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Active Microcellular Intervention In Modern Personal Care Products For Multiple Cosmetic Applications

Author Full Names (Without abbreviation): Pragati Baghel*, Neeraj Sharma

Affiliations (Department, Faculty, University, City, Country):

Department of Pharmacy, Bhagwant University, Sikar Road, Ajmer 305004, Rajasthan, India

Corresponding Author (Name, Addresses, Phone, email):
Ms. Pragati Baghel
Research Scholar,
Department of Pharmacy, Bhagwant University,
Sikar Road, Ajmer 305004, Rajasthan, India
pragatipharma20@gmail.com
+91-7773808140

ABSTRACT

For centuries, Mushrooms, Microalgae, and Cyanobacteria have been valued as a traditional source of natural bioactive compounds. Recently, representative ingredients such as polyphenolics, phenolics, alkaloids, terpenoids, polysaccharides, selenium, vitamins, proteins, and volatile organic compounds have been exploited for potential components in the cosmetics industry due to their anti-aging, antioxidant, skin whitening, anti-wrinkle, etc. Because of their properties, they are good candidates for cosmetics. This article offers some viewpoints on cyanobacteria, mushrooms, and microalgae extracts and/or their constituents, which are being employed in both topical and oral cosmeceuticals and nutricosmetics. All of these microcellular interventions point to the personal care products business being exploited and developed further.

Keywords: Cosmetics, Cyanobacteria, Mushroom, Microalgae, Microbial surfactants, Applications

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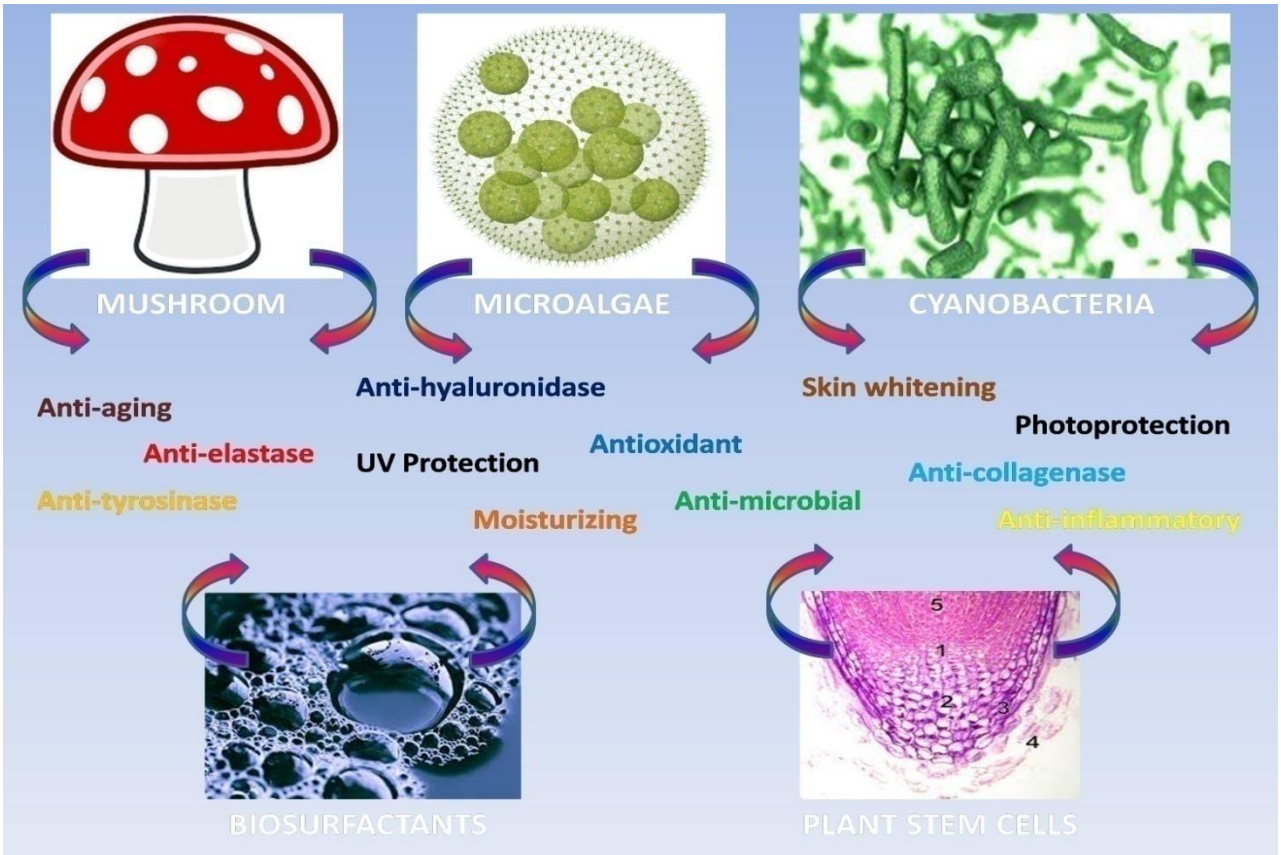
GRAPHICAL ABSTRACT



INTRODUCTION

Protecting the body against desiccation and UV radiation are the fundamental responsibilities of the skin, as is regulating body temperature and osmolarity in order to maintain homeostasis. Aside from its social, self-esteem-enhancing, and health exteriorization functions, the skin is also an organ of self-representation. As life expectancy has risen and concerns about skin health and ageing have grown, the demand for skin care products has skyrocketed. Topical treatments meant to defend against exogenous and endogenous harmful substances have been developed in response to the necessity of having healthy skin. The majorities of these goods is classified as cosmetics and include a wide range of product categories, including UV-protectors, skin creams, hypoallergenic items, and anti-aging [1].

Aside from the cosmetic phrase, cosmeceutical language has recently been adopted, which refers to a cosmetic product containing active substances that have a pharmacological therapeutic value, such as anti-inflammatory properties. Consumers demand a diversity of choice alternatives and improved effectiveness from cosmetic and cosmeceutical goods since they are a part of everyone's everyday lives. Concerns for both human and environmental health have contributed to a rise in recent years in the desire for skin care products that are less harmful to both. Products from the pharmaceutical and personal care product (PPCP) industries, including cosmetics, are increasingly being found in wild environments across the world.

Studies show that municipal sewage treatment plant (STP) PPCP eradication is frequently inadequate, and that this has far-reaching negative consequences for ecosystems and wildlife [2].

Cosmetic research has increasingly concentrated on natural substances as a consequence of the adverse effects ascribed to the usage of synthetic components. Although cosmetics derived from natural sources, particularly those derived from plants, macroalgae, and eukaryotic microalgae, have long been utilized, recent recognition has been given to the usage of natural ingredients in cosmetics. Scientific research keeps demonstrating that cosmetics made from all-natural materials are superior in every way (to the skin, the body, and the environment) and are safe for use. Natural compound research has attracted greater funding because of rising public concern about the dangers of manufactured chemicals [3].

In addition to plants and algae, cyanobacteria are being studied as a source of compounds that might be used in skin care products. In addition to producing metabolites with potential use as nutraceuticals, medicines, food conservators, cosmetics, and biosensors, cyanobacteria have the ability to self-renew, ensuring long-term supply, cultivation without arable land, and minimum environmental effect. Cyanobacteria have been demonstrated to be useful bioagents in a wide variety of contexts, including agriculture, biofuel production, and the synthesis of bioactive chemicals with uses in human health, all of which are safe for the environment. Some cyanobacterial compounds have been found to have moisturizing, photoprotective, anti-inflammatory, regenerative properties, and antioxidant enabling their use in thalassotherapy and other health and wellness procedures, as well as the preservation and equilibrium of the integumentary system and its derivatives [4].

Several reviews on the topic of natural compounds in cosmetics have been published in recent years, but little attention has been paid to the utility of various cyanobacteria, mushrooms, microalgae, microbial biosurfactants, and plant stem cells. In order to strengthen the role of these natural organisms as a source of chemicals with potential applications in cosmetics and cosmeceuticals and to expand the potential avenue that may be interesting to explore for co-development of these natural organisms, the objective of this review is to compile the research work that has been done thus far in this field.

CYANOBACTERIA IN COSMETICS

Cyanobacteria, often known as blue-green algae, are photosynthetic prokaryotes with a lengthy course of evolution that has culminated in a diverse range of species that live in a variety of environments. Cyanobacteria are found everywhere, including Antarctic dry valleys, thermophilic lakes, and lava caverns, in both land and freshwater ecosystems. Cyanobacteria have created specialized symbiotic relationships with some other creatures throughout the duration of their history. Despite the fact that invertebrates contain an infinite number of secondary metabolites with biologically active qualities, the microbiota connected with them appears to be the primary source of the substances. This is especially intriguing in the instance of marine animals, because the ability of sea invertebrates to supply important secondary metabolites is dependent on their fantastic microbiota, specifically cyanobacteria [5].

In past few years, cyanobacteria have been touted as a viable substitute for natural chemicals used in the personal care industry. Cyanobacteria may produce a variety of metabolites, including flavonoids, pigments (e.g. c-phycoerythrin, ß-carotene, and phycobiliproteins), saponins, phenols, tannins, steroids, vitamins, terpenes; thanks to their

sophisticated photosynthetic system, adaption system(s), and defensive system(s). Many cyanobacteria species thrive in harsh conditions, such as intense sun radiation and lengthy periods of dehydration. Cyanobacteria have developed chemicals that protect them from ultraviolet (UV) light and compounds that prevent dehydration and oxidative stress from occurring [6].

It has been shown that *Spirulina* and other cyanobacteria genera are rich in nutrients such essential fatty acids, proteins and minerals that are essential in the formulation of cosmetics (**Table 1**).

Table 1. Bioactive compounds in cyanobacteria and their uses in cosmetics.

Cyanobacteria	Bioactive compounds	Activities
Anabaena vaginicola	Lycopene	Anti-ageing
Arthrospira platensis	Methanolic extracts of exopolysaccharides	Antioxidant
Chromohalobacter israelensis	Ectoine	Immune protection
Chromohalobacter salexigens		UV protection
Halomonas boliviensis		Stress protection
Halomonas elongata		Moisturizing agent
Nostoc flagelliforme	Β-1,3-Glucan	Anti-inflammatory

Anti-aging

Skin ageing, like ageing in general, is difficult to quantify since it is the product of hereditary and environmental influences. Premature skin ageing, also known as photoaging, differs from chronological ageing in that it is caused by exposure to environmental stimuli. Extrinsic factors such as air pollution, UV radiation, meteorological conditions (wind and cold), smoking, and accelerate ageing, especially in exposed skin. Dryness, hyper-pigmentation and hypopigmentation, loss of elasticity, firmness, wrinkles, and a leathery texture are all clinical symptoms of photoaging [7].

Cyanobacteria produce compounds that might be helpful for skin moisture (EPS, for example), UV protection, and anti-oxidant protection, making them appropriate for use in anti-aging treatments. Additionally identified were fibroblastic contributions to skin elasticity and suppleness. In the dermis, fibroblasts create extracellular matrix (ECM), which is mostly made of collagen and elastin and gives firmness and elasticity. *Arthrospira platensis* extracts have been shown to improve cell viability and lessen DNA damage in normal human dermal fibroblasts (nHDFs) exposed to UV-B radiation by suppressing thymine dimers and matrix metalloproteinases (MMP). A clinical investigation involving 10 volunteers aged 25 to 54 who received 0.7 g of powdered *Spirulina platensis* twice daily for 8 weeks also shown a substantial rise in the concentrations of cutaneous carotenoids as well as a small rise in the collagen/elastin skin index. UV defense, skin hydration, increase in antioxidant capacity, and fibroblast proliferation stimulation have all been related to a decrease in skin aging. As was previously indicated, cyanobacteria produce chemicals that may disrupt all of these processes, making them appealing for use in anti-aging cosmetics [8].

Antioxidant

Skin cells create reactive oxygen species (ROS) as a result of ordinary metabolic endogenous processes or external aggressions, which are the cause of skin damage and ageing. Despite the fact that cells have their own endogenous antioxidant mechanisms, oxidative stress is often triggered by excessive ROS generation caused by external harmful stimuli such as UV radiation and smoking. The antioxidant activity of EPS and the UV absorption compounds MAAs and SCY in cyanobacteria was demonstrated, demonstrating its use in cosmetics. In reality, EPS' antioxidant capacity is another feature that makes them feasible and useful in cosmetic applications in addition to their function in skin hydration. The antioxidant activity of EPS isolated from a Nostoc strain *in vitro* was dose-dependent [9].

Antioxidant enzymes such as catalase (CAT), glutathione peroxidase (GPX), and superoxide dismutase (SOD) were shown to be more active in *Caenorhabditis elegans*, which was used as an animal model. The scientists found that lipid peroxidation levels were reduced to 13.5%. The findings demonstrated antioxidant activity comparable to that of the well-known antioxidant resveratrol, which may prevent the oxidation of lipids and other macromolecules both in vitro and in vivo and is frequently used in cosmetics. In light of this, EPS from cyanobacteria has been described as having the capacity to sequester superoxide anions and hydroxyl radicals, as well as enhance the activity of enzymes involved in the process of reducing oxidative stress and prevent lipid peroxidation. In the case of MAAs and SCY, they have been identified as potential antioxidants in addition to their photoprotective effect [10].

Several investigations have shown that MAAs and SCY are effective at scavenging free radicals. There was a dose-dependent antioxidant activity for *Lyngbya sp*. CU2555 MAAs and SCYs, with antioxidant rates of 14.5 percent - 68.9 percent at MAA concentrations of 0.115 mg/mL - 0.460 mg/mL, respectively, and 12.5 percent - 57 percent for SCY concentrations of 0.5 mg/mL - 2.0 mg/mL. UV-induced thymine dimers (CPD) and intracellular ROS production was reduced *in vivo* by the SCY pigment from *Scytonema sp*. R77DM. When cyanobacterial cells were exposed to UVA + UVB + PAR, they demonstrated substantial inhibition of ROS formation when treated with ascorbic acid (45.75 percent), SCY (20.83 percent), or SCY and ascorbic acid combined (58.65 percent) showed photosynthetically active radiation [11].

Furthermore, under identical conditions, the amount of ROS decrease was perfectly proportional to the percentage of CPD inhibition (16.3%, 30.7%, and 41.91 percent, respectively). In earlier studies, SCY from the cyanobacteria *Nostoc commune* and *Rivularia sp*. was demonstrated to significantly lessen ROS formation as well as the damaging effects of UV radiation and associated damages, supporting its use as an active antioxidant and photo protective ingredient in cosmeceuticals. Similar to other glycosylated MAAs from *N. commune*, such as Hexose-bound-P334 and 7-O-(-arabinopyranosyl)-P334, the MAA -Gal-P334 was shown to have an IC50 of 17 M of antioxidant activity [12].

In addition to acting as antioxidants, polyphenols are a group of secondary metabolites that contribute to the body's defense mechanisms against abiotic stress. 2,2-diphenyl-1-picrylhydrazyl (DPPH•) antioxidant assay and 2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) antioxidant assay measured 63.45 µg/mL and 67.49 µg/mL, respectively, for a *Leptolyngbya* strain and 65.79 µg/mL and 69.38 µg/mL for *Calothrix* It was discovered that the amount and type of phenolic chemicals recovered from the cyanobacteria biomass were significantly related to the antioxidant capacity. The DPPH antioxidant experiment revealed IC50 values for *Synechocystis* strains of 54.59 µg/mL

and 65.16 µg/mL, and for *Calothrix* strains of 30.72 µg/mL, showing that these cyanobacteria species have promising antioxidant potential [13].

Numerous other studies point to a wide range of cyanobacteria genera, including coccoid and filamentous forms, that span practically all phylum-wide groupings, from which antioxidant characteristics have been discovered, in addition to the ones listed above. *Synechocystis*, *Nostoc*, *Spirulina*, *Cyanosarcina*, *Phormidium*, *Scytonema*, and *Leptolyngbya*, as well as *Microcystis*, *Lyngbya*, and *Oscillatoria*, were studied. Phycobiliproteins (PBPs), which are pigments involved in light absorption and are also referred to as photoprotectors, as well as phenolic compounds, flavonoids, and other pigments, seems to be connected to this antioxidant capability. Phycocyanin (PC-blue) and phycoerythrin are the two primary PBPs found in cyanobacteria (PEred). The anti-inflammatory and antioxidant properties of PC and PE have been established. Cell-free extracts from the four thermotolerant strains; *Phormidium sp*. PD40-1, *Cyanosarcina sp*. SK40, *Leptolyngbya sp*. KC45, and *Scytonema sp*. TP40 revealed that phenolic compounds and PBPs are both responsible for the strains' high thermostability and antioxidant activities, with the strain *Leptolyngbya sp*. KC45 being the most responsible Furthermore, 248.39 mg of ascorbic acid per gram of dry weight and 465.31 mg, respectively, were found in the DPPH radical scavenging activities of the *Lyngbya sp*. and *Oscillatoria sp*. strains. These results are most likely attributable to total phenolic content (TPC), total flavonoid content (TFC), and total PBPs. In contrast to an *Oscillatoria sp*. strain, which had a TPC of 2.96 mg/g, a *Lyngbya sp*. strain had a total PBPs content of 127.01 mg/g, a TPC of 5.02 mg/g, and a TFC of 664.07 mg/g. *Spirulina platensis* and phycocyanobilin (PCB), the active form of the main component C-phy PC-C has a potent antioxidant effect that may sequester peroxyl and hydroxyl radicals as well as stop lipid peroxidation. This phycobiliprotein has been used in the food and cosmetics sectors as a natural colorant to replace synthetic colors in addition to its antioxidant characteristics since it is non-toxic, non-carcinogenic, and has a deep blue hue [14].

Anti-inflammatory

Skin plays an active role in immunological activities such as allergic dermatitis and inflammatory reactions, in addition to providing a protective physical barrier. The most common medications used to prevent adverse dermatitis are topical corticosteroids. However, the development of severe symptoms such as striae, cutaneous atrophy, and adrenal restriction limits therapeutic therapy. In contrast to hydrocortisone, the polysaccharide sacran from *Aphanothece sacrum* had a greater anti-inflammatory impact in provoked allergic dermatitis in mice. Sacran also inhibited the secretion of chemokines and cytokines that are implicated in skin allergies. Sacran's powerful anti-inflammatory actions in rats were also documented, with swelling and neutrophil infiltration in carrageenan-induced rat paw edema being inhibited. Additionally, sacran decreased 12-O-tetradecanoylphorbol-13-acetate (TPA)-induced mouse ear edema and pro-inflammatory cytokines. In addition to sacran, SCY contains anti-inflammatory and anti-proliferative properties. SCY was shown to have an IC_{50} of 3.4 µM for inhibiting the activity of the rhPKCb1 inflammatory enzyme mediator and an IC_{50} of 5.4 µM for inhibiting the proliferation of human fibroblasts. A mouse ear edema model was used to assess SCY's anti-inflammatory potential. SCY therapy reduced edema with an ED_{50} of 10.9 mg/ear. These findings highlight SCY's anti-inflammatory potential by showing that it has an effect that is comparable to other anti-inflammatory substances [15].

Moisturizing

Daily moisturizing practices are practiced by people of all socioeconomic backgrounds, demonstrating a strong desire for good skin. Moisturizers include a variety of chemical components, such as emollients, occlusives, and humectants, to draw in, retain, and raise the skin's moisture contents and minimize transepidermal water loss (TEWL). However, topical formulations may cause unpleasant skin responses, such as sensory or subjective feelings without evidence of inflammation and certain subclinical lesions. For example, occlusive agents have drawbacks in terms of smells, allergic responses, and greasy texture. Despite the fact that humectants may promote water absorption from the dermis into the epidermis, where it may eventually be lost into the environment, they are nearly usually coupled with an occlusive agent to provide a hydrophobic barrier over the skin [16].

The fact that cyanobacteria contain defensive mechanisms against dryness, notably the formation and excretion of exopolysaccharides (EPS), suggests that they might be used as moisturizing agents in cosmetics. Various sugars and uronic acid make up cyanobacteria EPS, which may account for more than 60 percent of the dry weight. EPS may form sheaths, capsules, and mucilage in cells when it is covalently bonded or connected to the cell surface. A thick EPS layer encircling the cells seems to be responsible for cyanobacteria's resilience to salt in highly saline settings. Commune of Nostoc Cells depleted of EPS and *N. commune* with a little amount of EPS were both sensitive to desiccation, indicating that the amount of EPS is a crucial factor in *N. commune*'s ability to withstand desiccation. EPS have been researched for this purpose in cosmetics in contrast to other substances since they are made up of molecules with water absorption and retention ability, such as uronic acid. When compared to urea, EPS has a better water absorption capacity (10.1 percent) for a Nostoc commune species (5.8 percent). According to the same study, EPS has a higher capacity to hold water (28%) than urea (15.9%) and chitosan (7.3%), indicating that cyanobacterial EPS has a greater potential to be used as a natural humectant in the cosmetics industry with the added benefit of not needing to be combined with an occlusive agent [17].

The cyanobacterium *Aphanothece sacrum*'s extracellular matrix contains a polysaccharide called sacran, which scientists extracted and found to be composed of sugar remnants such muramic acid, mannose, and uronic acid. Sacran exhibited a higher viscosity, better water absorption efficiency, and the capacity to absorb salines containing multivalent metal ions, such as Mg^{2+} and Ca^{2+}, in a research comparing the ability of sacran and hyaluronic acid to retain moisture. These results were especially intriguing since hyaluronic acid is one of the most often used components in cosmetics despite its high cost and restricted manufacturing. Sacran, a cyanobacteria gel, has the potential to be used as a high-moisturizing agent as a consequence [18].

UV Protection

Solar radiation is one of the major environmental variables that contribute to cancer growth and skin aging. Because melanin absorbs a wide range of UV rays and eliminates ROS, one of the principal UV-induced cellular consequences, skin pigmentation serves as an endogenous defense mechanism against the damage brought on by excessive UV exposure. Every year, tons of UV filters are created to meet customer demand for sunscreens in products including moisturisers, sunscreen lotions, lipsticks, and facial cosmetics [19].

There are sunscreens on the market that include both inorganic and organic UV filters. Mineral particles such as titanium dioxide and zinc

oxide, which produce highly oxidizing radicals while absorbing considerable UV light, are included in inorganic UV filters, which are physical blockers. Even when utilized as nanoparticles, these particles have been discovered to cause toxicity in human dermal fibroblasts in culture, owing to their ability to penetrate through the cell membrane. Organic filters have been widely employed as an alternative to inorganic filters, with ethylhexylmethoxycinnamate (EHMC), butyl methoxydibenzoylmethane (BM-DBM), benzophenone-4 (BP-4), and octocrylene (OCR) being the most common in PCPs and sunscreens. These compounds do, however, have some unfavorable side effects, including endocrine disruption and contact dermatitis in children, according to some research. Human skin's free peptides have been found to interact with UV filters like BM-DBM, EHMC, and OCR, suggesting a connection between the formation of contact dermatitis and protein adducts. Additionally, UV synthetic filter remnants have been discovered in STP surface waters and river sediments, and several research have revealed damage to a variety of species. As a result, cosmetics and sunscreens with synthetic UV filters may damage people and ecosystems even if they can block ultraviolet rays [20].

Adaptation to situations with intense sun radiation was accomplished in cyanobacteria by the formation of photoprotective chemicals such as mycosporine like scytonemin (SCY) and amino acids (MAAs). MAAs are metabolites that play a role in bacteria, lichens, fungus, and cyanobacteria's photoprotective processes. Three *Nodularia* species—*N. baltica*, *N. harveyana*, and *N. spumigena* - as well as two types of glycosylated MAAs in a *Nostoc* commune strain—were discovered in cyanobacteria as the MAAs shinorine and porphyra-334. According to the trolox equivalent antioxidant capacity (TEAC), a 1050-Da MAA in a cyanobacteria water extract was shown to provide around 27% of the overall radical-scavenging activity, showing a strong *in vitro* radical-scavenging effect. Following that, many MAAs glycosylated from Nostoc commune were discovered. Other prevalent MAAs, such as mycosporine-tau, mycosporine-glycine, asterina-330, palythinol, mycosporine-2-glycine, palythene, and euhalothece-362, has also been discovered in cyanobacteria [21].

In view of MAAs' possible skin effects, a study involving 20 middle-aged women found that a cream containing 0.005 percent MAAs generated from red algae may counteract the effects of UV-A rays and enhance skin smoothness. Furthermore, the MAAs isolated from red algae, shinorine and porfira-334, have previously been sold for usage in sunscreens. These two chemicals, together with 13-b-Gal-P334, a cyanobacterium derived from *Nostoc sphaericum*, have been shown to protect the human keratinocyte HaCaT cell line against UVA + 8-methoxypsoralen radiation. With EC_{50}s of 27 μM and 39 μM, the 13--Gal-P334 and porphyra-334 were discovered to have cell photoprotective action, respectively, in contrast to the mycosporineglycine, which had an EC_{50} of 294 μM, indicating its potential utility in skin photoprotection. The exopolysaccharide sheath contains SCY, which is mostly generated by cyanobacteria and is not present in MAAs. Indolic and phenolic subunits combine to form the dimeric, lipid-soluble compound known as SCY. It was found that it was produced in reaction to UV-A radiation and that in cyanobacteria cells, it decreased UV-A penetration by 90%. When purified, SCY absorbs at a maximum wavelength of 370 nm *in vivo* and adsorbs at a wavelength of 386 nm [22].

Tyrosine and tryptophan derivatives are believed to be connected to SCY production. Four different SCY derivatives, tetramethoxyscytonemin, dimethoxyscytonemin, scytonemin-3a-imine, and scytonin have been discovered. SCY is present in both oxidized and reduced forms [23].

The presence of SCY in addition to MAAs was found to confer UVA and UVB resistance on the *Nostoc flagelliforme* strain, indicating the significance of these compounds in photoprotection. The exceptionally stable pigments MAAs and SCY may be employed as sunscreens due to their photoprotective properties [24].

Whitening

Whitening is among the needs in cosmetic formulations for such management of hyperpigmentation diseases characterized by abnormalities buildup of melanin, such as melasma, freckles, and lentigo senilis. Tyrosinase is a melanin production enzyme whose inhibition is a focus for whitening agents. Despite the fact that there have been few studies in this field, cyanobacteria have showed some promise in terms of isolating chemicals with tyrosinase inhibitory action and, as a result, in the management of pigmentation disorders. The chemical osccillapeptin G, discovered from *Oscillatoria agardhii*, was shown to inhibit tyrosinase by 55 percent when compared to control. As a consequence of tyrosinase gene expression being negatively regulated in PC isolated from Spirulina species, very little melanin was produced from these cells [25].

MUSHROOMS IN COSMETICS

Due to their nutritional content, taste, and texture, mushrooms have been a staple of human diets for a very long time. They have undergone substantial research, and several studies have shown that a variety of bioactive metabolites exist in them, including as terpenoids, phenolic compounds, lectins, polysaccharides, glycoproteins, steroids, and a variety of lipid components. Key biological benefits such as antioxidant, antibacterial, anticancer, immunomodulator, antiinflammatory, hypoglycemic, and antiatherogenic activities have been demonstrated for a number of mushroom extracts and secondary metabolites. On the other hand, very little research on the anti-collagenase, anti-tyrosinase, anti-hyaluronidase, and anti-elastase effects of mushroom extracts and specific compounds has been reported [26]. These investigations, as well as the stated bioctivities, have led dermatologists and cosmetic researchers to be enthusiastic about the future of mushrooms and their components in the beauty business (**Table 2**).

Table 2. Cosmetics made using mushrooms and their components.

Mushroom	Function	Product	Country of Origin
Agaricus subrufescens	Renew and revitalize skin	Vitamega Facial Moisturizing Mask	Brazil
Cordyceps sinensis	Moisturizer and suppress melanin production	Kose Sekkisei Cream	Japan
Ganoderma lucidum	Wound healing and anti-inflammatory	CV Skinlabs Body Repair Lotion	USA
	Immunity boost	Four Sigma Foods Instant Reishi Herbal Mushroom Tea	UK
	Skin anti-aging	Menard Embellir Refresh Massage	France
Inonotus obliquus	Anti-inflammatory to help soothe irritated skin	Root Science RS Reborn	USA

		Organic Face Mask	
Lentinula edodes	Part lightweight moisturizer and part toner	One Love Organics Vitamin D Moisture Mist	UK
Mucor miehei	Anti-age and anti-fade	Pureology NanoWorks Shineluxe	France
Schizophyllum commune	Anti-aging and lifting	Alqvimia Eternal Youth Cream Facial Máxima Regeneración	Spain
	Hydrating cream promoting clear, radiant skin	Sulwhasoo Hydroaid	South Korea
Tremella fuciformis	Moisturizer which nourishes, revitalizes and hydrates skin	La Prairie Advanced Marine Biology Night Solution	Switzerland
Tremella polysaccharide	Moisturizing gel	BeautyDiy Aqua Circulation Hydrating Gel	Taiwan
	Improve skin around eyes	Surkran Grape Seed Lift Eye Mask	USA
Mushroom peptides	Diminish fine lines and wrinkles by aiding regulation of collagen and elastin	Murad Invisiblur Perfecting Shield	USA

Anti-collagenase activity

The underlying dermis of human skin is held securely in place and linked to the epidermis by connective tissue. Two structural proteins produced by dermal fibroblasts in the extracellular matrix (ECM), collagen and elastin, are essential for a number of protective functions in the skin. The elasticity of connective tissues, such as the lung, aorta, elastic ligaments, skin, and cartilage is provided by the ECM protein elastin. A metalloproteinase called elastase has the potential to break down elastin. Although elastin is resistant to proteolytic degradation, prolonged contact with elastases destroys elastic fibers, causing skin fragility and wrinkles. Elastase activity has been demonstrated to increase with aging, which has increased interest in screening natural matrices such mushrooms, plants, marine algae, and rhizomes for the development of active cosmetic ingredients that lessen skin ageing and wrinkles. The most crucial element of the skin's extracellular matrix, collagen is in charge of restoring the suppleness, elasticity, and strength of the skin. As a result, UV radiation-induced collagen degradation is what contributes to aging. As we age, the amount of elastin, hyaluronic acid, and collagen in the extracellular matrix of the skin decreases, leading to a loss of strength and flexibility as well as the development of wrinkles [27].

MMPs are extracellular matrix-degrading zinc-dependent endopeptidases that have been connected to a wide range of clinical and physiological conditions, including carcinogenesis, inflammatory, wound healing, vascular diseases, and bone resorption, to mention a few. The main collagen-degrading metalloproteinase, MMP-1, is membrane-anchored. Natural inhibitors known as tissue inhibitors of metalloproteinases (TIMPs) have been proven to control the synthesis of MMPs and protect the ECM. The excessive creation of ROS brought on by UV radiation speeds up the aging process of the skin. These ROS stimulate the production of MMPs, which break down collagen and create wrinkles, by activating mitogen-activated protein kinases and activator protein factor 1 (AP-1). In order to find natural AP-1 inhibitors that might be

employed as cosmeceutical agents to lower MMP production, numerous research projects are being carried out. There haven't been many studies on anti-collagenase activity of mushroom extracts, but there have been many studies on the anti-elastase activity of plant extracts, earthworm extracts, and marine algae extracts [28].

By incubating dermal fibroblast cells with *Tricholoma matsutake* mycelial extract at concentrations ranging from 1-100 µg/mL for 72 hrs and analyzing the expression of MMPs, type-1 collagen, and elastase, researchers investigated the anti-collagenase and anti-elastase activity of *T. matsutake* extract. In contrast to phophoramidon, used as a positive control, which had a lowering effect of up to 89.67 percent at a concentration of 10 µM, the extract was reported to reduce protein expression of MMP-1/3 and elastase mRNA in a dose-independent manner up to 81.4 percent. The results demonstrate that *T. matsutake* extract has anti-aging potential by preventing ECM degradation, despite the fact that the extract did not reduce collagen expression. The antioxidant, anti-tyrosinase, and anti-collagenase properties of *Grifola fondosa* (GF-M) mycelial extract and an exopolysaccharide (EPS) obtained from it. To measure anti-collagenase activity, it was determined if the test sample could lower the amount of MMP-1 production in human dermal fibroblasts that had been exposed to UVA radiation. Both EPS and GF-M significantly suppressed MMP-1 expression at 100 µg/mL (20% and 40%, respectively), with EPS exhibiting an even more potent suppression than trans-retinoic acid (tRA), a well-known inhibitor of UVA-induced MMPs. The extract also induced a 53% rise in collagen production. To a significant degree, EPS and GFM inhibited melanogenesis in B16 murine melanoma cells, decreasing it by 25% and 17%, respectively. In light of these results, it seems plausible that mushrooms and isolated polysaccharides might be used to slow the aging and darkening of the skin, respectively [29].

From the submerged mycelial culture of *Grifola frondosa*, researchers isolated an exopolysaccharide. After exposure to UVA, the ability of exopolysaccharide (EXP) to reduce the synthesis of MMP-1 protein in cutaneous fibroblasts was examined. Exopolysaccharide (EXP) may be a key component influencing the mushroom extract's photo-aging capability as evidenced by the fact that MMP-1 mRNA expression was decreased by up to 61.1 percent at a concentration of 250 µg/mL of EXP [30].

The amino acid histidine has a derivative called L-ergothioneine (EGT), which is typically found in animal diets and contains sulfur. Publications on EGT's antioxidant and cytoprotective properties have been reported in several studies since it is commonly found in cells and tissues that are regularly subjected to oxidative stress. All of these factors—capacity EGT's to lower MMP-1 protein production in dermal fibroblasts, its capacity to scavenge free radicals, and its potential to decrease inflammation by lowering TNF-α expression—were investigated. Dermal fibroblasts exposed to UVA produced 52% less MMP-1 protein when EGT at 2 mg/mL was present, demonstrating strong ROS scavenging effectiveness as well as TNF-α suppression. According to these results, EGT could be a key factor in the creation of anti-aging cosmetics [31].

L-ascorbic acid (AA), a potent antioxidant, is a common ingredient in cosmetics. As multipurpose cosmeceutical agents, researchers developed ascorbyl-3-pcoumarate (A-3-p-C) and ascorbyl-2-p-coumarate, two hybrid compounds made of AA and p-coumaric acid (A-2-p-C). Scientists looked at how well these compounds stimulated human dermal fibroblast collagen synthesis. A-2-p-C and A-3-p-C increased collagen release from human dermal fibroblasts by 120–144 percent and 125–191 percent at 100–300 µM. They

also decreased MMP-1 expression. Additionally, the compounds were shown to prevent the production of melanin, which raises the possibility that A-2-p-C and A-3-p-C might be used as hyperpigmentation and multifunctional anti-aging treatments [32].

Anti-hyaluronidase activity

When it comes to maintaining the skin's structural and mechanical integrity, the extracellular matrix is where it's at. In the progression of skin ageing, the breakdown of the skin matrix is critical. Collagen and elastin are structural proteins that are essential for skin health but not sufficient to maintain a healthy skin matrix. Dermal regeneration, proliferation, and migration need certain components to be supported by the skin.

Naturally occurring hyaluronic acid (HA) is a polymer that is derived from glucose that stores moisture, improves viscosity, and lowers extracellular fluid permeability. Both prokaryotic and eukaryotic cells are uniformly dispersed with HA. It is particularly prevalent in umbilical cord, human epidermis, heart valves, skeletal tissues, lung, aorta, synovial fluid, erectile tissues of the penis, and vitreous of the eye. As we become older, our skin produces less hyaluronic acid, causing moisture loss and the skin's inability to repair and revitalize itself. The cosmetic sector offers creams and lotions for topical administration of HA, but they confront significant hurdles because to their proclivity for causing inflammation. It has been demonstrated that natural substances such flavones and saponins from horse chestnut seeds (*Aesculus hippocastanum* L.) display non-competitive anti-hyaluronidase activity, which is crucial for maintaining the connective tissues of the skin [33].

The golden oyster mushroom, *Pleurotus citrinopileatus*, is an edible fungus. Numerous studies have shown that these compounds have antioxidant, antigenotoxic, anticancer, ACE-inhibitory, antihyperlipidemic, and anti-atopic dermatitis properties. These researchers looked at the n-butanol/aqueous/methanol extracts for anti-hyaluronidase activity. These extracts were shown to reduce hyaluroridase activity by 9.7 - 25.4%, respectively, at dosages of 1 - 4 mg/mL, making it a useful ingredient in cosmetics. *Lactinea trametes* (Berk.) Sacc is a Polyporaceae macrofungus that has been shown to block the hyaluronidase enzyme when hyaluronic acid is present as a substrate. Two distinct solvents for extraction were used to measure the level of activity; the aqueous extract inhibited hyaluronidase the most, up to 88.60 percent, followed by the acetone extract, which inhibited hyaluronidase by 88.3 percent. Hyaluronidase activity was reduced by as much as 87.40 percent using the positive control, however the scientists were unable to link the extract's phenolic content to the hyaluronidase activity suppression [34].

Only a few studies have documented mushroom extracts' anti-hyaluronidase activity, this is an enzyme that breaks down the connective tissue between cells. These enzymes drive a number of signalling pathways that hydrolyze the ECM, and they've become major targets in the creation of anti-aging cosmetics.

Anti-inflammatory activity

Inflammation is a natural reaction to damage that causes loss of function, discomfort, redness, and swelling. Tumor necrosis factor (TNF-α), Interleukins (IL-6, IL-8, and IL-1), intercellular adhesion molecule-1 (ICAM-1), nuclear factor-B (NF-κB), prostaglandin E_2 (PGE2), inducible type cyclooxygenase-2 (COX-2), inducible nitric oxide synthase (iNOS), and 5-lipoxygenase (5-LOX) are only a few of Numerous studies have shown that mushrooms, as well as isolated components such terpenes, polysaccharides, sterols, phenolic compounds, polysaccharide–protein complexes, fatty

acids, and bioactive metabolites have anti-inflammatory properties [35].

Investigating the anti-inflammatory activities of mushrooms and the bioactive compounds responsible for this activity was a focus of Taofiq et al.'s 2016. The most examined species were *Phellinus linteus* Teng, *Agaricus bisporus* Imbach, *Antrodia camphorata Pleurotus species*, *Cordyceps species*, *Ganoderma lucidum* (Curtis) P. Karst., etc. and the chemicals responsible for anti-inflammatory action were terpenes, polysaccharides, phenolic derivatives, etc. Lower levels of nitric oxide (NO) and other inflammatory mediators like interleukins, TNF-α, PGE_2, etc. from inflammatory cells have been related to the mechanism of anti-inflammation. NF-κB is a transcription factor that controls the production of IL-1, TNF-α, iNOS, and COX-2, among other pro-inflammatory cytokines and enzymes. Finding natural inhibitors of one or two stages in the NF-κB pathway is thus critical for preventing inflammation. Atopic dermatitis is a chronic inflammatory skin condition characterised by redness, rash, and extreme itching, which may be triggered by a variety of environmental and physiological variables. In recent years, it has been estimated that 10–20 percent of children and 1–2 percent of adults are affected by this condition. Overproduction of inflammatory mediators by pro-inflammatory cells like macrophages has been linked to the illness, even if the underlying physiological mechanism of the condition is unclear [36].

Mice subjected to repeated applications of picryl chloride developed atopic dermatitis, which was prevented by *Lyophyllum decastes* (Fr.) Singer extract. Based on the severity of the lesions, researchers compared their results to those of a control group. It was previously established that the extract inhibited the generation of IL-4 and reduced blood IgE levels [37].

Researchers extracted a polysaccharide (GFP) from *Grifola frondosa* (Dicks.) Gray and tested its capacity to reduce atopic dermatitis-like skin lesion in NC/ Nga mice produced by 2,4-dinitrochlorobenzene. When paired with the anti-inflammatory drug dexamethasone, GFP treatment was shown to significantly reduce the skin lesion, and a synergistic effect in the reduction of serum IgE and cytokine expression was seen in skin lesions that resembled AD. *Pleurotus eryngii* (DC.) Quél. and *Cordyceps bassiana* butanol extract, are the two mushroom extracts having anti-inflammatory effects on chemically-induced skin inflammation [38].

Anti-microbial activity

Colonization of the skin by non-pathogenic microorganisms such as fungi, *Streptococcus species*, and *Staphylococcus aureus* is ongoing. Distribution and density of skin microflora are affected by factors such as age and environmental conditions including temperature, sebum production, and humidity. These microorganisms have been associated to a variety of inflammatory skin diseases, including psoriasis, eczema, seborrheic dermatitis, atopic dermatitis, erysipelas, cellulitis, folliculitis, impetigo, carbuncle abscess, furuncle, and atopic dermatiti Increased skin colonization by germs like *Staphylococcus aureus* has been associated to a variety of skin conditions, including atopic dermatitis, and has been found to aggravate the symptoms of the illness. Since these microbes also acquire resistance to standard topical antimicrobials, the beauty industry is always looking for novel bioactive substances from natural sources to replace synthetic antimicrobial agents. Herbal pastes and infusions have been used topically for many years to treat inflammatory skin diseases [39].

Numerous studies have shown that mushrooms, because to their bioactive constituents, have antibacterial properties. Both edible and non-edible mushrooms were shown to exhibit antimicrobial action against pathogenic bacteria in a 2012 study by Alves *et al.*, who also looked at the

antibacterial potential of mushroom extracts and bioactive compounds. *Lentinula edodes* was the most interesting species since it inhibited the growth of gram-positive and gram-negative bacteria. This was followed by species from the genera Ganoderma, Lepista, and Boletus. To protect against things like ultraviolet light, insects, viruses, and bacteria, plants produce secondary metabolites known as phenolic compounds. There is a chance that mushrooms and other plants will provide them. Studies have demonstrated that they have antibacterial activity by disrupting the membrane and wall of an invading infection, killing it [40].

Caffeic acid, ferulic acid, ellagic acid, syringic acid, and chlorogenic acid have also shown promising results against Gram-positive and Gram-negative bacteria; however, phenolic acids like protocatechuic acid, 2,4-dihydroxybenzoic acid, *p*-coumaric acid, and vanillic acid have a higher antimicrobial potential. Even if some of the compounds on the list show antibacterial activity, these researchers stressed that a complete understanding of their mechanism of action is necessary before the problem of antibiotic resistance in bacteria can be solved [41].

Antioxidant

Several biological processes occur in body cells and tissues that are necessary for the organism's basic functioning. These reactions often result in the formation of free radicals, which are entities with unpaired electrons. RNS, RSS, and ROS are examples of free radicals. The body normally possesses methods to manage ROS generation and neutralization via its intrinsic antioxidant pool (superoxide dismutase, glutathione peroxidase, and catalase), but it may get depleted due to excessive ROS synthesis, causing oxidative stress in human cells. The body typically requires endogenous sources to meet its antioxidant requirements, and mushrooms, when consumed as a dietary source, may assist in overcoming this deficiency by containing high levels of bioactive chemicals with antioxidant activity. Vitamin C/E/K, phenolic acids, ß-carotene, zinc, flavonoids, and selenium are all good sources of antioxidants that help to keep oxidative stress in check. High UV exposure causes the production of ROS, which causes skin inflammation, DNA damage, stimulation of dermal fibroblasts for the expression of MMP-1, hyperpigmentation, and a decrease in collagen synthesis, resulting in the appearance of photo-aged skin [42].

Researchers are continually on the lookout for new natural chemicals that may scavenge reactive oxygen species (ROS), inhibit the tyrosinase enzyme, and decrease MMP-1 synthesis because of the vital role antioxidants play in skin health. Despite its common use in these products, ascorbic acid's effectiveness has been questioned due to its inability to infiltrate the skin and its poor stability in cosmetic formulations. A powerful anti-wrinkle and anti-hyperpigmentation drug, -tocopherol is a necessary antioxidant that has been found to reduce MMP-1 production and inhibit the tyrosinase enzyme. The antioxidant activity of mushroom extracts has been reported in several publications, primarily as reducing power (FRAP ferric reducing antioxidant power), radical scavengers (DPPH; H_2O_2 and O_2 scavenging activity; and ABTS 2,2'-azinobis 3-ethylbenzothiazoline-6-sulfonic acid), lipid peroxidation inhibitors (Heme degradation of peroxides; FOX ferrous oxidation-xylenol) and FRAP ferric reducing (TBARS thiobarbituric acid reactive substances) [43].

Anti-tyrosinase activity

The main pigment that gives skin its color is melanin. UV radiation is continually present on human skin, affecting both its function and structure. Overexposure to UV light induces an increase in the activity of the tyrosinase enzyme,

which leads to an increase in melanin synthesis in the skin. Tyrosinase transforms tyrosine to dihydroxyphenylalanine (DOPA) and subsequently oxidises it to dopaquinone, which is the rate-limiting enzyme in the melanin production pathway. In the presence of dopachrome tautomerase, dopaquinone is auto-oxidized to generate dopachrome, which is subsequently converted to eumelanin (brown-black pigment). In the presence of glutathione or cysteine, dopaquinone may be transformed to cysteinyl DOPA to generate pheomelanin (yellow red pigment) [44].

Autoimmune disorders, UV exposure, hormonal changes resulting in the production of hereditary factors, melanocyte-stimulating hormone, medicine causing drug reactions, and hormonal treatment or birth control pills are the most common causes of skin hyperpigmentation. All of these variables cause melanocytes to produce too much melanin, resulting in hyperpigmentation. Increased melanin synthesis is caused by multiple signal transduction mechanisms that regulate tyrosinase and tyrosinase-related protein mRNA expression (TRP1 and TRP2). Melanin production is triggered by a variety of hormonal and pharmacological mediators, with the cAMP-mediated route being the most prevalent. Through the activation of cAMP-dependent protein kinase A (PKA) and cAMP-response element binding protein (CREB), it is well established that cAMP upregulates expression of the micropthalmia-associated transcription factor (MITF). Through its interactions with the promoter area of TRP-1 and TRP-2, MITF regulates the intricate process of melanogenesis, which is the biosynthesis of melanin. Drugs that lower MITF expression will therefore act as inhibitors of the entire melanogenesis process [45].

Hyperpigmentation diseases, characterized by darker skin, light to dark brown blotches, irregular grey patches on the neck, trunk, and face, have prompted the search for novel chemicals or combinations of compounds to cure these unattractive anomalies. There is a lot of hope in using natural substances. Reduction of melanogenesis, or depigmentation, takes place when melanin production is stifled at any point along the melanogenic pathway or during melanosome transfer. Hydroquinone has been used to address hyperpigmentation issues; nevertheless, it has been linked to a number of unwanted side effects, including as the development of cancer, cell irritation, exogenous ochronosis, and the emission of an unpleasant fishy smell from the skin. Others believe that, despite their great efficacy, corticosteroids and kojic acid have been found to have a local or systemic detrimental impact after long-term use. Because of the undesirable side effects of the aforesaid depigmenting agents, researchers are looking for alternative natural products rich in bioactive compounds that may cure various conditions, such as those derived from mushrooms, plants, marine algae, and rhizomes. Several plant-derived substances, particularly phenolics like resveratrol, arbutin, gentisic acid, and ellagic acid have been shown to block one or more stages in the melanogenic pathway. Additional benefits of these phytochemicals for skin health include their capacity to hydrate, support, and stabilize the skin, and slow the aging process [46].

Pleurotus species are among the world's most widely grown edible mushrooms. They have a high nutritional value and pharmacological qualities such as antioxidant, anti-inflammatory, antibacterial, and immunomodulatory activity, according to reports. Scientists are enthusiastic about their potential as cosmetic elements because of their medical characteristics.

Meng et al. (2011) looked at how extracts from *P. citrinopileatus* Singer's fruiting bodies may inhibit the production of tyrosinase and melanin. Kojic acid was utilized as a positive control, and the findings revealed that at a concentration of 100 µg/mL, it effectively reduced tyrosinase activity by

100 percent. The inhibitory activity of ethyl acetate, n-hexane, and n-butanol-soluble extracts was 28.8 percent, 27.4 percent, and 41 percent, respectively, under the same circumstances. The extracts' depigmentation method was linked to the blocking of signals involved in the melanogenesis pathway, according to reports. B16 melanoma cells treated to *P. citrinopileatus* extract, particularly the *n*-hexane-soluble (50 µg/mL), diethyl ether-soluble (75 µg/mL), and ethyl acetate-soluble (100 µg/mL) fractions, demonstrated 63.1 percent, 64.0 percent, and 58.8 percent suppression of melanin formation, respectively. *Pleurotus nebrodensis* (Inzenga) Quél., *Pleurotus ferulae* Quél., *Pleurotus salmoneostramineus* Vassil, and *Pleurotus ostreatus* (Jacq. ex Fr.) P. Kumm. are other *Pleurotus* species exhibiting antityrosinase activity. Despite being the mushroom species with anti-tyrosinase activity that has been studied the most, Pleurotus species, no research has been able to identify the specific bioactive substances that cause this effect [47].

Park et al. (2015) investigated the efficacy of different ethanolic mycelium extracts as tyrosinase inhibitors in the presence of arbutin and ascorbic acid as positive controls. At 10 mg/mL, Inonotus mikadoi (Lloyd) Gilb. & Ryvarden considerably suppressed tyrosinase activity by up to 46.07 percent among the extracts examined. At the same quantity, *Coriolus versicolor* Quél. and *Fomitopsis sp*. decreased tyrosinase activity by 26.38 percent and 23.92.5 percent, respectively. The scientists suggested that some of these extracts with a tyrosinase inhibitory action may be explored further as aesthetic functional additions [48].

The medicinal fungus *Inonotus obliquus* (Ach. ex Pers.) Pilát, generally known as "chaga mushroom," is widely used in Russia and other North-European nations and has been shown to have anti-tumor and immunomodulatory activities. In their study, Yan et al. (2014) assessed the tyrosinase inhibitory activity of *Inonotus obliquus* petroleum ether and n-butanol extracts. Tyrosinase was inhibited by petroleum ether and n-butanol extracts at 10 µg/mL, with IC_{50} values of 3.81 µg/mL and 6.32 µg/mL, respectively. Betulin and trametenolic acid, two bioactive compounds with the capacity to decrease melanin content and inhibit tyrosinase in a noncompetitive way, have been identified as the bioactive molecules in charge of the activity. With an IC_{50} of 5.13 µM, betulin substantially suppressed tyrosinase activity, outperforming the positive control, kojic acid (6.43 µM). The findings imply that these compounds should be investigated further in the hopes of developing cosmetic components for the treatment of hyperpigmentation [49].

Anti-tyrosinase action has been observed in certain phenolic substances and their derivatives. Chaiprasongsuk et al. (2016) investigated the antimelanogenesis impact of dietary phenolic substances (ferulic acid, caffeic acid, rutin, quercetin, and avobenzone) quickly after UVA radiation exposure in B16F10 melanoma cells. The effects of inhibiting melanin concentration and tyrosinase activity were studied. The compounds' capacity to suppress UVA-mediated melanin content and tyrosinase activity was ranked as QU>RUCAAV>FA, and the findings were reported in terms of IC_{30} values. The findings imply that CA inhibited tyrosinase more effectively than FA. Thangboonjit et al. (2014) reported IC_{50} values for the tyrosinase inhibitory activity of caffeic acid, ferulic acid, and *p*-coumaric acid as 22.862 µM, 51.851 µM, and 43.092 µM, respectively. In UVA-irradiated B16F10 cells, the chemicals' anti-melanogenesis mechanism was shown to be related to reduction of tyrosinase protein expression [50].

MICROALGAE IN COSMETICS

Microalgae are a varied collection of photosynthetic eukaryotic microorganisms with a wide range of sizes, structures, and shapes (from 0.2 µm to more than 70 mm). Despite the fact that they

are completely separate species, cyanobacteria, often known as blue-green algae, are frequently addressed with microalgae. Cyanobacteria are a highly diverse, first oxygen-evolving group of photosynthetic Gram-negative prokaryotes that are very unique due to their ability to exist in almost all habitats, including freshwater, marine, biological soil crusts, soil, snow, etc., and can even tolerate extreme conditions such as salted soils and volcanic ash, due to the extent of evolution of being such an ancient organism. Because microalgae, like cyanobacteria, exist in severe habitats such as ice, volcanic water, and soil, they are often subjected to harsh circumstances such as high salinity and UV radiation. Microalgae are continually subjected to stress conditions in their natural environment, thus they have developed different strategies to cope with them [51].

Microalgae are potential candidates for use in cosmetic or cosmeceutical products, particularly for preventing skin damage from the sun, because they produce valuable products to protect themselves when exposed to UV radiation, ROS, and free radicals, among other things. This has caught the attention of the cosmetic industry. Microalgal cells transform solar energy into chemical energy, which is subsequently stored as chemical molecules. Their secondary metabolites are known as "bioactive substances" because they have biological functions. Pigments (carotenoids, phycobiliproteins, and chlorophylls), polyunsaturated fatty acids (PUFAs), proteins, carbohydrates, amino acids, peptides, polyphenols, vitamins, and phytosterols are examples of bioactive substances. These chemicals have antioxidant, anticancer, antibacterial, antiviral, antifungal, and antiviral properties, as well as immunostimulatory properties [52].

Microalgal chemicals also have an anti-inflammatory action that regulates macrophage activity in the immune system to preserve tissue homeostasis. Oxidative activity, which may be assessed in several ways, is the most concentrated action of microalgal chemicals such as hydroxyl radical scavenging, superoxide radical scavenging, thiobarbituric acid (TBA), DPPH radical scavenging, 2,2'-azinobis-3-ethylbenzothizoline, and ferric thiocyanate (FTC). Researchers concluded that microalgal extracts or bioactive compounds derived from microalgae have huge potential for being accessional new bio-based products like pharmaceuticals, cosmetics, bioplastics, biopolymers, and nutraceuticals after several studies showed that microalgae have high antioxidant activity. Fatty acids, proteins, chlorophyll, and carotenoids are among the secondary metabolites produced by microalgae [53].

Secondary metabolites from microalgae contain anti-blemish and anti-microbial properties, as well as the ability to repair and mend skin and prevent inflammation. *S. platensis*, for example, has high protein content (50–70 percent) and may be employed as a bioactive ingredient to heal skin ageing and prevent wrinkle development. *Chlorella vulgaris* extracts have been shown to enhance new-tissue regeneration by stimulating collagen synthesis in the skin. *Dunaliella salina* extract promotes cell development while also enhancing energy metabolism. In the presence of UV light, *C. vulgaris*, *Nostoc*, and *S. platensis* generate more chlorophyll and carotenoids, which have antioxidant qualities. PUFAs, monounsaturated fatty acids (MUFAs), saturated fatty acids (SFAs), docosahexaneoic acid (DHA), and eicosapentaenoic acid (EPA) are all produced by the diatom *Odontella aurita* (DHA). Some components of microalgae extracts (**Table 3**) react with various proteins on the skin's surface to generate a protective gel that prevents moisture loss. *Synechocystis sp.*, for example, has excellent antibacterial action against *Candida albicans*, *Escherichia coli*, *Aspergillus niger*, and *Staphylococcus aureus*, allowing it to maintain the

balance of skin flora via protection against pathogens [54].

Table 3. Bioactive compounds in microalgae and their uses in cosmetics.

Microalgae	Bioactive compounds	Activities
Chlorella sp.	Polysaccharides	To mask odors in dentifrices and deodorants
Dunaliella salina	ß-carotenes	Antioxidant
Dunaliella tertiolecta	ß-Cryptoxanthin	Anti-inflammatory Promote Hialuronan synthesis
Haematococcus pluvialis	Asthaxanthin	Sunscreen protection
Nannochloropsis gaditana	Canthaxanthin	Tanning cosmetics and cosmeceutic
Nannochloropsis oculata		
Nannochloropsis salina		
Odontella aurita	Chrysolaminarin	Antioxidant
Porphyridium	Phycoerythrobilin	Pigment for eye-liner and lipsticks
Rhodella reticulata	Sulfated polysacharides	Antioxidant
Scenedesmus vacuolatus	Extract	Antioxidant
Skeletonema	ß-1,3-Glucan	Immune system booster
Spirulina	Phycocyanobilin	Antioxidant

Anti-aging

Aging is described as the accumulation of damage to cells over time, induced by heredity, endogenous or environmental causes, resulting in function loss and ultimate cell death. Intrinsic and extrinsic ageing are two types of skin ageing. Internal variables such as genetic alterations, hormone imbalances, vitamin deficiencies produce intrinsic ageing, etc. while external factors such as pollutants, UV radiation, poor skin care, etc. cause extrinsic ageing. The skin deteriorates as a consequence of intrinsic ageing in terms of quality, increased transparency, loss of elasticity owing to more apparent vascularity, etc. Skin loosening, skin thinning, pore porosity development, increased dryness, line development, and wrinkle creation as a consequence of elastic fiber production and collagen breakdown in the dermis, as well as hyperpigmentation, all increase with age. Exposure to UV light is the most important component in skin ageing; in fact, extrinsic ageing is referred to as photo ageing. There are about 300 hypotheses concerning the ageing process, with the most significant processes being the creation of AGE (advanced glycation end products), the impact of ROS, and MMPs. Pharmaceutical firms have been interested in molecules that suppress AGE in recent years [55].

M2G, a rather uncommon mycosporine-like amino acid, has recently been described as an inhibitor of AGE production and it has been hypothesized that M2G might be useful in anti-aging treatments. Mycosporine-2-glycine can be synthesized by *Anabaena variabilis*, *Aphanothece halophytica*, and *Nostoc commune*, according to research. However, no research has been done on the use of this bioactive chemical derived from these species in cosmetics. ROS may bind to cell surface

receptors, triggering a number of signaling cascades that are involved in growth, differentiation, ageing, and tissue breakdown. In order to avoid cellular instability due to ROS generation and accumulation, the skin produces its own antioxidative agents on demand. However, as we age, this natural defense system begins to have downsides as our antioxidant levels decline. As a result, different microalgae extracts and antioxidants such as squalene from various microalgae may be used to prevent the development of lipid peroxidation (lipid peroxidation, peroxidation, and superoxide production), as well as to protect the skin from harm. As a consequence, the antioxidant content is maintained and ROS damage to the skin is prevented. Also, since the oxygen supply is significantly greater than the microalgae requires, microalgae have been found to be subjected to oxygen stress throughout the growing phase. The buildup of antioxidative chemicals is enhanced as a consequence of these circumstances, and the detoxification process is facilitated [56].

Oxygen stress increases antioxidant components of *S. platensis* by 2.3 times, according to experiments. The main extracellular matrix enzymes are MMPs that cause skin elasticity loss, collagen breakdown, skin ageing, and wrinkle development. The transcription factor Activator Protein 1 (AP-1) plays a key role in the transcriptional control of MMP-1. In addition, AP-1's cooperation with the nuclear-light chain-enhancer of activated B cells (NF-κB) is required for complete MMP-1 transcription activation. The expression of MMP-1 will be decreased if NF-κB and AP-1 are blocked by bioactive substances. Fucosterol is a natural sterol molecule with antioxidant and anticancer effects that is a structural component of cell membranes. In addition, it has the potential to reduce MMP expression while increasing collagen synthesis. Fucosterol is found in high concentrations in *Olisthodiscus luteus*, which accounts for 31.3 percent of total biomass, and *Nannochloropsis salina*. There have been no studies on utilising these species as cosmetics, although extracts from them might be a viable contender in the cosmetics business. The most crucial thing you can do to keep your skin looking young is to moisturise. It may increase the skin's elasticity and beauty while also shielding it from potentially harmful environmental factors. The amount of skin moisturization is proportional to the frequency with which it is washed with tensioactive supplies or its ability to defend itself against irritants. Because it aids the skin with those two methods, hydroxy acid has been utilized in cosmetic goods to moisturize the skin. Plants can create hydroxy acids, however as a consequence of the limitation on plant HA synthesis, interest in algal polysaccharides has grown [57].

According to studies, *Pediastrum duplex* extract has a considerable quantity of polysaccharides and may be used to moisturize and preserve the skin. There are three types of HA: α-HA, ß-HA, and salicylic acid. Alpha-HA is also referred to as 2-hydroxy acid because to the hydroxyl group attached to the carbon atom next to the carboxyl group. The two 2-hydroxy acids that are most frequently used in cosmetics are lactic acid and glycolic acid. Additionally, because the hydroxyl group is attached to the carbon atom in the second place, counting from the carboxyl group, beta-HA is sometimes referred to as a 3-hydroxy acid. Citric acid is the most well-known 3-hydroxy acid utilized in cosmetic formulation. Furthermore, *Anacystis nidulans*, *A. variabilis*, *Chlamydomonas reinhardtii*, *Chlorella pyrenoidosa*, *Phormidium foveolarum*, *Cyanidium caldarium*, and *Oscillatoria species* have been shown to generate 2-hydroxy acids and 3-hydroxy acids, and their extracts might be attractive cosmetic prospects. Exopolysaccharides (EPS), which are generated by microalgae, may also be regarded an important moisturizer. EPS is made up of numerous large biopolymers with a high molecular

weight. These biopolymers are produced by microalgae and secreted into the culture medium during their growth. One of them is glucuronic acid, which may be used to protect the skin from dry environments and control the skin's water content. As a consequence of differences in the biosynthesis pathway as a result of nutrition, culture conditions, and strains, EPS generated by microalgae varies. Because of their glucuronic acid content, *Chlorococcum sp.*, *C. pyrenoidosa* FACHB-9, *S. plantesis*, *P. cruentum*, and *Scenedesmus sp*. are recognized EPS producers, and their cell-free culture media might be assessed as cosmetics. Because of its glucuronic acid concentration, cell-free growth medium of *P. cruentum* and *S. platensis* has been suggested as a potential cosmetic product [58].

Carotenoids are not synthesized by humans and must be obtained via food. Through the metabolising process, they have the potential to divide carotenoids such as ß-carotene. *D. salina*, *Scenedesmus sp.*, and *Spirulina sp*. were shown to generate significant levels of ß-carotene with strong antioxidant activity in a previous research. This pigment produces two molecules of vitamin A for every molecule it contains (retinol). Vitamin A protects the skin from photo oxidative damage and protects it against sunburns, ageing, and wrinkle development. Squalene and its hydrogenated counterpart, squalane, are two microalgal products that may be utilized in cosmetics. They have the capacity to keep moisturizing creams' antistatic and emollient properties to provide optimal skin quality. Due to their non-toxic, non-sensitizing, and non-irritating qualities, they also exhibit significant antioxidant activity to moisturise skin and reduce age spots and hyperpigmentation. Squalene is now employed in a variety of applications in various parts of the globe. In Europe, it's used in 0.1–10 percent concentrations in lotions, eye pencils, eye shadows, eye makeup remover, and fragrances, as well as 50 percent concentrations in lipstick and facial products, whereas in the United States, it's utilized in liniment [59].

Scientists isolated squalene, a triterpene, from squaloid shark liver oil for the first time in 1916. Although shark liver is the most common source of squalene, microalgae may also be considered as a viable source. Although shark liver contains more squalene than plants and microalgae, seasonal availability and environmental contaminants are major obstacles to employing sharks as squalene sources. Although microalgae cannot collect squalene at the same rate as shark liver, the cosmetic industry has lately concentrated on squalene manufacturing from microalgae as a fish-free alternative owing to its ease of culture and quick development. Furthermore, when comparing the squalene production capability of microalgae and plants, it has been observed that microalgae may generate 15–300 times more than plants. Squalene is produced by microalgae through a series of stages. The production of Acetoacetyl-CoA by 2 units of Acetyl-CoA through the thiolase enzyme is the first step in the synthesis of squalene. HMG-synthase then adds one unit of Acetyl-CoA to Acetoacetyl-CoA, resulting in Hydroxy-Methylglutaryl-CoA (HMG-CoA). Mevalonate is produced by HMG-CoA reductase. Dimethylallyl pyrophosphate is produced by adding two phosphates from ATP and reacting with enzymes such as phosphomevalonate kinase, mevalonate kinase, isopentenyl pyrophosphate isomerase, and mevalonate-5-phosphotransferase. Phenyl-transferase then converts dimethylallyl pyrophosphate to Farnesyl pyrophosphate. Squalene synthase converts farnesyl pyrophosphate to squalene in the final step. *Schizochytrium mangrovei*, *Thraustochytrium sp.*, and *Botryococcus braunii* have been identified as squalene makers as a consequence of various tests. *Botryococcus braunii* generates lipid-rich biomass with 80 percent lipid content. Unsaturated hydrocarbons have isoprene units instead of glycerol esters in their oil structure.

The most promising microalgae strain for squalene production is Aurantiochytrium, which accumulates an impressive 198 mg/g of squalene [60].

Photoprotection potential

The amount of UV radiation that reaches the Earth's surface has grown due to the ozone layer being depleted and the increased emission of pollutants into the atmosphere. The ozone layer absorbs ultraviolet-C (UVC) light (100–280 nm). The ozone layer blocks most ultraviolet-B (UVB) radiation (280–315 nm) from reaching the Earth's surface, but some goes through, and as the ozone layer depletes, the intensity of UVB radiation (315–400 nm) increases. The ozone layer, on the other hand, has no effect on ultraviolet-A (UVA) light (320–400 nm). UVB is the most damaging kind of incoming solar radiation, causing DNA strand breaks, membrane rupture, enzyme deactivation, and the creation of cytotoxic DNA lesions in sun-exposed organisms. Because UVA radiation is not absorbed by native DNA molecules, it destroys DNA indirectly by forming ROS. UVA and UVB have carcinogenic and mutagenic effects on the human body as a consequence of these impacts, and they speed up skin ageing and photo-skin disorders [61].

To defend themselves from UV radiation, microalgae evolved many methods, including (i) the expression of DNA repair enzymes, (ii) the creation of antioxidant enzymes, (iii) UV avoidance, and (iv) the development and storage of UV filter metabolites. These processes are critical for microalgae to survive in harsh environments, and the manufacturing of UV filter metabolites, sometimes known as "microbial sunscreens," makes microalgae ideal candidates for use in natural sunscreens in the beauty sector. UV protection may be achieved in one of two ways: by absorbing or reflecting the rays. Solar radiation is reflected by physical filters, which prevents it from penetrating the skin. UV light is absorbed by chemical absorbers, which prevents it from reaching DNA and damaging it. Most sunscreens include both absorbers and reflectors; nevertheless, sunscreens may not be protecting the skin against UV radiation of various wavelengths while also hurting the environment, particularly marine species. Chemical absorber oxybenzone has been shown to be hazardous to marine creatures. Sunscreens containing oxybenzone and octinoxate have been prohibited in Hawaii due to their fatal effects on coral reefs. As a result of their high amount of UV filter molecules, biological absorbers began to increase in popularity owing to their environmental friendliness. In this respect, microalgae garnered greater attention due to their high concentration of UV filter molecules [62].

To protect themselves from solar radiation, microalgae produce sporopollenin, scytonemin, mycosporine-like amino acids, carotenoids, and other compounds such biopterin glucoside, lycopene as UV filter molecules, and ectoine for UV protection and photoaging. These bioactive substances protect the human body against sunburn, skin cancer, and limit melanin formation, among other things. Extracts from *Chlorogloeopsis spp.*, for example, prevent wrinkle development, skin sagging, and photoaging. UV transmission is likewise inhibited by *Isochrysis* and *Nannochloropsis*. By boosting the proteasome activity in the skin, *Phaeodactylum tricornutum* extracts protect the skin from the detrimental effects of UV exposure, delay the production of wrinkles, and minimise their depth. *Nannochloropsis oculata* extracts, which include an antityrosinase substrate, help to whiten the skin and prevent pigmentation. *Scenedesmus almeriensis*, *Chlorella protothecoides*, *Neospongiococcus gelatinosum*, *Muriellopsis sp.*, *Chlorella zofingiensis*, *Chlorococcum citriforme*, *Galdieria sulphuraria*, and *D. salina* contain lutein, which protects the skin from UV damage. Because it has the ability to improve the look of healthy skin, a mixture of extracts from *C. protothecoides* (UTEX 31) and

parachlorella might be a novel cosmetic product [63].

It has been demonstrated that microalgal extracts or their constituent parts can shield the skin from UV damage. The most significant and well researched ingredients in sunscreens made from microalgae are scytonemin and amino acids that resemble mycosporine. To shield themselves from UVA radiation with a 90% absorption rate, cyanobacteria create the small lipophilic extracellular yellow-brown pigment scytonemin in their sheath when exposed to strong sunlight. Scytonemin has a maximum absorption wavelength of 252 nm to 386 nm. UVA activates the gene responsible for scytonemin biosynthesis, which causes scytonemin to be produced and deposited in the extracellular matrix. *Calothrix*, *Anabaena*, *Diplocolon*, *Chlorogloeopsis*, *Hapalosiphon*, *Gloeocapsa*, *Nostoc*, *Lyngbya*, *Pleurocapsa*, *Phormidium*, *Schizothrix*, *Rivularia*, *Tolypothrix*, and *Scytonema* species may all manufacture scytonemin and its derivatives. Colorless and water-soluble molecules, mycosporine-like amino acids (MMAs) are a kind of mycosporine. Marine organisms such as microalgae, cyanobacteria, fungi, macroalgae, and others produce more than 22 MMAs, which act as photoprotectants by absorbing UVB and UVA radiation and dissipating excess heat energy into the cell and surroundings, as well as antioxidants by preventing ROS-induced DNA damage [64].

Physical and chemical filters on the market usually protect against UVA or UVB; just a few can protect against both, which is referred to as "broad-spectrum sunscreen." However, MAAs should be used as a UV filter agent in sunscreens since they can absorb UV light at wavelengths of 309–362 nm, making them a broad-spectrum sunscreen. They're also incredibly photosensitive and resistant to heat, pH fluctuations, and a variety of solvents, making them a very stable cosmetic. Mibelle AG Biotechnology, a Swiss business, was the first to develop a sunscreen called Helioguard 365 that contains a natural UVA screening ingredient called an MAA (porphyra-334 and shinorine) derived from the red algae *Porphyra umbilicalis*. As a result, MAAs derived from microalgae may have the potential to be employed in sunscreens. It has long been known that *Nostoc sphaericum*, *Nostoc sp*. R76DM, and *Nostoc commune* generate MAAs with antioxidant and anti-inflammatory activities in vitro, as well as the ability to scavenge ROS in vivo. MAAs made by *Lyngbya sp*. also provides photo protection [65].

Skin whitening agent

One of the most essential challenges in cosmetics is skin lightening. Because of UV radiation, ageing, and pregnancy, skin darkens in some areas, resulting in dark spots. Even while some dark spots are innocuous and others might lead to significant issues like melanoma, these dark spots generate an uneven skin tone, which is unacceptable as a so-called "beauty standard." The pigment melanin, which gives hair, skin, and eyes their color, is produced to shield the skin from UV ray damage. However, excessive melanin synthesis results in skin that is of a different hue. Melanocytes absorb high-energy ROS generated in the epidermis of the skin, the colored inner membrane of the eye, and the pigmented epithelium of the retina, and utilize their energy to oxidize tyrosinase into melanin. The enzyme tyrosinase hydrolyzes L-tyrosine to L-dopa (3,4-dihydroxy-L-phenylalanine) and subsequently oxidizes L-dopa to dopaquinone, the initial step in the formation of melanin. Tyrosinase and melanosome production rise when the skin is exposed to the sun. Melanosomes produce melanin in four stages: melanosome creation, internal fibril growth, and progressive and high melanin deposition [66].

Tyrosinase is the main enzyme that begins melanin production, and tyrosinase inhibitors may

prevent skin pigmentation. Copper chelation inside the active site of the enzyme and preventing substrate-enzyme interactions are two ways used by tyrosinase inhibitors, which comprise phenolic structures or metal chelating groups. Unfortunately, research have shown that tyrosinase inhibitors such as arbutin, hydroquinone, azelaic acid, kojic acid, ellagic acid, L-ascorbic acid, and tranexamic acid have negative consequences such as mutagenicity in mammalian cells, skin irritation, allergic dermatitis, and DNA damage. The use of hydroquinone has been prohibited by the European Union and the Food and Drug Administration. In 2003, Japan's Ministry of Health, Labour, and Welfare prohibited kojic acid due to its potential carcinogenicity, until it was revalued and allowed as a safe cosmetic component. It is crucial to find fresh natural alternatives to these manufactured tyrosinase inhibitors due to their limited stability, high toxicity, poor skin penetration, inadequate action, and microalgae might serve as a viable contender [67].

S. plantensis extracts may be employed as a tyrosinase inhibitor. The phenolic content of this species, as well as ferulic acid and caffeic acid, had lower IC_{50} values than arbutin (IC_{50}: 0.183 μM) and kojic acid (IC_{50}: 0.118 μM). Furthermore, the structure of these molecules is comparable to that of L-dopa, and there is no danger to the human body at the active concentration. *Pavlova lutheri* inhibits tyrosinase activity, whereas asthaxanthin from *Haematococcus pluvialis*, zeaxanthin from *N. oculata*, and Oscillapeptin G from *Oscillatoria agardhii* decrease melanogenesis. Melanosome production in the skin may be inhibited by taking vitamins C and E in addition to blocking the tyrosinase enzyme. Mammalian skin is protected from UV radiation damage by the self-acting synergistic systems of vitamins C and E, which are dependent on Nicotinamide Adenine Dinucleotide Hydrate (NADH). Additionally, the stratum corneum (per unit epidermal thickness), which is found on top of the skin and regulates passive water transport, may absorb vitamin E particularly efficiently. Vitamins C and vitamin E, on the other hand, may be taken alone or in combination. When mice treated with vitamins C and vitamin E were compared to untreated control mice, melanocyte population density was found to be decreased by 35 percent. Unfortunately, no experiment exists that compares the creation and proliferation of melanocytes in skins with and without vitamins C and vitamin E when exposed to UV light. Because of its high level of vitamin C and vitamin E, research on microalgae species as prospective vitamin makers suggests that *Pediastrum cruentum* might be a promising choice as a cosmetic for melanoma prevention [68].

Cultivation and purification

To generate the necessary number of target products, the microalgae cultivation process comprises numerous key processes. Microalgae selection is critical for production since the process design, growing conditions, harvesting and extraction procedures all alter as a result, impacting production efficiency, yield, and product quality. For example, if the cultivation will take place outside, the strain should be able to withstand harsh climatic conditions in order to avoid infection. In addition, if it is to function in a closed system, the strain must be able to withstand significant shear stress. Cultivation may be done in two ways: open system or closed system. Unstirred ponds, tanks, circular ponds, and raceway ponds are examples of open air systems. Bubble column, flat panel, plates, airlift column, stirred tank, and tubular photobioreactors are examples of closed systems. The appropriate photobioreactor must be chosen based on the microalgae species. *Dunaliella sp*. and *Dunaliella tertiolecta*, for example, are known to be very adaptable to temperature variations and to need a lot of light throughout growth. As a result, the flat panel photobioreactor will be more

beneficial than conventional photobioreactors when dealing with these two microalgae species [69].

It has been demonstrated that when comparing the open and closed systems, the open system has a higher risk of contamination and water evaporation, while the closed system has poorer light usage, product quality, and controllability. The open system, where only a few species may be farmed, has lower operating costs than the closed system, but harvesting costs are greater owing to the high water content. The closed system produces less microalgal biomass than the open system, but only the high additive chemicals generated in this system may be utilized in food and cosmetics. Temperature, nutrients, aeration, pH level, light intensity, mixing, and growth mode (photoautotrophic, autotrophic, photoheterotrophic, heterotrophic, and mixotrophic) are all adjusted to meet the needs of the microalgae species in question. These factors influence metabolic pathways, and when the culture method is altered, the same species produces various products as a consequence of metabolic shift. *S. platensis*, for example, may be grown under photoautotrophic, heterotrophic, and mixotrophic environments, with the most successful condition determined by the intended end products. This product has also been found to have an impact on the culture mode choices, such as batch, fed-batch, and continuous. Counting total cells, utilizing a particle analyzer, calculating doubling time, and biomass productivity are all approaches to monitor microalgae development during culture [70].

Volumetric productivity, areal productivity, and illuminated surface productivity after culture are indicators of microalgal productivity components. When the required quantity of target final is generated, the harvesting procedure is used to remove a large volume of water from the culture medium. Filtration, centrifugation, sedimentation, ultrafiltration, chemical flocculation, coagulation, electrical-based technologies,, foam flotation, and ultrasound may all be used to complete this crucial stage, and they are occasionally combined. These techniques are adequate to employ for the intended purpose if the goal product is a biomass of microalgae. However, extraction techniques are occasionally required to get certain compounds, such as pigments. Extraction methods using organic solvents, like ultra-high-pressure soxhlet and ultra-high-pressure percolation, soaking, pressure liquid, and soxhlet, are typically selected based on the biochemical properties of molecules and solvents (such as isopropanol, methanol, chloroform, and hexane) as well as extraction time and yield. High-pressure, milling, high-speed homogenization, pulsed electric field application, ultrasonication, enzymatic application, and microwave application are utilised to enhance extraction efficiency. Membranes and resins are used for fractionation, while caustic refining, degumming, filtering, deodorization, and chromatographic procedures are used for purification. Thermal drying or freeze-drying is used to eliminate moisture from the microalgal extract after all of these steps. Laboratory scale and photobioreactors should be used to determine the optimal cultivation conditions and procedures [71].

Industrial development

Chlorella, *Spirulina*, *Dunaliella*, and *Haematoccocus* are four microalgae that have caught the interest of industrial manufacturers. Their ability to adapt to large-scale manufacturing systems and high-value commodities gave them biotechnological significance. One of the most important microalgae in algal biotechnology is chlorella, and Beijerinck's 1890 cultivation of these green microalgae was the first instance of "applied phycology." Although it has a brief history, applied phycology still has to be improved in order to produce a big amount of viable microalgae. Nihon Chlorella Inc. began commercial production of

Chlorella in open ponds in 1961, and it was determined that the CO_2 utilization rate was ineffective. This discovery prompted the transition of Chlorella from a photoautotrophic to a mixotrophic culture in 1964, where acetic acid serves as the carbon source and is easily assimilated by Chlorella. However, acetic acid kept the culture generally axenic, with the exception of acetic acid bacteria, which can be easily removed from the culture by centrifuging and washing. Bacterial contamination was another serious problem with mass cultivation in open ponds. Rate of mixing, algal population density, and culture depth are essential operational parameters of mass production, whether in open ponds or photobioreactors, because these aspects are related to light utilization and light is the most critical element in microalgae development [72].

Similar to kelp, spirulina is produced in open ponds for commercial production, and it is another important microalga in algal biotechnology. Spirulina has a high protein content, which makes it particularly healthy for vegans. Its importance as a source of the blue pigment phycocyanin, which may be utilized as a coloring agent in cosmetics like eyeliner and lipsticks, increases its commercial value. Manufacturing, harvesting, drying, and packing are the four phases involved in spirulina production. Raceway ponds are used for cultivation, and filtration is typically used for harvesting. However, because to the possibility of filament breakage, this method may not be as efficient as it may be, which could lead to bacterial contamination. Spray, drum, or sun drying may all be used to dry algal biomass, while there are significant downsides to these methods, such as pigment damage from spray drying and sun drying being difficult owing to the high water content of algal biomass. Spray drying should be used to dry biomass if the product is intended for human consumption [73].

Dunaliella is simpler to cultivate in open ponds than other economically significant species because it can be produced in high salinity or at a variety of temperatures ranging from -5°C to over 40°C, making it the most ideal microalgae for mass production. Since it doesn't require acetic acid for metabolism, unlike Chlorella, Dunaliella can be cultivated autotrophically, despite some efforts to create heterotrophic strains to speed up production even further. Large-scale -carotene synthesis from Dunaliella requires certain environmental conditions such high salinity and a lack of nitrogen, whether in open ponds or photobioreactors. Manufacturing facilities are constructed in locations with high solar output because strong light intensity may also start production. Haematococcus, on the other hand, thrives on a basic medium with no particular nutrients of its own, which makes contamination a severe issue, necessitating the use of more modern technologies. Because Haematococcus is the most major astaxanthin producer, there are projects underway to create new technologies or cultivate it more easily [74].

Astaxanthin is commercially manufactured via a two-step method that begins with the creation of vegetative cells and ends with the synthesis of astaxanthin from haemocystis, a stressed form of vegetative Haematococcus cells. Commercial procedures stress the cells by depriving them of nitrate and phosphate, adding salt, or subjecting them to intense light and heat. Because Haemocystis has a greater density than water, it is readily extracted by sedimentation followed by centrifugation. To release astanxathin, cells must be disrupted, although the specific methods are not disclosed by the makers. The final product is affected by the cultivation mode and circumstances, therefore having the necessary know-how to build a process for the product are critical, since various methods must be used depending on the cell attributes and production route [75].

BIOSURFACTANTS IN COSMETICS

Biosurfactants may be produced by microorganisms such as bacteria, filamentous fungi, and yeasts using a variety of carbon sources, such as carbohydrates, hydrocarbons, lipids, and oils as carbon sources. In order to manufacture high quantities of good quality biosurfactants, scientists have recently grown more and more interested in isolating and even genetically modifying microorganisms that can produce tensioactive molecules with enough surface activity, emulsifying ability, and low toxicity. The kind of generating microbe and chemical makeup of microbial biosurfactants are used to classify them. Polymeric surfactants, glycolipids, fatty acids, lipopetides, phospholipids, and particle surfactants are some of the most common types of microbial biosurfactants. In contrast, glycolipids and phospholipids have a low molecular mass, whereas lipopetides and lipoproteins have high molecular weight. Surface activity is higher in the former and emulsifying capability is higher in the latter. The majority of biosurfactants are neutral or negatively charged, while cationic biosurfactants include amine groups. Phospholipids, protein hydrolysates, proteins, saponins, etc. are examples of biosurfactants that come from plants. Due to the high amount of esterified essential fatty acids, particularly linoleic acid, phospholipids are commonly employed for topical treatments in cosmetics and dermatology. Proteins and protein hydrolysates are utilized in the food, cosmetics, and pharmaceutical sectors to improve viscosity, produce gels, and encapsulate things [76].

Saponins are nonionic tensioactive chemicals that have been utilized in folk medicines as well as detergents. The effectiveness and efficiency of surfactants and biosurfactant in general are influenced by a biosurfactant's ability to reduce emulsifying capacity, critical micelle concentration (CMC), and surface/interfacial tension. Emulsification index and Surface/interfacial tension are the two most important properties of surfactants. Tension is a term used to describe the attraction force between the molecules of fluids. Surface tension is the force exerted by a liquid against the air, whereas interfacial tension is the force exerted by two liquids against one another. When biosurfactants agglomerate on surfaces or at the interfaces of insoluble compounds, they may influence hydrogen bonds and other hydrophobic-hydrophilic interactions by expanding the contact surface, reducing tensions between molecules via molecular displacement. The detection of the presence of a surfactant in the medium is based on the measurement of tension. The propensity of the liquid's surface to retract per unit of length is measured by surface tension. MilliNewton per metre (mN/m) is the most frequent unit. Surface tension may be reduced to between 25 mN/m and 30 mN/m when using effective biosurfactants. The CMC is the minimal biosurfactant concentration necessary to achieve maximal surface tension decrease. As a result, a low CMC denotes a more efficient surfactant that is more cost-effective for industrial operations.

CMCs range from 1 to 2000 mg/L for biosurfactants. Glycolipids (rhamnolipids) and lipopetides (surfactin) have the smallest CMCs, according to the literature. The capacity to solubilize hydrocarbons is correlated with emulsifying activity. Emulsions are inherently unstable, however with the addition of a biosurfactant, an emulsion may be kept stable for months, even years. Biosurfactants have been shown to have emulsifying activity ranging from 50 percent to 90 percent [77].

Natural products in the cosmetic industry

Shampoo, soap, deodorant, toothpaste, perfume, skin cream, makeup, etc. are all examples of cosmetics that people use on a regular basis. The

cosmetic sector is responsible for an increasing share of the global economy and the creation of employment due to its high consumption. Cosmetics can encourage personal hygiene and sickness prevention, as well as social inclusion, wellbeing, and self-esteem, all of which contribute to population health and quality of life improvements [78].

Cosmetics, on the other hand, have an environmental effect, prompting some firms to pursue sustainable practices via innovation, which entails producing goods that respect ecosystems and biodiversity while simultaneously providing cosmetics that cater to a wide range of desires. This is accomplished by limiting the influence of synthetic elements by selecting raw materials based on the notion of "green" chemistry. The notion of sustainable innovation also includes the creation of more efficient industrial methods that reduce waste. As a result, the market for biologically derived goods is growing, prompting the cosmetics sector to look for ways to enhance product composition by using natural elements from a range of sources, particularly plants, as an alternative to synthetic ones. This tendency has been bolstered by changes in the consumer market's profile, which has shown an interest in items made with natural components. In contrast to cosmetics with chemical components, "green" customers favor cosmetics with natural components owing to higher sustainability and reduced toxicity, as well as equal, better, or extra advantages [79].

Novel active components have been discovered as a result of biotechnological breakthroughs, paving the way for the creation of a new category of cosmetics known as biocosmetics. Biosurfactants may be used in these products because of their surface qualities and biological activity, making them suitable for use in cosmetics. Due to their multifunctional character, glycolipids (rhamnolipids, MELs, and sophorolipids) and lipopetides (surfactin) are the most extensively utilized biosurfactants in cosmetics. Biosurfactant-based microemulsions may be utilized to add functional components and antioxidants to cosmetics. Surfactins have been investigated as transportation agents, and the surfactant MEL derived from Pseudozyma spp. has been shown to create stable water/oil microemulsions. Beyond their surfactant function, biosurfactants' potential as carriers of active ingredients in cosmetic formulations may be quantified by the rate at which the compounds diffuse across the lipid bilayer of skin cells, which is determined by their affinity for grease. Permeation of lipophilic substances through skin, for example, is a necessary condition for topical administration of bioactive chemicals. The ability of such formulations to permeate the skin's primary barrier determines their efficacy. As a result, biosurfactants may be used in cosmetic formulations to aid in the penetration of active substances into the skin. However, before adding biosurfactants into such formulations, the toxicity of these tensioactive chemicals on cells and/or animals must be assessed [80].

Biosurfactant properties for cosmetic industry

Surfactants are used as solubilizers, wetting agents, foaming agents, dispersants, detergents, and emulsion-forming agents in cosmetic goods. Polyethylene glycol esters are the most common commercial surfactants used in cosmetics. The possibility for skin irritation and allergic responses, as well as the detrimental influence on the environment due to pollution of oil and groundwater, are the most significant issues associated with the use of chemical tensioactive substances in cosmetics. As a result, biocompatibility and biodegradability have become almost as critical as product functionality, necessitating the development and implementation

of effective surfactants that pose no damage to human health or the environment [81].

Biosurfactants may be utilized to minimize or mitigate the negative effects of synthetic surfactants. Biosurfactants are appropriate for use in cosmetics because of their low toxicity, ecological acceptability, and biodegradability. The choice of a biosurfactant for a given cosmetic product is a sensitive undertaking that is influenced by a number of elements, including the product's intended function. Some factors linked to the biosurfactant's qualities should be considered. The key factors that influence the kind or application of biosurfactants in cosmetic formulations are the hydrophilic-lipophilic balance (HLB), ionic performance, and CMC [82].

Water-soluble biosurfactants are the best stabilizers for oil-in-water (O/W) emulsions, whereas oil-soluble biosurfactants are the best stabilizers for water-in-oil (W/O) emulsions. A biosurfactant may be used as an anti-foaming agent, emulsifier, and wetter in dermatological applications depending on the HLB value. When utilizing a biosurfactant in cosmetics, it is especially important to take into account its ionic nature, since the ionic charge is linked to hair absorption, skin irritation, eye irritation, and antibacterial characteristics [83].

Biosurfactants include biological activity in addition to structural and chemical features, making them multifunctional substances. The antibacterial and antioxidant capabilities, for example, are important in the personal care business. In cosmetics, microbiological safety is critical since contamination by microorganisms may cause the product to deteriorate and pathogenic agents can put customers' health at risk. Furthermore, formulations strong in antioxidant activity safeguard the body by reducing oxidative stress, which helps to slow down the ageing process [84].

It was discovered a significant antioxidant and antibacterial activity in crude saponin extracts from the plant species *Spergularia marginata* and *Paronychia argentea*. Because of their benign nature, extracts with these qualities are prospective cosmetic components that may be used at larger quantities than synthetic antioxidants and conservatives. In a study by Jemil et al., a lipopetide produced by *Bacillus methylotrophicus* DCS1 exerted antioxidant activity through a variety of mechanisms, including metal ion chelation, hydrogen or electron donation, and free radical elimination during peroxidation, as well as antimicrobial activity against a variety of microorganisms. Antimicrobial (antifungal, antiviral, and antibacterial) and antioxidant activity has been reported in biosurfactants such as sophorolipids, rhamnolipids, MELs, and surfactin cosmetics need antioxidants and conservants, hence these compounds might serve as preservation and conditioning agents [85].

Microbial biosurfactants

Biosurfactants are produced by microorganisms, particularly bacteria, in a wide range of structures. Microorganisms create biosurfactants, which are made up of a variety of congeners built around a fundamental structure that determines the molecule's characteristics and, as a result, its potential uses in commercial goods. Pharmaceuticals, foods, insecticides, and cosmetics all use microbial biosurfactants. These organic materials may also be used in environmental protection projects including improving oil recovery, stopping oil spills, and decontaminating soil and industrial effluents that have been polluted with petroleum [86].

A number of obstacles stand in the way of these biomolecules being used in industry, including high manufacturing costs owing to costly substrates and limited yield. Some efforts, such as improving the composition of the growth medium, using genetically engineered microbes, and process engineering, have been taken to address these issues. An enhanced fermentation method for strains

capable of exploiting renewable, low-cost carbon sources, such as petroleum industry residuals, glycerol, agroindustry waste water, maize steep liquor, sugarcane molasses, starch-rich effluents and whey, is one option to save costs. Furthermore, studies of critical aspects of the biosurfactant manufacturing process, such as metabolic optimization of biosynthesis and physicochemical qualities, must be carried out in order to investigate all conceivable industrial applications [87].

Some biosurfactants, such as sophorolipids, rhamnolipids, and MELs, are already used in industry. This is owing to the ease with which these biosurfactants may be manufactured in vast numbers. Due to the existence of compounds that are extremely promising for application in cosmetic formulations, glycolipids and lipopeptides are the most intensively investigated families of microbial biosurfactants. The majority of low molecular weight biosurfactants are glycolipids. A long-chain fatty acid (which may be aliphatic, hydroxylated, or unsaturated) and a hydrophilic carbohydrate component make up the hydrophobic moiety (trehalose, glucose, galactose, mannose, rhamnose, and sophorose). The most well-known glycolipids are rhamnolipids, sophorolipids, and MELs. Linear or cyclic peptides are joined to a polypeptide tail to generate lipopetides. Surfactin is the most well-known member of the lipopeptide family [88].

PLANT STEM CELLS IN COSMETICS

The mother cells in an animal's stem cell pool can develop into any type of more specialized cell for different bodily tissues, such as heart muscles, skin tissues, and liver problems. Plants, on the other hand, are better at adapting this mechanism to create stem cell niches in new places. The cosmetic business has a significant problem in providing useful, 'trendy,' creative, and safe products with a longer shelf life. All cosmetic research and development for new products is now focused on biotechnology and plant cell culture techniques to circumvent the industrial, consumer, and legal limits imposed by the undesirable use of human or animal sources. The usage of beautiful plants has been hampered by their slow development, seasonal harvest, variability in active concentration from plant to plant and harvest to harvest, and the presence of harmful metabolites [89].

For cosmetics, plant cell culture techniques have been discovered to tackle these crucial difficulties, with the additional benefit of higher active concentrations owing to stimuli like UV light, jasmonic acid or toxic compounds. To ensure that plant cells, tissues, and organs grow in an environment free of microbes, this technique employs a slew of complicated methods. Bioactive chemicals found in plants that are either scarce in nature or difficult to synthesise through chemical synthesis may be created using this approach. To make both everyday and professional cosmetics, plant stem cell extracts, such as arbutin from *Catharanthus roseus* and colours like safflower and saflorin from *C. tincorius*, are now being used. Cell lines may be chosen based on their ability to produce the most biomass with the least amount of time spent doubling [90].

High pressure homogenization may be used to totally break down suspended cells and liberate the active ingredients. As a result, plant stem cell extracts may be encapsulated in a variety of carrier systems for improved topical distribution as a cosmetic product. Plant stem cell research for skin care is still in its early stages. Plant cell culture technique has been shown to be an excellent way for extracting stem cells in the production of innovative cosmetic plant derived actives in recent study. Schmid et al., for example, used plant cell culture to produce stem cells from an ancient unusual apple plant cultivated in Switzerland with excellent preservation qualities. After lysis of the plant cells

using high pressure homogenization, the extract of grown apple stem cells was produced, which had various advantageous uses [91].

Uttwiler Spätlauber stem cell extract, which contains 2 percent of the active ingredient, was found to be able to reverse the ageing process of human skin fibroblasts by upregulating the expression of several key genes involved in cell proliferation and growth and stimulating the expression of hemeoxygenase-1, a valid antioxidant enzyme. Isolated human hair follicles lived longer after being treated with it, as did umbilical cord blood stem cells. The extract was delivered using lecithin liposomes as a carrier. *Malus domestica*, a liposome encapsulated extract of cultivated apple stem cells, has demonstrated substantial ability to eliminate wrinkles in the crow's feet region of the face in a clinical investigation. The depth of wrinkles was assessed using optical equipment called the PRIMOS system for 3D skin surface display, and the results indicated that wrinkles shrank by 8 percent after two weeks and 15 percent after four weeks [92].

Another group of scientists has devised a bioreactor that can grow cloudberry (*Rubus chamaemorus*) cells from preexisting callus and suspension cultures grown in Murashige and Skoog conditions supplemented with the phytohormones kinetin and naphthalene acetic acid. The generated cloudberry cell material has the potential to be employed in the cosmetics industry as a raw material and natural preservative. For many plant species, the described method might be used for the sustainable production of fresh cells or cell fractions, extracts, and isolated chemicals with potential bioactivities, freeze-dried cell material, smell, or color [93].

There is hope that *Lycopersicon esculentum* stem cells grown in a lab may protect skin against heavy metal toxicity. *L. esculentum* liquid cultures produced cosmetic products with much higher levels of flavonoids and phenolic acids such rutin, coumaric, protocatechuic, and chlorogenic acids. Given its high levels of antioxidants and phytochelatins, a metal-chelating molecule that traps metals and prevents damage to cellular structures, tomato stem cell extract shows promise for application in skin care cosmetic formulations [94].

Plant cells from the Asian ginger plant that have been dedifferentiated and grown in a culture that controls the production of active compounds are used in the production of refined ginger. During a clinical experiment involving 22 women, the company claims that pore reduction led to a 50% improvement in skin structure and a 15% reduction in shininess after 6 hours, as well as a 19% reduction in sebum after 28 days. Elastin and fiber production increased, but sebum production decreased, in *in vitro* studies [95].

Italian researchers studied an antiaging material made from edelweiss stem cells and found that it had an anticollagenase and antihyaluronidase activity that was noteworthy. Antioxidant Leontopodic acids A and B are found in abundance in *Leontopodium alpinum*. They employed proprietary High Tech Nature technique to create components in industrial quantities, assuring predictable composition and active ingredient titer [96].

Instead of using harsh chemicals, XtemCell's cutting-edge stem cell technology creates new cells that are high in purity and nutrition using active plant cells from rare, 100% organic, nutrient-rich plants. High amounts of lipids, proteins, amino acids, and phytoalexins are guaranteed by this proprietary technique. Medical studies demonstrate that the active cells in XtemCell products readily penetrate the outermost cells of the epidermis, enabling almost immediate skin cell renewal and nutrient absorption as well as an increase in the level of filaggrin proteins, which shield the skin from further sun and aging damage [97].

CONCLUSION

In the cosmetics business, cyanobacteria, mushrooms, and microalgae are being investigated as potential cosmetic ingredients. These organisms have long been known as traditional sources of natural bioactive compounds. In order to exploit their anti-aging, antioxidant, skin whitening, anti-wrinkle, and moisturizing capabilities among other things, a number of ingredients and their extracts are either now used in cosmetic goods or have been trademarked for use in such products. It has already been stated that the species that have been recognized and used so far account for a tiny proportion of the overall number, and that additional species will be found, validated, and grown in the future. All of these imply that the cosmetic sector will continue to be exploited and developed in the foreseeable future. The molecular processes of medicinal benefits will be disclosed via interdisciplinary research combining genomes, proteomics, metabolomics, and systems pharmacology, and more mushrooms will be able to make their way into cosmetics through a variety of ways. In response to growing concern about skin health, especially with respect to look and ageing, there has been a surge in demand for new cosmetic products, which are mostly of natural origin, have fewer side effects, and are ecologically friendly. This category of organisms is promising in the cosmeceutical sector because of its efficient mechanisms against dissection, radiation, and oxidative stress, which are accomplished via the creation of particular chemicals. As well as having the potentialities necessary for aesthetic formulations, these bioactives also have the ability to provide facilities in terms of culture for biomass and compound synthesis, which may reduce the cost of manufacturing. The review highlighted the biotechnological potential of these organisms as a foundation for the cosmetic manufacturing industry that is both economically and environmentally sustainable. It also reflects the effort that has been put forth in the application of these ingredients in cosmetics.

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