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The Revitalizing Potential of Microalgae in Cosmeceuticals

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ABSTRACT: Microalgae, the aquatic photosynthetic organisms are a stable source of several bioactive compounds. Many secondary metabolites derived from algae have potential skin benefits that protect the skin against UV rays, anti-aging, rough skin, wrinkles, pigmentation, and skin laxity. Currently, cosmetic formulations based on microalgae are gradually being replaced by equivalent synthetic products. Bioactive components derived from algal biomass include polysaccharides, proteins, peptides, amino acids, fatty acids, sterols, glycolipids, phospholipids, pigments, phenolic compounds, and vitamins. The cosmetic properties of algae include anti-aging, antioxidant, anti-inflammatory, anti-melanogenic, anti-cancer, and anti-bacterial properties. The purpose of this review is to draw attention to the commercial use of products derived from microalgae as appropriate skin care formulations in cosmetics.

KEYWORDS: Microalgae, secondary metabolites, UV radiations, aging, antioxidant, cosmeceuticals

I. INTRODUCTION

Three-fourths of the earth's surface is covered by water, and approximately 97% of the total water on earth is sea water. The space habitable by marine organisms is far greater than that available for terrestrial plants. Algae are major autotrophs and microalgae cover approximately 75% of algal species in marine ecosystems [1]. The most abundant microalgal classes are Cyanophyceae (blue-green algae), Chlorophyceae (green algae), Bacillariophyceae (including the diatoms), and Chrysophyceae (including golden algae) [2]. Considering the wide biodiversity of microalgae, this group of microorganisms is one of the most promising sources of several biologically active compounds namely carbohydrates, proteins, minerals, fatty acids, antioxidants, pigments etc. [3,4]. In most microalgae, bioactive compounds accumulate in the biomass, while in other species these metabolites are secreted into the environment known as exometabolites [5]. Currently, microalgae metabolites have attracted much attention from researchers due to their potential applications in the food, pharmaceutical, cosmetic, and pharmaceutical industries [6]. According to a recent analysis by Vantage Market Research, the global algae products market size is expected to reach USD 36 billion by 2028 and is expected to grow at a compound annual growth rate (CAGR) of 10.5% [7]. More recently, the cosmeceutical industry is progressively shifting to natural bioactive ingredients because of the ineffectiveness of synthetic cosmetics [8].

The limitations of synthetic cosmetics are multifaceted, encompassing both their adverse effects and their suboptimal absorption rates. One key factor contributing to their reduced absorption is the large size of their molecular compounds, which hinders effective penetration into the skin. Compounds with the molecular weight lesser than 500 Dalton (Da) only can penetrate through the skin [9]. Hydroxybenzoic acid esters, commonly known as parabens are frequently being utilized in cosmetic formulations as preservatives to prevent the growth of harmful bacteria and moulds. The parabens have been reported to mimic estrogenic properties with a potential role on the elevated risk of breast cancer and the development of malignant melanoma [10].

Bioactive compounds

The external environment has a significant effect on the cellular composition of microalgae. Therefore, the biosynthesis of secondary metabolites by microalgae can be stimulated by changing the culture conditions through the presence or absence of certain nutrients [11]. Bioactive compounds, namely cyanovirin, oleic acid, linolenic acid, palmitoleic acid, vitamin E, B₁₂, β -carotene, phycocyanin, lutein, and zeaxanthin are derived from the primary metabolism of proteins,

fatty acids, vitamins, and pigments. Several secondary metabolites derived from microalgae (Table–1), such as fucoidan, fucoxanthin, sulphated polysaccharide, polyphenol, and fucosterols have anti-inflammatory, antioxidant, antifungal, anticancer, antibacterial, photo protective, hypocholesterolemic, and antiaging effects. [12].

II. MICROALGAE IN COSMECEUTICALS

Cosmeceuticals are a combination of cosmetic and pharmaceutical active ingredients that exhibit medicinal or drug-like effects on skin health [13]. Due to the side effects and poor absorption of synthetic cosmetics, consumers are gradually moving towards natural bioactive ingredients. Several research studies have proven the efficacy of herbal products as a suitable alternative to synthetic products and their potential benefits (Figure.1) even after long-term use [14]. Incorporating microalgae into cosmeceutical formulations involves advanced extraction techniques to preserve the bioactive compounds' efficacy. These formulations can include serums, creams, masks, and supplements tailored to address specific skin concerns, such as aging, hydration, and sun protection [15].

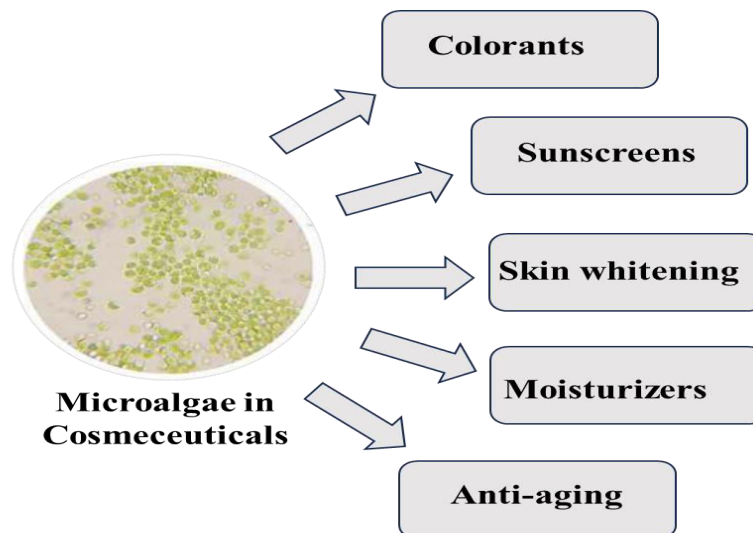


Figure 1. Overview on applications of microalgae in cosmetics

Colorants

Of late, natural dyes and pigments have become increasingly popular in colour cosmetics. Microalgae produce a diverse range of pigments, including chlorophylls, astaxanthin, lutein, β -carotene, and phycobiliproteins, which exhibit colors ranging from green to red, orange, and blue. Phycobiliproteins namely phycocyanin, phycoerythrin, and allophycocyanin are found predominantly in microalgae of the Rhodophyceae or Cryptophyceae family and these photosynthetic pigments constitute a set of water-soluble, vibrant, antioxidant and intensely fluorescent components. Since these pigments are highly stable and impart long lasting colours they are currently used as natural colorants in eye shadows, eye liner, face makeup, lipsticks, blushes and hair colours too [16, 17, 18, 19]. The blue coloured Phycocyanins are extracted from blue-green algae namely, *Spirulina platensis*, *Galdieria sulphuraria*, *Coccochloris elabens*, *Aphanizomenon flos-aquae*, *Gracilaria chilensis*, *Oscillatoria quadripunctulata* etc. The intense pink/red coloured Phycoerythrins are sourced from *Palmaria palmate*, *Porphyridium cruentum*, *Ceramium rubrum*, *Porphyra yezoensis*, *Grateloupia turuturu*, *Kappaphycus alvarezii* etc. Major algal carotenoids namely astaxanthin, β -cryptoxanthin, canthaxanthin, lutein and zeaxanthin imparting yellow to orange colour are produced by *Spirulina platensis*, *Galdieria sulphuraria*, *Coccochloris elabens*, *Aphanizomenon flos-aquae*, *Gracilaria chilensis*, *Oscillatoria quadripunctulata* etc.

Sunscreens

Although skin cells have several defense mechanisms such as antioxidants, DNA repair enzymes, and stress signaling, excessive exposure of the skin to UVR causes ROS production, resulting in DNA damage. [20]. Oxidative DNA damage causes a wide range of pathological disorders, including the aging process [21]. Microalgae are often exposed to oxidative stress because they grow in harsh environmental conditions with intense sunlight and UV rays. Therefore, they develop defense systems to protect themselves against reactive oxygen species (ROS) and free radicals. These compounds can potentially be used in cosmetics to protect cells from the harmful effects of UV rays [22]. Carotenoids are abundant pigments in blue-green and red-brown algae that have significant antioxidant properties and are used in sunscreen formulations. Carotenoids such as astaxanthin, β -carotene, lycopene, and lutein are widely included in topical cosmetics as they are known to protect the skin from UV damage and act as stabilizers and preservatives [23]. *Scenedesmus*, *Chlorella*, *Coccomyxa*, *Parachlorella* and *Tetraselmis* are the potential candidates for carotenoid production [24]. Phenolics, phlorotannins, and Scytonemin are unique natural sunscreen formulations because of their multiple roles as UV sunscreens and as potent antioxidants with strong radical scavenging activity [25, 26]. Phlorotannins, hydrophilic polyphenols are derived from marine brown algae namely *Eisenia bicyclis*, *Ecklonia cava*, *Ecklonia kurome*, *Ecklonia stolonifera*, *Ishige okamurae*, *Eisenia arborea* [27]. Scytonemin, lipid soluble and yellow-brown pigment is distributed in the exopolysaccharide sheath of *Nostoc*, *Scytonema*, *Calothrix*, *Lyngbya*, *Rivularia*, and *Chlorogloeopsis* species of cyanobacteria [28]. Mycosporine-like amino acids (MAAs) such as shinorine, porphyra-334, mycosporine-glycine, asterina-330, and palythine, aplysiapaly-thine B, usujirene, collemin A etc, extracted from green algae, brown algae, red algae, and cyanobacteria act as primary sunscreens that reduce short-wavelength light in addition to scavenging reactive oxygen radicals [29]. Lipid-based cosmetics such as creams and lotions rich in algal polyunsaturated fatty acids (PUFA) like alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), gamma-linolenic acid (GLA) provide both nourishing and photoprotection and are therefore commonly used in skin care, toning or revitalizing products [30]. *Chlorella*, *Chlamydomonas*, *Nannochloropsis*, *Scenedesmus*, *Haematococcus*, *Dunaliella* are the chief sources of PUFA [31].

Skin whitening

Irregular dark spots often appear on the skin due to aging, hormonal imbalance and continued exposure to UV rays, Melanin, the primary pigment responsible for skin colour is synthesized by melanogenesis in the melanocytes of epidermis. Tyrosinase is an important regulatory enzyme that catalyses melanin biosynthesis [32]. Prolonged exposure to UV radiation causes the accumulation of reactive oxygen species that stimulate the enzyme Tyrosinase and hence hypermelanogenesis. Several herbal products are known to control/prevent melanogenesis by inhibiting tyrosinase activity. Zeaxanthin, β -carotene, lutein, astaxanthin, phycocyanin, Fucoxanthin, in addition to strong radical scavenging activity, show significant inhibitory activity against melanogenesis pathway [33, 34]. *Chlorella vulgaris*, *Chondrus crispus*, *Corallina officinalis*, *Spirulina platensis*, *Fucus vesiculosus*, *Ulva compressa*, *Ulva lactuca* and several species of the genus *Laminaria* namely *ochroleuca*, *hyperborea*, *digitata* and *saccharina* are the most prominent algal species extensively used for skin whitening cosmetic products [35].

Moisturizers

Well-hydrated and moisturized skin is healthier, brighter, and better protected against harsh environmental conditions. Polysaccharides namely alginates, agarose, carrageenan, fucoidan, ulvan, laminarin, chitin extracted from microalgae are important as humectants and moisturizers in cosmetic formulations. *Agardhiella*, *Euclima*, *Chondrus*, *Gigartina*, *Furcellaria*, *Hypnea*, *Porphyra capensis*, *Porphyra haitanensis*, *P. umbilicalis*, *Pelvetia canaliculata*, *Fucus vesiculosus*, *Sargassum stenophyllum*, *Ulva* etc. seems to be the potential sources of both sulfated and non-sulfated polysaccharides [36]. Chitin, derived from the cell wall components of terrestrial and thermophilic algae viz., of the genus *Isochrysis*, *Chlorella*, *Bracteacoccus*, *Chlorococcum*, *Scenedesmus*, *Dunaliella*, *Haematococcus*, *Thalassiosira* and *Nannochloropsis* is used as a moisturizing and hydrating agent in creams, soaps, and lotions [37]. β -carotene, β -cryptoxanthin, lutein, zeaxanthin, and astaxanthin have been shown to stimulate hyaluronic acid synthesis and increase skin elasticity and skin hydration. Squalene extracted from microalgae *Schizochytrium limacinum* and *Chlamydomonas* has been included in moisturizing creams as an anti-static and emollient agent, increasing penetration into the skin without leaving any greasy residue on the skin [38]. Amino acids, proteins, and serum formulations from algae are also included in skin moisturizers [39].

Anti-aging

Skin aging is a complex process caused by intrinsic and extrinsic factors that cause numerous skin changes such as skin thinning, dryness, laxity, fragility, enlarged pores, hyperpigmentation, fine lines, and wrinkles [40]. In the dermis, collagen, elastin, and hyaluronic acid help to maintain good texture, radiance, and elasticity of the skin in addition to strengthening against harmful environmental factors [41]. Exopolysaccharides from microalgae can be used as conditioners, moisturizers, healing agents, emulsifiers, and as a substitute for hyaluronic acid. Polysaccharide extract from *Saccharina japonica* and *Porphyridium*, brown algae, showed the ability to retain deep moisture with excellent moisturizing and bio-lubricant properties to replace hyaluronic acid [42]. Laminarin, alginate, and fucoidan derived from brown algae (*Turbinaria conoides*) enhance thickening and water-binding properties when incorporated into antiaging cosmetics [43]. Active compounds extracted from *Pyropia yezoensis* (red algae) and *Chlamydomonas hedleyi* (green microalgae) promote the biosynthesis of collagen and elastin in the extracellular matrix of the dermis [44]. Fucoidan (sulfated polysaccharides) derived from brown algae has been shown to minimize the activity of elastase, which protects the skin's elastic fibre network. The protein extract derived from *Chlorella vulgaris* and *Arthrospira platensis* has demonstrated the ability to enhance collagen synthesis. This, in turn, contributes to a notable decrease in vascular inadequacies and promotes a heightened capacity for tissue regeneration. [45, 46].

Table 1: Bioactive compounds derived from microalgae

Micro algae	Species	Bioactive compound	References
Blue green algae (Cyanophyceae)	<i>Chlorella, spirulina sp.</i>	Flavonoids	[21]
	<i>Spirulina platensis,</i> <i>Galdieria sulphuraria,</i> <i>Coccochloris elabens,</i> <i>Aphanizomenon flos-aquae,</i> <i>Gracilaria chilensis,</i> <i>Oscillatoria quadripunctulata</i>	Phycocyanins (Blue coloured) Astaxanthin, β-cryptoxanthin, canthaxanthin, lutein and zeaxanthin (yellow to orange colour)	[1], [35]
	<i>Palmaria palmate,</i> <i>Porphyridium cruentum,</i> <i>Ceramium rubrum,</i> <i>Porphyra yezoensis,</i> <i>Grateloupia turuturu,</i> <i>Kappaphycus alvarezii</i>	Phycocerythrins (Pink/red coloured)	[18]
	<i>Scenedesmus,</i> <i>Chlorella,</i> <i>Coccomyxa,</i> <i>Parachlorella</i> <i>Tetraselmis</i>	Carotenoid	[24]
	<i>Nostoc,</i> <i>Scytonema,</i> <i>Calothrix, Lyngbya,</i> <i>Rivularia,</i> <i>Chlorogloeopsis sp</i>	Scytonemin	[28]
Chlorophyceae (green algae),	<i>Chlamydomonas hedleyi,</i> <i>Aphanizomenon flos-aquae,</i> <i>Nostoc verrucosum</i>	Mycosporine-like amino acids (MAAs): shinorine, porphyra- 334, mycosporine-glycine, asterina-330, and palythine, aplysiapaly-thine B, usujirene, collemin A	[29]
	<i>Porphyra capensis,</i> <i>Porphyra haitanensis,</i>	Sulfated and non-sulfated polysaccharides	[36]

	<i>P. umbilicalis</i> , <i>Pelvetia canaliculata</i> , <i>Fucus vesiculosus</i> , <i>Sargassum stenophyllum</i> , <i>Ulvaes</i>		
	<i>Schizochytrium limacinum</i> , <i>Chlamydomonas</i>	Squalene	[38]
	<i>Chlorella</i> , <i>Chlamydomonas</i> , <i>Nannochloropsis</i> , <i>Scenedesmus</i> , <i>Haematococcus</i> , <i>Dunaliella</i>	Polyunsaturated fatty acids (PUFA) like alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), gamma-linolenic acid (GLA)	[31]
Laminaria (genus)	<i>ochroleuca</i> , <i>hyperborea</i> , <i>digitate</i> , <i>saccharina sp.</i>	Zeaxanthin, β -carotene, lutein, astaxanthin, phycocyanin, Fucoxanthin,	[33], [34]
Phaeophyceae (Brown algae)	<i>Eisenia bicyclis</i> , <i>Ecklonia cava</i> , <i>Ecklonia kurome</i> , <i>Ecklonia stolonifera</i> , <i>Ishige okamurae</i> , <i>Eisenia arbored</i>	Phlorotannins, hydrophilic polyphenols	[27]
	<i>Turbinaria conoides</i>	Laminarin, alginate, fucoidan	[43]
Rhodophyceae, Cryptophyceae (red, blue-green algae)	<i>Porphyridium cruentum</i>	Phycocyanin, phycoerythrin, allophycocyanin	[16], [17], [18], [19]

III. CONCLUSION

This review attempts to highlight the potential role of microalgae-derived nutraceuticals in cosmetic formulations. Several species of microalgae are adapted to grow under harsh environmental conditions, such as pH, temperature, high salinity, and exposure to UV light, while producing diverse groups of primary and secondary metabolites. Therefore, microalgae are considered an optimal source of nutraceuticals for inclusion in cosmetic products. Cultivating microalgae for skincare products also offers a renewable alternative to traditional cosmetic ingredients, contributing to the growing trend of eco-friendly beauty products. Additionally, microalgae cultivation can help mitigate carbon dioxide levels and reduce environmental pollution, making it an eco-conscious choice for cosmetic manufacturers. Algae bioactive compounds have low cytotoxicity and can effectively penetrate the skin layer, thus becoming a better alternative to chemical cosmetics. Microalgae compounds are effective antioxidants that combat skin damage caused by UV rays, stable colors, and are excellent moisturizers and moisturizers. In addition, these compounds increase the elasticity, radiance, and firmness of the skin by promoting the accretion of collagen, elastin, and hyaluronic acid in the extracellular matrix of the dermis. Therefore, appropriate bioassay techniques can help the commercial use of microalgae products in cosmetics. Microalgae derived bioactive compounds used in cosmetics must comply with regulatory standards set by organizations like the FDA (U.S. Food and Drug Administration) and the EU Cosmetics Regulation. These standards ensure product safety, quality, and labelling transparency, provide the confidence in consumers with the products they use.

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