one of the control. Shao et al. [44] evaluated enhancement of *Spirulina platensis* biomass with the application of 30 mT for 22 d. Different exposures times (3, 6 and 12 h d⁻¹) were evaluated and the highest biomass concentration was reached when MF were applied for 6 h d⁻¹, increasing 30.4% in relation to the control assay, with carbohydrate content of 12.8%.

5. MF application to increase biomass and lipid production

Cultivation strategies have been studied to increase biomass production and lipid synthesis by microalgae [23]. MF application affected the composition and production of biomass, fundamental parameters in biofuel production [21].

According to Albuquerque et al. [45], MF are capable of regulating metabolic pathways of microorganisms, gene expression and chemical reactions. The authors also commented that the influence of MF on cell metabolism and on the growth of biomass depends on the interaction between the intracellular and extracellular environment, such as the type of cell, characteristics of the culture medium and the existence of biomolecules which are susceptible to MF.

MF can affect the growth and metabolism of microorganisms positively and negatively, depending on its intensity, frequency, pulse shape, type of modulation and exposure time [9]. MF have been shown to be efficient to increase biomass and lipids, since their action can cause oxidative stress in cells of microorganisms, change energy levels and orientation of free radicals and affect enzymatic activity of cells [46–48].

Changes promoted by the MF are responses of the interaction between them and microorganisms, i. e., alteration in permeability of membranes and, consequently, in their cellular metabolism [49]. MF application is considered a low cost and promising tool to overcome some limitations of microalgae, such as lipid productivity [50]. **Table 2** shows the effects of MF on biomass concentration and lipid content.

Microalga species	Intensity and exposure time MF	Lipid content (%w w ⁻¹)	Biomass concentration (g L ⁻¹)	References
<i>Chlorella pyrenoidosa</i> FACHB-9	50 mT for 3 h d ⁻¹	—	Increased 12.8%	[51]
<i>Chlorella kessleri</i> UTEX 398	10 mT for 0.3 h d ⁻¹	Increased 47%	Increased 43%	[42]
<i>Chlorella fusca</i> LEB 111	60 mT for 24 h d ⁻¹	Inhibition 23.2%	Increased 20.5%	[17]
<i>Spirulina</i> sp. LEB 18	60 mT for 1 h d ⁻¹	Null effect	Increased 95.1%	[43]
<i>Chlorella minutissima</i> sp	30 mT for 24 h d ⁻¹	—	Increased 30%	[19]
<i>Chlorella pyrenoidosa</i> FACHB-9	50 mT for 1 h d ⁻¹	Increased 12.9%	Increased 8.2%	[52]
<i>Chlorella homosphaera</i> sp	15 mT for 1 h d ⁻¹	Increased 22.4%	Inhibition 33%	[18]

Table 2.
 Influence of the MF on the synthesis of biomass and lipids in different species of microalga.

Studies have shown that lipid content and productivity can be increased when there is an association between nitrogen reduction and MF application. Bauer et al. [16] identified that, when *Chlorella kessleri* was cultured in BG 11 medium and exposed to 60 mT for 1 h d⁻¹, there was an increase in biomass concentration of 15% and 13.7% in lipid synthesis by comparison with the control. Chu et al. [28] evaluated the influence of MF application on *Nannochloropsis oculata* culture with modified Walne's medium. The highest lipid productivity (30.9 mg L⁻¹ d⁻¹) and lipid content (42.4%) were obtained when 20 mT was applied during 7 days of cultivation.

Nannochloropsis oculata was exposed to different intensities of MF (5, 10 and 15 mT) to evaluate the influence its biochemical composition and cell growth. Cultivation under influence of 10 mT increased biomass productivity (45%) and lipid productivity (57%) by comparison with the control [53]. Costa et al. [18] reported that the *Chlorella homosphaera* cultivated in the Bristol's Modified Medium (BMM) with 50% reduction in the nitrogen source associated with exposure to 30 mT and 60 mT for 1 h d⁻¹, increased lipid productivity in 108.4% (35 mg L⁻¹ d⁻¹) and 135.1% (39.5 mg L⁻¹ d⁻¹), respectively.

6. Conclusion

This chapter reported the potential of microalgal cultivation with MF application for biofuel production. The use of microalgae as raw material is an attractive alternative that can reduce the use of fossil sources and CO₂ emissions, and consequent pollution in the environment. Studies have suggested that MF application may be the most commercial production due to increased production of carbohydrates and lipids. For best results, in the case of every microalga species, parameters, such as MF intensity, exposure time, application period during cultivation and devices used to apply MF, should be evaluated. However, large-scale production of biofuels derived from microalgae has yet to be achieved if it is to be cost-effective.

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Conflict of interest

The authors declare no conflict of interest.

Appendices and nomenclatures

MF	magnetic fields
GHG	greenhouse Gas
GTR	global trends report
RFS	renewable fuels standard
BG-11	blue-green medium
AO	Aiba and Ogawa medium
BMM	Bristol's modified medium

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