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Algae as a Source of Natural Colorants in Modern Cosmetics

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Introduction

The cosmetics industry is now embracing the use of natural ingredients. This is the result of response to consumer demand for sustainability, safety, and eco-friendly products. The natural ingredients include natural pigments derived from plants, algae, and microorganisms. They are getting noticed as alternatives to synthetic colorants. As these are often associated with toxicity and environmental concerns (Negi, 2025).

However historically, cosmetics were tinted with minerals like ochre, plant extracts, and insect-based dyes such as cochineal. Synthetic dyes only became famous in the 20th century. But increase in allergies and ecological toxicity made people come back to natural pigments (Chen *et al.*, 2023). Driven by clean beauty and vegan formulations (Negi, 2025) the business related to the natural ingredients infused cosmetics show a rise in demand. In specific the algal pigments have emerged as versatile bioactive compounds with bright colours and functional benefits.This article highlights algal pigment and its broad applicability in modern cosmetics (Chen *et al.*, 2023).

HISTORICAL PERSPECTIVES IN COSMETICS:

Microorganisms and fungi have historically contributed pigments to cosmetic practices. Fungal pigments, such as carotenoids and polyketides, have been used as natural dyes. Mostly for textiles and occasionally in cosmetics, like lipsticks (Lagashetti *et al.*, 2019). Although fungal pigments presented challenges like stability and safety, their historical role highlights the human desire for natural colorants.

Algae has been the important source as food, medicine, and raw materials for the coastal people for many years. The human desire to embrace colour has led the old civilization people to use the color from natural resources available more at that time. They used these colours for decorative purposes and also painted the human body. This early tradition set the stage for algae to emerge as a safer, more sustainable alternative in the modern cosmetic industry.

ECO-BIOLOGICAL ROLE OF ALGAE IN COLORANT PRODUCTION:

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Due to their rapid growth, minimal resource requirements, and high pigment yields. Algae represents an environmentally sustainable source of natural colorants. Microalgae such as Spirulina and Chlorella produce a range of valuable compounds. This includes phycobiliproteins and carotenoids. These pigments are used in both nutraceuticals and cosmetics (Ramos *et al.*, 2025).

Algae utilize pigments to capture sunlight, which is a process that produces oxygen. This is a basic part of aquatic ecosystems. Furthermore, the cultivation of algae contributes to carbon capture. This reduces environmental burden compared to synthetic dye production. Algae also recycle industrial CO_2 emissions. This provides a circular economy model where pigment production is linked to carbon sequestration efforts.

They help in processing the nutrients and provide them for the aquatic ecosystems . The algae which are isolated from the waste water treatment produces the pigments containing biomasses. This led to the both benefits which include the purification and the product preparation. Unlike terrestrial crops, algae do not require fertile soil,so it is easy to grow. They can be cultivated in photobioreactors or open ponds. This makes large-scale pigment production feasible (Ramos *et al.*, 2025). So these products are not seasonal.

ALGAL PIGMENTS:

Algal pigments can be broadly classified into carotenoids, phycobiliproteins, and other accessory pigments like fucoxanthin. Carotenoids like beta-carotene and astaxanthin provide orange-red hues . This acts as antioxidants. This offers skin protection and anti-aging properties (Chini Zittelli *et al.*, 2023). Phycobiliproteins, particularly phycocyanin from Spirulina, give deep blue shades. This colour is highly valued in cosmetics and food applications (Aizpuru & González-Sánchez, 2024). Fucoxanthin, a brown carotenoid from marine algae. This pigment is known for its skin-lightening and photoprotective effects (Dini, 2023).

- **Astaxanthin:** It is derived from *Haematococcus pluvialis*. It is 6000 times stronger than vitamin C in antioxidant capacity. This makes it useful in anti-aging creams (Chini Zittelli *et al., 2*023).
- **Lutein & Zeaxanthin:** These carotenoids protect against skin against blue-light damage. This is useful for consumers exposed to digital screens. These pigments are low in algae by dry weight on average (~0.1 %). But if it is grown and cultivated under favorable conditions then it can be in higher amounts (e.g. Dunaliella salina). Lipophilic carotenoids (e.g. β-carotene, lutein, fucoxanthin) could be incorporated into oil phases of cosmetics.

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- **Fucoxanthin:** This brown-orange pigment is a natural-looking colour in skin-tint formulations. Clinical trials reveal fucoxanthin improves skin elasticity. And it can also be used in reducing hyperpigmentation(darkening) of the skin. These xanthophyll pigments have high market value because of its bioactivities like anti-inflammatory and helps to reduce body obesity. It could also offer niche "cosmeceutical" claims (e.g. for body / anti-cellulite products).
- **Chlorophylls**:Chlorophyll a, b, c, d, f and derivatives (pheophytin, chlorophyllide etc) have limitations like poor water solubility and are unstable to light, acid , base. But it works as an antioxidant, anti-inflammatory inflammatory, lowering the lipids. So these colours are mostly used in food industries.

Many algal pigment's stability degrades under light, heat and shift in the pH. Cosmetic formulations must protect them by using techniques like encapsulation, antioxidant synergy.

These must also test the algal pigments for its compatibility of pigments with other cosmetic ingredients like emulsifiers, pH agents and surfactants. Algal pigments are expensive when it comes to extraction especially for the highly pure algal pigments. This high cost disturbs the scalability and limits its usage in mainstream cosmetics. As these are used in cosmetics, the regulation testing is very vital to avoid the irritation, allergic reactions and phototoxicity of the skin of the consumers.

Adoption of strategic approaches is much needed when it comes to bulk production and businesses. Instead of using natural forms the industries can use derivatives like chlorophyllide , metal-substituted chlorophyll to improve the stability of the pigments. To avoid the deterioration of the pigment quality techniques like microencapsulation, nanocarriers, and liposomes can be used. In order to increase the durability the industries can combine it with UV filter, antioxidants co-ingredients. The business can use niche cosmetics rather than marketing in a broad spectrum.

APPLICATIONS OF ALGAL PIGMENTS IN MODERN COSMETICS:

The algal pigments in cosmetics function in multiple domains. For instance, in skincare, antioxidants such as astaxanthin reduces oxidative stress (Bogdan *et al.*, 2025). Phycocyanin and carotenoids serve as natural substitutes for synthetic colours in lipsticks, eyeliners, and blush formulations (Kiki, 2023). Additionally, nutricosmetics oral supplements targeting skin health have included Spirulina-derived pigments for both color and bioactive benefits (Dini, 2023). These pigments are also used in making nail polishes.

There were rising concerns of health issues which are related to the contact of the skin with harmful chemicals such as titanium dioxide (white) , iron oxides (red, yellow, and brown)

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and chromium oxides (green). These pigments are not only harmless but also provide various benefits like biodegradable, non-toxic, and renewable. They can be even produced through energy-efficient processes that use very low quantities of harmful chemicals. It is not only used for topical formulations,but also as liposomal carriers. This improves penetration and stability.Beauty brands in Japan and Europe have pioneered “blue cosmetics” using Spirulina phycocyanin as a branding element. By highlighting natural and ocean-inspired themes. In nutricosmetics, algal powders are marketed for “beauty from within,” combining colorant and nutraceutical value.

ADVANTAGES OF ALGAL COLORANTS OVER SYNTHETIC DYES:

Algal pigments are chosen to reduce and to get rid of its negative effects on human health as well as the environment like aquatic ecosystems. To be specific these synthetic dyes like Coal tar, Carbon black, Titanium dioxide and many more have toxic,mutagenic and carcinogenic properties. These are used in hair dyes and sunscreen. As discussed earlier it also disrupts the environment, specifically marine. This imbalance affects diversity, growth and existence of different species which necessitates a treatment of liquid effluents from washing textiles before releasing them to the external environment.

Algal colorants is advantageous over synthetic colorants in following ways,

- As the name suggests these pigments are natural and eco-friendly alternatives to synthetic dyes. This makes them highly desirable in food, cosmetics, pharmaceutical and other industries.
- Synthetic dyes release toxic by-products during production and usage. But pigments from algae such as chlorophylls, carotenoids, and phycobiliproteins are biodegradable, renewable, and safer for human use.
- The algal pigments also provide added health benefits, which includes antioxidant, anti-inflammatory, and photoprotective properties. Whereas synthetic dyes don't have any such things. This dual role as both colorant and functional bioactive compound enhances their appeal in modern “clean label” and sustainable formulations.
- In cosmetics, algal pigments not only provide beautiful colors ranging from green to red and blue but also deliver skin-protective effects. These include reducing oxidative stress and slowing premature aging.
- Their natural origin aligns with the growing consumer demand for plant- and marine-based ingredients in beauty products. Also it aligns with the new ideology of the consumers like being vegan.

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- Additionally, algae cultivation requires fewer resources compared to chemical synthesis, supporting sustainability goals.

These advantages make algal colorants an efficient replacement for synthetic dyes in industries seeking safe, multifunctional, and environmentally responsible solutions.

COMMERCIALISATION AND MARKET TRENDS:

The algal pigments market is segmented by type, form, source, and application. Driven by its antioxidant benefits and its usage in food, beverages, cosmetics, and animal feed by 2025, the beta-carotene segment is projected to hold the largest share (22.3%). While phycocyanin is expected to record the fastest growth due to its high demand in pharmaceuticals and clean-label products. The powder form segment will dominate because of its comfortability of handling, longer shelf life, and reduced degradation risks. Among sources, microalgae will lead the market, supported by rising health awareness, preference for natural food colors, and growth in the nutraceutical industry. In terms of application, the nutraceuticals segment will account for the largest share (38.2%), reflecting consumer demand for natural, health-promoting ingredients. Geographically, Europe is set to dominate with 32.1% of the global market share in 2025, valued at USD 141.7 million, driven by strict regulations on synthetic colors, strong wellness trends, and high demand for natural pigments.

EXTRACTION AND FORMULATION CHALLENGES:

Algal pigments face technical challenges in extraction, stabilization, and formulation. As discussed these cultivation of algae via open ponds are prone to other air borne contaminants. This contamination affects the algal pigments and its quality. Resource dependency is one of the significant things we need to care about. These algae are grown under a particular temperature and water requirement if it is changed or fluctuated then again this disrupts the quality of the pigments. For example, phycobiliproteins are sensitive to heat and light. This limits their long-term stability in cosmetic formulations (Aizpuru & González-Sánchez, 2024).

To enhance pigment stability and delivery, novel biotechnological approaches are explored. This includes genetic engineering and advanced encapsulation techniques. (Chini Zittelli *et al.*, 2023). Other techniques include High-pressure homogenization, ultrasound-assisted extraction, and green solvents (like supercritical CO_2). They are studied to improve pigment yield while keeping the process eco-friendly (Aizpuru & González-Sánchez, 2024). Another challenge is regulatory approval. Though phycocyanin is approved as a natural food colorant (E18), its use in cosmetics requires additional safety testing in some regions.

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There should be a balance with the environment while producing these pigments via algae. This is followed in order to secure the ecosystem by avoiding over usage of marine algae for these pigments by companies. So every source is checked for sustainability. The economic challenges come with the combination costs of the cultivation, extraction and purification. These steps cost more to prepare a single cosmetic product. This affects the business by not allowing them to compete with the companies who use synthetic chemical colors and produce the same product for a low price.

PROSPECTIVE INNOVATIONS:

The future of algal pigments in cosmetics is strongly related to progress in biotechnology. Nowadays consumers prefer clean-label products, and eco-friendly production methods. This has pushed companies to make organic based cosmetic products. Research is progressively concentrating on expanding microalgal production, by improving pigment extraction methods, and increasing cost-effectiveness. There is increasing interest in multifunctional pigments that merge color with skincare advantages. This includes the antioxidant, anti-inflammatory, and UV-protective properties (Negi, 2025).

Synthetic biology has the capacity to create algae that can be engineered to produce high quantities of specific pigments like astaxanthin or lutein on an industrial scale. So that it will be feasible on a business basis. Delivery systems utilizing nanotechnology, such as pigment nanoparticles encapsulated in alginate, are being developed to enhance shelf-life and biological activity (Bogdan *et al.*, 2025). This again helps the company to yield profit and to gain . The demand from consumers for cosmetics with compelling sustainability is expected to propel algae pigments into mainstream markets.

The other fields in which the algae can be used other than cosmetics are as follows:

- **Clothing dyes:** As discussed earlier the algae contains pigments like chlorophyll, carotenoids and phycocyanin. These can also be used in dying both natural and synthetic fires.
- **Food colorants**: These principles have already been used. In the form of adding colors to the foods. But in future we can anticipate few changes which can be done according to food safety guidelines and the technical to produce high yield for pigments from algae
- **Biopaints:** This can also be used in the biopaints as it offers more pigments. This goes well with the sustainability projects. The company who loves to make projects by following sustainable goals can adopt these ideas in their business.

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- **Furniture's raw materials:** Powdered microalgae are mixed with natural resins to create unique, sustainable materials for furniture and other design applications.

CONCLUSION:

Algae have become a potential source of natural pigments in modern cosmetics. Their variety of pigments offer not only safe and excellent substitutes for synthetic dyes but also provide functional advantages that align with modern wellness and sustainability trends. Through continuous technology advancements, pigments produced from algae influence the future of sustainable, bioactive cosmetic products.Although fungi and microbial pigments influenced initial cosmetic practices, algae now provide a scientifically evaluated, eco-friendly, and prospective approach in cosmetics.The combination of vibrant colors, health advantages, and eco-friendliness makes algae pigments not just substitutes but also pioneers in the cosmetic pigment industry.

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