Chapter

Cyanobacteria as the Source of Antioxidants

Rashi Tyagi, Pankaj Kumar Singh and Archana Tiwari

Abstract

The present-day scenario in the health sector calls for alternative medicine sources with no risk of resistance, effective in the mode of action, and eco-friendly. Cyanobacteria are microbial factories for a wide range of products. They are reservoirs of bioactive compounds which have the potential to act as precursors of novel drug molecules. A plethora of algae have been documented for their therapeutic abilities in treating diseases. A plethora of antioxidative compounds along with enzymes are present in cyanobacteria, possessing applications in nutraceuticals and cosmeceuticals, which is quite evident from the products available in the market. This chapter highlights the significant leads in the area of cyanobacteria-based antioxidants. A sustainable approach to envisaging cyanobacteria as competent antioxidants can open new doors in prevention, treatment, and control of a plethora of diseases.

Keywords: algae, antioxidants, cyanobacteria, cosmeceuticals, nutraceuticals

1. Introduction

Cyanobacteria exist in various habitats that are exposed to various adverse environmental variables, such as ultraviolet light, salinity, climate, and food supplements. Algae are multicellular creatures found in freshwater, saltwater, and marine environments. They synthesize a wide range of metabolites to acclimate to these demanding environments quickly [1]. Cyanobacteria's antioxidants can be used in the pharmaceutical and medical fields. The search for safe antioxidants derived from natural sources is currently generating interest on a global scale. Algae could biogenically create, consume, collect, and develop a wide variety of metabolites [2]. The agricultural, medicinal, pharmaceutical, food, nutritional, cosmetic, and other industries employ algae. In the absence of light, they can also grow under heterotrophic conditions by utilizing an organic carbon substrate as an energy source [3].

The existence of several proterozoic oil deposits is related to cyanobacterial activity. Additionally, they are significant suppliers of nitrogen fertilizer for growing rice and beans. Throughout the planet's history, cyanobacteria also played a major role in determining ecological change and evolution. Many cyanobacteria produce the oxygen atmosphere on which we rely. Before it, the atmosphere's chemistry was significantly different and unsuitable for modern species.

The nascent, most diversified, and wide cluster of photosynthetic prokaryotes known as cyanobacteria (blue-green algae) exhibits similarities to green plant life in oxygenic photosynthesis and to Gram-negative bacteria in the cellular organization [4]. Almost all terrestrial and aquatic freshwater and marine habitats support the growth and colonization of blue-green algae, which adapt to diverse ecological circumstances [5]. Microalgae exist as a standard source of bioactive chemicals and have been used in various pharmacological applications due to their richness in primary and secondary metabolites [6]. Bioactive substances are physiologically active molecules that can either benefit or harm a living thing, tissue, or cell when present in small amounts [7].

Proteins called antioxidant enzymes to play a catalytic role in converting reactive oxygen species (ROS) and their byproducts into stable, harmless compounds, making them the most effective protection against oxidative stress-related cell damage. Antioxidant enzymes can stabilize or inactivate free radicals before damaging cellular components. They work by lowering the free radicals' energy or by sacrificing part of their electrons for its use, making the radicals more stable. To lessen the harm by free radicals, they may also halt the oxidative chain reaction. Over the last 10 years, numerous studies have been conducted on the advantages of antioxidant enzymes. Antioxidants protect cells against the harm caused by free ions, even when their concentration is lower than the substance being oxidized [8]. However, various harmful side effects, including cancer and liver damage, are associated with these synthetic antioxidants. As a result, scientists are looking for natural antioxidants that may be used in place of synthetic antioxidants in the food and pharmaceutical industries that are safe and efficient [9]. Our body's capacity to lower the risk of free radical-related health issues is made more tangible by minimizing exposure to free radicals and increasing the intake of foods or supplements rich in antioxidant enzymes [8]. Therefore, antioxidant enzymes are vitally essential for preserving the best possible cellular and systemic health and well-being. Free radicals are included in the highly reactive oxygen-containing molecules known as reactive oxygen species (ROS). The hydroxyl radical, superoxide anion radical, hydrogen peroxide, singlet oxygen, nitric oxide, and chlorine ions radicals, and other lipid peroxides are examples of ROS. All have the potential to interact with cellular membranes, phospholipids, nucleic acids, proteins, enzymes, and other tiny molecules to cause cellular harm [8].

Algae's numerous bioactive chemicals are being examined. PUFA, sterols, terpenoids, carotenoids, and alkaloids are just a few functional chemical components found in the diverse group of organisms known as algae. These have been shown to protect against various diseases, including cancer [9].

2. Algae antioxidants

Algae are photoautotroph organisms. There is no damage to the structure, and it can produce the substances they need to defend itself against oxidation. They are a rich source of powerful antioxidants that can shield our bodies from the harmful effects of oxygen species created during regular bodily metabolism. Carotenoids and vitamin E (gamma-tocopherol) are two types of powerful fat-soluble antioxidants found in algae, whereas vitamins, phycobiliproteins (PBPs), and polyphenols are adequate water-soluble antioxidants [9].

As naturally obtained bioactive compounds with a wide variety of biological potencies, such as antibacterial, antiviral, antioxidant, and anti-inflammatory, cyanobacteria have attracted much attention [1]. Antioxidants and phycobiliproteins (PBPs), which are cyanobacteria's distinctive photosynthetic pigments, are thought to be abundant in cyanobacteria. In particular, these pigments have been exploited as organic coloring replacements in nutritive, cosmetic, and pharmaceutical products. Due to their fluorescent qualities, PBPs are also utilized in the branch of immunology [2]. Phycobiliproteins are highly effective fluorescent substances due to their distinctive characteristics of high molar absorbance coefficients, high fluorescence quantum yield, big stokes shift, high oligomer stability, and high photostability [10]. The primary endogenous damage to the biological system is caused by free radicals generated during oxidative stress. This kind of damage is frequently linked to several degenerative diseases and disorders, including cancer, cardiovascular disease, aging, and immune function loss. Free radicals are the main factor in lipid oxidation, the process by which food degrades and finally loses its properties to sense it through sensory organs and edibility, in addition to harming live cells [11]. Many individuals use antioxidants in the form of commercial food additives, which are produced synthetically and may contain significant amounts of preservatives, to combat the effects of oxidative stress [12]. However, most antioxidant sources identified to date compete with conventional meals and commodities.

Most biologically active compounds in algae, including pigments like carotene, astaxanthin, lutein, zeaxanthin, and phycobiliproteins [13], exhibit both anti-inflammatory and antioxidant properties [14]. One of the key factors driving the hunt for bioactive substances like anti-inflammatory kinetic molecules from natural sources such as microalgae is the rising demand for medications with few adverse effects. The cell that showed anti-inflammatory action will accumulate metabolites from the various microalgae. Several research has already shown the chemical makeup, structural details, and biosynthesis routes of the bioactive substances displaying anti-inflammatory chemicals produced by microalgae [15]. Proteins, phycobiliproteins, flavonoids, carotenoids like astaxanthin and lutein, and the fatty acids DHA, EPA, and SPs produced by metabolically active microalgae species are all present examples of substances with anti-inflammatory properties [2]. To be a valuable target product, these bioactive compounds must fulfill two requirements: (1) they must accumulate in relatively large amounts in cultures grown under standard test conditions throughout commercial production, and (2) they should continuously be overexpressed as an algal reaction to unpleasant development surroundings or when exposed to the synthetic or actual pressure. This can be achieved by differing the circumstances, like changing the physicochemical boundaries and the retention of supplements, as well as changes in temperature, pH, light quality, and irradiance [16]. The species of algae and the growing circumstances significantly impact the generation of anti-inflammatory chemicals [14]. Only a peptide from *P. tricornutum* with anti-inflammatory characteristics made it to market. Carotenoids, an algae stain, are discovered to positively influence immune response modulations and anti-inflammatory cellular response pathways [2]. *H. pluvialis* microalgae produce the carotenoid astaxanthin, which has strong anti-inflammatory properties [14]. One extremophilic microalga, *D. salina*, is used in industry to create a valuable substance with anti-inflammatory properties [17]. Microalgae-produced compounds have also been shown to have antioxidant as well as anti-inflammatory activity. Microalgal anti-inflammatory compounds known as sugars have also demonstrated antioxidant potential. Several excellent reviews have been published recently to discuss their uses and advantages for human health [2]. The antioxidant microalgae sugars extracted from *Porphyridium* [18] and *Rhodella* [19] are two excellent patterns.

Cyanobacteria inherently produce ROS throughout the photosynthetic activity. These species are created by abiotic causes such as ultraviolet radiation, osmotic disturbances, desiccation, and heat. Multiple strategies are needed for cyanobacteria

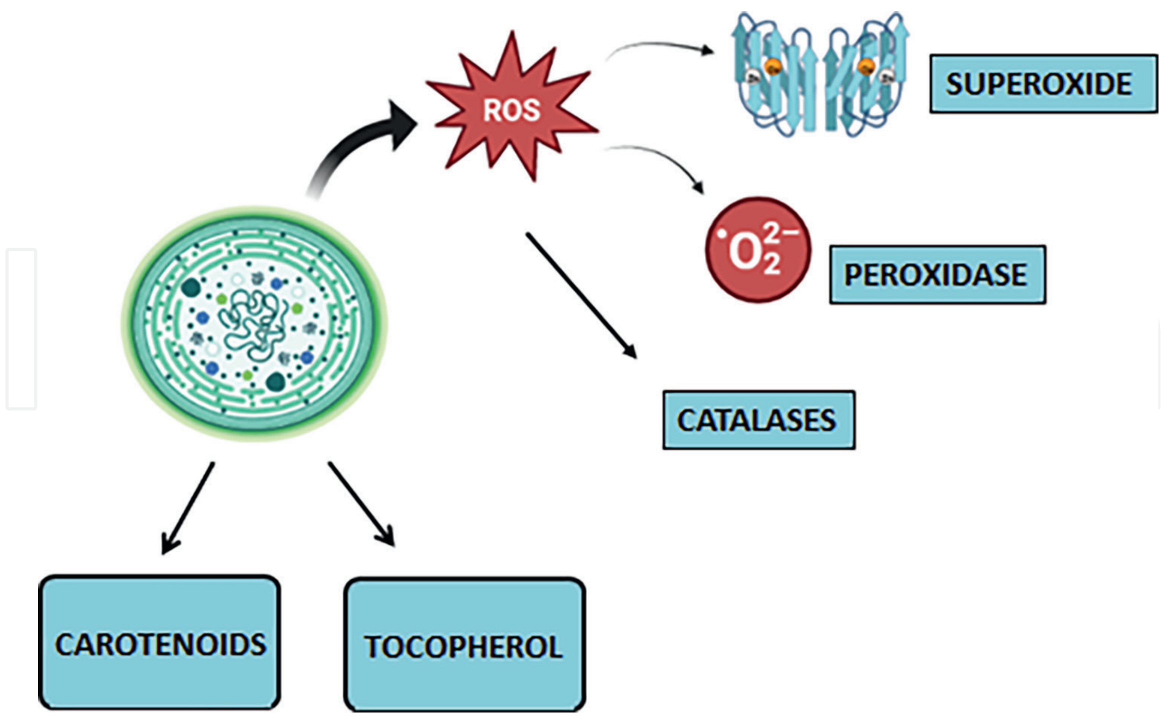

Figure 1.
ROS removing bioactive compounds.

to avoid the inhibitory effects of harsh conditions. By reducing the amount of energy lost during the photosynthetic process, they can reduce the generation of ROS. One approach uses the carotenoid zeaxanthin to non-photochemically quench (NPQ) excitation energy through photosystem II [20]. Cyanobacteria remove ROS using various bioactive compounds, as mentioned in **Figure 1**, and their genetic relationship can be elucidated using various methods of molecular phylogenetics [21]. Although peroxidases and catalases accelerate the removal of peroxides (such as H_2O_2 and R-O-O-H)13, SORs and SODs eliminate superoxide free radicals (O_2). These O_2 molecules are produced by photosynthetic and respiratory electron transport chains12, as well as extracellular processes on the cell surface. This promotes various processes like a ferrous deposition, cell signaling, and growth; however, if O_2 is allowed to accumulate inside the cell, it reacts with solvent-exposed 4Fe-4S clusters in proteins, including those needed for amino acid biosynthesis17 and photosynthesis18, resulting in Fenton reactants, which can eventually cause cell death. Therefore, SODs and SORs are discovered in all three branches – Eukarya, Archaea, and Bacteria [21].

Some of the important antioxidants found in algal species are listed below in **Table 1**.

S.no.	Algal species	Antioxidants	References
1.	*Chlorella zofingiensis, Chaetoceros gracilis*	Exopolysaccharides	[22, 23]
2.	*Chlorella ellipsoidea*	Carotenoids (mainly violaxanthin)	[24]
3.	*Chlorella vulgaris*	Carotenoids (mainly lutein)	[24]
4.	*Chaetoceros calcitrans, C. gracilis*	Fucoxanthin	[23, 25]

S.no.	Algal species	Antioxidants	References
5.	*Codium fragile*	Siphonaxanthin	[26]
6.	*Cyanophora Paradoxa*	β-Cryptoxanthin	[27]
7.	*Dunaliella salina*	β-carotene	[28, 29]
8.	*Dunaliella tertiolecta*	Violaxanthin	[29, 30]
9.	*Haematococcus pluvialis*	Astaxanthin	[31]
10.	*Nannochloropsis oculata*	Sterols	[32]
11.	*Nannochloropsis salina,*	PUFA	[33]
12.	*Skeletonema* sp.,	PUFA	[34]
13.	*Chaetoceros* sp.,	PUFA	[35]
14.	*Thalassiosira weissflogii*	PUFA	[36]
15.	*Phaeodactylum tricornutum*	Sulfated Polysaccharides	[29, 37]
16.	*Porphyridium purpureum*	Zeaxanthin	[38]
17.	*Porphyridium cruentum*	Sulfolipids	[39]
18.	*Spirulina platensis*	C-Phycocyanin	[40]
19.	*Tribonema* sp.	Sulfated polysaccharides	[29, 41]

Table 1.
Antioxidants from algae.

3. Antioxidative enzymes

3.1 Catalases

Initially, cyanobacteria were partitioned into two forms, those that have and those that need ascorbate peroxidase [42]. This depended on the perception that the principal bunch searches H_2O_2 with a peroxidase utilizing a photo-reductant as an electron benefactor. Cyanobacteria have three types of catalases (**Figure 2**) which differ significantly in terms of their structure and amino acid sequence. Bernroitner [43] examined the presence of these three catalases in 44 cyanobacterial genomes and executed a phylogenetic exploration of the enzymatic activities. The findings show that while monofunctional heme-containing catalase (KatE) is the most common type of catalase found in bacteria, archaea, and eukarya, it is extremely rare in cyanobacteria. Only one complete KatE gene was found in *Nostoc punctiforme* PCC73102, whereas pseudogenes (incomplete or fusion genes) were found in *Nostoc sp.* PCC7120, *Cyanothece sp.* ATCC51142, *and Synechococcus elongatus* [43].

KatG bifunctional catalase/peroxidase has both catalases and peroxidase activity. Unlike KatE, it was found in a variety of known cyanobacterial genomes. Cyanobacterial KatGs are known to form a well-segregated clade in the evolutionary representation, implying that KatG evolved in cyanobacterial evolution [43]. Mn catalase (MnCat) is a di-manganese catalase that does not contain heme. Except for *Gloeobacter violaceus* PCC7421, all species have MnCat. It is thought to be found only in diazotrophic cyanobacteria, except for *Gloeobacter violaceus* PCC7421 [43] (**Figure 2**).

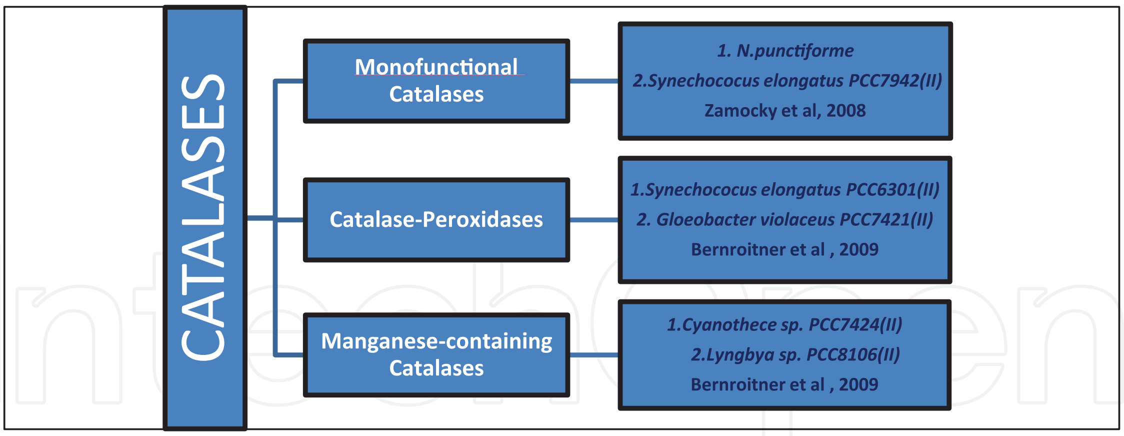

Figure 2.
Types of catalase enzyme.

3.2 Superoxide dismutase

SODs are common metalloenzymes and are classified into four types based on FeSOD, CuZnSOD, MnSOD, and NiSOD. All have metal redox-active centers that, respectively, include Fe (III), Cu (II), Zn (II), Mn (III), and Ni (II/III) at the active site [44]. Cyanobacteria have all four kinds of SOD, and many cyanobacterial species include more than one type of SOD [45]. It should be emphasized that some actinobacteria and archaea have a single gene that, depending on the environment, can either make FeSOD or MnSOD [46]. Cambialistic SOD refers to Fe/MnSOD that exhibits similar activity in Fe- and Mn-bound forms (Sheng et al. 2014). There are currently no known cabalistic Fe/MnSODs. While FeSOD and NiSOD or FeSOD and MnSOD are present in various other single-celled strains, the marine species of *Prochlorococcus* has only one NiSOD [44]. In contrast, strains that are heterocystous, heterotrichous, and flagellated exclusively have iron and manganese forms. Despite having comparable structural characteristics, FeSOD and MnSOD can be identified from one another by structural traits due to the existence of a transmembrane domain, residues mainly for some metals that differ between the two representations, and highly conserved residues found only in the manganese form [47]. Many investigations have found SODs to be involved in protective processes in cyanobacteria.

3.3 Peroxidases

Ascorbate peroxidase is essential for the detoxification of H_2O_2 in plants [48]. These enzymes convert H_2O_2 to monodehydroascorbate and water using ascorbate as the electron source. Ascorbate and dehydroascorbate are produced spontaneously by monodehydroascorbate. Dehydroascorbate reductase converts dehydroascorbate to ascorbate by using glutamine. NADPH-glutamine reductase then regenerates oxidized glutamine. This highlights the importance of the ascorbate-glutamine cycle in plant oxidative stress response. *Nostoc muscorum* PCC 7119 and *Synechococcus* PCC 6311 have both been found to contain ascorbate peroxidase-like activities, and dehydroascorbate reductase and glutamine reductase were both engaged in the regeneration of ascorbate and glutamine, respectively, in *Synechococcus* PCC 7942.

Peroxiredoxins (Prx-s), also known as alkyl-hydro peroxidases, are another widespread group of thiol-explicit cell reinforcement proteins that utilize thioredoxin and other thiol-containing decreasing specialists as electron givers to diminish H_2O_2, alkyl hydroperoxides, and peroxynitrite [49]. It is believed that peroxiredoxins are crucial for decreasing endogenously produced ROS.

3.4 Superoxide reductases

All species interacting with air produce superoxide, or O2•-, which, depending on the biological environment, can function as a signaling agent, a poisonous lifeform, or a nontoxic precursor that breaks down spontaneously. Superoxide reductase (SOR) and superoxide dismutase (SOD) are two enzymes that limit their levels in vivo (SOD) [46]. SORs are simple enzymes with a sequence of 110–180 amino acids. SORs

S. No	Antioxidant compounds	Health benefits	References
1.	Astaxanthin	Influence the immune system and support cognitive health.	[50]
2.	β-Carotene	Preventative for breast cancer	[51]
3.	Bromophenol, Carrageenan	Inhibition of α glycosidase Antitumor, antiviral	[52]
4.	Carotenoids	Reduce the risk of cancer and eye disease.	[53]
5.	Chlorophyll	Prevent cancer and heal damaged skin	[54]
6.	Flavonoids	Anticancer activity prevents coronary heart disease	[55]
7.	Fucophlorethol	Chemopreventive	[56]
8.	Fucoidan	Improves hyperoxaluria Anticancer Protection against monogenic Disorder	[57, 58]
9.	Fucoxanthins	Ontogenesis	[59]
10.	Galactan sulfate	Antiviral	[60]
11.	Lutein	Anti-inflammatory	[51]
12.	Oligosaccharides	Anti-HIV	[61]
13.	Polyphenols	Vascular chemoprotection Antimicrobial α glycosidase inhibition	[55, 62]
14.	Phenolic functional groups and MAAs	Antiproliferative	[55, 63]
15.	Phycobiliproteins (PBPs)	Antiallergic, anti-inflammatory, neuroprotective.	[10, 64]
16.	Phlorotannin	reduce inflammation Kills bacteria	[65]
17.	Phycoerythrin	Reduce the effects of diabetes complications	[66]
18.	Xanthophylls	Neuroprotective	[50]

Table 2.
The advantages of algal antioxidants for health.

can be categorized in several ways. Neelaredoxins and desulfoferrodoxins have only one or two Fe atoms per polypeptide chain, respectively, which was the most distinguishing feature of these enzymes [44]. As a result, the most accurate classification for the procedure is to categorize them as 1Fe-SORs (neelaredoxins) and 2Fe-SORs (the desulfoferrodoxins). The most current exploration the methanoferrodoxin, a SOR from some methanogens with a domain harboring a $[4Fe\text{-}4S]^{2+/1+}$ cluster, may lead to an extension of this classification in the near future [46] (**Table 2**).

4. Non-enzymatic antioxidants

4.1 Carotenoids

Carotenoids are the most common and naturally occurring pigment. One such example is hydrophobic terpenoids. The polyene chain of carotenoids, which is made up of double bonds, gives them their coloration and the capacity to absorb photons of visible wavelengths. Both photosynthetic and non-photosynthetic species can produce carotenoids. Carotenes and xanthophylls are the two major categories of naturally occurring carotenoid algae [67]. Carotenes are linear or cyclic hydrocarbons, e.g., β-carotene and α-carotene. Oxygenated carotenoid derivatives are known as xanthophylls. The xanthophylls, violaxanthin, antheraxanthin, zeaxanthin, neoxanthin, and lutein produced by higher species are synthesized by green algae [67].

Freshwater pond cyanobacterial blooms emit a foul stench because of their adaptation to human-induced conditions exposed. These blooms of blue-green algae spread widely and produce cyanotoxin, poisonous to other creatures. However, these poisons have demonstrated potential properties as cancer treatments. Consider microcystins, numerous peptide toxins, including cryptophycins and anatoxin-A, have shown clinical effectiveness for various cancers [68].

Carotenoids, which are byproducts of photosynthesis and include carotene, xanthene, lutein, and lycopene, are often abundant in algae and cyanobacteria. As foragers of electron species with a singlet, or ROS, carotenoids and other terpenoids are crucial. Therefore, these scavengers are used as antioxidants to stop the growth of cancer cells. There are not many reports on carotenoids' ability to fight different types of cancer [69].

Astaxanthin and β-carotene, generated by *Haematococcus pluvialis* and *Dunaliella salina*, respectively, are two main carotenoids produced by microalgae. A vital component known as β-carotene is extensively looked for as a food coloring agent, for cosmetics addition, and as healthy food. It is frequently used in soft drinks, cheeses, butter, and margarine and is well-known for being safe and having health benefits due to its pro-vitamin A activity [70]. Astaxanthin has advantages, including increasing eye health, boosting muscle power and endurance, and shielding the skin from UVA damage, inflammation, and early aging. Animals need it for various purposes, such as immune system functions and regeneration. It is a potent coloring agent. Other carotenoids are catechin and phycocyanobilin (**Figure 3**).

4.2 Phycobilin pigments

Microalgae form accessory pigments like phycobiliproteins. These pigments improve the light energy utilization efficiency of algae and protect it from solar

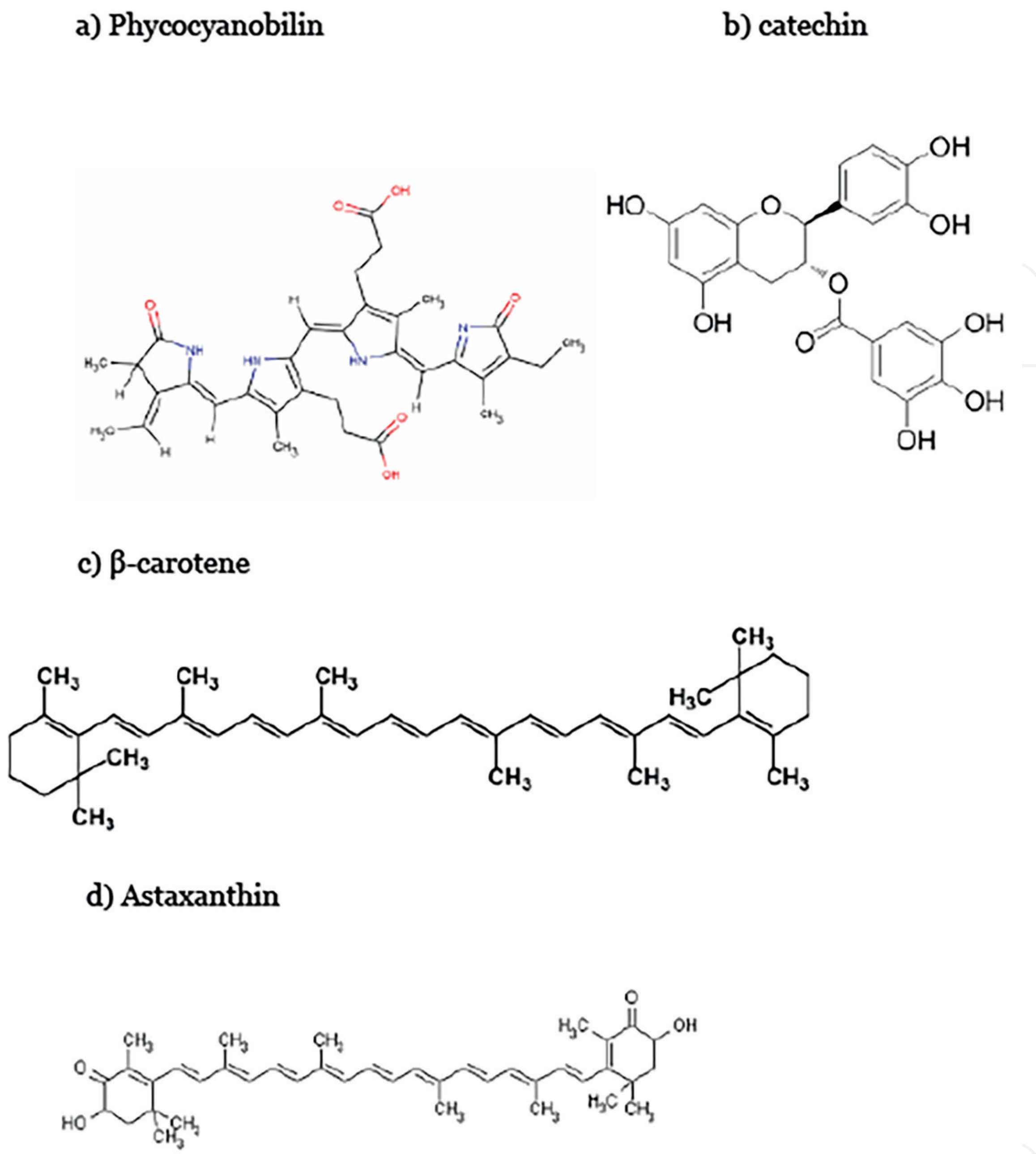

Figure 3.
Chemical structure of some carotenoids. a) Phycocyanobilin b) Catechin, c) β-carotene d) Astaxanthin.

radiation and its effects. They are antioxidants in feed and humans. Phycobiliproteins are the major component of light-harvesting antenna pigments called phycobilisomes. They are present in Rhodophyta (red algae), Cryptomonads algae, and Cyanobacteria (blue-green algae) [71].

The cyanobacterium *Spirulina* (Arthrospira), which produces phycocyanin (blue), and the rhodophyte porphyridium, which produces phycoerythrin(red), are the main sources of phycobiliproteins. In Japan and China, phycocyanin is utilized in chewing gum, candies, dairy goods, jellies, ice cream, soft beverages, as well as in cosmetics like lipsticks. Phycocyanin is a versatile blue coloring agent that gives jelly and confections a vibrant blue color [71].

4.3 Phenolic and polyphenols compounds

The secondary metabolites are polyphenols. They are a collection of chemical substances found in aquatic macrophytes and terrestrial plants. Phenolic compounds are present in edible plants, and their structure contains benzene [71]. Plants frequently contain phenolic chemicals. Polyphenols contain tannins, phenolic acids, flavonoids, tocopherols, and lignin.

Class	Metabolites	Species	Reference
1. Carotenoids	Asctaxanthin	*Chlorella zofingiensis, Chlorococcum* sp., *Haematococcus pluvialis, Scenedesmus* sp.	[71, 72]
	β-carotene	*Dunaliella bardawil, Dunaliella salina, Dunaliella tertiolecta, Scenedesmus almeriensis*	
	Canthaxanthin	*Coelastrella striolata, C. zofingiensis, D. salina, Scenedesmus komareckii*	
	Echinenone	*Botryococcus braunii*	
	Fucoxanthin	*Isochrysis galbana, Phaeodactylu tricornutum*	
	Lutein	*Chlorella protothecoides, Chlorella zofingiensis, Chlorococcum citriforme, Muriellopsis sp., S. almeriensis*	
	Lycopene	*Chlorella ellipsoidea, Chlorella marina, D. tertiolecta*	
	Peridinin	*Amphidinium carterae*	
	Phytoene	*Dunaliella* sp.	
	Phytofluene	*Dunaliella* sp.	
2. Polysaccharides	Crude polysaccharide extracts	*Chlorella stigmatophora, P. tricornutum, P. cruentum, Rhodella reticulata*	[73]
3. Phycobiliproteins	(A) Phycoerythrin – Red (B) Phycoerythrin – Blue	*Arthrospira platensis, Limnothrix* sp., *Nostoc* sp., *Phorphyridium aerugineum, Phormidium ceylanicum, Synechococcus lividus*	[74]
4. Polyphenols	(A) Phenolic acids, (B) Flavonoids-Marennin	*Ankistrodesmus* sp., *A. platensis, Caespitella pascheri, Euglena cantabrica, Leptolyngbya protospira, Nostoc commune, Nodularia spumigena, Phormidiochaete* sp., *Spirogyra* sp.	[75]

Table 3.
Algal metabolites.

4.4 Sulfated polysaccharides

There are substances called polysaccharides in plants, animals, algae, microbes, and other natural products. They comprise numerous monosaccharides connected by various glycosidic linkages and contain polymeric carbohydrate structures. Sulfated polysaccharides are of non-animal origin and are most abundant. Most sulfated polysaccharides found in nature are complex combinations of molecules with a wide range of structures and activity [71]. They frequently occur in nature. Sulfated polysaccharides with a variety of biological functions are primarily found in seaweed. Fucoidan is a complex sulfated polysaccharide that is present mainly in the cell wall fluid of several species. It contains L-fructose and sulfate, ester groups.

Some of the important metabolites found in different algal species are listed in **Table 3**.

5. Applications

5.1 Potential uses for antioxidants

Cyanobacteria's ancestors produced the first biogenic molecular oxygen on Earth, but they are still unknown how they handled oxidative stress [71]. We explore the advancement of superoxide dismutase proteins (Turfs) equipped for eliminating superoxide-free revolutionaries and gauge the beginning of Cyanobacteria. Our microfossil-adjusted Bayesian atomic timekeepers foresee that stem cyanobacteria emerged quite a while back. The development of NiSOD is especially captivating because it concurs with the intrusion of the vast sea by cyanobacteria [21]. Microalgal biotechnology can expand into regions and climates that are unfavorable for agriculture, such as deserts and seashores, and can reach higher productivity. Additionally, aquaculture and life-support systems depend on microalgae cultivation as feed, and they effectively remove nutrients from water [70].

5.2 Potential application in the agricultural sector

Cyanobacteria have been studied thoroughly and have established a solid ground in the agricultural sector. Utilizing microalgae and cyanobacteria to increase agricultural productivity sustainably and efficiently has various potential advantages [76]. A significant source of a wide range of bioactive substances that can control numerous plant response processes is microalgae and cyanobacteria: the enhancement of soil fertility and plant nutrition; the defense of plants against factors both biotic and abiotic; and promotion of growth. Hence, we can conclude that using microalgal/cyanobacterial biomass (or their extracts) instead of chemical-based fertilizers, insecticides, and growth promoters can be an extremely feasible and sustainable option in the agricultural sector. Additionally, the utilization of these biologically based organisms gives rise to a significant step in improving agricultural productivity, which is crucial to achieving the ever-increasing objectives for food items, pharmaceutical items, toxic items, and antitoxic items which are heavily mandated by growing global population [71].

5.3 Potential application in pharmaceuticals and cosmetics sector

Cyanobacteria are a rich source of organic chemicals and can be utilized to make food. Cyanobacteria-derived compounds are often used in cosmetics as thickening, water-binding, and antioxidant ingredients. Cosmetic companies typically base their skin or health claims on ingredients such as carrageenan, vitamin A, polysaccharides, iron, phosphorus, salt, copper, vitamin B1, and minerals such as calcium, magnesium, or others [71].

Since they frequently target tubulin or actin filaments in eukaryotic cells, cyanobacteria cytotoxic metabolites are appealing anticancer medicines. Dolastatins, produced by NRPS-PKS enzymes and present in *Leptolyngbya* and *Simploca* sp., can interfere with the development of microtubules. Other cyanobacterial byproducts, such as the cyclic depsipeptide derivatives known as lyngbyastatins, which are also suspected elastase inhibitors, function as protease inhibitors [70]. A mixture NRPS-PKS pathway is utilized in the biosynthesis of apratoxins such apratoxin-a from *Lyngbya majuscule*. Due to its capacity to cause G1-phase cell cycle arrest and death, it is cytotoxic.

In the cosmetics sector, secondary metabolites can be employed as natural components. Sunscreens contain photoprotective MAAs that protect the skin from UVR damage. In addition to serving as natural colorants, pigments like carotenoids and phycobiliproteins can act as antioxidants to shield the skin from UV-induced mutilation [71].

6. Future prospects

Due to their intricate structures and a range of bioactivities, these secondary metabolites can also be used as lead molecules in developing new drugs. A biosynthetic pathway study employing genomic data with over 208 publicly available cyanobacterial genome sequences can find new natural compounds. Even though cyanobacterial secondary metabolites have been the subject of intensive research, a variety of species still need to be sequenced and examined, and there are still a lot of secondary metabolites that may be significant but have not yet been identified. The growth study of cyanobacteria under peroxidation is still in its initial phases. Most of the information we know about the production of reactive oxygen species in the photosystem mechanism comes from plant findings. Still, cyanobacteria, as a distinct type for photochemical research, will help us understand peroxidation in photosynthesis in general. Analyzing the particular reaction for each reactive form is challenging because many ROS are created concurrently in cells. Future studies should concentrate on the biological consequences and particular targets of specific ROS species in cyanobacteria and the functional reactions they cause. In recent years, significant advancements have been achieved in identifying ROS-scavenging enzymes. The recognition or finding of ROS-scavenging enzymes has advanced significantly in recent years. Still, much more investigation is required to comprehend their function in vivo fully, as well as to determine which areas of the cell they act in and the range of oxidants they can detoxify.

7. Conclusion

Natural algae antioxidants are significant bioactive substances that help fight various ailments and shield cells from oxidative stress. It is an important source of chemicals that are neuroprotective. Algae have exceptional nutritional value, and therapeutic properties have higher demands for natural algal products. This gives microalgae clear benefits over conventional components, making them worth investigating for future use in the feed, food, cosmetic, and pharmaceutical industries. The extensive evolutionary history of cyanobacteria has resulted in adaptations that allow them to cope with natural and man-made stress. The enormous quantity of secondary metabolites produced by cyanobacteria, each with its unique roles supporting the organism's survival, results from the diversity of their morphological, biochemical, and physiological makeup.

Conflict of interest

The authors declare no conflict of interest.

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