Review

Microalgae and Cyanobacteria Exopolysaccharides: An Untapped Raw Material for Cosmetic Use

Marala Lourdes Mourelle * , Francisco Díaz-Seoane , Sheyma Inoubli , Carmen Paula Gómez , José Luis Legido

Posted Date: 6 August 2025

doi: 10.20944/preprints202508.0395.v1

Keywords: exopolysaccharides; microalgae; cyanobacteria; skin care cosmetics; cosmeceuticals

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 August 2025 doi:10.20944/preprints202508.0395.v1

Review

Microalgae and Cyanobacteria Exopolysaccharides: An Untapped Raw Material for Cosmetic Use

Marla. Lourdes Mourelle [1,*], Francisco Díaz-Seoane [2], Sheyma Inoubli [2], Carmen Paula. Gómez [1] and José Luis. Legido [1]

[1] FA2 Research Group. Department of Applied Physics, University of Vigo, Campus Lagoas-Marcosende s/n, 36310 Vigo, Spain

[2] Faculty of Science, Campus As Lagoas s/n, 32004 Ourense, Spain

* Correspondence: lmourelle@uvigo.es

Abstract

Microalgae and cyanobacteria produce extracellular polysaccharides that are exuded and released into the medium, typically referred to as exopolysaccharides (EPS). Microalgae-derived EPS have garnered attention in the last decade, as they may exhibit specific bioactivities and therefore hold promise for biofunctional applications in the biomedical, food, agricultural, and cosmetic fields. In cosmetic formulations, EPS can be included both to improve techno-functional and sensorial properties, and as active ingredients, showing great potential in the preparation of cosmetic products aimed at hydration and anti-aging. This review surveys the literature on the potential of EPS-microalgae in skin care and cosmeceutical formulations, to reveal a material that is sometimes discarded during the microalgae cultivation process and that can be recovered for cosmetic use. The conclusions of this review highlight that EPS from microalgae and cyanobacteria exhibit different physicochemical and biological functionalities, making them attractive for potential exploitation as commercial sources of new polysaccharides.

Keywords: exopolysaccharides; microalgae; cyanobacteria; skin care cosmetics; cosmeceuticals

1. Introduction

Algae can be regarded as cost-effective renewable resources with higher photosynthetic efficiency and productivity than terrestrial biomass; they can promote carbon neutrality since they can be grown in non-arable land with non-potable water, even in low-cost or waste culture medium [1,2]. In addition, they can be cultivated using cheap substrates of carbon dioxide from industrial emissions, wastewaters, and saline waters [3].

Compared to macroalgae, microalgae offer advantages in large-scale cultivation, as they can be grown rapidly under controlled conditions, without the constraints of seasonal variation or restrictive coastal laws. They also have the advantage of being able to be cultivated in closed photobioreactors or open pond systems, allowing for sustainable and scalable production of polysaccharides (PS). These characteristics, combined with the growing global interest in bioactive natural products, position microalgal PS as a promising resource for next-generation biotechnological innovations aimed at improving human health and well-being [4]. Therefore, in recent years, there has been an increase in publications regarding microalgae-derived PS and their bioactivity, aimed at improving their growth and purification, with the aim of their use in the food and cosmetics industries.

Microalgae and cyanobacteria are microorganisms that produce a wide range of high-value functional and bioactive compounds, such as lipids, polyunsaturated fatty acids, pigments, vitamins, proteins/peptides, carbohydrates, and exopolysaccharides, among others [5,6]. These microbial autotrophs produce and secrete extracellular polymeric substances, mainly consisting of PS, but in this surrounding biofilm, also proteins, nucleic acids, and lipids may be present [7]. These diverse extracellular PS can be released to the medium as a byproduct [3].

Microalgae and cyanobacteria contain PS on their outer cell surface (as their main constituent of the cell wall), which forms a protective gel-like matrix to protect the microalgae from different environmental stressors, such as temperature changes, UV radiation, and predation [8].

Most microalgal and cyanobacterial extracellular polysaccharides are heteropolymers with complex chemical structures, consisting of glucose, galactose and xylose, other monosaccharides such as rhamnose, iduronic acid, and fucose, and different sulfate content. These eukaryotic and prokaryotic microbial PS have various biological functions, protection from fluctuations in environmental conditions and/or predators, sorption of organic and/or inorganic compounds, adhesion, biofilm, protection from antimicrobial agents, exportation of cell components, water retention and protection against desiccation, bacteria aggregation, also being pioneers in the colonization of soils and a nutrient source for a bacterial community [9–11]. Cyanobacterial PS could protect from harmful effects of oxygen and serve as a chelator for iron and calcium [12], aid in the fixation of nutrients, locomotion, attachment to solid substrates, formation of colonies and especially to provide protection against adverse conditions and predators, sorption of organic and/or inorganic compounds, binding of enzymes, sink for excess energy, adhesion, biofilm, water retention, aggregation, and nutrient source for a bacterial community adhesive, structural, protection against abiotic stress, bio weathering processes, gliding motility, and nutrient repositories in phototrophic biofilms or biological soil crusts [11,13,14].

These extracellular polysaccharides that are exuded and released to the medium are usually denoted as exopolysaccharides, extracellular, exocellular, or released polysaccharides (R-EPS). However, part of the polysaccharides is not completely excreted into the medium and remains more or less attached to the cell surface (also known as bound-EPS, B-EPS) [10,11,15]. Those produced from cyanobacteria can be divided into i) slime or released polysaccharides, poorly linked to the cell surface, ii) sheath polysaccharides in a thin layer next to the outer cell membrane, and iii) capsular polysaccharides (CPS) tightly bound [10,13,16,17].

For extracellular polysaccharides extraction and purification, different methods can be used; alcoholic precipitation with coprecipitation of salts to obtain R-EPS gives a low-purity product, so that, to achieve higher purity, purification techniques such as dialysis or ultrafiltration are used combined with alcoholic precipitation. Different chemical methods, such as acid or alkali extraction (using ethylene diamine tetra acetic acid (EDTA) or sodium hydroxide), and physical methods, such as hot water extraction or cationic resin, are used for releasing B-EPS, before proceeding with the alcoholic precipitation [8].

Since EPS derived from these natural sources are nontoxic, biodegradable, and biocompatible, they can represent an alternative source of polysaccharides [18,19]. Their recovery and valorization contribute to the economic and environmental compatibility and sustainability of zero-waste microalgal biorefineries [20]. However, EPS-derived commercial products are still being developed, and significant research remains to be completed [21].

The increasing interest in the production of value-added compounds and biofuels from algae requires the production of microalgal biomass. The extracellular polysaccharide produced simultaneously with biomass and secreted to the culture medium in the algal culture process remains as a by-product in the waste liquid streams, which are often discarded into the environment. They can be valorized, thus reducing the production cost of the microalgae lipids for preparing the biodiesel [7,22]. At the end of cell growth, the medium, generally regarded as waste [23], so that the recovery of R-EPS from spent cultivation medium is a practicable proposition in a bio-refinery-like approach to *Spirulina* sp. cultivation [8].

The ease of recovery from the extracellular environment has increased the attention of researchers on EPS for applications in different sectors based on their biocompatibility, biodegradability, and unique rheological and biological properties [24]. Microalgae and cyanobacteria can produce exopolysaccharides' compounds which exhibit various physico-chemical properties, including stabilizing, thickening, gelling, texturizing, flocculating, emulsifying and water retention, of interest for a range of industrial applications in cosmetics, textiles, pharmaceuticals, adhesives, detergents, food additives and wastewater treatment [25–27]. In addition, these EPS exhibit biological properties including antioxidant, anti-inflammatory, antimicrobial, antiviral, antiproliferative, antihypertensive, antilipidemic, anti-diabetic, and immunomodulatory [28,29], with application in cosmetics, pharmaceuticals, nutraceuticals, and functional foods [1,15,30,31].

The mechanical properties can offer commercial applications such as bio-lubricant, emulsifier, foaming agent, thickener, and water retention activity [7,24], but they are not competitive with those from other sources. Their wide variety of biological activities, biodegradability, natural origin, and nontoxicity make them ideal bioactive compounds to be used in the cosmetic and health care industry [7,15].

Despite the unique composition, structure, with interesting rheological and biological activities of EPS from microalgae and from cyanobacteria, the research on seaweed polysaccharides is still more intense, and also the industrial exploitation [32,33]. Due to the higher production costs compared to polysaccharides from terrestrial plants and macroalgae, only microbial polysaccharides with unique properties, having a niche market, are commercialized and this could be the case for microalgal and cyanobacterial EPS [10,15].

As Pierre et al. [11] have proposed, low market value industrial products are not the best option for microalgal EPS because the production costs remain 10-100 times higher than for terrestrial, bacterial, and seaweed polysaccharides. Other microbial polysaccharides became commercially relevant and overcame the producing costs by operating in a niche market. Some pharmaceutical and cosmetic high value applications could be potential. The need for well-defined polysaccharidic structures and authorizations required in the pharmaceutical applications, makes this market not yet adequate for microalgae polysaccharides. Although the cosmetic market could receive polysaccharides of microalgae, only a small number of examples are commercialized; for example, EPS from red microalgae or spirulan from *Arthrospira* strains [11,13]. There is interest in screening algal strains for new polysaccharides that may compete with traditional polysaccharides for rheological properties, bioactivities, as well as for the integration into nanobiotechnology applications for stabilization of nanostructures with antimicrobial, antioxidant, and/or anticancer properties [19,26].

Several recent reviews have addressed the strategies for sustainable production, recovery, purification, chemical and structural determination, biological activities and applications, of EPS obtained by microalgae and cyanobacteria [1,2,4,6,9,10,13,15,24,27,30,34–36]. The main opportunities and challenges in relation to the manufacture of these compounds. Also, insights into the main challenges and future prospects for market investments were surveyed [11,26]. In any case, their use in cosmetics as active ingredients is still limited.

Figure 1 summarizes the key steps in microalgal polysaccharide production, extraction, and biofunctional applications.

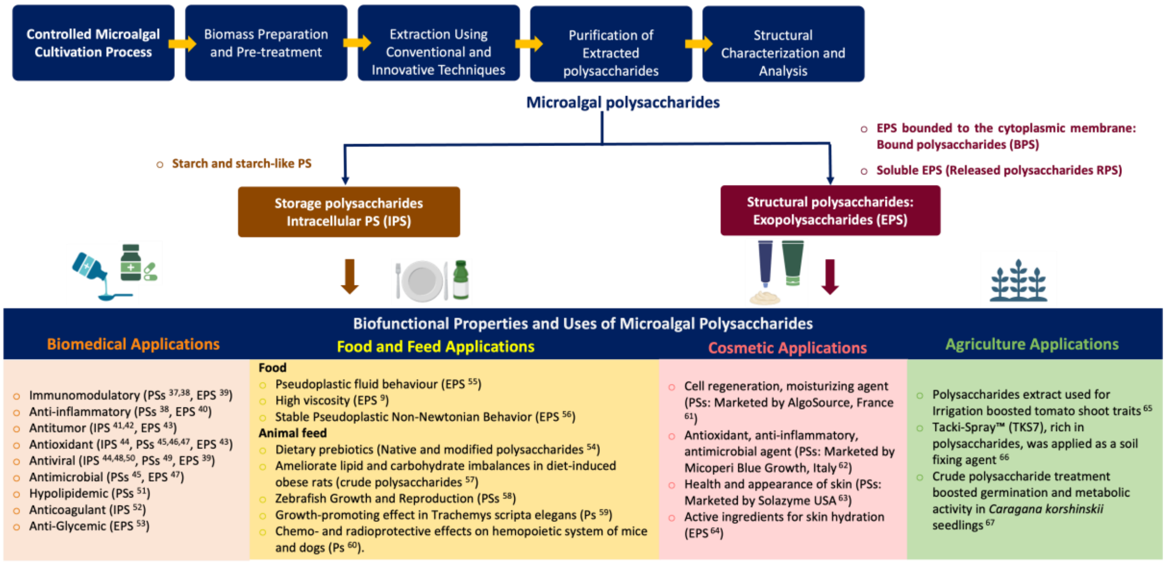

Figure 1. Flowchart illustrating key steps in microalgal polysaccharide production, extraction, and biofunctional applications, with examples from biomedical, food, cosmetic, and agricultural fields (Ps: polysaccharides, PSs: Sulfated polysaccharides, EPS: Exopolysaccharides, and IPS: Intracellular polysaccharides). [9,37–67].

2. Composition and Structure

Microalgae and cyanobacteria EPS are complex heteropolymers. Their composition varies between 3 and 8 monosaccharides, with a variety of substituents, sulfation, and a high molecular mass of around 106 Da [15]. The diversity of monosaccharide constituents, the presence of non-sugar substituents, the apparent absence of repeating units, and the branched structure collectively complicate their characterization.

EPS from microalgae and cyanobacteria are heteropolymers mainly composed of xylose, glucose, and galactose, in different ratios [33]. Other sugar constituents, such as mannose, rhamnose, arabinose, fucose, fructose, and ribose are also present. The polymers have different sulfate contents (1–9%, w/w), with the sulfate groups being attached to glucose and galactose in the 6 or 3 position [9]. Minor components have also been reported, i.e., *Porphyridium* sp. mucilaginous polysaccharide; it is generally composed of about ten monosaccharides, sulfate, proteins, and possibly phenols [68].

The composition of some EPS is variable from species to species and sometimes affected by the growth conditions, recovery, and purification/analysis methods [10,15]. So that the compositions can vary both with culture conditions and with the methodology used for extraction and quantification [33. In addition, contradictory results which can be explained by the culture conditions of microalgae, the analytical methods, and the origins of strains usually non-axenic.

The chemical and structural complexity has experienced limited research despite the critical need to determine potential applications [4,18]. The variations in monosaccharide compositions have also resulted in different physicochemical and biological functionalities. The composition influences the bioactivity and also structural features, such as sulfate groups for antiviral, antitumor, anti-inflammatory, and anti-oxidative, antitumor, antiviral, or antioxidant agents. The type and content of monosaccharides are closely related to biological activities, including antioxidant, anti-inflammatory, antitumor, and antimicrobial have been related to their molecular weight, sulfate, uronic acid, or charged group content [2].

Some examples are: uronic acids will confer a negative charge to the polymer, which can influence biological and/or physico-chemical properties. The presence of non-sugar components is also of great importance because they can also influence these properties. Methyl groups can cause high viscosity via hydrophobic interactions [24], and sulfate content is another important component, and could be responsible for important bioactivities. For instance, in red microalgal species, the highest antiviral activity was found in the polysaccharide having the highest sulfate content [9].

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 August 2025 doi:10.20944/preprints202508.0395.v1

The other unique feature of cyanobacterial strains exposed to high sunlight areas is the presence of scytonemin, mycosporine, and other found in capsule-bound EPS [24].

On the other hand, there is growing interest in the large-scale production of cyanobacterial EPSs due to their potential industrial applications, such as their use as gums, bio-flocculants, soil conditioners, and biosorbents. Some commercial examples are Nostoflan, Spirulan, Immulan, and Emulcyan produced by *Nostoc flagelliforme*, *Arthrospira platensis*, *Aphanotece halophytica*, and *Phormidium*, respectively [13]. Other cyanobacterial EPSs also deserve mention, as cyanoflan from *Cyanothece* sp. [69], and sacran from *Aphanothece sacrum* [24].

3. Properties of EPS of Interest for Skin Care Products

In the formulation of cosmetic and cosmeceutical products, different ingredients are required, including i) those conferring techno-functional and sensorial properties, including thickeners, emulsifiers, antioxidants, preservatives, etc., and ii) the active ingredients, responsible for the final action of the product.

Figure 2 summarizes the main composition of cosmetics and cosmeceuticals.

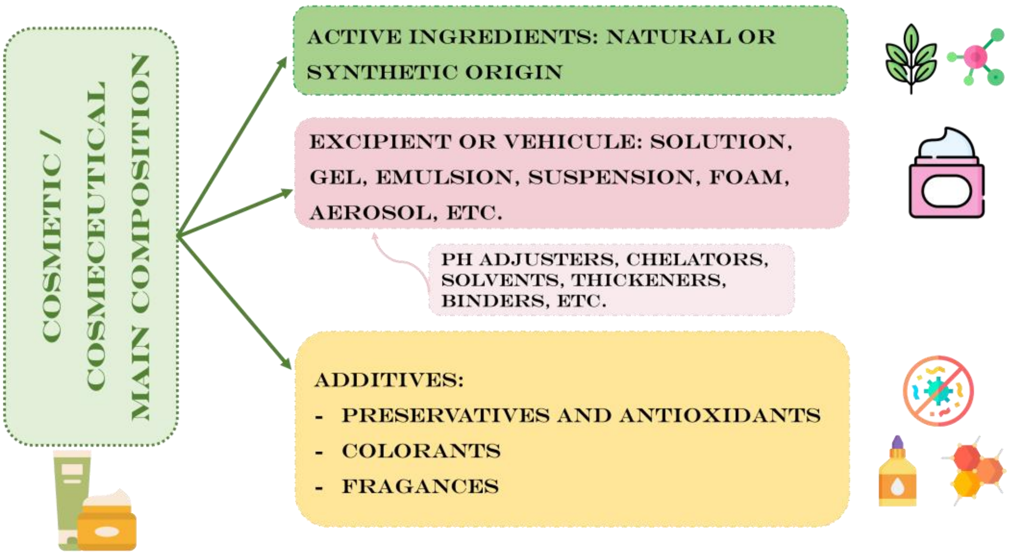

Figure 2. Main composition of cosmetics and cosmeceuticals.

3.1. Techno-Functional Properties of Microalgal EPS

Microalgal and cyanobacterial EPS exhibit mechanical properties of interest for the formulation of cosmetics, and with the potential to replace those from chemical synthesis.

Rheological properties of EPS are of deep interest since they can be used as excipients as well as gelling agents, thickeners, etc.

The presence of acidic components has been related to the protective role against desiccation due to the water retaining ability [3]. The development of novel and specific applications based on their weak gel behavior is expanding. Furthermore, their combination of cell wall polysaccharides and microalgal biomass to join both structural and bioactive properties has been proposed for food applications [70]. For instance, the solution with 1% EPS from whey wastewater cultivated *Chlorella vulgaris* showed rheological profiles similar to those of the 0.4 % commercial xanthan gum [21], one of the most used gelifying agents in organic cosmetics. The rheological properties of microalgae and cyanobacteria EPS are comparable to those of industrial polysaccharides, such as xanthan, making them suitable for industrial applications [71].

Extracellular polymeric substances can be alternative encapsulating agents, a cosmetic use on the rise, so that controlled release systems made of EPS may have potential use in cosmetics and nutraceuticals. Estevinho et al. used the EPS from the marine cyanobacterium *Cyanothece* sp. CCY

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 August 2025 doi:10.20944/preprints202508.0395.v1

0110 to encapsulate vitamin B_{12} in spherical 8 μm microparticles, the addition of arabic gum allowed smaller sizes [72].

EPS from microalgae may also be used as emulsifying agents and stabilizers. Phormidium J-1, a hydrophobic, benthic cyanobacterium, produced a polymeric extracellular emulsifying agent called emulcyan [73], which can be regarded as a renewable and eco-friendly emulsifying agent [74]. Exopolymers from the cyanobacterium *Nostoc muscorum* at 1% in hydrocarbons and vegetable oils exhibited good emulsifying properties with excellent stability [75]. Their anti-settling properties have also been confirmed; rhamnofucans EPS from *Glossomastix* sp. have been proposed as anti-settling stabilizers, showing more stable microcrystalline cellulose particle suspensions than alginate solutions [71].

Microalgae and cyanobacteria EPSs are also being investigated as preservatives and antioxidant additives in skin care product formulations. Cosmetics antimicrobial preservatives are ingredients added to beauty and personal care products to prevent microbial growth, which can lead to spoilage, product degradation, and potential health risks, aimed to extend the shelf life of products and ensure they remain safe for use over time. Green cosmetics formulation seeks antimicrobial preservatives less harmful and safer, and algal EPS can fulfill that function. One of the most well-known antimicrobials is calcium spirulan from *Arthrospira platensis* that showed strong antiviral activity [76,77].

Other preserving additives are antioxidants, which are needed to protect from oxidation and to prolong the shelf life of lipid-containing products. They can be of interest in cosmetics to prevent lipid oxidation; for example, sulfated algal EPS can prevent the accumulation of free radicals and reactive species [10], with significant reducing and antiradical properties, although lower than those of ascorbic acid [25].

3.2. Microalgal EPS Bio-Activities

Biological properties of EPS have been investigated, mainly for pharmacological and nutritional purposes. Several studies showed the anti-inflammatory [31,78], antitumor [4,14,79], anti-hyperglycemic [68], anticoagulant [80], and the aforementioned antioxidant activity [10,25]. Other actions have been reported, among them antitussive and bronchodilator effects [40,81], and immunomodulatory activity [82].

Another field of interest is the use of microalga EPS as a source of prebiotics, both for nutraceuticals and cosmetics [83].

All of this leads us to consider that EPS can be included in cosmetic formulations as active ingredients, exerting antioxidant, anti-inflammatory, and immunomodulatory activities. The following section summarizes the potential uses of EPS in cosmetics and cosmeceuticals. The main patents currently on the market are also described in section 5.

4. Microalgae and Cyanobacteria Exopolysaccharides: Cosmetic Properties and Potential Uses

The use of algae-derived metabolites in cosmetics is currently increasing, driven by the wide variety of biologically active compounds that can be obtained, and the growing consumer awareness and preference for eco-friendly, natural ingredients [84].

As has been previously mentioned, the biological activities of exopolysaccharides from microalgae and cyanobacteria have been investigated for nutritional and pharmacological uses (mainly their anti-inflammatory, immunomodulatory, and antiviral activity). However, its uses in cosmetic and cosmeceutical formulations are recent. In addition to their potential as active ingredients, microalgae EPSs may be of interest in the cosmetic industry for uses as thickeners and gelling agents.

Table 1 shows a short description of the composition and the properties of microalgae EPS and their potential use in the cosmetic field.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 August 2025 doi:10.20944/preprints202508.0395.v1

Table 1. Activities of microalgal EPS and its potential use in the cosmetic field.

Genus /Species / Strain	EPS	Activity	Reference	Potential cosmetic use
Spirulina platensis	Calcium spirulan (Rha, Rib, Man, Fru, Gal, Xyl, Glu, GlcA, GalA, sulfate, and calcium)	Antiviral: replication inhibition of several enveloped viruses	[76]	Antimicrobial (active ingredient/preservative)
Porphyridium sp	Main sugars: Xyl, Glc, Gal Glycoproteins and sulfate	In vitro: Inhibition migration of polymorphonuclear leucocytes In vivo: Inhibition induced cutaneous erythema	[85]	Anti-inflammatory
Nostoc flagelliforme	Nostoflan (Glc, Gal, Xyl, and Man)	Potent anti-herpes simplex virus type 1 (HSV-1) activity	[86]	Antimicrobial (active ingredient/preservative)
Arthrospira platensis	Calcium spirulan	Antiviral: Inhibition of orthopoxvirus and other enveloped viruses	[77]	Antimicrobial (active ingredient/preservative)
Rhodella reticulata	Deproteinized EPS	Antioxidant	[87]	Antioxidant
Arthrospira platensis	Methanolic and aqueous EPS extracts (composition not reported)	Antibacterial Antioxidant	[88]	Antibacterial (preservative) Antioxidant
Porphyridium cruentum	Main sugars: Xyl, Gal, Glu	Inhibition of the collagenase, elastase, and hyaluronidase activity	[89]	Antiaging
Nostoc flagelliforme	41.2 % Glc, 21.1 % Gal, 21.0 % Man, 2.5 % Fru, 3.6 % Rib, 1.7 % Xyl, 0.6 % Ara, 3.0 % Rha, 0.9 % Fuc, and 4.3 % GlcA	Strong emulsion-stabilizing capacity	[90]	Emulsifier and stabilizer
Porphyridium cruentum	Carbohydrates and uronic acids Main sugars: Gal, Glu, and Ara; Minor: Man, Fuc, Xyl, Rha	Antibacterial and antiviral activities High viscosity values at low shear rates	[91]	Antibacterial (preservative) Rheological agent
Nostoc carneum	Xyl, Glu, and uronic acid	Antioxidant Pseudoplastic fluid behavior	[92]	Antioxidant Gelling and emulsifier agent
Cyanobacterium aponinum	GalA/Fuc/3-OMe-GalA/Glc/Ara/Gal/Man/Rha in a molar ratio of 24:24:17:16:10:4:3:2	Production of immunosuppressive cytokine IL-10	[93]	Anti-inflammatory
Graesiella sp.	Carbohydrate (52 %), uronic acids (23 %), ester	Scavenging activity	[94]	Antioxidant

 doi:10.20944/preprints202508.0395.v1

	sulfate (11 %), and protein (12 %) Carbohydrate fraction: Glc, Gal, Man, Fuc, Rha, Xyl, Ara, and Rib			
Anabaena sp. CCC 745	Heteropolysaccharide composed of Glc, Xyl, Rha, and GlcA	Antioxidant Pseudoplastic fluid behavior	[55]	Antioxidant Rheological agent
Anabaena sp. CCC 746	Main monosaccharides Glc, Xyl, and GlcA	Antioxidant Scavenging activity Pseudoplastic fluid behavior	[95]	Antioxidant Rheological agent
Phormidium sp ETS05	Xyl, Rha, Glc, Man, Ara, GlcN, GalA, and GlcA	Anti-inflammatory activity	[96]	Anti-inflammatory
Porphyridium cruentum	Glc and carboxylic acid compounds	Immune response against vibriosis	[97]	Antibacterial (preservative)
Tetraselmis suecica	Glc (23–37%), GlcA (20–25%), Man (2–36%), Gal (3–25%) and galactoryranoside (5–27%), GalA, (0.1–3%), Ara (5%), Xyl (0.3–3%) and Rib, Rha and Fuc (1%)	Antioxidant	[98]	Antioxidant
Porphyridium sordidum	Gal (~40%), Xyl (~30%) and Glu (~30%)	Plant antifungal activity	[99]	Antifungal (preservative)
Nostoc sp	α-Rib, α-Glc, α-LAra, α-Xyl, α-LRha, β-Man, β-Gal, GalA, and β-LFuc	Fibroblast proliferation and migration	[100]	Wound healing Skin barrier repair
Scenedesmus acutus	Octa-saccharides	Antioxidant	[101]	Antioxidant
Chlorella sorokiniana, Chlorella sp., Picochlorum sp	Sulfated EPS	Antioxidant	[80]	Antioxidant
Nostoc cf. *linckia*	Dominant neutral saccharides, Glu, Gal, Xyl, and Man, and minor amounts of Rha, Fuc, and Ara	Antioxidant	[102]	Antioxidant
Gloeocapsa gelatinosa	Man (~22%), Xyl (~9%), Ara (~10%) GalA (~7%), and GlcA (~8%), Rha (~12%), Fuc (~40%)	Free radicals' scavenger Antioxidant Metal chelating activity	[103]	Antioxidant Chelating agent
Botryococcus braunii	HMW heteropolysaccharides: uronic acid (7.43–8.83%), protein (2.30–4.04%), and sulfate groups (1.52–1.95%). Gal (52.34–54.12%), Glc (34.60–35.53%), Ara (9.41–10.32%), and Fuc (1.80–1.99%)	Antioxidant	[104]	Antioxidant

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 August 2025 doi:10.20944/preprints202508.0395.v1

Porphyridium cruentum (CCALA415)	Neutral monosaccharides: D- and L-Gal, D-Glc, D-Xyl, D-GlcA, and sulfate groups	Anti-inflammatory Antioxidant Enhancement of wound closure	[23]	Anti-inflammatory Antioxidant Skin barrier repair
Porphyridium cruentum, Chrysotila dentata, Pavlova sp., *Diacronema ennorea, Glossomastix* sp., *Phaeodactylum tricornutum, Synechococcus* sp.	*P. cruentum* EPS: Gal (44%), Xyl (39%), and Glc (14%). *C. dentata, Pavlova* sp., *D. ennorea, P. tricornutum*, and *Synechococcus* sp. EPS: Gal (26–38%) and Ara/Xyl (36%/17%), Rha/Glc (47%/11%), Rha/Ara (33%/17%), Glc/Ara (42%/13%), and Glc/Fuc (38%/ 24%), respectively. *Glossomastix* sp. EPS Fuc/Rha/ GalA (40%/31%/21%)	MMP-1 inhibition Stimulation of collagen production in cell lines CDD-1059Sk and CDD-1090Sk	[105]	Stimulation of skin collagen production (preventing ageing)
Auxenochlorella protothecoides	Gal (42.41 %) and Rha (35.29 %)	Inhibition of the inflammatory response in lipopolysaccharide induced RAW264.7 cells	[31]	Anti-inflammatory
Halamphora sp	Xyl (40.55%), l-Gal (13.25%), d-Gal (13.00%), Glc (9.95%) and ribitol (9.82%)	Antimicrobial activity	[106]	Antimicrobial (preservative)
Glossomastix sp	Rha and Fuc as major monosaccharides and Gal, GalA and GlcA as minor monosaccharides	Anti-settling stabilizers	[71]	Rheological agent
Arthrospira maxima	Heteropolymer, with Man, Xyl, and GlcA	Antibacterial activity Antioxidant	[107]	Antibacterial (preservative) Antioxidant

Ara, arabinose; Fuc, fucose; Gal, galactose; GalA, galacturonic acid; Glc, glucose; GlcA, glucuronic acid; GlcN, glucosamine; Man, mannose; ManA, mannuronic acid; Rha, rhamnose; Rib, ribose; Xyl, xylose.

The first studies published in the 1990s emphasized the antiviral properties of exopolysaccharides. Two studies related to Calcium Spirulan (Ca-SP) obtained from *Spirulina platensis* (currently *Arthrospira platensis*) demonstrated that Ca-SP was able to inhibit the replication of several enveloped viruses, including herpes simplex virus type 1, human cytomegalovirus, measles virus, mumps virus, influenza A virus, and HIV-1. Ca-SP was found to selectively inhibit virus penetration into host cells. The antiviral effect was suggested to be related to the retention of molecular conformation by chelating calcium ions with sulfate groups [76,77]. Later studies showed that *Arthrospira platensis* EPS methanolic and aqueous extract (exact composition not reported) exerted antibacterial activities on both Gram (+) and Gram (−) organisms, highlighting that the methanolic extract showed the broadest activity spectrum, resulting in effective inhibition against three microbial strains *P. aeruginosa*, *S. typhimurium*, and *M. luteus*. And the aqueous extracts were only effective against two strains, *S. epidermis* and *S. typhimurium* [88]. Recent investigations showed that *Arthrospira maxima* also exert antibacterial activity against several strains, such us *Bacillus subtilis* (MIC: 0.6 ± 0.05 mg/mL), *Bacillus cereus* (MIC: 1 ± 0.01 mg/mL), *Escherichia coli* (MIC: 0.8 ± 0.01 mg/mL)

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 August 2025 doi:10.20944/preprints202508.0395.v1

and *Klebsiella pneumonia* (MIC: 0.8 ± 0.01 mg/mL). This strain also showed antioxidant activity (DPPH radical scavenging assay), and also denoted interesting emulsifying properties [107].

Other microalgal and cyanobacterial EPS showed antimicrobial activities. Nostoflan (Glc, Gal, Xyl, and Man rich), from *Nostoc flagelliforme*, showed a potent anti-herpes simplex virus type 1 (HSV-1) activity, and also antiviral activities against HSV-2, human cytomegalovirus, and influenza A virus, with the advantage that it does not show antithrombin activity, unlike other sulfated polysaccharides [86]. EPS from genus *Porphyridium* also showed antibacterial and antiviral activities [91,97; some of them also have antifungal activity as *Porphyridium sordidum* characterized by a high content on Gal (~40%), Xyl (~30%), and Glu (~30%) [99]. And diatom *Halamphora* sp EPS demonstrated low activity against Gram (+) bacteria, and moderate activity against Gram (−) such as *Escherichia coli* [106].

These antimicrobial activities are of great interest, as the cosmetic industry seeks natural antimicrobial preservatives to mitigate and prevent adverse reactions caused by synthetic ones. On the other hand, they may also be of interest as active ingredients in the treatment of acne. Antifungal activity could also be relevant for the development of natural cosmetic preservatives.

The antioxidant capacity of EPS has also been demonstrated in several studies. Thus, the aforementioned EPS methanolic extracts from *Arthrospira platensis* showed a high antioxidant activity [88]. Chen et al. compared crude ESP and deproteinized EPS from *Rhodella reticulata,* finding that both of them exerted free radical scavenging and antioxidant activity in a dose-dependent manner, but crude EPS exhibited higher free radical scavenging capacity and better antioxidant activity than the various treatments of crude EPS samples. In addition, the superoxide anion radical scavenging ability of various samples was significantly higher compared to the standard antioxidant (α-tocopherol) [87]. And the aqueous extracellular polysaccharides from the thermophilic microalgae *Graesiella* sp. exerted a moderate scavenging activity [94].

Nostoc species and strains EPS also showed antioxidant activity. Thus, *Nostoc carneum* ESP demonstrated to possess antioxidant activity, but also showed non-Newtonian pseudoplastic behavior or shear thinning property in aqueous solutions, that could be of interest in the cosmetic industry to be used as gelling and emulsifier agents (allowing products like lotions to flow through a pump and spread easily on the skin) [92]. *Nostoc* cf. *linckia* also showed antioxidant properties, finding that the crude polymer and its purified fractions, as well as deproteinized EPS, possessed higher antioxidant capacity than other similar polysaccharides from *Nostoc flagelliforme*, and *N. commune* [102].

EPS from *Anabaena* sp. CCC 745, and *Anabaena* sp. CCC 746 exhibited significant antioxidant and scavenging activity [55,95]. EPS from *Tetraselmis suecica* (Kylin) Butcher also showed antioxidant activity; the authors suggested that this could be related to the percentage of galacturonic and glucuronic acids present in the constitution of the EPS of *T. suecica* [98]. Octa-saccharides from *Scenedesmus acutus* also presented scavenging activity [101], and EPS from the thermophilic *Gloeocapsa gelatinosa* demonstrated a high activity as free radicals' scavenger, as well as metal chelating activity, both activities being of interest in the field of cosmetics [103].

Other studies showed that crude EPS from a very well-known energy microalgae strain *Botryococcus braunii* showed strong antioxidant activity, so that it can be considered a good source of antioxidants for the food and cosmetic industry [104]. Mousavian et al. investigated sulfated EPS from the marine green microalgae *Chlorella sorokiniana, Chlorella* sp., and *Picochlorum* sp, finding that sulfated EPS with the higher sulfate/sugar ratio presented potent ABTS radical scavenging activity [80].

Other studies focused on reversing the activity of some enzymes involved in aging. *Porphyridium cruentum* EPS were shown to inhibit the activity of enzymes like collagenase, elastase, and hyaluronidase, which play roles in skin degradation and aging. This inhibition suggests a potential role for *Porphyridium cruentum* SPs in developing cosmetic products with anti-aging and regenerative effects [89].

Studies have also been carried out on the applications of a mixture of *Haslea ostrearia* EPS and marennine (a blue pigment obtained from this marine diatom) to improve skin hydration and prevent aging, although the composition of the EPS is not shown in this work [108].

In addition to the aforementioned antioxidant activities, EPS from the genus *Porphyridium*, with acidic characteristics, may have potential applications in cosmetics as an inhibitor hyaluronidase, anti-allergic and anti-inflammatory agents [85], as well as antioxidant activity, and anti-inflammatory properties [91]. For example, *Porphyridium cruentum* (CCALA415) EPS showed anti-inflammatory activity comparable to that of ibuprofen and helped tissue regeneration [23].

Other microalgal strains can also exert anti-inflammatory properties. EPS from *Cyanobacterium aponinum*, the dominating member of the Blue Lagoon's microbial ecosystem, was able to stimulate DCs to produce vast amounts of the immunosuppressive cytokine IL-10 [93]. EPS from *Phormidium* sp. ETS05, the most abundant cyanobacterium of the therapeutic Euganean thermal muds, exerted anti-inflammatory and pro-resolution activities in chemical and injury-induced zebrafish inflammation models [96]. And *Auxenochlorella protothecoides* EPS, rich in Gal (42.41 %) and Rha (35.29 %), inhibited the inflammatory response in lipopolysaccharide induced RAW264.7 cells by quenching inflammatory factor levels such as ROS, iNOS, TNF-α, and IL-6 [31].

In order to investigate the potential anti-aging properties, Toucheteau et al. studied several microalgal strains, as *Porphyridium cruentum*, *Chrysotila dentata*, *Pavlova* sp., *Diacronema ennorea, Glossomastix* sp., *Phaeodactylum tricornutum*, *Synechococcus* sp. EPS were isolated and depolymerized, and tested, finding that native microalgae EPS were able to inhibit 27% of human matrix metalloproteinase-1 (MMP-1) activity while the depolymerized forms were able to enhance collagen production by two different human fibroblast lines. Results also showed that MMP-1 inhibition was strongly correlated to the sulfate group content of EPS whereas collagen production by fibroblasts was mostly related to their proportion of LMW polysaccharides (<10 kDa) [105].

As preventing and slowing aging is one of the goals of cosmeceuticals and skin care products, EPS seems to be a suitable ingredient, combined with other natural bioactive substances, in the formulation of specific dermocosmetics focused on antioxidant and anti-ROS bioactivities.

The wound healing properties of certain EPSs are also of interest in the formulation of cosmeceuticals aimed at enhancing skin barrier repair and promoting epithelialization. Thus, Álvarez et al. investigated two *Nostoc* sp. strains (PCC7936 and PCC7413) to be used as a biomaterial for new wound dressings, finding that both strains could promote fibroblast migration and proliferation, been greater activity in PCC7936 (in vitro assay) [100]). Vázquez-Ayala et al. designed wound dressings loaded with metformin for diabetic foot healing, combining EPS from *Porphyridium purpureum* with fucoidan and chitosan. Interestingly, metformin-loaded chitosan sponges regenerated skin tissue after 21 days of treatment, highlighting the healing rate achieved when exopolysaccharides were added to promote tissue regeneration. Additionally, the sponge composites exerted antibacterial activity and were neither cytotoxic or hemolytic [109].

Other properties of microalgal and cyanobacterial EPS may have potential applications in cosmetics, as they can be used as emulsifiers and stabilizers. *Nostoc flagelliforme* EPS demonstrated strong emulsion-stabilizing capacity [90], and *Porphyridium cruentum* EPS in aqueous solutions with 2% (w/v) showed high viscosity values at low shear rates [91]. *Nostoc carneum EPS,* rich in Xyl, Glu, and uronic acid, presented pseudoplastic fluid behavior [92]. *Anabaena* sp. CCC 746 and *Anabaena* sp. CCC 746 both presented pseudoplastic fluid behavior, in addition to the aforementioned scavenging activity [55,95]. Finally, the *Glossomastix* sp EPS anti-settling stabilizers properties deserve to be cited, as they may have potential use as rheological agents in the cosmetic formulation of gels and creams [71].

5. Patents Claiming the Use of Microalgal and Cyanobacterial EPS in Skin Care

Different patents claiming the incorporation of microalgal and cyanobacterial EPS for skin care non-therapeutic formulations to enhance the health and appearance or texture of skin have been registered [110–113]. Most of them are designed for topical application but also for oral or injection into skin tissue [111]. Some examples are shown in Table 2. The products are not always obtained from pure cultures, also exopolysaccharides obtained by fermentation are isolated from marine bacteria found in a cyanobacterial population on a kopara microbial mat [114].

Polysaccharides can be precipitated by adding compounds such as cetylpyridinium chloride, isopropanol, ethanol, or methanol to an aqueous solution containing the polysaccharide. Membrane filtration can be used to concentrate polysaccharides and remove salts. Polysaccharides can also be dialyzed to remove excess salt and other small molecules. Anionic polysaccharides can be purified by anion exchange chromatography [110,111] or by immobilized metal affinity chromatography [115].

Polysaccharides can be treated with proteases to degrade contaminating proteins attached, either covalently or noncovalently, and after digestion, the polysaccharide is purified from residual proteins, peptide fragments, and amino acids. Heat treatment can also be used to eliminate proteins, amino acids, peptides, and salts [111]. In some cases, heterotrophically produced microalgal polysaccharides or extracts have pigments as a by-product of the fermentation process. In some cases, discoloration is used to remove undesirable coloration and pigments destined for cosmetic or nutraceutical formulation. Among the methods are bleaching, solvent extraction, adsorption, enzyme treatment, washing with acid, alcohol or with salt solution [111]. In other cases, simplicity is preferred and low-cost obtention of the product allows high presence of glycoproteins rich in hydroxyproline, an important component of collagen [115].

The obtained polysaccharides may be with any level of sulfation [111], with molecular weights in the range 30-100 kDa [116], and they can be structurally modified both enzymatically and chemically, and modifications include sulfation, phosphorylation, methylation, O-acetylation, fatty acylation, amino N-acetylation, N-sulfation, branching, and carboxyl lactonization [111]. Depolymerization has been also explored after a pretreatment by high pressure (2.7 kbar) and freeze-drying, i.e., by acid hydrolysis onto cationic resins (Amberlityst® 15 DRY) in batch or in continuous mode to increase the production of collagen and/or hyaluronic acid, in order to delay the effects of skin aging [116] (. Normal human dermal fibroblast viability was reduced by 20-80% in the presence of depolymerized EPS, due to the ralentization of growth metabolism and orientation to collagen and hyaluronic acid synthesis.

Different formulations in the cosmetic products add the exopolysaccharides wet, dialyzed or non-dialyzed [117], or dried by lyophilization or dried to form a film by heating the microalgal EPS at 135-160 °C [112].

The EPS can be added to the cosmetic at 0.1 to 10% (w / w) of the cream formulation [117]. Higher content has also been proposed, i.e., [118] is a composition comprising 2-60 wt% of a sulfated polysaccharide for moisturizing the skin. The final composition has to be sterile or substantially free of endotoxins and/or proteins [111]. Products may contain one or more microalgal polysaccharides, purified or semi-purified [110,111]. In some cases, secreted polysaccharides and also polysaccharides present in the cell wall, either crude, purified, or semi-purified, have been used to obtain nutraceutical, cosmeceutical, and pharmaceutical compositions [110,111].

The mixture of microalgal biomass and polysaccharides has been proposed, thus microalgal extract can include microalgal oil, proteins, lipids, carbohydrates, phospholipids, polysaccharides, macromolecules, minerals, cell wall, trace elements, carotenoids, and sterols [111], a combination of microalgal bio-products from different species to produce a product of interest. Other patent claimed the production of a water-soluble carotenoid from *Haematococcus pluvialis* or a capsular EPA from *Parachlorella* sp. and formulated compositions containing the carotenoid as sunscreen and others containing the EPS as moisturizing cream [119].

EPS are formulated with at least one excipient suitable for topical administration with a carrier, pigments, emulsifiers, fillers, preservatives, antioxidants, and optionally odor absorbers and fragrances [110,111,118]. These polysaccharides can also confer some of these actions, i.e., of forming a gel and swelling with water [110,113] can be used as enhancers of rheological and sensory characteristics, providing products with greater spread ability, consistency, less residual grease sensation, shine, drying speed, among others [117]). They also protect from oxidation. Other patent used them for making microcapsules in emulsion with DHA, which can enhance the antioxidant stability, the peroxide value data of microcapsule product relative value then reduces nearly 60%-80% [32].

Different formats are claimed, such as gel, oil, lotion, spray, cream, emulsion, and ointments for facial care and makeup, lip care, hair care, tooth and mouth washes [111,119]. Other topical formulations include impregnated bandages, biodegradable microcapsules, polymers, and artificial skin. However, the most valuable properties could be of interest to formulate cosmeceuticals, with interesting biological activities: anti-aging, healing, anti-acne, oil-reducing or cellulite properties, stimulating elastin synthesis in skin, or as anti-inflammatory agent, to improve barrier function of skin and/or to hydrate the skin [111,118], anti-inflammatory properties [111], reducing the effects of ultraviolet radiation [111], to aid in wrinkle reduction [113], antiaging [89], which can be due to inhibition of elastase, by chelating the calcium necessary for activation of the enzyme, and collagenase [89,111] or exerting antioxidant activity [22,120]. In addition, combining a growth factor, and a microalgal culture supernatant, a synergistic effect was observed increased proliferation of fibroblasts for the treatment of skin aging, photoaging and cutaneous senescence [115], to increase the production of collagen and/or hyaluronic acid, to delay the effects of skin aging [116]. In other embodiments, the composition further comprises hyaluronic acid or another agent suitable or desirable for the treatment of skin [111]. In addition, the EPS could be incorporated in nutraceuticals, i.e., as an antioxidant based on the confirmed potential for protecting food from oxidation [121].

Table 2 shows some examples of patents, including a short explanation of the production and/or main composition.

Table 2. Examples of patents claiming the utilization of microalgal EPS for the improvement of skin health and appearance.

Microalgae or cyanobacteria	EPS preparation and main composition	Application / Potential use	Applicant / Patent number	Reference
Arthrospira spirulina or *Spirulina platensis* and *Spirulina maxima*	Sulfated polysaccharide comprising from 2% to 60% by weight, based on the total weight of the polymer, of a rhamnose unit	Cosmetic skin moisturizing product compatible with cutaneous tissues (skin, scalp) Compositions with the appearance of a white or colored compositions in any form, such as ointment, milk, lotion, serum, paste, foam, aerosol or stick	L'Oréal SA FR2982152A1	[118]
Several microalgal and Cyanobacteria strains; for example, *Chlorella* sp., *Dunaliella* sp., *Tetraselmis* sp., *Anabaena* sp, *Aphanizomenon* sp., *Arthrospira* sp., *Nostoc* sp., *Isochrysis* sp., *Phaeodactylum* sp., *Skeletonema* sp., *Thalassiosira* sp., *Nannochloropsis* sp., *Porphyridium* sp., among others	An EPS of wet, non-dialyzed and non-lyophilized origin added at 0.1-10% (wt) to the cream formulation EPS composition not mentioned	Cosmetic formulation for topical use on human hair, skin, mucous membranes and nails Microalgal EPS as an enhancer of rheology, stability and sensory properties. Base cream for the addition of microalgal extracts as antioxidant, surfactant, emulsifier, emollient emulsifier; preservative and antimicrobials	Univ Fed Do Parana BR102012004631A2	[117]
Genus *Parachlorella*	Isolation and precipitation with an alcohol, ii) drying and forming a film, iii) contacting with water and forming a gel, air drying EPS average size of between 0.1 and 400 microns EPS composition not mentioned	Skin care compositions for wrinkle reduction and for improving the health and appearance of skin	Solazyme Inc Algenist Brands Inc US9095733B2	[110]

Parachlorella kessleri, *Parachlorella beijerinckii* or *Chlorella sorokiniana*	EPS composition: 15-55 mole percent of rhamnose, 3-30 percent of moles of xylose, 1-25 mole percent of mannose, 1-45 mole percent of galactose, 0.5-10 mole percent of glucose and 0.1-15 mole percent of glucuronic acid	Skin care products to deliver cosmeceutical ingredients such as carotenoids, polyunsaturated fatty acids, moisturizing polysaccharides, superoxide dismutase, etc.	Algenist Holdings Inc ES2718275T3	[111]
EPS from PUFA-producing microalgae fermentation waste liquid of *Schizochytrium* sp., or *Cryptidnodinium koushii*, or *Crypthecodinium cohnii* SD401, or *Nannochloropsis* sp	Disc centrifuge separation, micro-filtration in ceramic membrane, ultrafiltration (30 kDa) to concentrate (50-70% solids), vacuum-drying (moisture 1%). 71-73 % EPS, 9.-11% peptide and protein, 3-4 % monosaccharide content	Formulation EPS as wall material in emulsions of DHA, Tween 80 and gelatin solution protected against oxidation, spray-dried in microcapsules	Qingdao Institute of Bioenergy and Bioprocess Technology of CAS CN108559006A	[32]
Parachlorella, *Porphyridium*, *Chaetoceros*, *Chlorella*, *Dunaliella*, *Isochrysis*, *Phaeodactylum*, *Tetraselmis*, *Botryococcus*, *Cholorococcum*, *Hormotilopsis*, *Neochloris*, *Ochromonas*, *Gyrodinium*, *Ellipsoidion*, *Rhodella*, *Gymnodinium*, *Spirulina*, *Cochlodinium*, *Nostoc*, *Cyanospira*, *Cyanothece*, *Tetraselmis*, *Chlamydomonas*, *Dysmorphococcus*, *Anabaena*, *Palmella*, *Anacystis*, *Phormidium*, *Anabaenopsis*, *Aphanocapsa*, *Cylindrotheca*, *Navicula*, *Gloeocapsa*, *Phaeocystis*, *Leptolyngbya*, *Symploca*, *Synechocystis*, *Stauroneis*, and *Achnanthes*, preferably *Parachlorella kessleri.*	Isolation of microalgal EPS from the culture medium, drying at 40-180 °C to form a film insoluble in water, homogenizing the film into particles, formulating the particles into a non-aqueous material, oil phase of an oil-in-water emulsion, generating 0.1-50 microns particles EPS composition not mentioned	Topical personal care products, or by injection into skin or a skin tissue and wrinkle reduction	TerraVia Holdings Inc EP3398606A1	[112]
Parachlorella sp	Capsular exopolysaccharide obtained by separating the exopolysaccharide producing microalgal cells from the culture medium, heating the microalgal cells to release the cellular capsule, and removing the insoluble solids to produce an aqueous solution containing the EPS EPS composition not mentioned	Vehicle for personal care products	KUEHNLE AGROSYSTEMS Inc US20200232003A1	[119]

Glossomastix sp, *Chrysotila dentata*, *Pavlova* sp, *Phaeodactylum tricornutum*, *Synechococcus* sp	New depolymerized exopolysaccharides (30-100 kDa) and method of obtaining consisting on: pretreatment by high pressure (2.7 kbar), freeze-drying, depolymerization by acid hydrolysis onto cationic resins (Amberlityst® 15 DRY) in batch or in continuous mode EPS composition not mentioned	Product to increase the production of collagen and/or hyaluronic acid, to delay the effects of skin aging	Centre National de la Recherche Scientifique CNRS, Univ. Nantes, La Rochelle Univ., Sorbonne Univ., Univ. Clermont Auvergne, Univ. Rouen Normandie FR2102020	[116]
Chlorella sp	Precipitation, centrifugation, purification, and freeze-drying 131.79 kDa EPS, mainly comprises xylose, mannose and ribose	Antioxidant activity (DPPH, hydroxyl, ABTS radicals and superoxide anions)	Xiangtan University CN110818814A	[22]
Cyanobacteria of the genus *Synechococcus* CCMP 1333, *Synechococcus* PCC 7002, and *Cyanothece* Miami BG 043511	EPS isolation, drying milling to a size of between 400 microns and 0.1 microns to prepare exopolysaccharide particles; and annealing the EPS particles EPS composition not mentioned	Topical personal care products, cosmetics for improving the health and appearance of skin, and wrinkle reduction composition	Heliobiosys, Inc. US20240358628A1	[113]
Cyanobacterium *Spirulina platensis*	Enhancer of rheology, stability and sensory properties and antioxidant EPS freeze-dried or wet, dialyzed or non-dialyzed 0.1-10% (wt) of the cream formulation EPS composition not mentioned	Novel products with antioxidant, antiaging, healing, oil-reducing, antiacne, rheological and sensory properties	Univ Fed Do Parana BRPI1004637A2	[120]
Cell wall-less microalgal strain *Chlorophyceae* class or *Volvocales* order, *Chlamydomonadaceae* family, *Chlamydomonas reinhardtii*	Concentration by lyophilization or by tangential flow filtration IMAC-enriched microalgal culture supernatant comprises between 1 μg/L and 0.1 g/L of protein and between 0.001 mg/L and 10 g/L of carbohydrates	Cosmetic or cosmeceutical composition for wound healing or skin damage repair, increased proliferation of fibroblasts for the treatment of skin aging, photoaging and cutaneous senescence	Greenaltech, S.L Gat Biosciencies SL US12268772B2	[115]

Based on previous research and development, cosmetic applications have emerged that have been developed by cosmetic raw material suppliers or the brands themselves. Some examples are described below.

Silidine® is a mix of trace elements and small EPS from *Porphyridium purpureum* obtained by applying an oxidative stress to microalgae by closing the air tightly in a culture batch of 1 m^3. Silidine® claims to fight against redness and heavy legs syndrome (https://www.greentech.fr/).

Epsiline® is a modified *Porphyridium purpureum* EPS sold as a melanin booster. It is obtained from an optimized cultivation process, adjusting parameters in terms of media composition, quantity of light, and injection of carbon dioxide to reduce by one-third the time it takes to obtain EPS in photobioreactors, followed by a hydrolysis that allows the creation of a new "medium molecular weight" EPS (https://www.greentech.fr/).

Other examples are AlgoSource (https://algosource.com/) that produces dry extracts from *Porphyridium cruentum* with a very high concentration of EPS, and Alguronic acid™ by Algenist® (https://www.algenist.com/) obtained from *Parachlorella kessleri* or *Parachlorella beijerinckii* strains, which claims anti-aging skincare properties.

6. Challenges and Expected Developments

Exopolysaccharides from microalgae and cyanobacteria exhibit higher structural diversity, associated with different physicochemical and biological functionalities, than those from terrestrial plants, fungi, and macroalgae, making them attractive for potential exploitation as commercial sources of new polysaccharides [122]. However, these EPS remain underexplored for many potential applications, the market is still developing [9,24].

The industrial applications could be based on their thickening, emulsifying, stabilizing, film film-forming properties. However, they could not be competitive with polysaccharides from macroalgae and terrestrial plants. Therefore, only special and niche applications requiring properties not fulfilled by the currently available products are promising [34,123], been the cosmetic field being one of the most promising. Even in this area, further research and developments are needed, and among the major challenges in this area of research, could be mentioned *i*) bioprospection of strains and methodologies to discover reliable EPS producers of potential microorganisms and exploitable polysaccharides and understanding the metabolic pathway involved in their synthesis and release, *ii*) engineering development to optimize their production cost, i.e solar energy for cultivation and to cut the costs of downstream processes both on laboratory and at the pilot or industrial scale, *iii*) detailed physicochemical, structural and biological characterization to establish structure-activity relationships; *iv*) process development for EPS production and also the downstream processes adapted to the specific with high salts contents; and *v*) development of novel applications and marketable products [1,11,15,21,24,29,122,124,125].

One of the major limitations for microalgal and cyanobacterial EPSs commercial exploitation is the high production costs [126]. The EPS productivity and the concentration in bacteria culture medium can be ten or more times higher than in microalgae culture medium, therefore, the costs of recovery and purification from microalgae are still prohibitive [11]. Additionally, the recovery of EPS that partially remains partially attached to the cells would require additional processing to recover the bound EPS without extracting intra-cellular compounds, and the economic reliability of this additional step should be considered [11]. Therefore, the industrial uses of microalgal EPS are still limited to few niche markets with high selling prices like cosmetics.

Emphasis and further studies on the valorization of waste and underutilized streams to obtain high-value-added products in the cosmetics and cosmeceutical sectors may allow for to reduction of the use of synthetic additives, responsible for the presence of micropollutants in water. This could be a way to reuse microalgae cultivation waste while promoting green cosmetics.

Author Contributions: M.L.M.: Conceptualization, methodology, investigation, writing—original draft preparation, writing—review and editing. F.D-S., S.I., C.P.G.: Methodology, investigation, writing—review, and editing. J.L.L.: Writing—review and editing, supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Costa, J. A. V.; Lucas, B. F.; Alvarenga, A. G. P.; Moreira, J. B.; De Morais, M. G. Microalgae Polysaccharides: An Overview of Production, Characterization, and Potential Applications. *Polysaccharides* **2021**, *2* (4), 759–772. https://doi.org/10.3390/polysaccharides2040046.
2. Franco-Morgado, M.; Amador-Espejo, G. G.; Pérez-Cortés, M.; Gutiérrez-Uribe, J. A. Microalgae and Cyanobacteria Polysaccharides: Important Link for Nutrient Recycling and Revalorization of Agro-Industrial Wastewater. *Applied Food Research* **2023**, *3* (1), 100296. https://doi.org/10.1016/j.afres.2023.100296.
3. De Philippis, R. Exocellular Polysaccharides from Cyanobacteria and Their Possible Applications. *FEMS Microbiology Reviews* **1998**, *22* (3), 151–175. https://doi.org/10.1016/S0168-6445(98)00012-6.
4. Magnabosco, C.; Santaniello, G.; Romano, G. Microalgae: A Promising Source of Bioactive Polysaccharides for Biotechnological Applications. *Molecules* **2025**, *30* (9), 2055. https://doi.org/10.3390/molecules30092055.

 doi:10.20944/preprints202508.0395.v1

5. Gupta, A.; Barrow, C. J.; Puri, M. Multiproduct Biorefinery from Marine Thraustochytrids towards a Circular Bioeconomy. *Trends in Biotechnology*.
6. Nguyen, D. T.; Johir, M. A. H.; Mahlia, T. M. I.; Silitonga, A. S.; Zhang, X.; Liu, Q.; Nghiem, L. D. Microalgae-Derived Biolubricants: Challenges and Opportunities. *Science of The Total Environment* **2024**, *954*, 176759. https://doi.org/10.1016/j.scitotenv.2024.176759.
7. Jakhu, S.; Sharma, Y.; Sharma, K.; Vaid, K.; Dhar, H.; Kumar, V.; Singh, R. P.; Shekh, A.; Kumar, G. Production and Characterization of Microalgal Exopolysaccharide as a Reducing and Stabilizing Agent for Green Synthesis of Gold-Nanoparticle: A Case Study with a Chlorella Sp. from Himalayan High-Altitude Psychrophilic Habitat. *J Appl Phycol* **2021**, *33* (6), 3899–3914. https://doi.org/10.1007/s10811-021-02580-3.
8. Chaudhuri, R.; Athiyappan, K. D.; Balasubramanian, P. From Algae to Medicine: Unveiling the Therapeutic Potential of Microalgal Exopolysaccharides. In *Microbial Biotechnology: Integrated Microbial Engineering for B3—Bioenergy, Bioremediation, and Bioproducts*; Elsevier, 2025; pp 271–305. https://doi.org/10.1016/B978-0-443-23796-6.00004-3.
9. Arad, S. (Malis); Levy-Ontman, O. Red Microalgal Cell-Wall Polysaccharides: Biotechnological Aspects. *Current Opinion in Biotechnology* **2010**, *21* (3), 358–364. https://doi.org/10.1016/j.copbio.2010.02.008.
10. Delattre, C.; Pierre, G.; Laroche, C.; Michaud, P. Production, Extraction and Characterization of Microalgal and Cyanobacterial Exopolysaccharides. *Biotechnology Advances* **2016**, *34* (7), 1159–1179. https://doi.org/10.1016/j.biotechadv.2016.08.001.
11. Pierre, G.; Delattre, C.; Dubessay, P.; Jubeau, S.; Vialleix, C.; Cadoret, J.-P.; Probert, I.; Michaud, P. What Is in Store for EPS Microalgae in the Next Decade? *Molecules* **2019**, *24* (23), 4296. https://doi.org/10.3390/molecules24234296.
12. De Philippis, R.; Colica, G.; Micheletti, E. Exopolysaccharide-Producing Cyanobacteria in Heavy Metal Removal from Water: Molecular Basis and Practical Applicability of the Biosorption Process. *Appl Microbiol Biotechnol* **2011**, *92* (4), 697–708. https://doi.org/10.1007/s00253-011-3601-z.
13. Cruz, D.; Vasconcelos, V.; Pierre, G.; Michaud, P.; Delattre, C. Exopolysaccharides from Cyanobacteria: Strategies for Bioprocess Development. *Applied Sciences* **2020**, *10* (11), 3763. https://doi.org/10.3390/app10113763.
14. Sanniyasi, E.; Patrick, A. P. R.; Rajagopalan, K.; Gopal, R. K.; Damodharan, R. Characterization and in Vitro Anticancer Potential of Exopolysaccharide Extracted from a Freshwater Diatom Nitzschia Palea (Kütz.) W.Sm. 1856. *Sci Rep* **2022**, *12* (1), 22114. https://doi.org/10.1038/s41598-022-24662-z.
15. Laroche, C. Exopolysaccharides from Microalgae and Cyanobacteria: Diversity of Strains, Production Strategies, and Applications. *Mar. Drugs* **2022**.
16. Gaignard, C.; Laroche, C.; Pierre, G.; Dubessay, P.; Delattre, C.; Gardarin, C.; Gourvil, P.; Probert, I.; Dubuffet, A.; Michaud, P. Screening of Marine Microalgae: Investigation of New Exopolysaccharide Producers. *Algal Research* **2019**, *44*, 101711. https://doi.org/10.1016/j.algal.2019.101711.
17. Baptista, S.; Torres, C. A. V.; Sevrin, C.; Grandfils, C.; Reis, M. A. M.; Freitas, F. Extraction of the Bacterial Extracellular Polysaccharide FucoPol by Membrane-Based Methods: Efficiency and Impact on Biopolymer Properties. *Polymers* **2022**, *14* (3), 390. https://doi.org/10.3390/polym14030390.
18. Navarro Gallón, S. M.; Alpaslan, E.; Wang, M.; Larese-Casanova, P.; Londoño, M. E.; Atehortúa, L.; Pavón, J. J.; Webster, T. J. Characterization and Study of the Antibacterial Mechanisms of Silver Nanoparticles Prepared with Microalgal Exopolysaccharides. *Materials Science and Engineering: C* **2019**, *99*, 685–695. https://doi.org/10.1016/j.msec.2019.01.134.
19. Tiwari, O. N.; Bobby, Md. N.; Kondi, V.; Halder, G.; Kargarzadeh, H.; Ikbal, A. M. A.; Bhunia, B.; Thomas, S.; Efferth, T.; Chattopadhyay, D.; Palit, P. Comprehensive Review on Recent Trends and Perspectives of Natural Exo-Polysaccharides: Pioneering Nano-Biotechnological Tools. *International Journal of Biological Macromolecules* **2024**, *265*, 130747. https://doi.org/10.1016/j.ijbiomac.2024.130747.
20. Cheirsilp, B.; Maneechote, W.; Srinuanpan, S.; Angelidaki, I. Microalgae as Tools for Bio-Circular-Green Economy: Zero-Waste Approaches for Sustainable Production and Biorefineries of Microalgal Biomass. *Bioresource Technology* **2023**, *387*, 129620. https://doi.org/10.1016/j.biortech.2023.129620.
21. Pessoa, L. C.; Attar, S. B.-E.; Sanchez-Zurano, A.; Ciardi, M.; Morillas-Espana, A.; Ruiz-Martínez, C.; Fernandez, I.; Arrabal-Campos, F. M.; Pontes, L. A. M.; Cardoso, L. G.; de Souza, C. O.; Acien, G.; Assis, D.

de J. Exopolysaccharides as Bio-Based Rheology Modifiers from Microalgae Produced on Dairy Industry Waste: Towards a Circular Bioeconomy Approach. *International Journal of Biological Macromolecules* **2024**.
22. *CN110818814A*. https://patents.google.com/patent/CN110818814A/en.
23. Liberti, D.; Imbimbo, P.; Giustino, E.; D'Elia, L.; Silva, M.; Barreira, L.; Monti, D. M. Shedding Light on the Hidden Benefit of Porphyridium Cruentum Culture. *Antioxidants* **2023**, *12* (2), 337. https://doi.org/10.3390/antiox12020337.
24. Debnath, S.; Muthuraj, M.; Bandyopadhyay, T. K.; Bobby, Md. N.; Vanitha, K.; Tiwari, O. N.; Bhunia, B. Engineering Strategies and Applications of Cyanobacterial Exopolysaccharides: A Review on Past Achievements and Recent Perspectives. *Carbohydrate Polymers* **2024**, *328*, 121686. https://doi.org/10.1016/j.carbpol.2023.121686.
25. Bafana, A. Characterization and Optimization of Production of Exopolysaccharide from Chlamydomonas Reinhardtii. *Carbohydrate Polymers* **2013**, *95* (2), 746–752. https://doi.org/10.1016/j.carbpol.2013.02.016.
26. Morais, M. G.; Santos, T. D.; Moraes, L.; Vaz, B. S.; Morais, E. G.; Costa, J. A. V. Exopolysaccharides from Microalgae: Production in a Biorefinery Framework and Potential Applications. *Bioresource Technology Reports* **2022**, *18*, 101006. https://doi.org/10.1016/j.biteb.2022.101006.
27. Moreira, J. B.; Kuntzler, S. G.; Bezerra, P. Q. M.; Cassuriaga, A. P. A.; Zaparoli, M.; Da Silva, J. L. V.; Costa, J. A. V.; De Morais, M. G. Recent Advances of Microalgae Exopolysaccharides for Application as Bioflocculants. *Polysaccharides* **2022**, *3* (1), 264–276. https://doi.org/10.3390/polysaccharides3010015.
28. Park, G.-T.; Go, R.-E.; Lee, H.-M.; Lee, G.-A.; Kim, C.-W.; Seo, J.-W.; Hong, W.-K.; Choi, K.-C.; Hwang, K.-A. Potential Anti-Proliferative and Immunomodulatory Effects of Marine Microalgal Exopolysaccharide on Various Human Cancer Cells and Lymphocytes In Vitro. *Mar Biotechnol* **2017**, *19* (2), 136–146. https://doi.org/10.1007/s10126-017-9735-y.
29. Capek, P.; Matulová, M.; Molitorisová, M.; Kazimierová, I. Chlorella Vulgaris α-L-Arabino-α-L-Rhamno-α,β-D-Galactan Structure and Mechanisms of Its Anti-Inflammatory and Anti-Remodelling Effects. *International Journal of Biological Macromolecules* **2020**.
30. Concórdio-Reis, P.; David, H.; Reis, M. A. M.; Amorim, A.; Freitas, F. Bioprospecting for New Exopolysaccharide-Producing Microalgae of Marine Origin. *Int Microbiol* **2023**, *26* (4), 1123–1130. https://doi.org/10.1007/s10123-023-00367-9.
31. Zhou, R. Production and Characterization of Exopolysaccharides from Salinity-Induced Auxenochlorella Protothecoides and the Analysis of Anti-Inflammatory Activity. *International Journal of Biological Macromolecules* **2023**.
32. *CN108559006A*. https://patents.google.com/patent/CN108559006A/en?oq=CN108559006A.
33. Borjas Esqueda, A.; Gardarin, C.; Laroche, C. Exploring the Diversity of Red Microalgae for Exopolysaccharide Production. *Marine Drugs* **2022**, *20* (4), 246. https://doi.org/10.3390/md20040246.
34. De Philippis, R.; Sili, C.; Paperi, R.; Vincenzini, M. Exopolysaccharide-Producing Cyanobacteria and Their Possible Exploitation: A Review. *Journal of Applied Phycology* **2001**, *13* (4), 293–299. https://doi.org/10.1023/A:1017590425924.
35. Severo, I. A.; Dias, R. R.; Do Nascimento, T. C.; Deprá, M. C.; Maroneze, M. M.; Zepka, L. Q.; Jacob-Lopes, E. Microalgae-Derived Polysaccharides: Potential Building Blocks for Biomedical Applications. *World J Microbiol Biotechnol* **2022**, *38* (9), 150. https://doi.org/10.1007/s11274-022-03342-0.
36. He, Y.; Ji, L.; Yuan, Y.; Rui, D.; Li, J.; Cheng, P.; Sun, L.; Fan, J. Recent Advances in Polysaccharide-Dominated Extracellular Polymeric Substances from Microalgae: A Review. *International Journal of Biological Macromolecules* **2025**, *302*, 140572. https://doi.org/10.1016/j.ijbiomac.2025.140572.
37. Qi, J.; Kim, S. M. Characterization and Immunomodulatory Activities of Polysaccharides Extracted from Green Alga Chlorella Ellipsoidea. *International Journal of Biological Macromolecules* **2017**, *95*, 106–114. https://doi.org/10.1016/j.ijbiomac.2016.11.039.
38. Guzmán, S.; Gato, A.; Lamela, M.; Freire-Garabal, M.; Calleja, J. M. Anti-inflammatory and Immunomodulatory Activities of Polysaccharide from *Chlorella Stigmatophora* and *Phaeodactylum Tricornutum*. *Phytotherapy Research* **2003**, *17* (6), 665–670. https://doi.org/10.1002/ptr.1227.

39. Yim, J. H.; Kim, S. J.; Ahn, S. H.; Lee, C. K.; Rhie, K. T.; Lee, H. K. Antiviral Effects of Sulfated Exopolysaccharide from the Marine Microalga Gyrodinium Impudicum Strain KG03. *Marine Biotechnology* **2004**, *6* (1), 17–25. https://doi.org/10.1007/s10126-003-0002-z.
40. Barboríková, J. Extracellular Polysaccharide Produced by Chlorella Vulgaris—Chemical Characterization and Anti-Asthmatic Profile. *International Journal of Biological Macromolecules* **2019**.
41. Gardeva, E.; Toshkova, R.; Minkova, K.; Gigova, L. Cancer Protective Action of Polysaccharide, Derived from Red Microalga *Porphyridium Cruentum* —A Biological Background. *Biotechnology & Biotechnological Equipment* **2009**, *23* (sup1), 783–787. https://doi.org/10.1080/13102818.2009.10818540.
42. Kang, Y.; Wang, Z.-J.; Xie, D.; Sun, X.; Yang, W.; Zhao, X.; Xu, N. Characterization and Potential Antitumor Activity of Polysaccharide from Gracilariopsis Lemaneiformis. *Marine Drugs* **2017**, *15* (4), 100. https://doi.org/10.3390/md15040100.
43. Zhang, J.; Liu, L.; Ren, Y.; Chen, F. Characterization of Exopolysaccharides Produced by Microalgae with Antitumor Activity on Human Colon Cancer Cells. *International Journal of Biological Macromolecules* **2019**.
44. Dai, J.; Wu, Y.; Chen, S.; Zhu, S.; Yin, H.; Wang, M.; Tang, J. Sugar Compositional Determination of Polysaccharides from Dunaliella Salina by Modified RP-HPLC Method of Precolumn Derivatization with 1-Phenyl-3-Methyl-5-Pyrazolone. *Carbohydrate Polymers* **2010**, *82* (3), 629–635. https://doi.org/10.1016/j.carbpol.2010.05.029.
45. Amna Kashif, S.; Hwang, Y. J.; Park, J. K. Potent Biomedical Applications of Isolated Polysaccharides from Marine Microalgae Tetraselmis Species. *Bioprocess Biosyst Eng* **2018**, *41* (11), 1611–1620. https://doi.org/10.1007/s00449-018-1987-z.
46. Shen, S.; Jia, S.; Wu, Y.; Yan, R.; Lin, Y.-H.; Zhao, D.; Han, P. Effect of Culture Conditions on the Physicochemical Properties and Antioxidant Activities of Polysaccharides from Nostoc Flagelliforme. *Carbohydrate Polymers* **2018**, *198*, 426–433. https://doi.org/10.1016/j.carbpol.2018.06.111.
47. Quan, Y.; Yang, S.; Wan, J.; Su, T.; Zhang, J.; Wang, Z. Optimization for the Extraction of Polysaccharides from Nostoc Commune and Its Antioxidant and Antibacterial Activities. *Journal of the Taiwan Institute of Chemical Engineers* **2015**, *52*, 14–21. https://doi.org/10.1016/j.jtice.2015.02.004.
48. Raposo, M.; De Morais, R.; Bernardo De Morais, A. Bioactivity and Applications of Sulphated Polysaccharides from Marine Microalgae. *Marine Drugs* **2013**, *11* (1), 233–252. https://doi.org/10.3390/md11010233.
49. Santoyo, S.; Jaime, L.; Plaza, M.; Herrero, M.; Rodriguez-Meizoso, I.; Ibañez, E.; Reglero, G. Antiviral Compounds Obtained from Microalgae Commonly Used as Carotenoid Sources. *J Appl Phycol* **2012**, *24* (4), 731–741. https://doi.org/10.1007/s10811-011-9692-1.
50. Hernandezcorona, A.; Nieves, I.; Meckes, M.; Chamorro, G.; Barron, B. Antiviral Activity of Spirulina Maxima against Herpes Simplex Virus Type 2. *Antiviral Research* **2002**, *56* (3), 279–285. https://doi.org/10.1016/S0166-3542(02)00132-8.
51. Wan, X.; Ai, C.; Chen, Y.; Gao, X.; Zhong, R.; Liu, B.; Chen, X.; Zhao, C. Physicochemical Characterization of a Polysaccharide from Green Microalga *Chlorella Pyrenoidosa* and Its Hypolipidemic Activity via Gut Microbiota Regulation in Rats. *J. Agric. Food Chem.* **2020**, *68* (5), 1186–1197. https://doi.org/10.1021/acs.jafc.9b06282.
52. Majdoub, H.; Mansour, M. B.; Chaubet, F.; Roudesli, M. S.; Maaroufi, R. M. Anticoagulant Activity of a Sulfated Polysaccharide from the Green Alga Arthrospira Platensis. *Biochimica et Biophysica Acta (BBA)—General Subjects* **2009**, *1790* (10), 1377–1381. https://doi.org/10.1016/j.bbagen.2009.07.013.
53. Setyaningsih, I.; Prasetyo, H.; Agungpriyono, D. R.; Tarman, K. Antihyperglycemic Activity of Porphyridium Cruentum Biomass and Extra-Cellular Polysaccharide in Streptozotocin-Induced Diabetic Rats. *International Journal of Biological Macromolecules* **2020**, *156*, 1381–1386. https://doi.org/10.1016/j.ijbiomac.2019.11.178.
54. De Medeiros, V. P. B.; De Souza, E. L.; De Albuquerque, T. M. R.; Da Costa Sassi, C. F.; Dos Santos Lima, M.; Sivieri, K.; Pimentel, T. C.; Magnani, M. Freshwater Microalgae Biomasses Exert a Prebiotic Effect on Human Colonic Microbiota. *Algal Research* **2021**, *60*, 102547. https://doi.org/10.1016/j.algal.2021.102547.
55. Tiwari, O. N. Purification, Characterization and Biotechnological Potential of New Exopolysaccharide Polymers Produced by Cyanobacterium Anabaena Sp. CCC 745. **2019**.

56. Jindal, N.; Pal Singh, D.; Singh Khattar, J. Optimization, Characterization, and Flow Properties of Exopolysaccharides Produced by the Cyanobacterium *Lyngbya Stagnina*: Exopolysaccharides from *Lyngbya Stagnina*. *J. Basic Microbiol.* **2013**, *53* (11), 902–912. https://doi.org/10.1002/jobm.201200201.
57. Li, T.-T.; Huang, Z.-R.; Jia, R.-B.; Lv, X.-C.; Zhao, C.; Liu, B. Spirulina Platensis Polysaccharides Attenuate Lipid and Carbohydrate Metabolism Disorder in High-Sucrose and High-Fat Diet-Fed Rats in Association with Intestinal Microbiota. *Food Research International* **2021**, *147*, 110530. https://doi.org/10.1016/j.foodres.2021.110530.
58. Rajasekar, P.; Palanisamy, S.; Anjali, R.; Vinosha, M.; Elakkiya, M.; Marudhupandi, T.; Tabarsa, M.; You, S.; Prabhu, N. M. Isolation and Structural Characterization of Sulfated Polysaccharide from Spirulina Platensis and Its Bioactive Potential: In Vitro Antioxidant, Antibacterial Activity and Zebrafish Growth and Reproductive Performance. *International Journal of Biological Macromolecules* **2019**, *141*, 809–821. https://doi.org/10.1016/j.ijbiomac.2019.09.024.
59. Chen, Y.-X.; Liu, X.-Y.; Xiao, Z.; Huang, Y.-F.; Liu, B. Antioxidant Activities of Polysaccharides Obtained from Chlorella Pyrenoidosa via Different Ethanol Concentrations. *International Journal of Biological Macromolecules* **2016**, *91*, 505–509. https://doi.org/10.1016/j.ijbiomac.2016.05.086.
60. Zhang, H.Q., Lin, A.P., Sun, Y., Deng, Y.M. Chemo- and Radio-Protective Effects of Polysaccharide of Spirulina Platensis on Hemopoietic System of Mice and Dogs. *Acta Pharmacol. Sin* **2001**, No. 22, 1121–1124.
61. *Algosource*. http://www.algosource.com.
62. *Micoperibeg*. http://www.micoperibg.eu.
63. *Solazyme*. http://solazymeindustrials.com.
64. *Givaudan*. https://www.givaudan.com/fragrance beauty/active-beauty/products/hydrintense.
65. Rachidi, F.; Benhima, R.; Sbabou, L.; El Arroussi, H. Microalgae Polysaccharides Bio-Stimulating Effect on Tomato Plants: Growth and Metabolic Distribution. *Biotechnology Reports* **2020**, *25*, e00426. https://doi.org/10.1016/j.btre.2020.e00426.
66. Park, C.-H.; Li, X. R.; Zhao, Y.; Jia, R. L.; Hur, J.-S. Rapid Development of Cyanobacterial Crust in the Field for Combating Desertification. *PLoS ONE* **2017**, *12* (6), e0179903. https://doi.org/10.1371/journal.pone.0179903.
67. Xu, Y.; Rossi, F.; Colica, G.; Deng, S.; De Philippis, R.; Chen, L. Use of Cyanobacterial Polysaccharides to Promote Shrub Performances in Desert Soils: A Potential Approach for the Restoration of Desertified Areas. *Biol Fertil Soils* **2013**, *49* (2), 143–152. https://doi.org/10.1007/s00374-012-0707-0.
68. Guehaz, K.; Boual, Z.; Abdou, I.; Telli, A.; Belkhalfa, H. Microalgae's Polysaccharides, Are They Potent Antioxidants? Critical Review. *Arch Microbiol* **2024**, *206* (1), 14. https://doi.org/10.1007/s00203-023-03738-y.
69. Mota, R.; Vidal, R.; Pandeirada, C.; Flores, C.; Adessi, A.; De Philippis, R.; Nunes, C.; Coimbra, M. A.; Tamagnini, P. Cyanoflan: A Cyanobacterial Sulfated Carbohydrate Polymer with Emulsifying Properties. *Carbohydrate Polymers* **2020**, *229*, 115525. https://doi.org/10.1016/j.carbpol.2019.115525.
70. Bernaerts, T. M. M.; Gheysen, L.; Foubert, I.; Hendrickx, M. E.; Van Loey, A. M. The Potential of Microalgae and Their Biopolymers as Structuring Ingredients in Food: A Review. *Biotechnology Advances* **2019**, *37* (8), 107419. https://doi.org/10.1016/j.biotechadv.2019.107419.
71. Dulong, V.; Rihouey, C.; Gaignard, C.; Bridiau, N.; Gourvil, P.; Laroche, C.; Pierre, G.; Varacavoudin, T.; Probert, I.; Maugard, T.; Michaud, P.; Picton, L. Exopolysaccharide from Marine Microalgae Belonging to the Glossomastix Genus: Fragile Gel Behavior and Suspension Stability.
72. Estevinho, B. N.; Mota, R.; Leite, J. P.; Tamagnini, P.; Gales, L.; Rocha, F. Application of a Cyanobacterial Extracellular Polymeric Substance in the Microencapsulation of Vitamin B12. *Powder Technology* **2019**, *343*, 644–651. https://doi.org/10.1016/j.powtec.2018.11.079.
73. Fattom, A.; Shilo, M. Production of Emulcyan by *Phormidium* J-1: Its Activity and Function. *FEMS Microbiology Letters* **1985**, *31* (1), 3–9. https://doi.org/10.1111/j.1574-6968.1985.tb01125.x.
74. *US5250201A*. https://patents.google.com/patent/US5250201A/en.
75. Borah, D.; Rethinam, G.; Gopalakrishnan, S.; Rout, J.; Alharbi, N. S.; Alharbi, S. A.; Nooruddin, T. Ozone Enhanced Production of Potentially Useful Exopolymers from the Cyanobacterium Nostoc Muscorum. *Polymer Testing* **2020**, *84*, 106385. https://doi.org/10.1016/j.polymertesting.2020.106385.

76. Hayashi, T.; Hayashi, K.; Maeda, M.; Kojima, I. Calcium Spirulan, an Inhibitor of Enveloped Virus Replication, from a Blue-Green Alga *Spirulina Platensis*. *J. Nat. Prod.* **1996**, *59* (1), 83–87. https://doi.org/10.1021/np960017o.
77. Radonić, A.; Thulke, S.; Achenbach, J.; Kurth, A.; Vreemann, A.; König, T.; Walter, C.; Possinger, K.; Nitsche, A. Anionic Polysaccharides From Phototrophic Microorganisms Exhibit Antiviral Activities to Vaccinia Virus. Robert Koch-Institut, Biologische Sicherheit January 3, 2011. https://doi.org/10.25646/748.
78. Motoyama, K.; Tanida, Y.; Hata, K.; Hayashi, T.; Hashim, I. I. A.; Higashi, T.; Ishitsuka, Y.; Kondo, Y.; Irie, T.; Kaneko, S.; Arima, H. Anti-Inflammatory Effects of Novel Polysaccharide Sacran Extracted from Cyanobacterium *Aphanothece Sacrum* in Various Inflammatory Animal Models. *Biological & Pharmaceutical Bulletin* **2016**, *39* (7), 1172–1178. https://doi.org/10.1248/bpb.b16-00208.
79. Ivanova, J.; Konstantinidou, A.; Kabaivanova, L.; Georgieva, A.; Vladov, I.; Petkova, S. Examination of Exopolysaccharides from Porphyridium Cruentum for Estimation of Their Potential Antitumour Activity in Vitro. *C. R. Acad. Bulg. Sci.* **2022**, *75* (8), 1146–1155. https://doi.org/10.7546/CRABS.2022.08.07.
80. Mousavian, Z.; Safavi, M.; Azizmohseni, F.; Hadizadeh, M.; Mirdamadi, S. Characterization, Antioxidant and Anticoagulant Properties of Exopolysaccharide from Marine Microalgae. *AMB Expr* **2022**, *12* (1), 27. https://doi.org/10.1186/s13568-022-01365-2.
81. Uhliariková, I.; Matulová, M.; Capek, P. Structural Features of the Bioactive Cyanobacterium Nostoc Sp. Exopolysaccharide. *International Journal of Biological Macromolecules* **2020**, *164*, 2284–2292. https://doi.org/10.1016/j.ijbiomac.2020.08.113.
82. Goyal, M.; Baranwal, M.; Pandey, S. K.; Reddy, M. S. Hetero-Polysaccharides Secreted from Dunaliella Salina Exhibit Immunomodulatory Activity Against Peripheral Blood Mononuclear Cells and RAW 264.7 Macrophages. *Indian J Microbiol* **2019**, *59* (4), 428–435. https://doi.org/10.1007/s12088-019-00818-w.
83. Gouda, M.; Tadda, M. A.; Zhao, Y.; Farmanullah, F.; Chu, B.; Li, X.; He, Y. Microalgae Bioactive Carbohydrates as a Novel Sustainable and Eco-Friendly Source of Prebiotics: Emerging Health Functionality and Recent Technologies for Extraction and Detection. *Front. Nutr.* **2022**, *9*, 806692. https://doi.org/10.3389/fnut.2022.806692.
84. Castro, V.; Oliveira, R.; Dias, A. C. P. Microalgae and Cyanobacteria as Sources of Bioactive Compounds for Cosmetic Applications: A Systematic Review. *Algal Research* **2023**, *76*, 103287. https://doi.org/10.1016/j.algal.2023.103287.
85. Matsui, M. S.; Muizzuddin, N.; Arad, S.; Marenus, K. Sulfated Polysaccharides from Red Microalgae Have Antiinflammatory Properties In Vitro and In Vivo. *ABAB* **2003**, *104* (1), 13–22. https://doi.org/10.1385/ABAB:104:1:13.
86. Kanekiyo, K.; Lee, J.-B.; Hayashi, K.; Takenaka, H.; Hayakawa, Y.; Endo, S.; Hayashi, T. Isolation of an Antiviral Polysaccharide, Nostoflan, from a Terrestrial Cyanobacterium, *Nostoc f Lagelliforme*. *J. Nat. Prod.* **2005**, *68* (7), 1037–1041. https://doi.org/10.1021/np050056c.
87. Chen, B.; You, W.; Huang, J.; Yu, Y.; Chen, W. Isolation and Antioxidant Property of the Extracellular Polysaccharide from Rhodella Reticulata. *World J Microbiol Biotechnol* **2010**, *26* (5), 833–840. https://doi.org/10.1007/s11274-009-0240-y.
88. Challouf, R.; Trabelsi, L.; Ben Dhieb, R.; El Abed, O.; Yahia, A.; Ghozzi, K.; Ben Ammar, J.; Omran, H.; Ben Ouada, H. Evaluation of Cytotoxicity and Biological Activities in Extracellular Polysaccharides Released by Cyanobacterium Arthrospira Platensis. *Braz. arch. biol. technol.* **2011**, *54* (4), 831–838. https://doi.org/10.1590/S1516-89132011000400024.
89. Kenny Cristian Díaz Bayona; Sandra Milena Navarro GallónSandra Milena Navarro Gallón; Andres Lara EstradaAndres Lara Estrada; Jhonny Colorado-Rios; Lucía Atehortúa G.; Alejandro Martinez Martinez. Activity of Sulfated Polysaccharides from Microalgae Porphyridium Cruentum over Degenerative Mechanisms of the Skin. *International Journal of Science and Advanced Technology* **2012**, *2* (8), 85–92.
90. Han, P.; Sun, Y.; Wu, X.; Yuan, Y.; Dai, Y.; Jia, S. Emulsifying, Flocculating, and Physicochemical Properties of Exopolysaccharide Produced by Cyanobacterium Nostoc Flagelliforme. *Appl Biochem Biotechnol* **2014**, *172* (1), 36–49. https://doi.org/10.1007/s12010-013-0505-7.

91. Raposo, M. F. D. J.; De Morais, A. M. M. B.; De Morais, R. M. S. C. Influence of Sulphate on the Composition and Antibacterial and Antiviral Properties of the Exopolysaccharide from Porphyridium Cruentum. *Life Sciences* **2014**, *101* (1–2), 56–63. https://doi.org/10.1016/j.lfs.2014.02.013.
92. Hussein, M. H.; Abou-ElWaf, G. S.; Shaaban-De, S. A.; Hassan, N. I. Characterization and Antioxidant Activity of Exopolysaccharide Secreted by Nostoc Carneum. *International J. of Pharmacology* **2015**, *11* (5), 432–439. https://doi.org/10.3923/ijp.2015.432.439.
93. Gudmundsdottir, A. B.; Omarsdottir, S.; Brynjolfsdottir, A.; Paulsen, B. S.; Olafsdottir, E. S.; Freysdottir, J. Exopolysaccharides from Cyanobacterium Aponinum from the Blue Lagoon in Iceland Increase IL-10 Secretion by Human Dendritic Cells and Their Ability to Reduce the IL-17+RORγt+/IL-10+FoxP3+ Ratio in CD4+ T Cells. *Immunology Letters* **2015**, *163* (2), 157–162. https://doi.org/10.1016/j.imlet.2014.11.008.
94. Trabelsi, L.; Chaieb, O.; Mnari, A.; Abid-Essafi, S.; Aleya, L. Partial Characterization and Antioxidant and Antiproliferative Activities of the Aqueous Extracellular Polysaccharides from the Thermophilic Microalgae Graesiella Sp. *BMC Complement Altern Med* **2016**, *16* (1), 210. https://doi.org/10.1186/s12906-016-1198-6.
95. Tiwari, O. N.; Muthuraj, M.; Bhunia, B.; Bandyopadhyay, T. K.; Annapurna, K.; Sahu, M.; Indrama, T. Biosynthesis, Purification and Structure-Property Relationships of New Cyanobacterial Exopolysaccharides. *Polymer Testing* **2020**, *89*, 106592. https://doi.org/10.1016/j.polymertesting.2020.106592.
96. Zampieri, R. M.; Adessi, A.; Caldara, F.; Codato, A.; Furlan, M.; Rampazzo, C.; De Philippis, R.; La Rocca, N.; Dalla Valle, L. Anti-Inflammatory Activity of Exopolysaccharides from Phormidium Sp. ETS05, the Most Abundant Cyanobacterium of the Therapeutic Euganean Thermal Muds, Using the Zebrafish Model. *Biomolecules* **2020**, *10* (4), 582. https://doi.org/10.3390/biom10040582.
97. Risjani, Y.; Mutmainnah, N.; Manurung, P.; Wulan, S. N.; Yunianta. Exopolysaccharide from Porphyridium Cruentum (Purpureum) Is Not Toxic and Stimulates Immune Response against Vibriosis: The Assessment Using Zebrafish and White Shrimp Litopenaeus Vannamei. *Marine Drugs* **2021**, *19* (3), 133. https://doi.org/10.3390/md19030133.
98. Parra-Riofrío, G.; García-Márquez, J.; Casas-Arrojo, V.; Uribe-Tapia, E.; Abdala-Díaz, R. T. Antioxidant and Cytotoxic Effects on Tumor Cells of Exopolysaccharides from Tetraselmis Suecica (Kylin) Butcher Grown Under Autotrophic and Heterotrophic Conditions. *Mar. Drugs* **2020**.
99. Drira, M.; Elleuch, J.; Ben Hlima, H.; Hentati, F.; Gardarin, C.; Rihouey, C.; Le Cerf, D.; Michaud, P.; Abdelkafi, S.; Fendri, I. Optimization of Exopolysaccharides Production by Porphyridium Sordidum and Their Potential to Induce Defense Responses in Arabidopsis Thaliana against Fusarium Oxysporum. *Biomolecules* **2021**, *11* (2), 282. https://doi.org/10.3390/biom11020282.
100. Alvarez, X.; Alves, A.; Ribeiro, M. P.; Lazzari, M.; Coutinho, P.; Otero, A. Biochemical Characterization of Nostoc Sp. Exopolysaccharides and Evaluation of Potential Use in Wound Healing. *Carbohydrate Polymers* **2021**, *254*, 117303. https://doi.org/10.1016/j.carbpol.2020.117303.
101. Patwal, T.; Baranwal, M. Scenedesmus Acutus Extracellular Polysaccharides Produced under Increased Concentration of Sulphur and Phosphorus Exhibited Enhanced Proliferation of Peripheral Blood Mononuclear Cells. *3 Biotech* **2021**, *11* (4), 171. https://doi.org/10.1007/s13205-021-02720-z.
102. Uhliariková, I.; Matulová, M.; Košťálová, Z.; Lukavský, J.; Capek, P. Lactylated Acidic Exopolysaccharide Produced by the Cyanobacterium Nostoc Cf. Linckia. *Carbohydrate Polymers* **2022**, *276*, 118801. https://doi.org/10.1016/j.carbpol.2021.118801.
103. Gongi, W.; Gomez Pinchetti, J. L.; Cordeiro, N.; Ouada, H. B. Extracellular Polymeric Substances Produced by the Thermophilic Cyanobacterium Gloeocapsa Gelatinosa: Characterization and Assessment of Their Antioxidant and Metal-Chelating Activities. *Marine Drugs* **2022**, *20* (4), 227. https://doi.org/10.3390/md20040227.
104. Wang, W.-N.; Li, T.; Li, Y.; Zhang, Y.; Wu, H.-L.; Xiang, W.-Z.; Li, A.-F. Exopolysaccharides from the Energy Microalga Strain Botryococcus Braunii: Purification, Characterization, and Antioxidant Activity. **2022**.
105. Toucheteau, C.; Deffains, V.; Gaignard, C.; Rihouey, C.; Laroche, C.; Pierre, G.; Lépine, O.; Probert, I.; Le Cerf, D.; Michaud, P.; Arnaudin-Fruitier, I.; Bridiau, N.; Maugard, T. Role of Some Structural Features in EPS from Microalgae Stimulating Collagen Production by Human Dermal Fibroblasts. *Bioengineered* **2023**, *14* (1), 2254027. https://doi.org/10.1080/21655979.2023.2254027.

106. Mansour, F. B.; Guermazi, W.; Chamkha, M.; Bellassoued, K.; Salah, H. B.; Harrath, A. H.; Aldahmash, W.; Rahman, M. A.; Ayadi, H. Bioactive Potential of the Sulfated Exopolysaccharides From the Brown Microalga *Halamphora* Sp.: Antioxidant, Antimicrobial, and Antiapoptotic Profiles. *Analytical Science Advances* **2024**, *5* (9–10), e202400030. https://doi.org/10.1002/ansa.202400030.
107. Harbaoui, A.; Khelifi, N.; Aissaoui, N.; Muzard, M.; Martinez, A.; Smaali, I. A Novel Bioactive and Functional Exopolysaccharide from the Cyanobacterial Strain Arthrospira Maxima Cultivated under Salinity Stress. *Bioprocess Biosyst Eng* **2025**, *48* (3), 445–460. https://doi.org/10.1007/s00449-024-03120-2.
108. Chehouri, M. Marennine et Exopolysaccharides de La Microalgue Bleue Haslea Ostrearia : Potentiel d'application Cosmétique et Pharmaceutique, 2024. https://semaphore.uqar.ca/id/eprint/3199/.
109. Vazquez-Ayala, L.; Angel-Olarte, C. D.; Escobar-García, D. M.; Rosales-Mendoza, S.; Solis-Andrade, I.; Pozos-Guillen, A.; Palestino, G. Chitosan Sponges Loaded with Metformin and Microalgae as Dressing for Wound Healing: A Study in Diabetic Bio-Models. *International Journal of Biological Macromolecules* **2024**.
110. *US9095733B2*. https://patents.google.com/patent/US9095733B2/en.
111. *ES2718275T3*. https://patents.google.com/patent/US8277849B2/en.
112. *EP3398606A1*. https://patents.google.com/patent/EP3398606A1/fr.
113. *US20240358628A1*. https://patents.google.com/patent/US20240358628A1/en?oq=US20240358628A1.
114. *EP2265249A1*. https://patents.google.com/patent/EP2265249A1/en?oq=EP2265249A1.
115. *US12268772B2*. https://patents.google.com/patent/US12268772B2/en?oq=US12268772B2.
116. *FR2102020*. https://hal.science/hal-03506901v1.
117. *Br102012004631a2*. https://patents.google.com/patent/BR102012004631A2/en?oq=BR102012004631A2.
118. *FR2982152A1*. https://patents.google.com/patent/FR2982152A1/en?oq=FR2982152A1.
119. *US20200232003A1*. https://patents.google.com/patent/US20200232003A1/en?oq=US20200232003A1.
120. *BRPI1004637A2*. https://patents.google.com/patent/BRPI1004637A2/en?oq=BRPI1004637A2.
121. *CN105685766A*. https://patents.google.com/patent/CN105685766A/en?oq=CN105685766A.
122. Michaud, P. Polysaccharides from Microalgae, What's Future? *aibm* **2018**, *08* (02). https://doi.org/10.19080/AIBM.2018.08.555732.
123. Cristofoli, N. L.; Lima, A. R.; Rosa Da Costa, A. M.; Evtyugin, D.; Silva, C.; Varela, J.; Vieira, M. C. Structural Characterization of Exopolysaccharides Obtained from Porphyridium Cruentum Exhausted Culture Medium. *Food and Bioproducts Processing* **2023**, *138*, 162–171. https://doi.org/10.1016/j.fbp.2023.02.001.
124. Gargouch, N.; Elleuch, F.; Karkouch, I.; Tabbene, O.; Pichon, C.; Gardarin, C.; Rihouey, C.; Picton, L.; Abdelkafi, S.; Fendri, I.; Laroche, C. Potential of Exopolysaccharide from Porphyridium Marinum to Contend with Bacterial Proliferation, Biofilm Formation, and Breast Cancer. *Marine Drugs* **2021**, *19* (2), 66. https://doi.org/10.3390/md19020066.
125. Kaur, M.; Bhatia, S.; Gupta, U.; Decker, E.; Tak, Y.; Bali, M.; Gupta, V. K.; Dar, R. A.; Bala, S. Microalgal Bioactive Metabolites as Promising Implements in Nutraceuticals and Pharmaceuticals: Inspiring Therapy for Health Benefits. *Phytochem Rev* **2023**, *22* (4), 903–933. https://doi.org/10.1007/s11101-022-09848-7.
126. Cruz, A. M.; Gonçalves, M. C.; Marques, M. S.; Veiga, F.; Paiva-Santos, A. C.; Pires, P. C. In Vitro Models for Anti-Aging Efficacy Assessment: A Critical Update in Dermocosmetic Research. *Cosmetics* **2023**, *10* (2), 66. https://doi.org/10.3390/cosmetics10020066.