USE OF MICROALGAE AND POTENTIAL NANOTECHNOLOGICAL APPLICATION: A REVIEW

USO DAS MICROALGAS E POTENCIAL APLICAÇÃO NANOTECNOLÓGICA: UMA REVISÃO

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ABSTRACT

Microalgae are eukaryotic and unicellular microorganisms of simple structure, colonial that need for their growth and reproduction, light, water, carbon dioxide and inorganic nutrients. Demonstrate commercial interest due to a biomass rich in bioactive substances, such as pigments, lipids, polyunsaturated fatty acids, carbohydrates, proteins, and vitamins. Among these substances, Chlorella microalgae oil contains lipids with a wide range of interesting properties. In this context, the present review aims to demonstrate the potential and applications of microalgae, mainly of the Chlorella species, as well as the methods and conditions of cultivation, the chemical composition, and its relationship with nanotechnology. The data for this review were obtained from a search in the main databases such as Scielo, Scopus and Science Direct, without restriction to the period of publication, using following descriptors: microalgae, Chlorella, biomass, oil, application, nanotechnology and their combinations. These microorganisms, as they are easy to cultivate and rapidly proliferate, are gaining ground in the area of new technologies involving species of the Chlorella type, which has several applications, including in the nutraceutical and cosmetics area, guaranteeing products with quality, efficacy and biodegradable assets.

Keywords: Biomass, Chlorella, Cosmetics, Microalgae, Nanotechnology.

RESUMO

As microalgas são microrganismos eucariontes e unicelulares de estrutura simples, coloniais e que necessitam, para seu crescimento e reprodução, luz, água, dióxido de carbono e nutrientes inorgânicos. Demostram interesse comercial em função de uma biomassa rica em substâncias bioativas, como pigmentos, lipídios, ácidos graxos poli-insaturados, carboidratos, proteínas e vitaminas. Dentre estas substâncias o óleo da microalga do tipo Chlorella contém lipídios com uma ampla gama de propriedades interessantes. Neste contexto, a presente revisão tem por objetivo demonstrar as potencialidades e aplicações das microalgas, principalmente da espécie Chlorella, bem como os métodos e condições de cultivo, a composição química e sua relação

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com a nanotecnologia. Os dados para esta revisão foram obtidos a partir de uma pesquisa nas principais bases de dados como Scielo, Scopus e Science Direct, sem restrição ao período de publicação, utilizando os seguintes descritores: microalgas, Chlorella, biomassa, óleo, aplicação, nanotecnologia e suas combinações. Estes microrganismos por serem de fácil cultivo e rápida proliferação estão ganhando espaço na área de novas tecnologias envolvendo as espécies do tipo Chlorella, a qual possui diversas aplicações, inclusive na área nutracêutica e de cosméticos, garantindo produtos com ativos de qualidade, eficácia e biodegradáveis.

Palavras-chave: Biomassa, Chlorella, Cosméticos, Microalga, Nanotecnology.

INTRODUCTION

Microalgae are photosynthetic single-celled microorganisms that form colonies or filaments and belong to various divisions of algae such as Chlorophyta, Charophyta, or also called green algae, in which chlorophyll is one of its main pigments, the species Haematococcus, Chlorella, Dunaliella, Graesiella, Scenedesmus are some examples of this type of algae (TAN et al., 2020). These single-celled microorganisms can be found in different habitats, both in seawater and fresh water (RANDRIANARISON; ASHRAF, 2017). They are also considered as raw material for food, feed, fuel, fertilizers, chemicals, and other value-added products, as they have a rapid growth rate and valuable intracellular components (JING-HAN et al., 2018).

Microalgae can convert solar energy and carbon dioxide into high levels of secondary lipids and carotenoids in their biomass. These microorganisms are emerging as a factory of important and economical products to produce commercial products, such as carotenoids (BOROWITZKA, 2013) and fatty acids (MENDES et al., 2008). These microalgae exhibit great biomass production compared to terrestrial plants in relation to the surface area needed to grow them, demonstrating that they represent a lower cost per production (CHIU et al., 2015; BEKIROUGULLARI et al., 2018). They also have advantages over other crops, such as high growth rate, short growth period and low land use (SANYANO et al., 2013).

Microalgae have long been explored, being sources of colloids used as thickeners, gelling agents, and stabilizers in the food industry, both human and animal. Due to its chemical composition, its applicability includes from aquaculture, wastewater treatment (JING-HAN et al., 2018), energy production (BIANCHINI et al., 2006; YANG et al., 2018) to cosmetics (SPOLAORE et al., 2006; LEE et al., 2018). Furthermore, microalgae also stand out for their biotechnological potential, for the identification of substances extracted by these algae (SPOLAORE et al., 2006; BIANCHINI et al., 2006; CARDOZO et al., 2007; BECKER, 2007).

The literature describes that microalgae perform very well in several areas where they are applied, with concentrations of valuable compounds found in their dry biomass, which is generated in laboratory experiments (CUELLAR-BERMUDEZ et al., 2014). These compounds have a high commercial value, since the biomass of microalgae contains: polyunsaturated fatty acids, carotenoids
(CHEN; LIU, 2018), phycobilins, polysaccharides, vitamins, steroids (LEVASSEUR et al., 2020) and other bioactive compounds, such as antioxidants and cholesterol, for example (YAÑEZ, 2006; BIANCHINI et al., 2006; CARDOZO et al., 2007; BECKER, 2007), which arouse great interest in the production of natural products, both in food and in cosmetics (MILLEDGE, 2011).

Based on the above, this review aims to highlight the use of microalgae in general, but also in particular *Chlorella*, in various scientific researches, both on a laboratory and industrial scale, as well as describing their various applications, cultivation conditions, biochemical composition and their relationship with nanotechnology.

**METHODOLOGY**

To carry out this review, a bibliographic search was performed on the materials of the scientific literature, featuring a bibliographic review (GIL, 2002).

The scientific materials found were analyzed in four stages of reading: exploratory, selective, analytical and finally interpretive (GIL, 2002).

The research was carried out in the main electronic databases, such as Scielo, Science Direct, Scopus, Google Scholar, with the following keywords: “MICROALGAS”, “CHLORELLA”, “BIOMASSA”, “OIL”, “APPLICATION”, “NANOTECHNOLOGY”, “COSMETICS” and their combinations, in Portuguese and English, without restriction of the publication period.

**DEVELOPMENT**

**Microalgae**

Microalgae are called single-celled aquatic microorganisms that are found both in fresh water and in marine systems (DANESHVAR et al., 2018), capable of photosynthesis (SHUBA; KIFLE, 2018) and are found in many shapes and sizes, which range from three to ten micrometers (VU et al., 2018). Its growth can occur as individual cells or associated in chains, as well as in small colonies (POSTMA et al., 2016), play an important role in aquatic ecosystems due to their photosynthetic capacity (MALCATA et al., 2018).

There are a variety of microalgae species evaluated, but still considered restricted, compared to the 40,000 that had their names published (GUIRY, 2012). Researchers have focused on those that showed high protein content (‘t LAM et al., 2018), ability to produce carotenoids and fatty acids (PERIN et al., 2019) and several other high-value products (‘t LAM et al., 2018).

With a short life cycle (which may vary from hours to days), a high rate of nutrient absorption (LEHMUSKERO et al., 2018) and a capacity for growth in both fresh and marine waters
microalgae allow researchers to screen a variety of species in miniaturized systems, thereby reducing development costs and intensifying the process. Such characteristics, associated with its high photosynthetic efficiency and the possibility of cultivation in mixotrophic or heterotrophic modes, are its main advantages compared to other organisms that perform photosynthesis (MORALES-SÁNCHEZ et al., 2017).

The cultivation of microalgae can be based on a variety of methods, from strictly controlled methods that can be photobioreactors, closed systems, as well as those in open systems that are more susceptible to environmental conditions (CONTRERAS-FLORES et al., 2003; TREDICI, 2004; POSTEN, 2009).

Some species of microalgae used as inputs in skin and hair care products, including extracts of Spirulina, Chlorella, Dunaliella and Nanochloropsis. More specifically, carotenoids such as astaxanthin, β-carotene and lutein can be included as part of topical cosmetic products to protect against hyperpigmentation or damage induced by ultraviolet rays (WANG et al., 2015; MOURELLE et al., 2017).

Dunaliella and Chlorella species do not produce toxic substances and are classified as safe food and some of the main species for animal and human consumption (WALKER et al., 2005). Thus, microalgae can be applied in nutritional and biomedical areas and are associated with therapeutic properties such as antioxidants, anti-inflammatory, anti-tumor, anti-obesity (PENG et al., 2011; GAMMONE; D’ORAZIO, 2015), immunostimulants and antivirals (YAAKOB et al., 2014).

Cultivation methods and conditions

Microalgae can be grown in both open and closed systems. Open systems are the simplest and have a low installation cost, they can be ponds, without any mechanical apparatus and these systems are generally made of materials such as sand, brick, cement, fiberglass and high density polyethylene (HDPE) or polyvinyl chloride (PVC) (CHISTI, 2007; BRENNA; OWENDE, 2010).

Among closed systems, photobioreactors stand out as the main system for cultivating microalgae on a large scale (BJERK, 2012). Photobioreactor is a transparent reactor made of glass or plastic, and can have several geometries (BITOG et al., 2011; TAMBARIC et al., 2011), the tubular being the most conventional, with the layout planned in order to minimize the exposure of biomass to light. The main characteristic is the control of almost all biotic and abiotic parameters of microalgae cultivation such as pH, temperature, agitation and aeration speed, nutrition, light intensity, which influence other factors (VOLOSHIN et al., 2016).

The development and growth of microalgae depends on the interaction between some factors, such as: biological, chemical, and physical, in which, biological factors are associated with the metabolic rates of the species under cultivation (RICHMOND, 2004).
Chemical factors such as nutrient availability, salinity and pH are the parameters that most interfere with the development of microalgae. For optimal growth and development of microalgae, additions of macronutrients (C, N, O, H, Ca, Mg, S and K), micronutrients (Mn, Mo, Fe, Co, Cu, Zn, Se and B), in addition to vitamins or specific substances that some species need (OSHE et al., 2007; OLIVEIRA, 2009). Carbon is considered the most important macronutrient, however, nitrogen and phosphorus are the limiting nutrients for the cultivation of microalgae (OSHE et al., 2007), potentiating the production of biomass and lipids in different concentrations of these nutrients (MATOUKE et al., 2018).

In studies carried out with microalgae cultivation by Kumar and collaborators (2018), the authors demonstrated that the C/N ratio is an indicator of bioconversion reactions. In this research they discovered a C/N ratio of 6.3 in a microalgae biomass concentration of 5 g/L. They were also evaluated under other conditions, and the C/N ratio ranged from 5.9 to 6.1, these values being like those found in the scientific literature with cultivation of Arthrospira platensis algae biomass. In general, the biomass of microalgae tends to have a high protein content instead of carbohydrates and the C/N ratio is partially lower than the biomass of macroalgae, with the maximum carbohydrate content being associated with biomass. For Chlorella sp., studies have shown values of 44.5% C, 6.2% H, 9.6% N and a C/N ratio of 4.63%, these values being higher than those found in terrestrial plants (THANGALAZHY-GOPAKUMAR et al., 2012).

Through experiments, it was found that the Chlorella strain can accumulate significant amounts of lipids under a condition of high salinity stress, but in return causes a limitation in the biomass production of this microalgae (KAKARLA et al., 2018).

In relation to pH, the control of this parameter is essential for the cultivation of microalgae, as it directly affects the availability of various chemical elements, influencing the absorption of nutrients from the culture medium by microalgal cells. It should be noted that different species of algae exhibit different levels of tolerance to the pH of the culture medium, affecting their growth rate, but the most common pH range for microalgae can vary from 6 to 8 (ZHU, 2015; RAI; GUPTA, 2017).

Parameters such as light and temperature are physical factors that also affect the development and growth of microalgae. Many microalgae species are photoautotrophic, that is, they can convert sunlight into energy and use the inorganic carbon necessary for building biomass through photosynthesis (DERNER et al., 2006; OHSE et al., 2007). Therefore, the intensity of light plays an extremely important role in the development of microalgae, the control of luminosity is directly linked to the carbon that will be fixed, influencing the growth rate of the crops (FONTOURA et al., 2017). In a study by Sang-II et al. (2019), it was found that when evaluating different growing conditions such as the intensity of LED lights (blue, red and white), in the cultivation of microalgae different yields of β-carotene were obtained.

Temperature is another parameter that must be observed, and should be monitored in small-scale crops grown in air-conditioned rooms, but for crops grown outdoors there are variations between
day and night cycles, in addition to seasonal differences, causing difficulty in the reproducibility of the animals. Growth results for the same species, even under apparently equivalent growing conditions (LOURENÇO, 2006). The temperature for cultivating microalgae can vary in a range between 28 and 35 ºC (PARK et al., 2011).

Militão and collaborators (2019) conducted a study with the objective of evaluating the development of three types of microalgae species in unialgal and mixed crops, at different temperatures, 20, 30 and 40 ºC, on a laboratory scale in order to analyze the biomass and the biochemical composition. The results showed that at 40 ºC there was no cell growth of the cultivated strains, at 30 ºC, obtained cell density of 13.6 x 10^6 cell. mL⁻¹ and biomass of 55 g. L⁻¹ in one of the species in the unialgal culture. High protein concentrations (672.6 mg. g⁻¹) were also observed in the unialgal cultures of two of the three cultivated species, at a temperature of 20 ºC and of carbohydrates (6.17 mg. g⁻¹) only in unialgal culture of one species in 30 ºC.

**Composition of microalgae**

From microalgae, natural bioactive compounds can be extracted (XU et al., 2009) such as pigments, lipids, polyunsaturated fatty acids, carbohydrates, proteins, and vitamins (GONG; BASSI, 2016).

Microalgae are able to produce more lipids than any other conventional crop, in addition, numerous other species can produce large amounts of essential fatty acids (EFA), especially omega-3 (ω-3) and 6 (ω-6), which they are the two most abundant fatty acids, as well as α-linolenic acid (ALA, C18: 3 ω-3) and linoleic acid (AL, C18: 2 ω-6) (HO et al., 2014; BELLOU et al., 2016), both precursors in the human body for long-chain polyunsaturated fatty acids (≥ C20) (PUFA) (RINCÓN-CERVERA et al., 2016).

Chen et al. (2011) highlight that the lipid content of microalgae is not the only factor that determines their oil production capacity, according to these authors, the lipid content and biomass production need to be considered simultaneously. Therefore, the lipid productivity that represents the combined effect of these two factors mentioned is the most appropriate performance index to indicate the productive capacity of lipids by a microalgae.

In general, microalgae present on average 27% of the dry cell weight in oil, a percentage that can double or even triple when grown under stress conditions (photo-oxidative or lack of specific nutrients) (BASOVA, 2005).

The microalgae have their oil composed mainly of a mixture of unsaturated fatty acids, although saturated fatty acids are also present, but in a smaller amount (BJERK, 2012). According to Arceo (2012), in some species, polyunsaturated fatty acids can reach between 25% and 60% of total lipids.

The oil extracted from the microalgae has aroused great interest in both the academic and industrial fields, since biodiesel can also be produced from this oil, due to the high capacity that some species of microalgae have to store lipids in their cells, and there may not be competition with food,
with high biomass productivity per hectare of cultivation and also a high CO$_2$ absorption (DEMIRBAS; DEMIRBAS, 2011; MOAZAMI et al., 2011).

Chlorella microalgae can produce in every 100 g of dry biomass, vitamin A (30.77 mg), vitamin C (10.4 mg), vitamin B1 (1.7 mg), vitamin B2 (4.3 mg), vitamin B3 (28.3 mg), vitamin B5 (1.1 mg), vitamin B6 (1.4 mg), vitamin B9 (94 µg), vitamin B12 (0.1 µg) and vitamin E (1.5 mg) (ANDRADE et al., 2018).

*Chlorella sp.*

*Chlorella* is a species of green alga from a single cell, which belongs to the phylum Chlorophyta, this microalga has a spherical shape, approximately 5 to 10 micrometers in diameter without flagella (figure 1). It has the photosynthetic pigments green chlorophyll in its chloroplast (ILLMAN et al., 2000). Through photosynthesis, this microalga multiplies rapidly, requiring carbon dioxide, water, and sunlight to reproduce (GONÇALVES et al., 2013). It also has a lot of resistance to contamination, in addition to fast growth and easy cultivation (HUNTLEY; REDALJE, 2007).

![Figure 1 - Microscopic 40X objective image of the microalgae Chlorella homosferae](image)

Source: Author’s construction.

The microalgae *Chlorella* started to be commercialized in 1961, when it was mass produced by the company Nihon Chlorella in the premises of the Institute of Research of Microalgae of Japan, also known as Instituto Chlorella, which was constituted in 1957 for the development of microalgae, in particular *Chlorella* (RICHMOND, 2004).

Due to specific characteristics, *Chlorella sp.* it becomes the group of microalgae that is most researched by the scientific community, with high nutritional value in terms of natural antioxidants (MATSUKAMA et al., 2000) and lipid production (ZHU et al., 2014). With a high content of bioactive compounds contained in *Chlorella*, it makes it an attractive source as a nutritional food and
In studies presented by González (2010), *Chlorella* sp. it proved to be a microalgae that is easy to grow and that adapts to various conditions, with rapid growth and that is hardly contaminated by other types of microalgae. This microalgae is also the most popular for its varied applications, such as biofuel, healthy foods, cosmetics, and bioremediation (HSIEH et al., 2012).

The use of *Chlorella* extracts shows many beneficial properties such as cholesterol reduction, antioxidant, antibacterial and anti-tumor activities (MEDINA-JARITZ et al., 2013; RYU et al., 2014; REYNA-MARTINEZ et al., 2018). *Chlorella* sp. it is also highly efficient due to its easy adaptation to laboratory conditions and represents an ideal biological system for several research areas (ORTEGA et al., 2004; REDÓN et al., 2013).

*Chlorella* sp. for presenting specific characteristics it is one of the most researched and scientifically studied microalgae. Among its characteristics, it stands out for its high nutritional value in terms of natural antioxidants (MATSUKAWA et al., 2000) and lipid production (ZHU et al., 2014).

According to the scientific literature, many *Chlorella* species have a potential to produce oil, reaching a lipid accumulation of 2% to 63% on a dry basis. For example, the species *Chlorella protothecoides* is an important raw material for producing biodiesel due to its high lipid content, which varies from 14.6% to 57.8% on a dry basis (MATA et al., 2010).

Batista and collaborators (2018) conducted a study to evaluate the production of ethyl biodiesel from microalgae oil of the *Chlorella* type. vegetable oils. They also observed that the values of acidity, water content, flash and pour points were better values than other traditional biodiesels, evidencing in this study that lipids derived from microalgae are a viable alternative source of raw material to produce biofuels.
Nanotechnology, nanocosmetics and microalgae

Nanotechnology is seen by the European Commission as one of its six “main enabling technologies” which contributes to sustainable competitiveness and growth in many fields of industrial application (EC, 2012). The new chemical and or physical properties that nanotechnology confers to nanoscale particles provide useful functions that are being explored very quickly in the sectors of medicine, biotechnology, electronics, materials science and energy, among others (OBSERVATORY NANOFIT, 2011).

The nanoscale refers to structures smaller than 1,000 nm in size, because on this scale the properties of materials differ in relation to the physical, chemical, and biological properties of a macro scale (ROSSI-BERGMANN, 2008; DIMER et al., 2013).

For cosmetic companies, it is not new that nanotechnology is the way of the future and, therefore, considered the rising technology available. Nanoscale versions of components are used by cosmetic manufacturers to better provide ultraviolet protection, greater penetration into the skin, color and finish quality, prolonged effects, among others (LAW 360, 2011). The use of nanoscale materials for cosmetics is given by the fact that nanoparticles have new properties that differentiate the properties of larger particles. Among the new properties, there are: color, transparency, solubility and chemical reactivity, making nanomaterials more attractive for the cosmetics and personal care industries (FRIENDS OF THE EARTH REPORT, 2006). Therefore, the most synthesized nanomaterials in this area are polymeric nanoparticles, described as colloidal suspensions with diameters smaller than 1 μm and which are divided into nanocapsules (NC) and nanospheres (NS), acting as nanocarriers with vesicular and matrix structures (MORA-HUERTAS et al., 2010).

In addition to influencing skin penetration/permeation behavior, nanocarriers can protect the substance from premature chemical degradation, improving its apparent solubility, greater stability, less toxicity and protection of the encapsulated substance, among others (OURIQUE et al., 2011).

The concept of beauty assets from natural origin is expanding, and its manufacturers seek to promote sustainability through the incorporation of local approaches and developments in biotechnology (ABIHPEC, 2019).

The Personal Hygiene, Perfumery and Cosmetics (HPPC) segment has undergone extremely significant changes. Concepts such as sustainability, personalization, social value, technology, and transparency become decisive when choosing a product. And this is the new consumer profile (ABIHPEC, 2019).

The relationship of the consumer market with brands and products is changing. In its 2018 Beauty and Personal Care Trends survey, Mintel Global explained that selling a great product will no longer be enough, it will be necessary to adapt to the new market and your marketing campaigns must be aware of this reality. Some research points in this direction: 37% of UK consumers take into
account whether or not a product is tested on animals; 56% of Americans stop buying products from a brand or a store if they think they are unethical and finally, 29% of Brazilians prefer to buy products from companies with sustainable practices. Thus, the consumer is increasingly demanding regarding the products he uses, seeking not only quality products, but also ensuring sustainability and good practices throughout the production segment (ABIHPEC, 2020).

According to the Brazilian Association of the Personal Hygiene, Perfumery and Cosmetics Industry (ABIHPEC), Brazil is the fourth country in the market for personal hygiene, perfumery and cosmetics items (HPPC), and the third country in new product launches in this field. Therefore, investing in innovation has been very strategic so that companies can meet the growing demand, since they have competence to contribute to overcome technological challenges with solutions in nanotechnology, biotechnology, advanced materials and information technologies, which ensure a more economical and sustainable production process (ABIHPEC, 2020).

The Innovation Award for the Personal Hygiene, Perfumery and Cosmetics Industry (ITEHPEC) launched at In-cosmetics Brazil in 2015, aimed to recognize companies that manufacture cosmetic components that have contributed to the increase in the competitiveness of the Brazilian HPPC industry, through implementation of innovative projects. The BASF company that transforms chemistry for a sustainable future, received the gold category award for biotechnology used in obtaining the first surfactant derived from microalgal oil in the world, developed in partnership with Solazyme (BRAZIL BEAUTY NEWS, 2015).

The scientific community, based on several studies showing that microalgae have a high antioxidant action, found that microalgae extracts or their bioactive compounds offer great potential to be new bio-based products, such as cosmetics, pharmaceuticals and nutraceuticals, as well as bioplastics and biopolymers (WANG et al., 2015; ARIEDE et al., 2017; KHANRA et al., 2018).

Among the assets that are extracted from microalgae with potential use in cosmetics are polysaccharides, which are used as gelling and thickening agents in various cosmetic formulations, mainly for hydration, in which the microalgae of the genus Chlorella is the most used (JAIN et al., 2005). Especially β-1,3-glucan polysaccharides are good collectors of free radicals and active immunostimulators, making them excellent candidates for use in skin cosmetics, mainly preventing external aging (SPOLAORE et al., 2006; KOLLER et al., 2014. The microalgae of the genus Chlorella and skeletonema diatom, as well as Porphyridium and Nostoc flegeliforme are the species richest in β-glucans (HAMED, 2016).

Due to their diversity and physiology, microalgae have versatility in the designed processes, occupying a special position in nanobiotechnology, in addition to having the resources of other types of microorganisms, they also offer additional advantages. Therefore, this field should evolve soon, since microalgae offer different forms of exploration in the biosynthesis of nanomaterials, on a molecular or cellular scale (DAHOUMANE et al., 2016).
Studies have shown that microalgae-derived compounds can be used as the main active ingredient in cosmetics and still have beneficial properties such as an excipient, stabilizer, dye or even thickening agents (RYU et al., 2015; LEVASSEUR et al., 2020).

CONCLUSION

Microalgae because they are photosynthetic and easy-to-grow single-cell microorganisms, they produce from their oil substances such as fatty acids, carbohydrates, proteins, vitamins, carotenoids and even pigments that offer various benefits and can be applied in various areas such as pharmaceutical, cosmetics, nutritional, environmental, ensuring advantages that make all the difference in the applied areas.

Chlorella has been the most researched and scientifically studied microalgae in recent years, which stands out for its beneficial properties such as natural antioxidants, antibacterial and anti-tumors, among others, with promising results for the designated purpose. Thus, Chlorella arouses interest mainly in the cosmetics industry, as it is an alternative source of important assets, in order, to obtain products with higher quality and efficiency combined with nanotechnology and thus guaranteeing the development of new biotechnologies. Therefore, microalgae have been explored for their potential and bioavailability, making the cosmetic industry more attractive not only for quality and efficacy products, but also ensuring biodegradable actives in their formulations, as this branch of the industry has been seeking to expand its final products with a green appeal, thus ensuring social sustainability.

REFERENCES

ABE, K.; HATTORI, H.; HIRANO, M. Accumulation and antioxidant activity of secondary carotenoids in the aerial microalga Coelastrella striolata var. Multistriata Food Chemistry, v. 100, n. 2, p. 656-661, 2007.

ABIHPEC. Associação Brasileira da Indústria de Higiene Pessoal, Perfumaria e Cosméticos. Caderno de Tendências 2019-2020. Disponível em: https://bit.ly/38lJ4yf. Acesso em: 30 out 2019.

ABIHPEC. Associação Brasileira da Indústria de Higiene Pessoal, Perfumaria e Cosméticos. Disponível em: https://bit.ly/2JWvAzO. Acesso em: 15 dez 2020.

ANDRADE, L. M.; ANDRADE, C. J.; DIAS, M.; NASCIMENTO, C. A. O.; MENDES, M. A. Chlorella and Spirulina Microalgae as Sources of Functional Foods, Nutraceuticals, and Food Supplements; an Overview. Food Processing and Technology, v. 6, n. 1, p. 45-58, 2018.
ARCEO, Á. A. Produção de biodiesel mediante processo de hidroesterificação da biomassa das microalgas Scenedesmus dimorphus e Nannochloropsis oculata. 2012. 201p. (Tese de Doutorado). Pós-Graduação da Escola de Química, Universidade Federal do Rio de Janeiro, Rio de Janeiro.

ARIEDE, M.; MARCÍLIO, T.; MOROCHO, A.; ROBLES, M.; CARVALHO, J.; ROLIM, A. Cosmetic attributes of algae - A review. Algal Research, v. 25, p. 483-487, 2017.

BASOVA, M. M. Fatty acid composition of lipids in microalgae. International Journal on Algae, v. 7, p. 33-57, 2005.

BASU, H. N.; DEL VECCHIO, A. J.; FLIDER, F.; ORTHOEFER, F. T. Nutritional and potential disease prevention properties of carotenoids. JAOCs, Journal of the American Oil Chemists’ Society, v. 78, n. 7, p. 665-675, 2001.

BATISTA, F. R.; LUCCHESI, K. W.; CARARETO, N. D.; COSTA, M. C. D.; MEIRELLES, A. J. A. Properties of microalgae oil from the species Chlorella protothecoides and its ethylic biodiesel. Brazilian Journal Chemical Engineering, v. 35, n. 4, p. 1383-1394, 2018.

BECKER, E. W. Microalgae as a source of protein. Biotechnology Advanced, v. 25, n. 2, p. 207-210, 2007.

BELLOU, S.; TRIANTAPHYLLIDOU, I. E.; ANGGELI, D.; ELAZZAZY, A. M.; BAESHEN, M. N.; AGGELIS, G. Microbial oils as food additives: recent approaches for improving microbial oil production and its polyunsaturated fatty acid content. Current Opinion in Biotechnology, v. 37, p. 24-35, 2016.

BEKIROGULLARI, M.; PITTMAN, J.; THEODOROPOULOS, C. Multi-factor kinetic modelling of microalgal biomass cultivation for optimised lipid production. Bioresource Technology, v. 269, p. 417-425, 2018.

BHOSALE, P.; BERNSTEIN, P. S. Microbial xanthophylls. Applied Microbiology and Biotechnology, v. 68, n. 4, p. 445-455, 2005.

BIANCHINI, R.; OHSE, S.; VILLELA, M.; CARVALHO, S. M.; FETT, R. Microalgas, produtos e aplicações. Ciência Rural, v. 366, p. 1959-1967, 2006.
BITOG, J. P.; LEE, I-B.; LEE, C-G.; KIM, K. S.; HWANG, H. S.; HNG, S. W.; SEO, I. H.; KWON, K. S., MOSTAFA, E. Application of computational fluid dynamics for modeling and design photobioreactors for microalgae production: A review. *Computers and Electronics in Agriculture*, v. 76, p. 131-147, 2011.

BJERK, T. R. *Cultivo de microalgas em fotobiorreator e reator misto visando a biorremediação e produção de biocombustível*. 2012. (Dissertação de Mestrado em Tecnologia Ambiental). Programa de Pós-Graduação em Tecnologia Ambiental, Universidade de Santa Cruz do Sul, Santa Cruz do Sul.

BOROWITZKA, M. A. High-value products from microalgae-their development and commercialization. *Journal of Applied Phycology*, v. 25, n. 3, p. 743-756, 2013.

BRAZIL BEAUTY NEWS, 2015. BASF e Solazyme lançam no Brasil primeira betaína derivada de microalgas. Disponível em: https://bit.ly/3hZBGfq. Acesso em: 10 jun. 2019.

BRENNAN, L.; OWENDE, P. Biofuels from microalgae-A review of technologies for production, processing, and extractions of biofuels and co-products. *Renewable and Sustainable Energy Reviews*, v. 14, p. 557-577, 2010.

CARDOZO, K.; GUARATINI, T.; BARROS, M. P.; FALCÃO, V. R.; TONON, A. P.; LOPES, N. P.; CAMPOS, S.; TORRES, M. A.; SOUZA, A. O.; COLEPICOLO, P.; PINTO, E. Metabolites from algae with economic impact. *Comparative Biochemistry and Physiology. Toxicology & Pharmacology*, v. 146, n. 1-2, p. 60-78, 2007.

CONTRERAS-FLORES, C.; PEÑA-CASTRO, J.; FLORES-COTERA, L.; CAÑIZARES-VILLANUEVA, R. Avances en el diseño conceptual de fotobiorreactores para el cultivo de microalgas. *Interciencia*, v. 28, n. 8, p. 450-456, 2003.

CUELLAR-BERMUDEZ, S. P.; AGUILAR-HERNANDEZ, E. U.; CARENAS-CHAVEZ, D. L.; ORNELAS-SOTO, N.; ROMERO-OGAWA, M. A.; PARRA-SALDIVAR, R. Extraction and purification of high-value metabolites from microalgae: essential lipids, astaxanthin and phycobiliproteins. *Microbial Biotechnology*, v. 8, p. 190-209, 2014.

CHEN, C-Y.; YEH, K-L.; AISYOH, R.; LEE, D-J.; CHANG, J-S. Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: A critical review. *Bioresource Technology*, v. 102, p. 71-81, 2011.
CHEN, C. Y.; LIU, C. C. Optimization of lutein production with a two-stage mixotrophic cultivation system with *Chlorella sorokiniana* MB-1. *Bioresource Technology*, v. 262, p. 74-79, 2018.

CHISTI, Y. Biodiesel from microalgae. Biotechnology Advances, v. 25, p. 294-306, 2007.

CHIU, S. Y.; KAO, C. Y.; CHEN, T. Y.; CHANG, Y.B.; KUO, C. M.; LIN, C. S. Cultivation of microalgal *Chlorella* for biomass and lipid production using wastewater as nutrient resource. *Bioresource Technology*, v. 184, p. 179-189, 2015.

DAHOUMANE, S. A.; MECHOUET, M.; ALVAREZ, F. J.; SPIROS, N. Agathos, Clayton Jeffryes. Microalgae: An outstanding tool in nanotechnology, v. 1; n. 4; p. 196-201, 2016.

DANESHVAR E., ZARRINMEHR M. J., HASHTJIN A. M., FARHADIAN O., BHATNAGAR A. Versatile applications of freshwater and marine water microalgae in dairy wastewater treatment, lipid extraction and tetracycline biosorption. *Bioresource Technology*, v. 268; p. 523-530, 2018.

DEL CAMPO, J. A., RODRÍGUEZ, H., MORENO, J., VARGAS, M. Á., RIVAS, J., & GUERRERO, M. G. Lutein production by Muriellopsis sp. in an outdoor tubular photobioreactor. *Journal of Biotechnology*; v. 85, n. 3, p. 289-295, 2001.

DEMIRBAS, A.; DEMIRBAS, M. F. Importance of algae oil as a source of biodiesel. *Energy Conversion Management*, v. 52, n. 1, p. 163-170, 2011.

DERNER, R. B.; OSHE, S.; VILLELA, M.; CARVALHO, S. M.; FETT, R. Microalgas, produtos e aplicações. *Ciência Rural, Santa Maria*, v. 36, n. 6, p. 1959-1967, 2006.

DIMER, F. A.; FRIEDRICH, R. B.; BECK, R. C. R.; GUTERRES, S. S.; POHLMANN, A. R. Impactos da nanotecnologia na saúde: produção de medicamentos. *Química Nova*, v. 36, n. 10, p. 1520-1526, 2013.

EC, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. ‘A European strategy for Key Enabling Technologies - A bridge to growth and jobs’, 2012. Disponível em: https://bit.ly/2XmnWls. Acesso em: 20 dez. 2019.
FERRUZZI, M. G.; BLAKESLEE, J. Digestion, absorption, and cancer preventative activity of dietary chlorophyll derivatives. *Nutrition Research*, v. 27, n. 1, p. 1-12, 2007.

FONTOURA, J. T. DA.; ROLIM, G. S.; FARENZENA, M.; GUTTERRES, M. Influence of light intensity and tannery wastewater concentration on biomass production and nutrient removal by microalgae *Scenedesmus* sp. *Process Safety and Environmental Protection*, v. 111, p. 355-362, 2017.

FRIENDS OF THE EARTH REPORT - Nanomaterials, Sunscreens and Cosmetics: Small Ingredients Big Risks. Disponível em: http://www.nano.foe.org.au; http://www.foe.org. Acesso em: 15 mai. 2019.

GAMMONE, M. A.; D’ORAZIO, N. Anti-obesity activity of the marine carotenoid fucoxanthin. *Marine Drugs*, v. 13, n. 4, p. 2196-2214, 2015.

GIL, A. C. *Como elaborar projetos de pesquisa*. 4. ed. São Paulo: Atlas, 2002.

GUIRY, M. D. How Many Species of Algae are there? *Journal Phycology*, v. 48; n. 5; p. 1057-1063, 2012.

GONG, M.; BASSI, A. Carotenoids from microalgae: a review of recent developments. *Biotechnology Advances*, v. 34, p. 1396-1412, 2016.

GONÇALVES, A. L; PIRES, J. C. M.; SIMÕES, M. Biodiesel from microalgal oil extraction. In: *Environmental Chemistry for a Sustainable World. Volume 3*. Edited by: Lichtfouse E, Schwarzbauer J, Robert D. Heidelberg: Springer; 2013.

GONZÁLEZ, L. M. Influencia de la deficiencia de Nitrógeno y Fósforo en las interacciones competitivas entre Chlorella vulgaris y Scenedesmus acutus. Colombia: Universidad Nacional de Colombia, 2010.

HAMED, I. The Evolution and Versatility of Microalgal Biotechnology: A Review. *Comprehensive Reviews in Food Science and Food Safety*, v. 15, p. 1104-1123, 2016.

HO, S-H.; NAKANISHI, A.; YE, X.; CHANG, J-S.; HARA, K.; HASUNUMA, T.; KONDO, A. Optimizing biodiesel production in marine *Chlamydomonas* sp. JSC4 through metabolic profiling and an innovative salinity-gradient strategy. *Biotechnology for Biofuels*, v. 7, p. 97-113, 2014.
HSIEH, H. J.; SU, C. H.; CHIEN, L. J. Accumulation of lipid production in *Chlorella minutissima* by triacylglycerol biosynthesis-related genes cloned from *Saccharomyces cerevisiae* and *Yarrowia lipolytica*. *Journal of Microbiology*, v. 50, n. 3, p. 526-534, 2012.

HUNTLEY, M. E.; REDALJE, D. G. CO₂ mitigation and renewable oil from photosynthetic microbes: a new appraisal. *Mitigation and Adaptation Strategies for Global Change*, v. 12, p. 573-608, 2007.

ILLMAN, A. M.; SCRAGG, A. H.; SHALES, S. W. Increase in Chlorella strains calorific values when grown in low nitrogen medium. *Enzyme and Microbial Technology*, v. 27, p. 631-635, 2000.

JAIN, R.; RAGHKUKUMAR, S.; THARANATHAN, R.; BHOSLE, NB. Produção de polissacarídeos extracelulares por protistas de thraustochytrid. *Marine Biotechnology*, v. 7, p. 184-192, 2005.

JING-HAN, W.; ZHUANG, L. L.; XU, X. Q. DEANTES-ESPINOSA, V. M.; WANG, X. X.; HU, H. Y. Microalgal attachment and attached systems for biomass production and wastewater treatment. *Renewable & Sustainable Energy Reviews*, v. 92, p 331-342, 2018.

KAKARLA, R.; CHOI, J. W.; YUN, J. H.; KIM, B. H.; HEO, J.; LEE, S.; CHO, D. H.; RAMANAN, R.; KIM, H. S. Application of high-salinity stress for enhancing the lipid productivity of *Chlorella sorokiniana* HS1 in a two-phase process. *Journal of Microbiology*, v. 56, n. 1, p. 56-64, 2018.

KIM, M.; AHN, J.; JEON, H.; JIN, E. S.; CUTIGNANO, A.; ROMANO, G. Development of a Dunaliella tertiolecta strain with increased zeaxanthin content using random mutagenesis. *Marine Drugs*, v. 15, n. 6, p. 189-202, 2017.

KOO, S. Y.; CHA, K. H.; SONG, D. G.; CHUNG, D.; PAN, C. H. Optimization of pressurized liquid extraction of zeaxanthin from Chlorella ellipsoidea. *Journal of Applied Phycology*, v. 24, n. 4, p. 725-730, 2012.

KOLLER, M.; MUHR, A.; BRAUNEGG, G. Microalgae as versatile cellular factories for valued products. *Algal Research*, v. 6, p. 52-63, 2014.
KUMAR, G.; NGUYEN, D. D.; SIVAGURUNATHAN, P.; KOBAYASHI, T.; XU, K.; CHANG, S. W. Cultivation of microalgal biomass using swine manure for biohydrogen production: impact of dilution ratio and pretreatment. *Bioresource Technology*, v. 260, p. 16-22, 2018.

LAW 360. Nano-cosmetics: Beyond skin deep, 2011. Disponível em: https://bit.ly/3pZBU8S. Acesso em: 15 out 2019.

LEHMUSKERO, A.; CHAUTON, M. S.; BOSTRÖM, T. Light and photosynthetic microalgae: A review of cellular-and molecular-scale optical processes. *Progress in Oceanography*, v. 168, p. 43-46, 2018.

LEE, J.; KIM, D. S. YANG, J. H.; CHUN, Y.; YOO, H. Y.; HAN, S. O.; LEE, J.; PARK, C.; KIM, S. W. Enhanced electron transfer mediator based on biochar from microagal sludge for application to bioelectrochemical systems. *Bioresource Technology*, v. 264, p. 387-390, 2018.

LEVASSEUR, W.; PERRÉ, P.; POZZOBON, V. A review of high value-added molecules production by microalgae in light of the classification. *Biotechnology Advances*, v. 41, p. 107545, 2020.

LOURENÇO, S. O. *Cultivo de Microalgas Marinhas-Princípios e Aplicações*. São Carlos: Rima, p. 606, 2006.

MALCATA, F. X.; PINTO, I. S.; GUEDES, A. C. Marine Macro-and Microalgae: An Overview: CRC Press; 2018.

MATA, T. M.; MARTINS, A. A.; CAETANO, N. S. Microalgaes for biodiesel production and other applications: a review. *Renewable & Sustainable Energy Reviews*, v. 14, n. 1, p. 217-232, 2010.

MATOUKE, M. M.; ELEWA, D. T.; ABDULLAHI, K. Binary effect of titanium dioxide nanoparticles (NTio₂) and phosphorus on microalgae (*Chlorella ‘Ellipsoides’ Gerneck, 1907*). *Aquatic Toxicology*, v. 198, p. 40-48, 2018.

MATSUKAWA, R.; HOTTA, M.; MASSUDA, Y.; CHIHARA, M.; KARUBE, I. Antioxidants from carbon dioxide fixing *Chlorella sorokiniana*. *Journal of Applied Phycology*, v. 12, p. 263-267, 2000.
MEDINA-JARITZ, N. B.; CARMONA-UGALDE, L. F.; LOPEZ-CEIDILLO, J. C.; RUJOBA-OS, LEON, F.S.L. Antibacterial activity of methanolic extracts from Dunaliella salina and Chlorella vulgaris. The FASEB Journal, v. 27, p. 1167.5-1167.5, 2013.

MENDES, A.; REIS, A.; VASCONCELOS, R.; GUERRA, P.; LOPES DA SILVA, T. Cryptothecodinium cohnii com ênfase na produção de DHA: uma revisão. Journal of Applied Phycology, v. 21, p. 99-214, 2008.

MILLEDGE, J. J. Commercial application of microalgae other than as biofuels: A brief review. Reviews in Environmental Science and Bio/Technology, v. 10, p. 31-41, 2011.

MILITÃO, F. P.; FERNANDES, V. O.; BASTOS, K. V.; MARTINS, A. P.; COLEPICOLO, P.; MACHADO, L. P. Nutritional value changes in response to temperature, microalgae mono and mixed cultures. Acta Limnologica Brasiliensia, v. 31, e17, 2019.

MOAZAMI, N.; RANJBAR, R.; ASHORI, A.; TANGESTANI, M.; NEJAD, A. S. Biomass and lipid productivities of marine microalgae isolated from the Persian Gulf and the Qeshm Island. Biomass Bioenergy, v. 35, p. 1935-1939, 2011.

MORALES-SÁNCHEZ, D.; MARTINEZ-RODRIGUEZ, O. A.; MARTINEZ, A. Heterotrophic cultivation of microalgae: production of metabolites of commercial interest. Journal Chemical. Technology Biotechnology, v. 92; n. 5; p. 925-936, 2017.

MORA-HUERTAS, C. E.; FESSI, H.; ELAISSARI, A. Polymer-based nanocapsules for drug delivery. International Journal Pharmaceutics, v. 385, n. 1-2, p. 113-142, 2010.

MOURELLE, M.; GÓMEZ, C.; LEGIDO, J. The potential use of marine microalgae and cyanobacteria in cosmetics and thalassotherapy. Cosmetics, v. 4, n. 4, p. 46-59, 2017.

OBSERVATORYNANO FP7, European nanotechnology landscape report, 2011. Disponível em: https://bit.ly/3hPRZvf. Acesso em: 30 set 2019.

OLIVEIRA, O. S. B. C. Optimização da produtividade lipídica da microalga Arthrospira platensis como matéria-prima para biocombustíveis. 2009. 114 p. (Dissertação de Mestrado em Bioenergia). Faculdade de Ciências e Tecnologia da Universidade de Nova de Lisboa, Universidade de Nova de Lisboa, Lisboa.
ORTEGA, J.; TEMPLE, S.; BAGGA, S.; GHOSHROY, S.; SENGUPTA-GOPALAN, C. Biochemical and molecular characterization of transgenic *Lotus japonicus* plants constitutively over-expressing a cytosolic glutamine synthetase gene. *Planta*, v. 219, n. 5, p. 817-818, 2004.

OSHE, S.; DERNER, R. B.; OZÓRIO, R. Á.; CUNHA, P. C. R.; LAMARCA, C. P.; SANTOS, M. E.; MENDES, L. S. B. Revisão: Sequestro do carbono realizado por microalgas e floresta e a capacidade de produção de lipídios pelas microalgas. *Insula*, v. 36, p. 39-74, 2007.

OURIQUE, A. F.; MELERO, A.; DA SILVA, C. B.; SCHAEFER, U. F.; POHLMANN, A. R.; GUTERRES, S. S.; LEHR, C-M.; KOSTKA, K-H.; BECK, R. C. Improved photostability and reduced skin permeation of tretinoin: development of a semisolid nanomedicine. *European Journal of Pharmaceutics Biopharmaceutics*, v. 79, n. 1, p. 95-101, 2011.

PARK, J.; CRAGGS, R.; SHILTON, A. Wastewater treatment high rate algal ponds for biofuel production. *Bioresource Technology*, v. 102, p. 35-42, 2011.

PENG, J.; YUAN, J. P.; WU, C. F.; WANG, J. H. Fucoxanthin, a marine carotenoid present in brown seaweeds and diatoms: metabolism and bioactivities relevant to human health. *Marine Drugs*, v. 9, n. 10, p. 1806-1828, 2011.

PERIN, G.; BELLAN, A.; BERNARDI, A.; BEZZO, F.; Morosinotto, T. The potential of quantitative models to improve microalgae photosynthetic efficiency. *Physiologia Plantarum*, v. 166, n. 1, p. 380-391, 2019.

POSTEN, C. Design principles of photo-bioreactors for cultivation of microalgae. *Engineering in Life Science*, v. 9, n. 3, p. 165-177, 2009.

POSTMA, P. R.; TLAM, G. P.; BARBOSA, M. J.; WIJFFELS, R. H.; EPPINK, M. H. M.; OLIVIERI, G. Microalgal Biorefinery for Bulk and High-Value Products: Product Extraction Within Cell Disintegration. In: Miklavcic D, editor. *Handbook of Electroporation*. Cham: Springer International Publishing; p. 1-20, 2016.

RAI, M. P.; GUPTA, S. Effect of media composition and light supply on biomass, lipid content and fatty acid profile for quality biofuel production from *Scenedesmus abundans*. *Energy Conversion and Management*, v. 141, p. 85-92, 2017.
Ramaraj, R.; Unpaprom, Y.; Dussadee, N. Cultivation of green microalga, *Chlorella vulgaris* for biogas purification. *International Journal of New Technology Research*, v. 2, p. 117-122, 2016.

Randrianarison, G.; Ashraf, MA. Microalgae: a potential plant for energy production. *Geology Ecology and Landscapes*, v. 1, n. 2, p. 104-120, 2017.

Rendón, L.; Ramírez, M.; Vélez, Y. Microalgas para la industria alimenticia. Medellín: Editorial Universidad Pontificia Bolivariana, 2013.

Reyna-Martínez, R.; Gómez-Flores, R.; López-Chukun, U.; Quintanilla-Licea, R.; Caballero-Hernandez, D.; Rodríguez-Padilla, C.; Beltrán-Rocha, J. C.; Tamez-Guerra, P. Antitumor activity of *Chlorella sorokiniana* and *Scenedesmus* sp. microalgae native of Nuevo León State, México. *PeerJ*, e4358, 2018.

Richmond, A. Biological principles of mass cultivation. In: Richmond A (ed). Handbook of microalgal culture: Biotechnology and applied phycology. *Blackwell Science*, p. 125-177, 2004.

Rincón-Cervera, M. A.; Valenzuela, R.; Hernández-Rodas, M. C.; Mambbio, M.; Espinosa, A.; Mayer, S.; Romero, N.; Sc, C. B. M.; Valenzuela, A.; Viedela, L. A. Supplementation with antioxidant-rich extra virgin olive oil prevents hepatic oxidative stress and reduction of desaturation capacity in mice fed a high-fat diet: effects on fatty acid composition in liver and extrahepatic tissues. *Nutrition*, v. 32, n. 11, p. 1254-1267, 2016.

Rossi-Bergmann, B. A Nanotecnologia: da saúde para além do determinismo tecnológico. *Ciência e Cultura*, v. 60, n. 2, p. 54-57, 2008.

Ryu, N. H.; Lim, Y.; Park, J. E.; Kim, J.; Kim, J. Y.; Kwon, S. W.; Kwon, O. Impact of daily Chlorella consumption on serum lipid and carotenoid profiles in mildly hypercholesterolemic adults: A double-blinded, randomized, placebo-controlled study. *Nutrition Journal* v. 11, p. 13-57, 2014.

Ryu, B. M.; Himaya, S. W. A.; Kim, S. K. Applications of Microalgae-Derived Active Ingredients as Cosmeceuticals. *Handbook of Marine Microalgae: Biotechnology Advances* Elsevier Inc, 2015.

Sang-il, H.; Sok, K.; Changsu, L.; Yoon-E, C. Blue-Red LED wavelength shifting strategy for enhancing beta-carotene production from halotolerant microalga, *Dunaliella salina*. *Journal of Microbiology*, v. 57, n. 2, p. 101-106, 2019.
SANYANO, N.; CHETPATTANANONDH, P.; CHONGKHONG, S. Coagulation-flocculation of marine Chlorella sp. for biodiesel production. *Bioresource Technology*, v. 147, p. 471-476, 2013.

SCHUBERT, N.; GARCÍA-MENDOZA, E.; PACHECO-RUIZ, I. Carotenoid composition of marine red algae. *Journal of Phycology*, v. 42, n. 6, p. 1208-1216, 2006.

SHI, X. M.; JIANG, Y.; CHEN, F. High-yield production of lutein by the green microalga Chlorella protothecoides in heterotrophic fed-batch culture. *Biotechnology Progress*, v. 18, n. 4, p. 723-727, 2002.

SHUBA, E. S.; KIFLE, D. Microalgae to biofuels: ‘Promising’ alternative and renewable energy, review. *Renewable Sustainable Energy Reviews*, v. 81; p. 743-755, 2018.

SPOLAORE, P.; JOANNIS-CASSAN, C.; DURAN, E.; ISAMBERT, A. Commercial Applications of Microalgae. *Journal of Bioscience and Bioengineering*, v. 101, n. 2, p. 87-96, 2006.

TAMBURIC, B.; ZEMICHAEEL, F. W.; CRUDGE, P.; MAITHAND, G. C.; HELLGARDT, K. Design of a novel flat-plate photobioreactor system for green algal hydrogen production. *International Journal of Hydrogen Energy*, v. 36, p. 6578-6591, 2011.

TAN, J. S.; LEE, S. Y.; CHEW, K. W.; LAM, M. K.; LIM, J. W.; HO, S-H.; SHOW, P. L. Uma revisão sobre cultivo e colheita de microalgas e seu processamento de extração de biomassa usando líquidos iônicos. *Bioengenharia*, v. 11, n. 1, p. 116-129, 2020.

THANGALAZHY-GOPAKUMAR, S.; ADHIKARI, S.; CHATTANATHAN, S. A. GUPTA, R. B. Catalytic pyrolysis of green algae for hydrocarbon production using H+ZSM-5 catalyst. *Bioresource Technology*, v. 118, p. 150-157, 2012.

’t LAM, G. P.; VERMUÊ, M. H.; EPPINK, M. H. M.; WIJFFELS, R. H.; VAN DEN BERG, C. Multi-Product Microalgae Biorefineries: From Concept Towards Reality. *Trends Biotechnology*.; v. 36; n. 2; p. 216-227, 2018.

TREDICI, M. R. Mass production of microalgae: Photobioreactors. In: Richmond A (ed). *Handbook of microalgal culture: Biotechnology and applied phycology*, p. 178-214. Blackwell Science, Iowa, 2004.
VOLOSHIN, R. A.; RODIONOV, M. V.; ZHARMUKHAMEDOV, S. K.; NEJAT VEZIROGLU, T.; ALLAKHVERDIEV, S. I. Review: Biofuel production from plant and algal biomass. *International Journal of Hydrogen Energy*, v. 41, p. 17257-17273, 2016

VU, C.H.T.; LEE, H.-G.; CHANG, Y.K.; OH, H.-M. Axenic cultures for microalgal biotechnology: establishment, assessment, maintenance, and applications. *Biotechnology Advances*, v. 36, n. 2, p. 380-396, 2018.

XU, L.; WEATHERS, P. J.; XIONG, X. R.; LIU, C. Z. Microalgal bioreactors: challenges and opportunities. *Engineering in Life Sciences*, v. 9, n. 3, p. 178-189, 2009.

ZHU, L. Microalgal culture strategies for biofuel production: A review. *Biofuels, Bioproducts and Biorefining*, v. 9, p. 801-814, 2015.

ZHU, S.; HUANG, W.; XU, J.; WANG, Z.; YUAN, Z. Metabolic changes of starch and lipid triggered by nitrogen starvation in the microalga *Chlorella zofingiensis*. *Bioresource Technology*, v. 152, p. 292-298, 2014.

WALKER, T. L.; PURTON, S.; BECKER, D. K.; COLLET, C. Microalgae as bioreactors. *Plant Cell Reports*, v. 24, n. 11, p. 629-641, 2005.

WANG, H-MD; CHEN, C-C; HUYNH, P.; CHANG, J-S. Exploring the potential of using algae in cosmetics. *Bioresource Technology*, v. 184, p. 355-362, 2015.

YAAKOB, Z.; ALI, E.; ZAINAL, A.; MOHAMAD, M.; TAKRIFF, M. S. An overview: Biomolecules from microalgae for animal feed and aquaculture. *Journal of Biological Research*, v. 21, n. 1, p. 1-10, 2014.

YAÑEZ, M. Desnutrición infantil en América Latina y el Caribe. *Desafíos: Boletín de la infancia y la adolescencia sobre el avance de los objetivos de desarrollo del Milenio*, n. 2, p. 1-12, 2006.

YANG, L.; WANG, L.; ZHANG, H.; LI, C.; ZHANG, X.; HU, Q. A novel low cost microalgal harvesting technique with coagulant recovery and recycling. *Bioresource Technology*, v. 266, p. 343-348, 2018.