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REVIEW ARTICLE

Microalgae and Diatom - Potential Pharmaceutical and Cosmetic Resources – Review

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ABSTRACT

Microalgae are aquatic resources containing several value-added products which have been and will be widely used in various industries. They have the high potential to be explored in cosmetics and cosmeceuticals, as active ingredients in the form of isolated molecules or extracts. The aim of this review is to exhibit the potential of microalgae and especially diatoms for their cosmetic application regarding their phytochemistry and pharmacological activity. Comprehensive study of previously published literature demonstrated the presence of several antioxidant, antimicrobial or anti-inflammatory molecules in microalgae and their efficiency on human cells, particularly in anti-aging and anti-UV products. This review summarizes and discusses the information on extraction process, the chemical composition and biological activity of natural microalgae biomass. Finally, the review attempts to reveal more global view on how to valorize natural microalgal biomass, including diatoms, in cosmetics to prevent a destruction of wild resources.

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Introduction

The cosmetic market tends to expand since the first notion of cosmetics have been imagined. The Roman, Egyptian, and Greek used oils to perfume themselves as well as pigments and clay for their bodies. Since this period, cosmetics have diversified into five main categories: skin care, hair care, make-up, perfume and hygiene products [1]. They all have different goals. Thus, skin care products will improve the global appearance of the skin when hair care products do the same for the hair. Some products can treat specific skin conditions or disorders: they are the dermo cosmetics. Hygiene products encompass all the products needed to clean body, face, hair, and teeth. Makeup products are intended to visually reduce skin imperfections and improve faces aesthetic qualities.

To make these cosmetics, many natural products are already used, but more and more products come from water and particularly from the sea. Recently, algae research is very popular because of the value-added metabolites found in them.

Algae are photosynthetic organisms and can be classified into three groups: macroalgae, microalgae and cyanobacteria. However, this last category is not always included in the term, being biologically bacteria and not plants [2]. Even if it is possible to define algae as "A large group of single or many-celled organisms, including so-called "cyanobacteria," which usually contain chlorophyll or other pigments" according to the TermiumPlus [3] dictionary.

Macroalgae are pluricellular eukaryotic organisms, larger than the millimeter. They can be visible to the naked eye and are able to develop in diverse environments

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affected by different climate conditions of temperature, salinity, or light. These algae include three types, commonly associated to three phyla (according to ITIS.gov): green algae (Chlorophyta), brown algae (Ochrophyta) and red algae (Rhodophyta) and each alga division contains several pigments, called secondary or accessory pigments, in addition to chlorophyll, which give them their colors. For the red ones like the genera *Gracilaria* sp., the phycobiliproteins make the algae be red [4], the green algae mainly contain chlorophyll like the genera *Cladophora* sp. and stay green [5], whereas the brown algae like *Fucus* sp. contain fucoxanthin which can inhibit the colors of the other pigments [6,7]. Macroalgae are used in cosmetics, pharmaceuticals, food and other applications because of their pharmacological properties [8].

Cyanobacteria are unicellular prokaryote organisms able to arrange in filaments longer than a meter. Often considered as algae as they are photosynthetic organisms, they can be called "blue-green algae". Cyanobacteria are increasingly studied in biotechnology field. For example, everyone knows Spirulina Platensis used in the food industry as a dietary supplement, or for a plastic and petroleum alternative [9,10]. For wastewater treatment, *Oscillatoria* sp. and *Chlorella Vulgaris* are currently evaluated in some research work [11,12]. *Lyngbya Majuscula* seem also interesting for its pharmaceutical application [10].

Microalgae are microscopic unicellular eukaryotic organisms. They can live in marine or fresh water and are usually divided into the same types as the macroalgae.

They are also more and more often used in industry because of the interest they represent as an oil alternative. Indeed, biomass from microalgae is rich in carbon compounds and has strong potential for the development of biofuels from some species like

Chlorella sp. Microalgae are also used in many other fields thanks to the rich extracts they can give, and the aim of this review is to see what extracts can be obtained and to what extent they could be used, especially in cosmetics. Indeed, using microalgae instead of terrestrial plants allows to obtain many compounds that doesn't exist on terrestrial plants because harsh living conditions under water have an influence on the metabolites of the organisms and this can lead to interesting new bioactive compounds [13,14].

Morphology and environment of growth

Microalgae can be unicellular or pluricellular [15]. Cells are made with a membrane and inside it, there are the nucleus, mitochondria and chloroplast (Figures 1-5) [16].

They can live under various conditions of temperature, pH, light, and salinity which influence their growth [17,18]. Some species and genus don't even live in water but on the ground as *Coleochaete* or *Penium* [19].

There are two options to grow microalgae: open ponds or photobioreactors. The first method is easier to set up, but parameters of growth are better controlled in photobioreactors as it is a closed environment and there are less chances to contaminate the species wanted with others [16,19].

Most common microalgae extraction procedures

Several conventional methods already exist to extract microalgae. For example, maceration, Bligh and Dyer or Soxhlet [20-23], but new methods are more and more often employed because of the advantages they offer. They generally imply mechanical disruption to access more easily to the cellular content and are usually vortexed before the extraction process [24]. Moreover, diatoms which are a particular class of brown microalgae possess a frustule and it is more difficult to access to the cellular content.

Ultrasound Assisted Extraction (UAE): Ultrasound assisted extraction is often employed and enables to have a better yield than a conventional maceration or Soxhlet and to use less solvent because the extraction time is considerably reduced [22,25-27]. Before the extraction, centrifugation is often used to harvest the cells at temperatures that usually do not exceed 15°C and for a few minutes (15-25min). Centrifugation is used again to collect the supernatant, at the end of the extraction process [28]. The diatom *Cylindrotheca Closterium* has already been extracted using this method, with acetone as solvent [22,26,27] and other microalgae more studied in research like *Chlorella Vulgaris* (ethanol), *Dunaliella Salina* (water), or *Haematococcus Pluvialis* (methanol, ethanol, acetone, and acetonitrile) [27].

Microwave-Assisted Extraction (MAE): Microwave-assisted extractions are also employed but in a less extent than ultrasounds. They are yet efficient and allow to lower the extraction time, notably to extract lipids and pigments from *C. vulgaris* or *Nannochloropsis* sp. with an extraction medium derived from Bligh and Dyer method [29,30]. *H. Pluvialis* and *C. Closterium* have also been extracted to obtain astaxanthin and fucoxanthin, using MAE [26,27]. Microwaves are also used as pre-treatment in order to improve the yield of lipids extracted [31].

Supercritical CO_2: Another method, good for the environment is the supercritical CO_2. It allows to extract astaxanthin mostly but also some other carotenoids, lipids and proteins [32]. The major problem being the cost of the method (31€/day) but the big advantage is that there is no solvent loss as it is reused so it is good for the environment [33].

These methods, conventional or not, have benefits and drawbacks and it is by considering both aspects that a company or a laboratory will choose one or another (Tables 1-3).

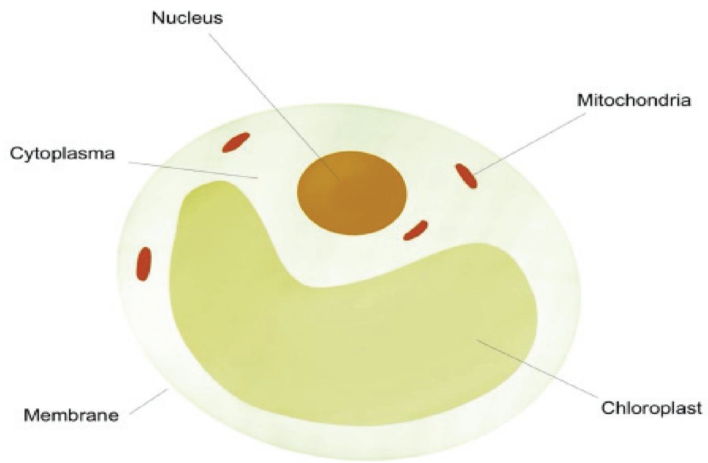

Figure 1 Microalgae cell.

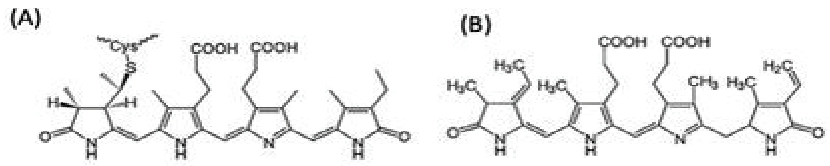

Figure 2 Phycocyanin (A) and phycoerythrin (B) isolated from red microalgae.

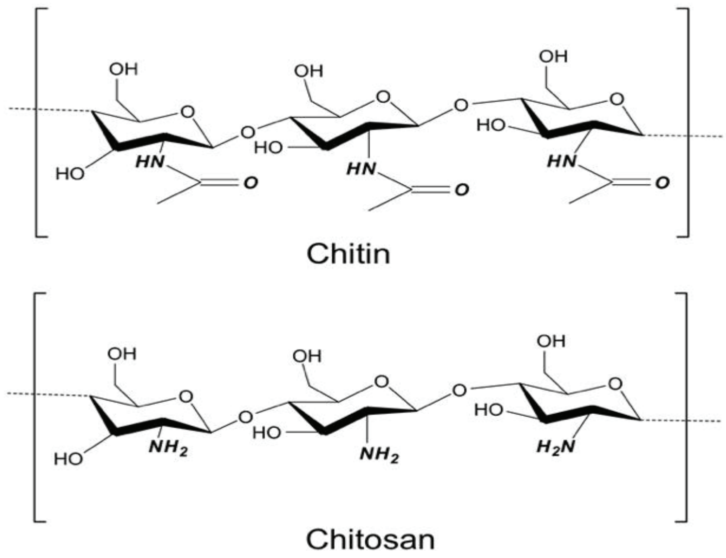

Figure 3 Polysaccharides found in microalgae shell.

Types of extracts according to the extraction process: All extractions processes do not allow to extract the same chemical classes with the same efficiency. The chemical classes that are most targeted and studied presently in microalgae for some industries, including cosmetics are added-value lipids and pigments. Ethanol is frequently preferred as a solvent because of its low toxicity for the human cells and body [35]. It also allows to extract pigments [36].

Several studies focus on lipid extraction with UAE, MAE or maceration because they have lots of application fields, especially as alternatives to fossil resources [37-39]. Other focus on pigment extraction [4,40,41].

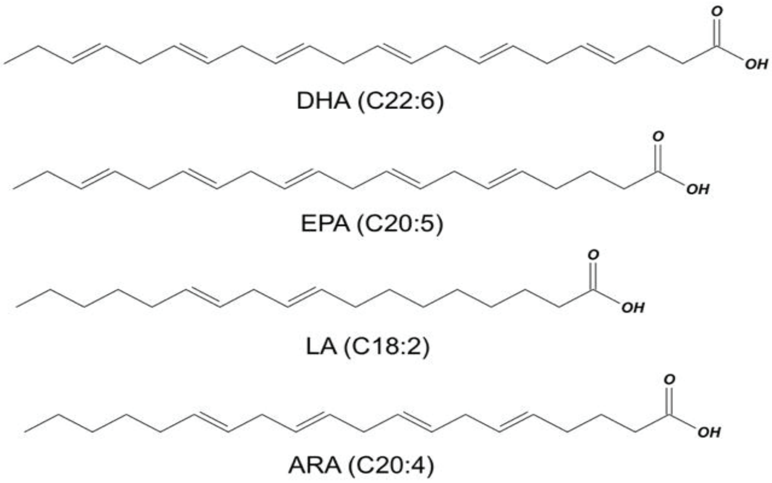

Figure 4 Most common polyunsaturated fatty acids of microalgae.

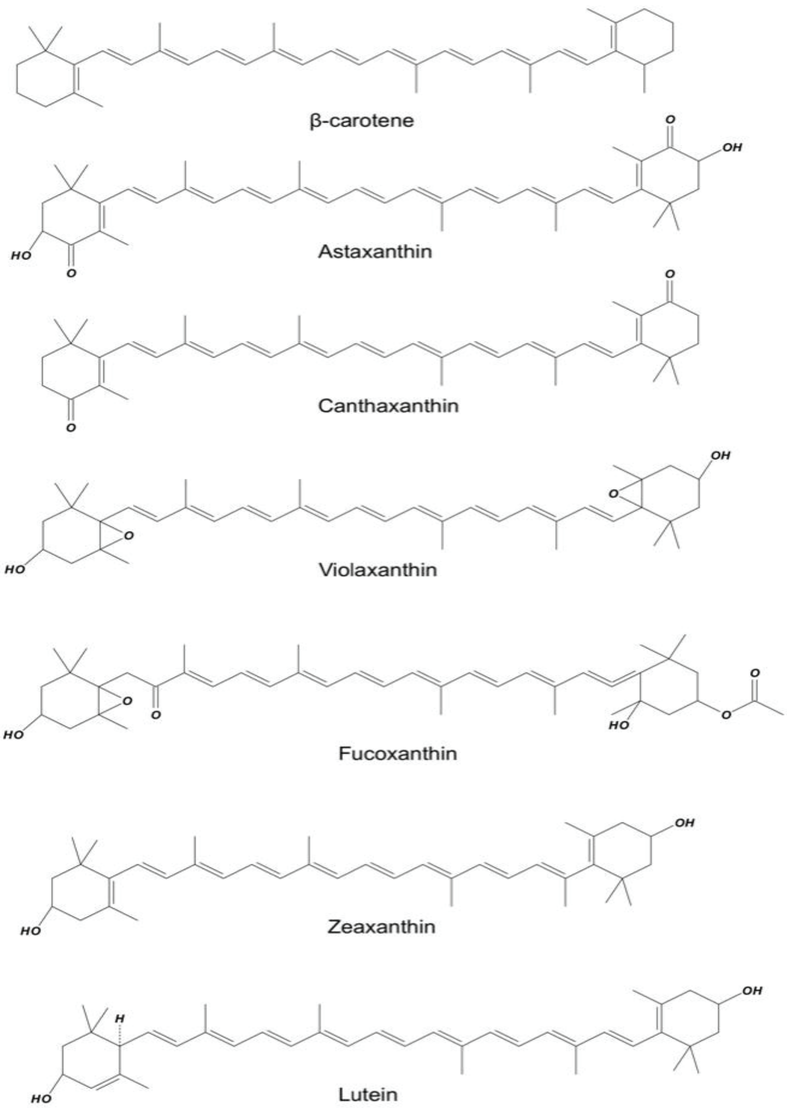

Figure 5 Carotenoids described in microalgae.

Table 1: Best non- conventional extraction conditions for microalgae.

		Solvent	Temperature	Extraction time	Specific operating conditions	Target	Yield	References
UAE	Freeze-dried biomass	Ethanol 100%	23°C	30min	70 kHz	Fucoxanthin	1.571%	[22]
	Freeze-dried biomass	Acetone	8.5°C, under argon	10min	12,2W	ß-carotene and chlorophylls	0.449%	[26]
	Fresh cells, 5% dry weight	none	35°C	30min	20kHz, 1000W	lipids	0.21%	[28]
MAE	Freeze dried	acetone	Rt	5min	50W	Fucoxanthin, chlorophyll a	0.865%	[26]
	Dried biomass	Methanol/n-hexane		40min	600W	lipids	12.5%	[29]
	Dried biomass	Water/sodium chloride 10%		30min	800W	lipids	6.9%	[29]
	Wet biomass	Methanol/hexane	65°C	5min	700W	lipids	38.31%	[30]
Supercritical CO_2	Freeze dried	CO_2	50°C	3h	300bar	carotenoids	0.1511%	[27]

Table 2: Advantages and limitations of the most common microalgae extraction processes [34].

	Benefits	Drawbacks
Maceration	Easy, large scale, low or no heat	Long process, low solubility
Soxhlet	Used even with a low solubility, low solvent consumption	High temperatures and long processes
Ultrasound-assisted extraction	Reduced extraction time, high yield, does not need heat	High costs
Microwave-assisted extractions	High efficiency, fast, low solvent consumption	Heat can deteriorate compounds
Supercritical fluid extraction (CO_2)	No toxicity, low cost for solvents, low temperatures, fast, no filtration needed	High costs of investment, need to maintain a particular pressure

Table 3: Chemical composition and biological activities of the microalgae mainly studied.

Species or genera	Compounds	Activity	References
Thalassiosira Pseudonana, Rotula, Weissflogii	TAG, methyl palmitic, methyl palmitoleic, diadinoxanthin, chlorophyll, fucoxanthin, phenolic acids, hydroxycinnamic acids, ß-carotene, pentadecanoic acid, galactolipids	Antioxidant, antibacterial, antioxidant, cancer-preventive, hypercholesterolemic, nematicide, anti-obesity, antifungal, antimicrobial, melanogenesis inhibitor, anti-inflammatory	[51-59]
Odontella Aurita	EPA, DHA, pigments, Chrysolaminarin, fucoxanthin	Antioxidant, anti-inflammatory, anti-obesity	[48,51,52,58,60,61]
Phaedodactylum tricornutum	PUFA (palmitoleic, palmitic acid, EPA), polyphenol, carotenoids (fucoxanthin, zeaxanthin, ß-carotene, diadinoxanthin, diatoxanthin, astaxanthin, violaxanthin), geraniol, galactolipids	Antioxidant, anti-obesity, antidiabetic, antibacterial, anti-inflammatory, anticancer, antihyperglycemic	[32,33,48,51,53,58,62-65]
Porphyridium Cruentum, Purpureum	Phycoerythrobilins, phycocyanobilins, polysaccharides (ß-1,3-glucan), PUFA (EPA, DHA), chlorophyll a,d, carbohydrates, galactolipids	Antiviral, anti-inflammatory, immunomodulating, antibiotic, antihyperglycemic, antioxidant, hyaluronidase, and COL-1 inhibitor	[51,52,58]
Cyclotella Cryptica	fucoxanthin, diadinoxanthin, diatoxanthin, zeaxanthin, β-carotene, astaxanthin, and violaxanthin, galactolipids	Antioxidant, anti-inflammatory, anti-obesity	[33,48,51,58]
Scenedesmus sp.	TAG, β-carotene, lutein, canthaxanathin, neoxanthin, loroxanthin, violaxanthin	Antioxidant, anti-aging, anti-cancer, anti-obesity, antimicrobial	[48,58,66-68]
Chlorella Vulgaris, Minutissima, Pyrenoidosa	Chlorophyll, polysaccharides (ß-1,3-glucan), violaxanthin, lutein, zeaxanthin, cantahxaqnthin, neoxanthin, peptides, proteins, EPA	Anticarcinogenic, immunostimulatory, antioxidant, anti-inflammatory, analgesic, antimicrobial, antifungal, anticancer, collagenase inhibitor, hyaluronidase and COL-1 inhibitor	[32.33,48,51,52,58,66,68,69]
Haematococcus Pluvialis	Astaxanthin, violaxanthin, astaxanthin esters, lutein, zeaxanthin, α-carotene, β-carotene	Antioxidant, anti-inflammatory, anti-aging, anti-cancer, anti-obesity, antimicrobial	[33,41,48,52,58,70]
Coccomyxa Acidophila	Phenolic compounds, carotenoids (fucoxanthin, astaxanthin, lutein), tocopherol	Cytotoxic, antioxidant	[49]
Chaetoceros Muelleri, Calcitrans	PUFA, methyl palmitic, methyl palmitoleic, sterols, galactolipids	Antibacterial, antimicrobial, anthelmintic, hyaluronidase and COL-1 inhibitor, anti-inflammatory	[51-54,58,61]
Skeletonema sp.	ß-1,3-glucan, methyl myristic, methyl palmitoleic, galactolipids	Anti-inflammatory, antibacterial	[51-54]
Cylindrotheca Closterium	Fatty acids, TAG	Anti-inflammatory, antiproliferative	[71]
Dunaliella Salina, Tertiolecta	ß-carotene, violaxanthin, ß-Cryptoxanthin, Tocopherol, provitamin A, astaxanthin, lutein, carotenoids	Anticarcinogenic, anti-inflammatory, antioxidant, antimicrobial, antifungal, collagenase inhibitor	[32,48,51,52,57]

Nannochloropsis Oculata, Gaditana	TAG, PUFA (EPA), canthaxanthin, zeaxanthin, astaxanthin, violaxanthin, chlorophyll, phenolic compounds, vitamin D3, galactolipids	antioxidant, anti-melanogenic, anti-inflammatory, antimicrobial, UV protective, anti-wrinkling, skin moisturizing, melanogenesis inhibitor	[24,32,48,51,52,68]
Tetraselmis Suecica, Tetrathele	Tocopherol, carotenoids, lutein	Antioxidant, anti-inflammatory, immunomodulating, and antiviral, melanogenesis inhibitor	[23,51,52]
Chlamydomonas reinhardtii, nivalis	ß-carotene and æ-carotene, lutein, violaxanthin, phenolic compounds	Antioxidant, anti-inflammatory, cytotoxic, melanogenesis inhibitor	[32,33,49,51,72]
Isochrysis	PUFA, fucoxanthin, galactolipids	anti-inflammatory, immunomodulating, and antiviral, antioxidant, antimicrobial, melanogenesis inductor	[51,52,57]

Chemical composition and biological activity

Microalgae contain numerous chemical families such as proteins/enzymes, lipids/fatty acids, carbohydrates, pigments, vitamins, minerals, and other chemical groups not included in these classes [42]. Thus, the components of microalgae even in the case of the same species, can vary if they are not cultivated under the same conditions.

In a general way, microalgae have sulfated polysaccharides that encapsulate the cells. Chlorophyceae contain ß-1-3 glucan, peptides, PUFAs, ß-carotene and astaxanthin, Rhodhophyceae contain phycobiliproteins (phycoerythrin, phycocyanin), carotenoids and PUFA and Bacillaryophyceae, including diatoms can contain fucoxanthin, EPA and phenolic compounds as phlorotannins [43-47]. The color of the different types of microalgae depends on the pigment composition. Then, green algae contain Chlorophyll-a and b, α-carotene, β-carotene, γ-carotene, lutein, siphonoxanthin and siphonein. Red algae have Chlorophyll-a, phycocyanin, phycoerythrin, α-carotene, β-carotene brown algae and more specifically diatoms contain Chlorophyll-a and c, β-carotene, fucoxanthin, diatoxanthin and diadinoxanthin [48].

Enlarging to the extremophilic and aeroterrestrial species, like *Chlamydomonas Nivalis* (snow algae) or *Coccomyxa Acidophila* (acid environment), microalgae can contain lutein in nonesterified and free form and are more likely to have PUFA SAFA and MUFA. Astaxanthin is also often found in extremophilic species which live under low temperatures or in aeroterrestrial species [49,50].

All these compounds can be isolated to be studied as value-added compounds for a specific target. In that way, pigment extracts can be used for several application. For example, fucoxanthin is anti-inflammatory, hepatoprotective, cardioprotective, anticancer, antidiabetic, antiobesity, antioxidant, skin protective (UV), neuroprotective, osteoprotective and eyes protective. Carotenoids in general have these activities as astaxanthin which is a strong antioxidant and UV protective [24,73] and some also have anti-proliferative and antiatherosclerosis activities like ß-carotene [49] and can act against cardiovascular diseases [74]. These compounds represent 8 to 14% of the biomass [34]. Astaxanthin is the strongest one, then we have zeaxanthin and fucoxanthin but the three of them are less active than quercetin [49]. Vitamins are also part of microalgae and can be found in several species notably pro vitamin A and vitamins C,E,B,D,K and folic acid [49]. Vitamin C can is an eye protective and vitamin E is antioxidant [44,49]. Chitin and chitosan which are cell wall component are antimicrobial, antiviral, antifungal and antioxidant and sulfated polysaccharides are antiviral, anti-tumor, immune regulator and antioxidant [49]. Proteins can also be found in microalgae and peptides from *Chlorella* extracts allow to eliminate more easily dioxins, prevent ulcers caused by stress and can boost immune function [75].

Traditional and current use

There are not really traces of traditional use for microalgae as such, but there are some of cyanobacteria. They were consumed in Mexico, Chad and China, as food a thousand years ago. These people used to integrate them in cakes and other recipes. Chinese people cooked *Nostoc* during famine to replace traditional food while in Mexico and Chad, the use of *Spirulina* was more frequent [44,76,77].

Nowadays, microalgae are more studied for their potential use in biofuels, biogases and biopolymers [35,78], but also in aquaculture and for the depollution of wastewaters [63]. Typically, the lipids are used for biodiesel but also in cosmetics, pharmaceuticals, and nutraceuticals and in the food industry [46,58].

Different species are already studied for their potential applications in industries. For example, *Chlorella* sp. in nutraceuticals and food [79,80] or the genera *Haematococcus*, also in the food industry for its value-added lipids [80]. They are the most common in this industry and are employed as dietary supplements or animal food [41,80]. *Chlamydomonas Reinhardtii, Porphyridium Cruentum, Chlorella, Scenedesmus* and *Dunaliella* are genera and species seen for pharmaceutical or cosmeceutical applications because of their recombinant proteins, fatty acids and pigments [46,80,81]. In nutraceuticals, microalgae are explored in the prevention of oxidative stress

In all the fields, microalgae are employed in the form of extracts or isolated compounds to be used for different purposes. Lutein which is an antioxidant pigment is used for eye treatment [34]. Another pigment, astaxanthin, is also used as a food dye and a strong antioxidant [33]. ß-carotene, offers protection against UVA and IR radiations [51]. Carotenoids in general are used in human food and dietary supplements, fish and pet food, nutraceuticals and pharmaceuticals [74].

Chlorella extracts are employed for pharmaceutical applications: for cervical and vaginal inflammation, and also to treat eczema, superficial wounds and burns. This species can be used as treatment for cardiovascular and liver diseases, for non-alcoholic fatty liver disease and cancer as co-treatment or preventive treatment in order to avoid side effects [34]. *Chlorella Vulgaris* is considered for wastewater treatment and solution to greenhouse gases [82].

It is known that some species extracts like *Chlorella Minutissima* are antioxidants and could be used in cosmetics and food industries but it is not possible to evaluate the activity of only one molecule: they have an activity when all the compounds are together because of the synergy between all the them [83].

In a more recent context, thanks to the anti-inflammatory effect of some microalgae species, non-aqueous extracts could be used as a treatment to heal the symptoms of COVID-19 and could induce better defense mechanisms and better responses in the lymphocytes [84].

Furthermore, different techniques of encapsulation were tested to improve the bioavailability and the stability of the extracts or isolated molecules in order to make mostly food but also beverages and pharmaceuticals. These encapsulations have been conducted on astaxanthin, phycocyanin or other extracts like carotenoids, fatty acids and phenolic extracts, or even, directly on the biomass or powder of the species [44].

Isolated compounds and targeted extracts for cosmetic use

A lot of microalgae are employed in cosmetics whether as pigments in lipsticks, make-up and eye shadows or as active ingredients in sunscreen and face lotions, anti-aging creams, shampoo and soap [85]. To obtain these products, isolated value-added molecules can be worked on in the research fields.

Pigment extracts: Carotenoids and specifically ß-carotene are known to be antioxidant and ß-carotene is often extracted from *Dunaliella Salina* to confer anti-aging and UV protection properties [40,49,80,86]. Other carotenoids can confer photoprotection against UV radiations and enhance collagen synthesis. Astaxanthin and fucoxanthin are both antioxidants and are used in sunscreen products, anti-aging creams and for hydration [40,44]. But carotenoids can also be used as stabilizers, preservatives or pigments: orange of ß-carotene is sometimes employed in make-up like eyeshadow and lipsticks and in hair products like hair conditioner or shampoo.

Red microalgae pigment extracts have ever been used to make eye shadows, lipsticks, face creams, and other makeup [45]. As pigment extracts are often not stable in cosmetics, it is possible to stabilize them with a synthetized copolymer [40,44,87]. Lutein and zeaxanthin, which are other pigments, can be used in sunscreens, face and eye creams [34,40,49] and lutein can be extracted from *Chlorella Sorokiniana* with ionic liquid [88]. ß-carotene, chlorophyll and other pigments and carbohydrates can be used in aftershaves, toothpastes or deodorants because of their property to absorb odors [49,52]. *Odontella Aurita* pigments extracts stimulates elastin synthesis [40].

Also, phycocyanin and phycoerythrin in red microalgae are used as red colorants for eye shadows, lipsticks, hair colors and other make up products but are also antioxidant even if they can be affected by heat, pH, and light [40,45,49,52]. Lycopene is sometimes used as a pigment for its red-orange color but also in sunscreens and to heal sunburns [49]. Astaxanthin is a red-pink pigment useful for makeup [33].

Zeaxanthin from *N. Oculata*, astaxanthin, ß-carotene, fucoxanthin and lutein reduce melanin production and then, can be considered as whitening and anti-hyperpigmentation agents and can be incorporated in creams in cosmeceuticals [49,59]. On the contrary, it is possible to extract canthaxanthin from *Nannochloropsis* which is a tanning agent [49,52]. Astaxanthin from *H. Pluvialis* extract has anti wrinkles and anti-aging properties [90].

Sometimes, microalgae antioxidant compounds are not stable and can be encapsulated to improve it, it is the case for carotenoids [91] and astaxanthin, encapsulated by solvent evaporation or non-aqueous nano-emulsion [44].

Lipid extracts: Lipid extract contain several activities useful in cosmetics like moisturizing, antioxidant, anti-inflammatory, photoprotective, or they can be used as emulsifier and texturizer agents or as active ingredients. Effectively, it is possible to obtain triacylglycerol, PUFA, sterol, waxes, and carotenoids from different species, including *Chlorella, Isochrysis, Dunaliella, Scenedesmus, Chlamydomonas, Nannochloropsis, Porphyridium, Haematococcus* or *Tetraselmis* [92,93].

Sulphoglycolipids existing in some species are antioxidant and anti-inflammatory [51].

Other targeted extracts: Vitamins from *Chlorella Vulgaris* extract can be employed to treat dandruff, in shampoos. Vitamin A, E and ß-carotene are often used in hair conditioners and shampoos and vitamin C whitens the skin [49].

Polysaccharides can be used as humectants and moisturizers and are extracted from *Nannochloropsis* sp. [49].

Flavonoids and phenol could be responsible for allowing synthesis of collagene in *Chlorella* sp. [49]. *O.Limnetica* and

D. Salina ethanolic extract could be used for tanning or antioxidative products thanks to their phenolic compounds [94].

Crude extracts for potential and current application in cosmetics

Crude extracts are often preferred to isolated compounds in cosmetics because the molecules inside them work in synergy which improves the benefits of the extracts.

Uses and activities of microalgae crude extracts for cosmetic products: Some species like *P.Tricornutum* and *Chlorella* extracts are mostly used for their carotenoids, in synergy with other molecules [33].

The snow microalgae *Chlamydocapsa* sp. extract can be used in cosmeceuticals for antiaging, anti UV and antipollution, moisturizing and for preventing wrinkles purposes in soaps, lotions, creams and hydrogels [49]. *Chlorella* sp. extracts are thickening agent and can be used in a whitening, antiaging and moisturizing cream [95] and aqueous extract specifically is antioxidant and a tyrosinase and elastase inhibitor and could be used in anti-wrinkle and dermatological treatments [69,83]. It also has an effect on cornified envelope proteins, elafin and small prolin rich proteins [51]. Dark circles can be treated with *Chlorella Vulgaris* extracts and employed in toners and creams and lotions can be conceived with chlorophyll [49]. *Porphyridium Cruentum* and *P. Purpureum* extracts are used as thickening agents because they produce sulfated polysaccharides or antioxidant agents [49]. Indeed, some microalgae extracts can stimulate or inhibit melanogenesis which can induce a tanning or whitening effect on the skin. This can help to treat hyperpigmentation or depigmentation, exerting an activity on tyrosinase which is implied in melanin synthesis [51]. *Chaetoceros* sp. ethanolic extract allows and improves hair follicle growth, modulates pigmentation, modifies ECM composition and improves cell proliferation in skin, with a reduced sebogenesis [51]. The genera *Isochrysis* sp. and *Nannochloropsis* sp. can be employed in sunscreen, and the *N. Oculata* extracts in creams, as a whitening agent [95]. Moreover, aqueous extract of this species can improve collagen production in fibroblast cultures and protects from oxidative stress. *Thalassiosira Pseudonana, N. Gaditana* and *T. Suecica* are all considered as skin lighteners as extracts and it can be attributed to fatty acids, including PUFA, and carotenoids. *C. Reinhardtii* hydro-alcoholic extract can inhibit melanogenesis so is a whitening agent too [51]. On the contrary, Ethyl acetate extract of T. Isochrysis is a tanner and can stimulate melanogenesis on skin and hair with lots of PUFAs [51].

Monodus Subterraneus, Chlorococcum Minutum, Thalassiosira sp. Chlorella sp. and *Chaetoceros* sp. ethanolic and methanolic extracts can be employed to reduce hair loss and in hair care products [49,51,95] and *Thalassiosira* sp. *Chlorococcum* sp. and *Chaetoceros* sp. extracts, in antiaging products. *Nannochloropsis* ethanolic extract seems to be antimelanogenic and can then be used as a skin whitening, is antioxidant, anti UV, skin moisturizing, promotes procollagen synthesis, elastin and collagene synthesis so it can be employed to reduce wrinkles and is anti-inflammatory. These activities can be attributed to PUFA, phenolic compounds and carotenoids but the activity is offered only when there is synergy between all the compounds [24]. The extracts, oil and powder obtained from *H. Pluvialis* and extract from *D. Salina* are antioxidant, anti-inflammatory, antiaging and collagenase inhibitors and can be used as skin conditioner or lotions. *P. Tricornutum* extract is suitable for UV protection of the epidermis [51].

Some extracts can drastically decrease or reduce the sebum production like the species *G. Sulphuraria, C. Calcitrans, T. Pseudonana, Nannochloropsis* and *T. Isochrysis* and could be used in products like acne treatments [51].

Diatoms potential use: Crude extracts of diatoms are not explored a lot yet but could be really interesting because of the secondary metabolites they contain, specifically when extremophilic species like *Thalassiosira* or *Chlamydocapsa* [17,93].

Encapsulation techniques: As natural compounds, it happens that some extracts can be unstable, so they need encapsulation. For example, *Haematococcus Pluvialis* extract has been encapsulated in liposomes as sunscreen protector [44]. Encapsulation with maltodextrin or polycaprolacton of microalgae water extracts is also conceivable [96,97]. Nanoemulsions of *T. Tetrathele* crude extract to create an antioxidant topical lotion allows a good stability and good skin absorption.

Existing and commercialized products with crude extracts: Some products containing isolated molecules or extracts are already commercialized. It is the case for Phytomer Rosée soin Radiance replenishing oil with soothing, humectant effects and *Phaedotactylum Tricornutum* and Thalassiosira extracts [32]. Daniel Jouvance has created Bain douche fraîcheur glacaire with *T. Pseudonana* extracts, which is a diatom, as protective skin agent. With the same species extract, there is the product Cytolnat Selenium, antiaging and antioxidant cream [98]. Estée Lauder uses *Chlorella* extracts for a moisturizing and antioxidant series of products named Nutricious Microalgae skincare. *H. Pluvialis* extracts in an eye-cream from Coco Brownie. Masks also exists with Chlorella and spirulina extracts incorporated in a product named Algal aqua expert hydrated facial mask, from Annabella.

There are also Pentapharm Pepha-Tight from *N. Oculata* extract, Biotherm Blue Retinol from *D. Salina*, Frutarom Alguard from *Porphyridium* sp. [85].

Also, products with isolated compounds like astaxanthin in a Voolga mask or lutein in an eye cream from Lipostides can be created by companies [34]. Carotenoids and especially fucoxanthin is used in cosmeceuticals by Asian companies using particularly *P. Tricornutum, I. Galbana and O. Aurita* for example [74]. At Givaudan, they use microalgae extracts as anti-wrinkle or anti- aging agents, film former and moisturizing agent. They are not always the main part of the product but serve as conditioning agent like *P. Cruentum*, at Asta Technology or as moisturizing, self-tanning, anti-acne, and anti-redness agents at Green-Tech.

Conclusion

Cultivating microalgae instead of plants allows not to use lands where we can cultivate vegetables. Maybe keeping the extracts rather than extracting each component like polyphenols, carotenoids... could be better because the biological activities in microalgae are resulting from a blend of different chemical component and not from one only. The combination of several components confers unique properties to the microalgae. Moreover, some extracts could have several activities that can treat several diseases so it could be interesting to develop them. Microalgae are used in pharmaceuticals, food and dietary supplements, energy industries and cosmetics for the main fields and each part of them could have an effective use in cosmetics particularly: proteins, carotenoids, pigments, and fatty acids, because they can prevent blemishes, restore damaged skin, and moisturize the skin. They can be put in many cosmetics products like anti-aging, sunscreen or skin whitening or tanning products.

Finally, extracts from microalgae and from diatom are material to explore and develop in fields like cosmetics because of the interesting properties they could provide.

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