**PIGMENTATION FROM MICROALGAE**

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**Abstract:**

 Microalgal pigments are widely used in a range of industries, including food, nutraceuticals, and cosmetics. Pharmaceutical aquaculture, as well as the cosmetics industry. Some microalgae have been gathered. For decades, people have relied on it for food and health care. Microalgae is now used in the nutraceutical business. They have evolved as novel bioresources for the production of food and aquafeed. Bioenergy, food and feed, and wastewater bioremediation are all encouraged. Both light sources Photoautotrophic microalgal production occurs in both natural and artificial contexts. Carotenoids are antioxidants. Tetraterpene pigments having yellow, orange, red, and purple colours. Carotenoids are antioxidants. They are the most widely distributed hues in nature, and may be found in photosynthetic bacteria, some archaea and fungi, algae, plants, and humans. These compounds are in significant demand in the fields of pharmacology, medicine, cosmetics, the chemical industry, fish farming, energy, and agriculture for feed and functional foods. Microalgae have gotten less attention than seaweeds, yet they offer advantages such as rapid growth, high photosynthetic efficiency, and the potential to be cultivated in industrial settings.

 **KEYWORDS:** Microalgal pigments, Bioenergy, photosynthetic bacteria, photosynthetic.

**INTRODUCTION**

 Microalgal pigments are widely employed in a variety of industries, including the food, nutraceutical, pharmaceutical, aquaculture, and cosmetic industries. Furthermore, it has been employed in clinical/research facilities as an effective label for antibodies and receptors (1). Phycobiliproteins have antioxidant, anti-inflammatory, neuroprotective, and hepatoprotective effects (2). Because microalgae culture is environmentally friendly and renewable, there is a growing interest in using microalgae in aquaculture applications such as live feed for the aviculture industry, premix for feed formulation/supplement, and bioremediation for improved water quality (3), production of high health organisms, and enhancement of animal color (astaxanthin). For ages, certain microalgae have been used for food and medicine.

 As consumers become increasingly concerned about healthy diets and food safety, they are gravitating towards nutritious, natural, and clean-label food goods (4). Microalgae are key sources of value-added goods such as proteins, lipids, polysaccharides, minerals, vitamins, pigments, and polyunsaturated fatty acids (PUFAs), which have high commercial and health value (5). Notably, "microalgae" comprise eukaryotic photosynthetic microorganisms as well as prokaryotic cyanobacteria, both of which are responsible for converting light energy to chemical energy via photosynthesis. In microalgae, the three principal groups of pigments, carotenoids (typically 0.1-0.2% of dry weight, DW or as high as 14% in specific species), chlorophylls (0.5-1.0% of DW), and phycobiliproteins (PBPs) (8% of DW), are important for photosynthetic processes and cell development. When compared to other natural sources of pigments (such as fruits, plants, or animals), microalgae-derived pigments have been shown to have superior physiological activities (such as antioxidant and antibacterial activity) and a broad range of health uses. Microalgal pigments may display a wide range of attractive tints, colors, and natural tones in meals, giving them a competitive advantage as edible colorants that can imitate the colour of real food (6). Furthermore, their greatest advantage stems from the microalgae's cultural properties.

 Some culture methods for increasing pigment accumulation in various organisms are being investigated. PBPs (blue pigment extracted from Spirulina), astaxanthin (yellow-to-red pigment extracted from Haematococcus), and -carotene (yellow pigment extracted from Dunaliella) are examples of active pigments that have been scaled into industrial production and are widely used in food, nutraceutical, pharmaceutical, aquaculture, cosmetic, and other industries. Pigments are synthesised in microalgae during vegetative development or under stress circumstances, and several biotic and abiotic variables in this process might alter product quality (7). The introduction of new trophic modes and strategies increases pigment-producing efficiency significantly (8). Furthermore, the structure of pigments may be altered or destroyed during the extraction, purification, and food processing procedures, compromising their colouring and nutritious function in meals. To ensure pigment stability and activity, it is critical to optimise extraction and processing procedures.

 Microalgal pigments are the molecules in charge of light collection and energy transmission to reaction centres, both of which are required for photosynthesis. They are organised into complexes termed antennae that are found in thylakoid membranes. This membrane is found inside the chloroplasts of eukaryotic microalgae, while it is found adjacent to and parallel to the cell surface of cyanobacteria (prokaryotic microalgae) (9,10,11). Microalgae are appealing for industrial production because of their ability to produce and accumulate valuable pigments. They also have advantages over other vegetable sources, such as their wide natural diversity and distribution, and their lack of need for arable land to be produced. Furthermore, their photosynthetic nature might lower production costs since, unlike heterotrophic organisms, microalgae do not require carbon supplementation and certain species can fixation nitrogen, eliminating the requirement for nitrogen supplements (12).

 These microbes are already being used in industry to manufacture pigments and other goods. However, as compared to other microalgae components, pigments constitute the primary source of revenue for companies, notably in the food, cosmetics, and healthcare industries, since pigment market prices are greater than those for other microalgae components (13). The most often employed microalgae are Dunaliella salina for -carotene production, Haematococcus pluvialis for astaxanthin production, and Arthrospira platensis for C-phycocyanin production. Pilot-scale lutein production efforts are also being carried out employing Muriellopsis sp. and Scenedesmus almeriensis (14).

**Microalgae and Pigments**

 Microalgae are a diverse group of cryptogamic plants that include 13 main phyla and numerous smaller ones that are currently understudied. They might be unicellular, colonial, filamentous, or siphonaceous in nature. Cyanobacteria are oxygenic photosynthetic prokaryotes with a wide range of morphology, physiology, ecology, biochemistry, and other features among the many phyla of microalgae. Chlorophyta are unicellular, multicellular, filamentous, siphonous, thallus algae that are predominantly found in freshwater, whereas cryptophytes are unicellular and found in both freshwater and marine habitats. Dinophytes are likewise unicellular with two different flagella, and the majority of them live in the sea (15). The pigments found in each phylum of microalgae are given in **Table 1**.



**Table 1 Pigments from different microalgae**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  **Phylum** ChlorophytaDiatomophyceae /DiatomsCryptophytesCyanobacteriaEuglenophytaDinophyta |  **No. of genera/species**Approximately 500/16,000>200/100,000About 12–23/200Total 10/>2000About 40/900About 130/220 |  **Common name**Green microalgaeBrown microalgaeCryptomonadsBlue-green microalgaeEuglenoidsDinoflagellates |  **Pigments**Chlorophyll a, b, b-carotene,prasinoxanthin, siphonaxanthin,astaxanthinChlorophyll a and c, b-carotene,fucoxanthin, diadinoxanthinChlorophyll a and c, carotenoids andPhycobiliproteinsChlorophyll a, xanthophyll andPhycobiliproteinsChlorophyll a and b, diadinoxanthin,neoxanthin, and b-caroteneChlorophyll a, c, carotenoid(b-carotene), peridinin |  **References**16, 1716,1716,1716,1716,1716,17 |

**CHARACTERISTICS OF MICROALGAL PIGMENTS**

 In microalgae, the three principal types of photosynthetic pigments are chlorophylls, carotenoids (carotenes and xanthophylls), and phycobilins. Phycobilins are water soluble, whereas chlorophylls and carotenoids are fat soluble. Chlorophylls are classified into three types: a, b, and c. The chlorophyll molecule's skeleton is a porphyrin macrocycle composed of tetrapyrrole rings (18). A single isocyclic ring is attached to one of the pyrrole rings to generate the phorbin structure (19). Because of these structural variations, chlorophyll a has a blue/green pigment with a maximum absorbance range of 660 to 665 nm, whereas chlorophyll b has a green/yellow pigment with a maximum absorbance range of 642 to 652 nm (18). When chlorophyll molecules are exposed to weak acids, oxygen, or light, several degradation products are generated.

 Carotenoids are terpenoid colours formed from a 40-carbon polyene chain. It produces carotenoids with different molecular structures and the related chemical characteristics, such as light-absorption qualities required for photosynthesis. Carotenoids can be supplemented with cyclic groups and oxygen-containing functional groups. As a result, hydrocarbon carotenoids are known as carotenes in general, whereas oxygenated derivatives are known specifically as xanthophylls, with oxygen present as hydroxyl groups (e.g., lutein), oxi-groups (e.g., cantaxanthin), or a mix of both (e.g., astaxanthin) (20). Phycobiliproteins have various spectral properties because of the bilins that have individual absorption spectra (23). According to Bryant et al. (1979), there are four primary groups of phycobiliproteins in cyanobacteria and red microalgae: allophycocyanin (APC, bluish green), phycocyanin (PC, blue), phycoerythrin (PE, red), and phycoerythrocyanin (PEC, orange). The absorbance maximum of each class is as follows: allophycocyanin λAmax 650–655 nm, phycocyanins λAmax 615–640 nm, phycoerythrin λAmax 565– 575 nm, and phycoerythrocyanin 577 nm, whereas they emit light at 660 nm, 637 nm, 577 nm, and 607 nm, respectively. Arad and Yaron (1992) also found that the microalgal extract of Pseudomonas aeruginosa was blue with maximum absorbance at a wavelength of 620 nm and a red fluorescence with maximum emission at 642 nm. In most cyanobacteria, the main phycobiliprotein is C-phycocyanin. Protein of C-phycocyanin isolated from wild-type cells of the blue-green microalgae Oscillatoria agardhii consists of two polypeptide chains with methionine (24,25). The chains are joined with a disulfide bridge and both contained at least one chromophore group per chain. The amino acid composition, peptide maps, and amino-terminal sequence of the two chains discovered are similar in structure.

**Factors Affecting the Microalgal Pigment Production**

 Microalgae fermentation is now one of the most successful natural pigment synthesis technologies. Pigments derived from the industrial production of microalgae offer several benefits over those obtained from plants and aquatic animals, including regulated production, facile extraction, high yields, no raw material shortage, and no seasonal changes. During the culture stage, every minor change in environmental conditions might alter pigment production and molecular structure, altering market acceptability and bio accessibility of final goods.

**Light**

 In phototrophic organisms, light is the most important factor in turning inorganic carbon into organic molecules. Light utilisation can boost microalgal development proportionately, which is regulated by precise light intensity and photoperiod [26]. Light intensity is the most visible and readily controllable element influencing cell photosynthesis and pigment production. Light has a detrimental effect on photosynthesis when it exceeds its tolerance limit, causing the death of photosynthetic machinery. The light collection-related adaptive response is the creation of phytobiliproteins and chlorophyll. Low light intensity causes cyanobacteria to have a lower specific maintenance energy ratio, which accelerates phycobiliprotein synthesis. Under some conditions, the impact of light quality on photosynthetic pigments extends beyond light intensity and effects cell maturity, culture density, light route, and medium nutritional profile. To achieve better light availability, discontinuous lighting solutions such as the light/dark photoperiod cycle and the flashing light effect have been applied. The photoperiod efficiently modulates microalgal chlorophyll levels [27], and using the flashing light effect in industrial culture can increase the astaxanthin synthesis rate inside H. pluvialis per photon by fourfold when compared to continuous light sources [28].

**Temperatures**

 High temperatures can often enhance the development of microalgal pigments. Higher temperatures may cause osmotic pressure to damage cells, hence a temperature range of 25-28 C has been identified as optimal for chlorophyll accumulation [29]. Similarly, H. pluvialis produces the most astaxanthin at 28 degrees Celsius [30], while C. zofingiensis produces the most at 30 degrees Celsius [31]. At high temperatures, blue-green microalgae may produce a variety of carotenoids, including -carotene [32]. Total carotenoid synthesis from the microalgae H. pluvialis and Phormidium autumnale has shown the highest yields at 23 C and 26 C, respectively [33,34]. D. salina produces the most -carotene when grown at 30 degrees Celsius [35]. When grown at 28 degrees Celsius, Muriellopsis sp., C. protothecoides, C. zofingiensis, and Neospongiococcus gelatinosum produce the most lutein [36]. The optimal temperature for PBP production is 25 degrees Celsius, 30 degrees Celsius, 35 degrees Celsius, and 36 degrees Celsius for S. platensis, Anabaena sp., Nostoc sp., and Synechococcus sp. [37].

**Culture Media**

**Nitrogen**

 Nitrogen is the most important ingredient for microalgae development and the formation of proteins, chlorophyll molecules, and nucleic acids. Nitrogen shortage has been linked to a variety of cell responses in microalgae, including increased free radical production. Because carotenoids are known to be the defensive response to photo-oxidative stress caused by an overly decreased photosynthetic electron transport chain, nitrogen deprivation can produce a significant rise in their concentration. Many blue-green microalgae (such as Anabaena sp.) have been shown to generate a significant number of PBPs under nitrogen-free conditions, whereas Fischerella sp. has the reverse tendency [38].

**PH and Salinity**

 Here has been little investigation into how pH impacts pigment formation in microalga, although it can effectively change nutrient bioavailability and solubility in a culture system. pH values of 5.0 and greater than 8.5 have been shown to inhibit microalgae development [26]. pH limits substance solubility and nutrient uptake in cells. At pH = 8.5, S. platensis produced the maximum quantities of C-PC (91 mg/g DW), carotenoids (2.4 mg/g DW), and chlorophyll a (10.6 mg/g DW), whereas PC (159 mg/g) was produced at pH = 9.0 [39]. However, pH changes in some microalgal culture media can inhibit carotenoid and chlorophyll production.

 Salinity is important in the commercial pigment synthesis of both marine and limnetic microalgae, and osmosis has a large influence on pigment accumulation. The concentration of chlorophylls and total carotenoids declines with increasing salinity; for most microalgae, optimal productivity was reported at low salinity (2-3 ppt) [40]. However, when salt levels increased, -carotene production increased inside blue-green microalgae. As a consequence, blue-green microalgae Anabaena sp. (135.73 mg/g) and Oscillatoria sp. (66.7 mg/g) produced the most PBPs at 10-15 ppt salinity [41].

**Micronutrients**

 Micronutrients (such as manganese, iron, and zinc) are essential for pigment metabolic pathways, although only trace quantities are required. Because iron is involved in the tricarboxylic acid cycle and other metabolic pathways in C. pyrenoidosa, chlorophyll levels drop when iron is restricted. The electrical valency of iron, as well as counter ions, influence astaxanthin accumulation [32]. After iron addition in the medium, astaxanthin synthesis can be increased [33]. Astaxanthin production may be efficiently boosted by adding 18 mM Fe2+-EDTA. When 450 mM FeSO4 was added, the -carotene level increased considerably [42]. Copper is a necessary cofactor for metalloenzymes in various metabolic processes, yet large quantities are harmful to microalgae development. High zinc and copper levels are linked to chloroplast membrane peroxidation caused by free radical generation, resulting in a decrease in chlorophyll concentration. Magnesium ions, the key chlorophyll ions, play a role in pigment production and are also involved in the pigment metabolic pathway as a cofactor for essential enzymes [43]. Chlorophyll levels in Chlorella sp. cells drop gradually with and without magnesium limitation. Another change in the microalgae culture environment is sulphur deficiency. Sulphur is required by microalgae to produce a variety of important metabolites, including the sulfur-containing amino acids cysteine and methionine. Sulphur deprivation lowers oxygenic photosynthesis, enhances hydrogenase activation, and diminishes microalgal chlorophyll accumulation in C. reinhardtii and C. fusca [44]. Sulphur deficiency, on the other hand, promotes the formation of carotenoids. It is a more efficient method of inducing astaxanthin and lipid accumulation in H. pluvialis than nitrogen limitation, as demonstrated in C. reinhardtii and Parachlorella kessleri [45,46].

**Application of microalgal pigments**

 Colour, one of the most noticeable aspects of microalgae, is influenced by the pigments found in its structure. Pigments are chemical compounds that exhibit various colours and are a component of the photosynthetic material of the microalgae system [47]. Temperature, irradiation, wavelength, photoperiod, pH, nutrition limitation, nitrogen, salinity, pesticides, and heavy metals are among environmental factors that can affect the amount of specific pigments in microalgae [48]. The carotenoid-to-chlorophyll ratio (Car/Chl) can be cited as an example of a preferable indicator of carotenogenesis in microalgae as a result of the influence of environmental conditions because it increases with combined stress of high irradiance and nitrogen deprivation due to the accumulation of secondary carotenoids [49]. The primary natural pigments found in microalgae are carotenoids, chlorophylls, and phycobiliproteins. These pigments are often used in human and animal feed, additives, cosmetics, pharmaceuticals, food colourants, and biomaterials [50]. Colours of chlorophyll, carotenoids, and phycobiliproteins range from green to yellow to brown to red. Blue pigment from Spirulina (given by phycocyanins), yellow pigment from Dunaliella (supplied by -carotene present), and yellow to red pigments from Haematococcus (provided by astaxanthin) [51]. **Figure 2** depicts the major pigments and their many uses. In the microalga Phormidium autumnale, Rodrigues et al. [52] discovered twenty-four carotenoids, three phycobiliproteins, and two chlorophylls. All-trans--carotene (225.44 g g1), all-trans-lutein (117.56 g g1), and all-trans-zeaxanthin (88.46 g g1) were the primary pigments detected in the biomass, along with chlorophyll a (2.700 g g1) and C-phycocyanin (2.05 105 g g1). When the microalga Coelastrum cf. pseudomicroporum Korshikov was grown in urban wastewater and under salt stress, it accumulated carotenoids ranging from 1.73 to 91.2 pg cell1.

 Due it has antioxidant, antiinflammatory, neuroprotective, and hepatoprotective effects, microalgal pigments have been recognised for their potential for commercial uses (2). They are already widely employed in a variety of industries such as food, nutraceuticals, medicines, aquaculture, and cosmetics. Some of the sectors described above are already using -carotene from Dunaliella, astaxanthin from Haematococcus, and phycocyanin and other phycobiliproteins from A. platensis (50). Microalgal pigments have also been employed in clinical/research facilities as a label for antibodies and receptors (1). Furthermore, because microalgae production is environmentally beneficial, there is growing interest in employing microalgal pigments in aquaculture for feed formulation/supplement (32).

 **Fig. 2 Main pigments obtained from microalgae and their main areas of application**

**Pharmaceutical use and prospecting**

 Microalgae pigments have long been recognised to exhibit a variety of bioactivities, the most well-known of which is antioxidant activity. Indeed, this may be the mechanism underpinning additional bioactivities, such as antiinflammatory or anticancer activity (53). Phycobiliproteins, such as phycocyanin, phycoerythrin, and allophycocyanin, are examples. Because of its proven antioxidant, antiinflammatory, neuroprotective, and hepatoprotective characteristics, phycocyanin, a pigment derived from cyanobacteria, has the highest potential to be employed in pharmaceutical formulations. The radical scavenging activities of phycocyanin have been demonstrated to reduce microsomal lipid peroxidation (54), and C-phycocyanin produced from A. platensis displayed hypocholesterolemic action when serum cholesterol concentrations were modelled (55).Antitumor properties of phycocyanins have also been demonstrated by lowering tumour necrosis factor in mice blood serum treated with endotoxin, and one derived from A. platensis was reported to suppress the development of human leukaemia K562 cells (56).

 Carotenoids (xanthophyll and carotenes) are the most researched category of microalgal pigments in terms of bioactivities; among the more than 600 carotenoids found in nature, -carotene is perhaps the most important. -Carotene has a wide variety of various biological roles connected to human health, including aiding to boost immunity and preventing cataracts, night blindness, and skin problems where it may be converted to vitamin A (57).

 Astaxanthin stands out among xanthophylls due to its bioactive potential, and it, like the other pigments discussed thus far, has a significant relationship with antioxidant capacity. Indeed, the antioxidant potential of astaxanthin is ten times that of -carotene and more than 500 times that of -tocoferol, making it a super vitamin E (58). This pigment can be used to prevent neuronal damage associated with age-related macular degeneration, treat Alzheimer's and Parkinson's diseases, ischemic reperfusion injury, and spinal cord and other types of central nervous system injuries due to its powerful bioactive antioxidant properties and ability to cross the blood brain barrier (32).

 Furthermore, in vitro investigations discovered that astaxanthin is efficient in preventing the oxidation of Pigments from microalgae 469 low-density protein, revealing a possible use for the prevention of arteriosclerosis, coronary heart disease, and ischemic brain development (59). It should be mentioned that the antioxidant activity of this pigment has been observed in both hydrophilic and hydrophobic circumstances (Kobayashi and Sakamoto, 1999).

 Furthermore, astaxanthin has been shown to stimulate xenobiotic metabolising enzymes in rat liver and to protect against aflatoxin carcinogenicity (59). In vitro, astaxanthin demonstrated an immune-stimulatory impact (58), regulating humoral and nonhumoral immune systems and increasing the release of interleukin-1 and tumour necrosis factor in mice (60). Astaxanthin also promotes the synthesis of immunoglobulins A, M, and G, as well as T-helper cell antibodies (58). Furthermore, astaxanthin has shown promise in the treatment of Helicobacter infections of the mammalian gastrointestinal tract, prompting the establishment of a patent for the manufacture of an oral preparation for the treatment of Helicobactersp. infections (61).

 Also, Reynoso-Camacho et al. (2011) found that lutein has a chemoprotective impact against DMH-induced colon cancer. Indeed, mice fed 0.002% lutein in their diet showed a preventative effect, reducing the number of tumours by 55% and 32%, respectively, when administered as a therapy following DMH administration.

**Food and nutraceuticals**

 Among the several types of microalgae-derived chemicals, those having antioxidant capabilities are likely to be the most appealing for industrial uses. Oxidation of important nutrients happens in the food business during industrial processing or storage, degrading them and potentially creating hazardous chemicals. 470 18th Chapter Thus, frequent remedies include the use of synthetic antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and EDTA (62). Despite the fact that their use is regulated and restricted by law, some synthetic chemicals have been linked to negative health consequences (63).

 As a result, the usage of colours derived from various natural sources has grown in popularity, making microalgae an efficient ecologically acceptable option. Nontoxic and noncarcinogenic natural pigments such as phycocyanin (blue pigment from A. platensis), -carotene (yellow pigment from Dunaliella), and astaxanthin (yellow to red pigment from Haematococcus) are gaining popularity (32).

 Carotenes from Dunaliella, such as -carotene, are extensively employed as food colourants to improve the look of margarine, fruit juices, cheese, baked goods, tinned foods, dairy products, and sweets. The United States Food and Drug Administration (US FDA) has certified it as a safe and natural food colour. As previously stated, -carotene is also employed in the creation of healthful meals as a pro-vitamin A (retinol) (2).

 A. platensis phycocyanin is already utilised as a food colourant in sweets, jellies, chewing gum, ice sherbets, popsicles, soft drinks, dairy products, and wasabi (1,2). Furthermore, phycocyanin extracts and entire A. platensis have been included into cookies to increase protein and fibre content, potentially with health advantages (64).

**Feed**

 The colour of the fish is critical in salmon farming. Carotenoids are typically obtained mostly from synthetic astaxanthin. As an alternative, canthaxanthin, astaxanthin, and lutein from Chlorella sp. have been widely used and, as a result, have been included as ingredients of feed for salmonid fish, trout, and poultry to improve their reddish colour or the yellowish colour of egg yolk (65,66). Furthermore, astaxanthin can boost fish and prawn immunity, boosting healthy development and survival (51). It should be mentioned that the US FDA allows astaxanthin as a colour addition in fish feed (32). -Carotene is also used in feed to enhance the look of fish and shellfish (51).

**Other applications**

 Because of their spectrum features, phycobiliproteins serve an important role in fluorescent-based detection systems, particularly in flow cytometry (67). Furthermore, phycocyanin is employed as a colouring component in lipsticks and eyeliners (1). Furthermore, because of its absorbance spectrum features, phycoerythrin has been employed as a second colour in fluorescent-labeling antibodies, and phycoerythrin labelled with streptavidin may be used to detect DNA and protein probes (54). Other low-molecular-weight cryptomonad-derived phycobiliproteins can be used in flow cytometry for extracellular and intracellular labelling (68).

**Microalgae in cosmetics and cosmeceuticals**

 Cosmetics are defined as "articles intended to be rubbed, poured, sprinkled, or sprayed on, introduced into, or otherwise applied to the human body or any part for cleansing, beautifying, promoting attractiveness, or altering appearance" (69). As a result, unlike drugs/medicines, cosmetics are not intended to disrupt human structure and function. Cosmeceuticals, on the other hand, are a step between cosmetics and medications that are not internationally harmonised and are frequently referred to as over-the-counter (OTC) goods in the United States or quasi-drugs in Japan. The nomenclature is contentious, focusing mostly on active component concentration, stratum corneum penetration, mechanism of action elucidation, and clinical studies to support claims (70). Herein, the terms “cosmetics” and “cosmeceuticals” will be addressed as one single class in this publication

 Because of their high productivity and ease of extraction under controlled circumstances, microalgae usage in cosmetics/cosmeceuticals is an intriguing technique to address the increase in the quest for novel natural components from ecologically sustainable biomass (71). Because the entire microalgae biomass is difficult to integrate into cosmetic formulations, innovative extraction and purification procedures have been developed to investigate its potential in cosmetics.

 Scientific study on the biological activities of microalgae extracts or their constituents aids in the creation of a variety of cosmetic products incorporating microalgae, such as rheology modifiers, such as certain polysaccharides (72,73). Other compounds that may initiate biochemical processes on the skin include biopeptides to stimulate collagen (74), astaxanthin and its esters with strong antioxidant qualities to suppress tyrosinase-induced hyperpigmentation (75). As a result, such compounds might be found in several commercial cosmetic formulations, such as anti-aging and regenerative lotions, emollients, sunscreens, and hair care products (76, 77). However, only a few goods are sold on a global scale. Thus, biopigments produced from microalgae biomass are attractive alternatives with commercial potential due to their fast-growing ability and high pigment content with a wide range of colour variations with no or little risk of skin allergic reactions (32,77).

 **Table 2: Cosmetic products on the market with pigments from microalgae**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Cosmetic** | **Cyanobacteria/microalgae** | **Pigment** | **Potential activity** |  **Referance** |
| Pepha®-Ctive | Dunaliella salina | β-Carotene | Antioxidant, stimulates cellproliferation | 78 |
| DermochlorellaD® | Chlorella vulgaris | Carotenoids | Photoprotection against UVlight and oxidative damage,enhances collagen synthesis | 79 |
| OceaRides™ | Odontella spp. | NI | Stimulates elastin synthesis | 80 |
| AstaPure® | Haematococcus pluvialis | Astaxanthin | Antioxidant properties | 81 |
| FucoVital™ | Phaeodactylum tricornutum | Fucoxanthin | Antioxidant properties | 81 |
| Megassane® | Phaeodactylum tricornutum | NI | Cell protection from UV, prevention of photo-agingand age-spots | 82 |
| Linablue® | Arthrospira spp. | Phycocyanin | Eye shadow | 83 |

**Table 2** summarises the use of microalgae pigments in cosmetics on the market. The colour of biomass is caused by natural pigments generated from the photosynthetic system of microalgae. Photosynthetic pigments are classified into three types: carotenoids, chlorophylls, and phycobiliproteins. Thus, autotrophic organisms like plants, algae, and cyanobacteria use them to collect solar energy, which is then converted into chemical energy via photosynthesis (84). Controlled environmental conditions during growth of microalgae, as widely described in specialised literature, might boost the synthesis of lipids, proteins, and pigments (85, 86, 87,88).Toxicological aspects (safety) of microalgae pigments

 There has recently been a focus on the negative consequences of algae on fisheries, aquaculture, and freshwater resources. To protect and adapt to their environment, algal cells have developed many tactics, which include the synthesis of metabolites, some of which have biological functions, as well as toxins known as phycotoxins (89,90).

 Nonetheless, of the hundreds of microalgae species that exist, only approximately 200 are thought to be dangerous, and only about 100 are capable of producing toxins. Dinoflagellates (planktonic and benthic genus) and diatoms (planktonic genus) are the most poisonous microalgae. Phycotoxins may have a variety of negative consequences in people, including gastrointestinal, cutaneous, and neurological issues, and they can even be fatal in rare situations (90,91).

 Furthermore, heavy metals, inorganic arsenic, and cyanotoxins can be found in microalgae and its preparations (92, 93). Furthermore, standard criteria issued by international regulatory organisations (for example, the Food and Drug Administration (FDA)) might be a useful tool for ensuring the quality and safety of microalgae-derived products (94). Furthermore, using suitable extraction procedures may be a helpful strategy for obtaining pigments or other components from microalgae while eliminating the presence of dangerous phycotoxins or other toxics residues. When compared to natural sources, microalgae from aquaculture, which has a more regulated environment, can avoid some toxicological hazards of contamination and bioaccumulation. Nonetheless, during the production process, business should deploy monitoring systems to detect the presence of dangerous algae species, phycotoxins, and other poisonous substances. Significant progress has been made in recent years towards the development of more precise, sensitive, and quick approaches for identifying distinct microalgae species and toxins (95).

 Furthermore, law and regulatory considerations concerning the commercialization of carotenoids derived from microalgae biomass for food and cosmetic applications have recently been discussed in the United States, Japan, China, and Europe (96). As a result of their nontoxic and noncarcinogenic qualities, astaxanthin, -carotene, and chloprophyll produced from select microalgae species are controlled and authorised by the FDA (32). In addition, Haematococcus pluvialis astaxanthin has been accepted as a colour additive in Europe, the United States, and Japan. As a result, it is permitted for direct human ingestion and has been deemed safe by the FDA through the use of "generally recognised as safe (GRAS)" designation (97).

**Conculsion**

 Major pigments such as chlorophyll a, b, and c, b-carotene, astaxanthin, xanthophylls, and phycobiliproteins have a wide range of intriguing uses in diagnostics, biomedical research, treatments, and colorings in cosmetics, dairy products, and other foods. They are gaining popularity over synthetic ones since they are harmless and noncarcinogenic. The pigment concentration of microalgae varies according to species and growing conditions. Temperature, salinity, irradiances, wavelength, photoperiods, pH, nutrition restriction, nitrogen supplements, pesticides, and heavy metals all have an impact on microalgal pigment formation. As a result, the parameters listed above should be considered when producing microalgal pigments for usage in a variety of applications. These benefits prove its broad application range and potential value in a variety of applications, and some of them have been successfully manufactured on an industrial scale. Thus, further research is needed to optimise existing methodologies and uncover untapped potential technologies related to microalgae features, pigment qualities, and biosynthetic metabolism. The continuous search for innovative technology is critical to overcoming these hurdles and finding effective ways to commercialise bioproducts. Furthermore, it is critical to identify methods of collecting and characterising bioproducts in order to utilise fewer solvents and minimise excessive energy expenses in order to reduce environmental impacts and costs. The data gathered by bibliometric mapping allows for a broad assessment of the things that were most often searched in the previous ten years. This allowed for an overview of the investigations that were being conducted as well as future developments concerning microalgae. All of these elements must be studied in order for microalgae to enter the market with more vigour and to accelerate the commercialization of items of interest in order to produce industrial-scale production.

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