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Future Challenges and Opportunities of Marine Algae in Cosmeceuticals

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Abstract: Marine algae have garnered significant attention in the cosmeceutical industry due to their diverse array of bioactive compounds and unique properties. As the demand for sustainable and effective skincare solutions rises, marine algae offer a promising avenue for innovation. This study explores the future challenges and opportunities of utilizing marine algae in cosmeceuticals. One of the foremost challenges lies in the sustainable sourcing and cultivation of marine algae to meet the growing demand while preserving marine ecosystems. Overcoming this challenge requires advancements in biotechnology, including the development of efficient cultivation techniques and sustainable harvesting practice. Cosmetics are widely used by people around the world to protect the skin from external stimuli. Consumer preference towards natural cosmetic products has increased as the synthetic cosmetic products caused adverse side effects and resulted in low absorption rate due to the chemicals' larger molecular size. The cosmetic industry uses the term "cosmeceutical", referring to a cosmetic product that is claimed to have medicinal or drug-like benefits. Marine algae are rich in bioactive substances that have shown to exhibit strong benefits to the skin, particularly in overcoming rashes, pigmentation, aging, and cancer. The current review provides a detailed survey of the literature on cosmeceutical potentials and applications of algae as skin whitening, anti-aging, anticancer, antioxidant, anti-inflammation, and antimicrobial agents. The biological functions of algae and the underlying mechanisms of all these activities are included in this review. In addition, the challenges of using algae in cosmeceutical applications, such as the effectiveness of different extraction methods and processing, quality assurance, and regulations concerning extracts of algae in this sector were also discussed.
Keywords: marine algae; cosmeceuticals; UV-radiation; anti-aging; anticancer; skin whitening

I. INTRODUCTION

Algae produce primary metabolites such as oleic acids, vitamin E, vitamin B12, lutein, etc. to protect its cell components. Secondary metabolites are also formed under harsh conditions. These metabolites have antibiotic and antimicrobial activity against pathogens and are known for their skin benefits, which include UV protection and prevention of rough texture, wrinkles and sagging skin. It also prevents skin aging due to the presence of antioxidant compounds. Various cosmetic products are obtained from bioactive compounds. Recently, there is demand for cosmetic products made from natural ingredients that are safe and effective in fighting skin complications. Algae, both macro and microalgae, are valuable because they contain beneficial bioactive compounds. Some useful metabolites such as antioxidants, carotenoids, mycosporin-like amino acids (MAA), pigments, polysaccharides and cytonemin can be obtained from algae. Today, different strains of algae are widely used in skin care products for various purposes, such as moisturizers, anti-wrinkle agents, texture improvers and sunscreens. (Singh and Purwar 2022) As the largest organ in the human body, the skin plays an important role in many physical functions. According to the definition of the US Federal Food, Drug and Cosmetic Act of the FDA and section L5131-1 of the French Public Health Code, a cosmetic product is any substance or preparation that is rubbed, poured, sprayed or sprayed. , which is worn or applied to the external parts of the body, especially the epidermis, hair and capillary systems, nails, lips and external genitalia or teeth and mucous membranes of the oral cavity, because the product cleans, perfumes and protects them, changes their appearance, keeps them in good condition or helps reduce body odor (Wang et al., 2013a, Wang et al., 2013b).Nowadays, consumers are suspicious of chemical ingredients and the need has returned to basic and natural cosmetics. The demand for natural and environmentally friendly products is growing, and for example extracts obtained from microalgae biomass have a significant market value in this regard. Scientists have discovered that compounds derived from algae can be used as cosmetic agents. For example, phylogenetically archaic cyanobacteria produce substances with antioxidant activity, polyunsaturated fatty acids (PUFA), heat-inducible proteins or immunologically effective and virostatic compounds (Pulz and Gross, 2004).

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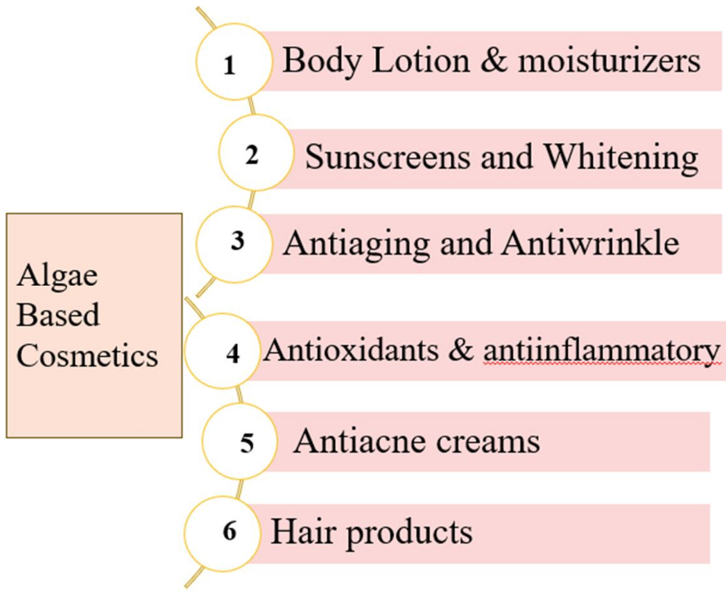
During the last 2. 5 billion years, algae have adapted to extremely harsh and competitive environments by producing various compounds and secondary metabolites for chemical defense and thus can inhabit many ecological niches (Kelman et al., 2012). They are found in all ecosystems, both in water and on land, even in places where plants cannot grow, such as deserts and coastlines. (Stengel et al., 2011).

So, the cosmetic industry is continuous researching for innovative and safe ingredients to develop new products with safe sheets protecting the consumers. The cosmetic industry is developing diverse cosmetic products based on natural ingredients, where seaweed compounds/extracts are used in the cosmetic formulas (Ariede et al 2017). However, natural ingredients are less harmful when compared to synthetic compounds (where the synthesis can result in harmful derivatives, and high chemical reactivity) (Thiyagarasaiyar et al 2020)

There are several types of algae-based cosmetics on the market. (Figure1)



Today, many cosmetic companies sell products that contain algae due to their natural origin (Pimente et al. 2018). Algae and various bioactive substances have different effects on skin health. Algae are used in various beauty products, not only in simple hygiene products such as body creams, face masks and shampoos, but also in advanced cosmetics and cosmetics used to treat acne, psoriasis or eczema (Mourelle et al 2017).

The classes of natural organic compounds extracted from algae differ from those used in cosmetic products (Figure 2).

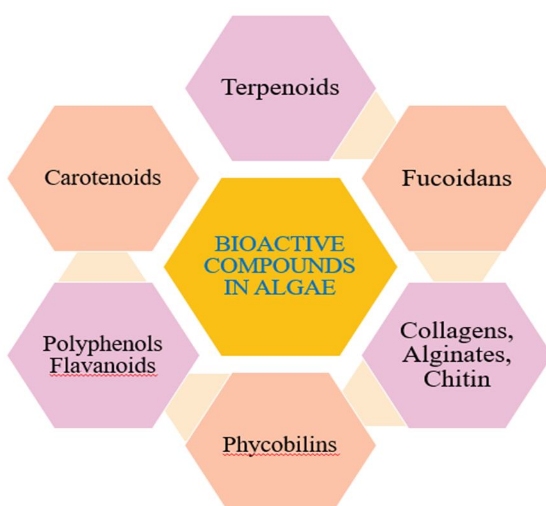


Table shows various bioactive compounds isolated from various algae and few application in cosmetics:

Table 1

	Bioactive compounds in Algae	Organisms from which the compound is isolated	Application in Cosmetics	References
1.	Carotenoids	*Chlorella, Chlamydomonas, Dunaliella, Muriellopsis, and Haematococcus sp*	as stabilizers and as preservative in creams and lotions for sun protection	Wawrzynczak A, Feliczak-Guzik A, Nowak I (2016)
2.	Phycobiliproteins	Rhodophyceae or Cryptophyceae (Cyanobacteria	s a natural coloring pigment in cosmetics a	Arroyo GV, Madrid AT, Gavilanes AF et al
3.	Fucoidans	brown seaweed	in skin protection, as antioxidant, and as anti-aging compound	Ferrer-Tasies L, Santana H, Cabrera-Puig I et al
4.	Carrageenans	Red algae such as Fucus vesiculosus and Turbinaria conoides	antiaging, antioxidant, and anticarcinogenic	Carroll IM, Andrus JM, Bruno-Bárcena JM et al
5.	Alginate	Brown algae such as Fucus vesiculosus and Turbinaria conoides	stabilizers, thickeners, and emulsifiers	Subhashini V, Bhojraj S, Keshav Prakash S, Shalilni T
6.	Polyphenols	Brown algae such as Fucus vesiculosus	As antioxidants	Miastkowska M, Sikora E

II. FUTURE CHALLENGES OF MARINE ALGAE IN COSMECEUTICALS

Marine algae have shown tremendous potential in the field of cosmeceuticals. They are a rich source of bioactive compounds that offer several benefits to the skin. However, the use of marine algae in cosmeceuticals is still in its infancy, and several challenges need to be addressed to fully realize their potential.

1) Sustainability and Harvesting Practices

Challenge: Ensuring sustainable harvesting practices to prevent over-exploitation of marine algae resources and addressing environmental concerns associated with large-scale cultivation.(Holdt, S. L., & Kraan, S. 2011).

2) Stability and Shelf Life of Formulations

Challenge: Maintaining the stability of bioactive compounds from marine algae in cosmetic formulations, particularly addressing issues related to oxidation and degradation over time.(Gómez-Guillén, M. C., 2011).

3) Standardization of Extracts

Challenge: Establishing standardized methods for extracting bioactive compounds from different species of marine algae to ensure consistency in product formulations and efficacy.(Pangestuti, R., & Kim, S. K. 2011).

4) Formulation Compatibility

Challenge: Overcoming challenges related to the compatibility of marine algae extracts with other cosmetic ingredients in formulations, ensuring optimal performance and sensory attributes.(Wang, T.2017).

5) Consumer Education and Acceptance

Challenge: Educating consumers about the benefits of marine algae in cosmeceuticals and addressing any potential skepticism or lack of awareness regarding the efficacy and safety of these ingredients (Thomas, N. V., & Kim, S. K. 2011).

6) Regulatory Compliance

Challenge: Navigating regulatory frameworks to ensure compliance with safety and efficacy standards for cosmeceutical products containing marine algae extracts.(Rasmussen, R. S. (2019).

7) Cost and Scalability

Challenge: Addressing the cost of production and scalability of obtaining high-quality marine algae extracts for use in cosmetic formulations to make them commercially viable.(Holdt, S. L., & Kraan, S. 2011).

8) Research Gaps and Knowledge Gaps

Challenge: Filling research and knowledge gaps related to the specific bioactive compounds present in different marine algae species, their mechanisms of action, and their potential synergies with other skincare ingredients.(Wijesinghe, W. A., & Jeon, Y. J. 2011).

III. OPPORTUNITIES FOR MARINE ALGAE IN COSMECEUTICALS

Despite the challenges, there are a number of opportunities for the use of marine algae in cosmeceuticals. One of the main opportunities is the potential for new and improved products. Marine algae are a rich source of active compounds and polysaccharides that can be used to create a range of cosmeceuticals.

1) *Antioxidant Properties:* Marine algae contain a variety of antioxidants, such as polyphenols, carotenoids, and vitamins, which can help protect the skin from oxidative stress and free radical damage. (Pallela, R., et al. 2017).
2) *Hydration and Moisturization:* Alginate, a polysaccharide found in algae, has excellent water-retaining properties, making algae extracts beneficial for skin hydration and moisturization. (Torres, M. D., et al. 2018).
3) *Anti-Aging Effects:* Algal extracts have shown potential in reducing the appearance of fine lines and wrinkles, attributed to their collagen-stimulating and elastin-promoting properties. (Wijesinghe, W. A., & Jeon, Y. J. 2011)
4) *Anti-Inflammatory Benefits:* Compounds such as fucoidans and phlorotannins found in algae exhibit anti-inflammatory properties, making them valuable for soothing irritated skin. (Cumashi, A., et al. 2007).
5) *Skin Whitening and Brightening:* Some algae species contain compounds that inhibit melanin production, offering potential benefits for skin whitening and reducing hyper pigmentation. (Kim, S. K., & Karadeniz, F. 2011).
6) *UV Protection:* Certain algae produce mycosporine-like amino acids (MAAs) that have UV-absorbing properties, providing natural protection against harmful UV rays. (Dunlap, W. C., & Shick, J. M. 1998).
7) *Collagen Enhancement:* Algae-derived peptides and proteins may contribute to collagen synthesis and skin firmness, offering potential benefits for anti-aging skincare. (Gómez-Guillén, M. C., et al.,2011).
8) *Wound Healing:* Compounds like alginates have been studied for their wound-healing properties, promoting tissue regeneration and reducing inflammation. (Draget, K. I., Taylor, C., & Chemical, F. 2011).

New products could be developed that combine marine algae with other active ingredients for improved efficacy.

Nanotechnology in cosmetics plays an important role in improving the efficacy, Cytotoxicity and bioavailability of active ingredients used in personal care products. The active ingredients are adsorbed on the surface of the nanoparticles and help improve absorption, improve color and finish quality and increase penetration through the skin. Changing the shape, chemical composition, size, solubility and chemical reactivity of nanoparticles used in cosmetic formulations can further improve the shelf life, efficacy and performance of cosmetic products (Chaudhri et al. 2015). Various metal nanoparticles such as silver (Ag), gold (Au), titanium (Ti), zinc oxide (ZnO), mica, platinum, aluminum oxide, copper and fullerenes are used in cosmetic products (Chiari-Andréo et al. 2019). TiO_2 and ZnO nanoparticles are noiseless and easily absorbed. TiO_2, ZnO, and ZrO_2 nanoparticles act as UV filters and are used in sunscreens, lip balms, and moisturizers (Wawrzynczak et al. 2016). Nanoparticles used in cosmetics include liposomes, nanoemulsions, nanocapsules, solid lipid nanoparticles, nanocrystals, nanosilver, nanoron, dendrimer, hydrogel, etc. However, due to the small size of these nanoparticles, they can easily enter the bloodstream through the skin or by inhalation and be carried to various organs. Organ dysfunction is also possible with higher doses and longer residence times of nanoparticles (Oberdörster et al. 2005; Subhashini et al. 2017).

Environmental problems have also been raised by the release of nanoparticles into the air, water and soil during their manufacture, use and disposal. The ability of zinc oxide (ZnO), silver (Ag), titanium dioxide (TiO2), cerium oxide (CeO2), Cu and Fe metal nanoparticles to induce oxidative stress has been reported (Manke et al. 2013). The toxicity and regulatory aspects of nanotechnology products must be carefully considered before they come into direct contact with our skin. Due to the shortcomings of traditional metal-based nanoparticle synthesis methods, the green synthesis of nanoparticles is gaining attention and is a great opportunity due to non-toxic, clean and environmentally friendly methods that protect ecology and restore environmental quality (Paiva-Santos et al 2021) (Arroyo et al. al 2020) (Keijok et al 2019). Green synthesis of silver nanoparticles from a natural extract, Arroyo et al. 2019 (Arroyo et al. 2020) was found to be a very effective and affordable alternative to the market. Abdullah et al. 2021.

A. Biotechnological 1Ingredients: Safe and Effective

The contribution of biotechnological processes to the cosmetic market is enormous which is due to the production of safe and effective active ingredients using cheap and pollution-free methods. Gomes et al. 2020 (. Some effective ingredients resulting from biotechnological processes are kojic acid (Lajis et al. 2013), hyaluronic acid (Pan et al. 2015; Cheng et al. 2017), resveratrol (Donnez et al. 2013). 2009), human epidermal growth factors (Ferrer-Tasies et al. 2021), superoxide dismutase (Carroll et al. 2007) and photolyases (Marizcurrena et al. 2020). Traditional biotechnology harnesses the potential of microbes through fermentation, while modern biotechnology manipulates genetic material and places it in a suitable host for a desired use. fermented ingredients in cosmetics such as fermented coconut (lactobacillus/Cocos nucifera fruit extract) (HANDAYANI et al. 2008), fermented chili (lactobacillus and Capsicum frutescens fruit extract) (Xu et al. 2021), fermented pumpkin (lactobacillus/pump) fruit fermented filtrate) (Park et al. 2019) offers the possibility of replacing conventional synthetic preservatives, and exfoliating properties. There are numerous options to use marine algae enzymes instead of synthetic preservatives..

Recombinant DNA technology (rDNA) is a process for the production of various pharmaceutical compounds from genetically modified microbial/plant/animal cells. Examples of rDNA technology include algal lipids/oil, proteins derived from stem cell lines, stabilized enzymes for topical use, etc. (Rinaldi 2008). Microalgae are a rich source of fatty acids, lipids, proteins, amino acids, and Spirulina algae extract has been used as an antioxidant and antiaging agent (Miranda et al. 1998; Bermejo et al. 2008; Koh et al. 2017). The ability of stem cells to regenerate old damaged cells is significant, and various plant stem cells have had a great effect in the treatment of wrinkles, improved skin elasticity and smoothness, and improved activity in collagen production (Bazylak and Gryn 2015; Miastkowska and Sikora 2018). The use of marine biotechnology to combat aging, inflammation, free radicals and skin cell degradation is gaining momentum (S. Babitha 2011; Wu and Lu 2011). Biotechnology also plays an important role in the development of bio-based polymers to replace plastic with bioplastics for recyclable and biodegradable cosmetic packaging, and this contributes to sustainable global growth (Degli Esposti et al. 2021).

Identify, predict and screen bioactives using artificial intelligence (AI) / machine learning (ML) approaches AI/ML-based tools such as SkinBug (Jaiswal et al. 2021) help predict the reaction between active molecules and skin microbes and determine whether it will biotransform or metabolize to other products to ensure product safety. Beiersdorf, the company behind Nivea and La Prairie, has announced a collaboration with biotech company "Insilico Medicine" to find new active ingredients for cosmetics using artificial intelligence. AI-powered skin analysis uses face mapping technology and looks for signs of aging, pigmentation, skin tone, elasticity, skin texture, moisture, radiance, etc. and allows shoppers to recommend the right cosmetic product for specific skin and health requirements. Atolla (Deanna Utroske 2021), an AI-driven startup founded at MIT, uses AI to develop a customized skin-based serum and claims its ingredients are vegan, cruelty-free, fragrance-free, allergy-free and responsibly grown. ..

Personalized cosmetics with 3D bioprinting, or additive manufacturing, is a process of building tissue-like structures in record time to mimic our body's natural tissues. This makes it possible to produce the patient's cells that match perfectly during skin grafting or even organ transplantation (Velasquillo et al. 2013; Yan et al. 2018). The bio-inks used in the bioprinter are biocompatible materials such as polysaccharides, proteins, synthetic polymers, etc., and depending on the application, an individual treatment can be developed, for example for the treatment of vitiligo, treating the depigmented surface with growth factors. stem cells and cytokines (Czajkowski 2011). Skin scars, often hyperpigmented, can be treated by bioprinting by adding a certain amount of melanocytes..

Pressed skin has been successfully used to treat burns and surgical wounds. This technology is revolutionizing the beauty industry as a game changer, attracting interest from cosmetic giants such as L'Oréal, BASF and Procter and Gamble in the skin care industry. (Tran et al 2020) Unlike the current face mask that leaks precious serum everywhere, facial recognition technology like MaskiD helps us scan and print 3D sheet masks that apply perfectly to face without leaking.

"Mink", the first 3D printer for wearable makeup, allows users to select a color from an image, either online or in the real world, and print that color as blush, eye shadow, lip gloss, etc(Gao, Y et al 2021)

IV. CONCLUSION

Marine algae have shown great potential as a source of active compounds for cosmeceutical products. They offer a safe, natural, and sustainable alternative to synthetic ingredients. The current research on marine algae has revealed a vast array of bioactive compounds that have shown promising results in the development of cosmeceutical products.

However, there are still several challenges that need to be addressed before marine algae can become a mainstream ingredient in the cosmetic industry. One of the major challenges is the standardization of the extraction and purification methods for bioactive compounds. The variability in the chemical composition of algae due to environmental factors can lead to inconsistent results in the efficacy of the final product.

Another challenge is the limited availability of certain species of algae that contain high concentrations of bioactive compounds. The cultivation of these species on a large scale is still a significant challenge due to the high cost and complexity of the process.

Despite these challenges, the future of marine algae in cosmeceuticals looks promising. The increasing demand for natural and sustainable ingredients in cosmetic products provides a significant opportunity for the development of marine algae-based cosmeceuticals. The ongoing research on the bioactive compounds and their mechanisms of action will provide further insights into the potential applications of marine algae in cosmeceuticals.

In conclusion, the use of marine algae in cosmeceuticals offers a promising avenue for the development of safe, natural, and sustainable cosmetic products. However, further research is needed to address the challenges associated with the standardization of extraction methods and the cultivation of high-yielding species. With continued research and development, marine algae-based cosmeceuticals have the potential to revolutionize the cosmetic industry.

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