Microalgae: An Untapped Resource for Natural Antimicrobials

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Abstract

Numerous biochemical compounds are synthesized by algae in a wide variety of ecosystems. To date, more than 18,000 new bioactive compounds have been isolated from marine algae; most are still uncharacterized. Therefore, the identification of novel prospective antimicrobials from microalgae presents a unique opportunity. A number of investigations have explored the therapeutic potential of algal extracts and extracellular compounds from a wide range of microalgae; they have confirmed antibacterial, antiprotozoal, antiviral, antifungal, and antiplasmodial activity. Chemical groups such as phenols, fatty acids, indoles, terpenes, acetogenins, and some volatile halogenated hydrocarbons derived from microalgae have shown antimicrobial activity. For example, supercritical extracts of the microalgal *Chaetoceros muelleri* have shown antimicrobial activity due to its lipid composition. Many algal species are also effective against a range of bacteria. For example, *Pithophora oedogonium* targets *Salmonella and Staphylococcus* spp. The algae *Rivularia bullata, Nostoc spongiaeforme, Codium fragile, Colpomenia peregrina Sauvageau, Cystoseira barbata,* and *Zanardiniatypus* are active against many Gram-negative and Gram-positive bacteria.

Multidrug-resistant bacteria pose an increasing challenge to global health, with the future efficacy of antimicrobial drugs being uncertain. Most antimicrobial agents that are successfully used in clinical practice have drawbacks such as toxicity, lack of efficacy, and high costs; furthermore, their frequent use can

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result in the emergence of resistant strains of bacteria. Therefore, the development of alternative biodegradable compounds from natural sources with limited side effects is urgently needed. To date, the commercial applications of microalgae-derived compounds has not received as much attention as the fields of antibiotics production, pharmaceuticals, and supplementary biologically active compounds. However, microalgae are destined to become an important raw material for the efficient production of amino acids, vitamins, and other pharmaceuticals. The cultivation of microalgae may provide detailed insights on their practical applications and biotechnological characteristics, which may help researchers develop compounds of interest for their biomedical potential.

8.1 Introduction

The current healthcare system is experiencing a number of clinical problems related to organ transplantations, complicated surgeries, medical device implantation, and chemotherapy. Patients who have undergone these procedures are immunocompromised and thus more susceptible to infections. Furthermore, the global spread of multidrug-resistant bacteria and lack of new antibiotics under development limits the treatment options available to clinicians [81].

The discovery and development of antibiotics are among the most important advances in modern medicine for the life-saving treatment of infectious diseases. However, these "miracle drugs" have lost their efficacy with the appearance of multidrug resistance. Higher rates of morbidity and mortality occur when infectious diseases are caused by multidrug-resistant organisms. In addition, the treatment of these infections is very expensive and requires prolonged hospital stays. This situation is a global epidemiological and public health crisis [13] that is spreading through poor sanitation, person-to-person contact, international travel, and the food chain [91].

The World Health Organization considers multidrug-resistant bacteria to be a major public health concern [103]. Pathogenic bacteria that are resistant to various antimicrobial compounds have been increasing in evolution, prevalence, and distribution. The rapid dissemination of antibiotic-resistant genes through mobile genetic elements, such as plasmids and transposons, has resulted in the emergence of multidrug-resistant strains of many clinically important organisms. Obviously, this situation creates difficulties for clinicians with regard to therapeutic options [37, 62].

8.2 Alternative Sources for Antimicrobial Agents

Bacterial resistance to existing antibiotics, which are mostly derived from bacterial origins, has been increasing rapidly. Thus, there is a need to develop novel efficient compounds using different technologies, including synthetic and semi-synthetic

antibiotics [28]. However, the frequently increasing rate of resistance to these antimicrobial compounds, in addition to the paucity of newer drugs, means that continuous investigation is required to find novel molecules and metabolic targets. One promising avenue is the investigation of natural compounds, particularly those from unexploited sources [93]. These alternative antimicrobial agents from natural sources are expected to have minimal side effects, in addition to being environmentally friendly and biodegradable. Researchers are examining bioactive compounds from algae and microalgae as a potential source. A number of functional compounds have been isolated from microalgae. They have the ability to produce a broad range of biologically active compounds, including those with antibacterial, antifungal, enzyme-inhibiting, antiviral, cytotoxic, antiplasmodial, and immunostimulating activities [52].

Microalgae are a rich source of widely distributed bioactive compounds with commercial importance [106]. Microalgal bioactive compounds can be synthesized from secondary metabolism or directly from primary metabolism. These compounds include proteins, vitamins, fatty acids, and pigments with various antimicrobial properties, such as antibiotic, antifungal, antiviral, anticancer, antiprotozoan, antialgal ,and antienzymatic activities [105]. Compounds such as B12, β-carotene, oleic acid, cyanovirin, palmitoleic acid, vitamin E, phycocyanin, linolenic acid, lutein, and zeaxanthin have antimicrobial, antioxidant, and anti-inflammatory properties for the reduction and prevention of diseases [36, 46, 64, 98]. In most microalgae, the bioactive compounds are accumulated in the biomass. In some cases, the metabolites are excreted into the medium; these are known as exometabolites. Bioactive metabolites of microalgal origin are of special interest in the development of new products for the medical, pharmaceutical, cosmetic, and food industries. Further research should be conducted with these bioactive compounds to verify their beneficial effects for humans, their degradability when released into the environment, and their effects when used in animals [106].

8.3 Algae

Algae are simple plants containing chlorophyll for photosynthesis. They may be single- or multi-cellular organisms; they may also exist in colonies, sometimes working together as simple tissues [10]. Algae range from unicellular organisms of 3–10 μm in size to 30-m-long giant kelp [43]. They are found ubiquitously on Earth, including in rivers, lakes, seas, and soils, as well as on walls, plants, and animals. Algae can be divided into two major groups: 1) macroalgae (seaweeds), including green algae, red algae, and brown algae; and 2) microalgae, which are described in the next section [31].

8.4 Microalgae

Microalgae are unicellular organisms consisting of both prokaryotes and eukaryotes. They grow in fresh or salt water and have varied shapes, with a diameter or length of approximately 3–10 μm. Cyanobacteria have very similar structural characteristics to bacteria, but they also contain the chlorophyll *a* required for photosynthesis. Microalgae are distributed all over the biosphere and are responsible for more than 40% of global photosynthesis [20].

Microalgae play a vital role in aquatic ecosystems as the basis of the food chain. They uptake H_2O and CO_2. With the help of solar energy, they synthesize organic compounds, which are then accumulated or secreted as primary or secondary metabolites. Microalgae have the ability to survive under many environmental stress conditions, including salinity, drought, osmotic pressure, photo-oxidation, heat, cold, and ultraviolet exposure [101]. Due to this ability, they can be found in diverse environments, such as fresh water, extreme salinity, blackish water, desert sands, and moist soil. Microalgae have an extra advantage of significant metabolic plasticity, which is dependent on their physiological state (i.e., stressed vs. nonstressed conditions). Therefore, their secondary metabolism can be easily triggered by applying external stress [34].

Until the 1950s, microalgae were not studied for therapeutic purposes. More recently, extensive research efforts have been directed toward microalgae to find novel compounds that might lead to therapeutically useful agents [16, 66, 67]. Microalgae are being investigated as possible antiviral agents [11] to treat infectious diseases caused by previously unexposed viruses that have re-emerged in recent years. A number of algal extracts and extracellular products have proven antifungal, antibacterial, antiprotozoal, antiviral, and antiplasmodial activity [33, 41, 42, 55, 75], as described in the following sections.

8.5 Antimicrobial Activity of Microalgae

The antimicrobial activity of microalgae has been recognized in compounds belonging to several chemical classes, including terpenes, indoles, acetogenins, phenols, volatile halogenated hydrocarbons, and fatty acids [16, 66]. Numerous pressurized extracts from *Dunaliella salina* have shown antimicrobial activity, with the presence of several fatty acids and compounds such as β-cyclocitral, α- and β-ionone, phytol, and neophytadiene [41, 42].

Microalgae are a natural source of highly interesting biologically active compounds. These compounds have received much attention from researchers and manufacturers in recent years due to their potential applications in different life science fields, including as biomass for food/feed and as bioactive compounds for the medical and pharmaceutical industries [36]. Microalgae are promising sources for novel products because of their great biodiversity and recent developments in genetic engineering [46]. The extraction of bioactive compounds has been investigated in a variety of microalgae, including *Botryococcus braunii, Arthrospira (Spirulina),*

Dunaliella salina, Chlorella vulgaris, Haematococcus pluvialis, and *Nostoc* [68, 72, 76], as described in the following sections.

8.5.1 Spirulina

Spirulina (*Arthrospira*) is prokaryotic cyanobacteria that belongs to Cyanophyta. It arose more than 3 million years ago, forming the current oxygen atmosphere, and has been important in the regulation of the terrestrial biosphere [87]. *Spirulina* is the richest source of proteins, containing approximately 60–70% protein [48].

Calcium spirulan (Ca-SP), a novel sulfated polysaccharide extracted with hot water from *Spirulina platensis*, has shown antiviral activity against herpes simplex virus (HSV) type 1, measles virus, human immunodeficiency virus (HIV) 1, and influenza virus [38]. Both extracellular and intracellular spirulan-like molecules from the polysaccharide fractions of *S. platensis* displayed significant antiviral activities against wide range of viruses, including human cytomegalovirus and HIV-1 [1]. Methanolic and aqueous extracts from *S. platensis* reduced HIV-1 viral loads by approximately 50% and 23%, respectively [4]. *Spirulina platensis* and *Spirulina maxima* also demonstrated antiviral activity against HSV-1 and HSV-2, respectively [25, 40].

In an animal study, suspensions of *Escherichia coli* or *Staphylococcus aureus* were injected into 3-week-old chickens; *Spirulina* (0.1%) enhanced the chicken's bacterial clearance abilities by improving the activities of different phagocytotic cells, such as thrombocytes, macrophages, heterophils, and monocytes [85]. In another study, cultures of *S. platensis* displayed antibacterial activity against six *Vibrio* strains: *Vibrio anguillarum, Vibrio parahaemolyticus, Vibrio scophthalmi, Vibrio alginolyticus*, *Vibrio splendidus* and *Vibrio lentus* [57]. Phycobiliproteins extracted from *Spirulina fusiformis* showed significant antibacterial activity against *Streptococcus pyogenes* and *S. aureus* [70]. Furthermore, the antibacterial activities of purified C-phycocyanin from *S. platensis* clearly inhibited the growth of some multidrug-resistant bacteria, such as *Klebsiella pneumoniae, E. coli, Pseudomonas aeruginosa, and S. aureus* [89].

Spirulina has also exhibited antifungal activity [22]. A butanol extract of *Spirulina* sp. was reported to have activity of 13 mm against *Candida glabrata* [97]. Balb/C mice infected with candidiasis showed a stimulatory effect when *S. platensis* extract was tested [99]. In another study, the antifungal activity of the methanolic extract of *S. platensis* was tested against *Aspergillus flavus*; the reduction of glucosamine production was reported to be nearly 56% [69].

8.5.2 Nostoc

Microalgal biomasses of *Nostoc* have been used in the medical field and as dietary supplements because of their protein, vitamin, and fatty acid content. *Nostoc* contains a spectrum of polyunsaturated fatty acids that include essential fatty acids,

such as linoleic, α-linolenic, γ-linolenic, octadecatetraenoic, and eicosapentaenoic acids [108]. Essential fatty acids are precursors of prostaglandins, thus engendering significant interest from the pharmaceutical industry. The medical value of these microalgae has been demonstrated by their use in the treatment of fistulas and some forms of cancer [102].

Nostoc sp. is reported to have a number of secondary metabolites, including antimicrobial compounds. For example, tenuecyclamide a-d was found from *Nostoc spongiaeforme* [111], and noscomin and coniston a-e were found from *Nostoc commune* [50]. The diverse polysaccharides in *N. commune* have been shown to possess antibacterial activity along with antitumor, antiviral, and anti-inflammatory effects [92]. Nostocyclyne A is another antimicrobial compound that has been isolated from *Nostoc* sp. [80]. Cyanovirin, a potential protein molecule produced by a *Nostoc* microalga, showed positive effects in the treatment of HIV and influenza A (H1N1) [98].

8.5.3 Chlorella

Chlorella was discovered by the Japanese, who are the traditional consumers of algae and use it as a food supplement. The microalga *Chlorella* is rich in chlorophyll, vitamins, proteins, minerals, polysaccharides, and essential amino acids. This microalga is 53% (w/w) protein, 23% (w/w) arbohydrate, 9% (w/w) lipids, and 5% (w/w) minerals and oligoelements [49].

Pratt et al. first isolated microalgal active compounds from *Chlorella*; in their study, a mixture of fatty acids (chlorellin) was isolated and demonstrated antibacterial activity against both Gram-negative and Gram-positive bacteria in vitro [82]. Interestingly, the authors also described a practical application during World War II derived from a previous experiment. *Chlorella* spp. were heavily inoculated in open sewage from military installations, rendering it bacteriologically safe for discharge into local streams. There was a reduction in the number of coliforms in the areas where *Chlorella* spp. were present compared with the areas where *Chlorella* spp. were absent [83].

8.5.4 Dunaliella

Dunaliella spp. are green, unicellular, halotolerant microalgae that belong to the Chlorophyceae group. These microalgae are extensively studied because of their diverse nature, including physiological aspects, tolerance of extreme habitats, and many biotechnological applications. *Dunaliella* spp. are a rich source of bioactive compounds, such as carotenoids, glycerol, lipids, enzymes, and vitamins [45, 84]. These microalgae are a major source of natural β-carotene; they are able to produce up to 14% of their dry weight under conditions of high salinity, light, and temperature as well as nutrient limitations [29].

Chang et al. reported that *Dunaliella* cells contained antibiotic substances. The crude extract of this microalga strongly inhibited the growth of *Bacillus cereus*, *S. aureus*, *Enterobacter aerogenes* and *Bacillus subtilis* [17]. In another study, *Dunaliella* microalga also showed antibacterial activity against various microorganisms of importance to the food industry, including *E. coli*, *S. aureus*, *Candida albicans,* and *Aspergillus niger* [41, 42, 45].

Minolenic acid extracted from *Dunaliella primolecta Butcher* (C-525) and *Chlorococcum* sp. (HS-101) [73] showed antibacterial activity against methicillin-resistant *S. aureus* (MRSA). Another study investigated extracts of *Dunaliella* spp. isolated from clean and polluted waters. The authors observed that a heat-labile non-proteinous substance produced by species from the polluted water had the ability to inhibit *E. coli*. It was therefore suggested that microalgae from highly competitive environments are more likely to produce compounds with antimicrobial activity [63] (Tables 8.1, 8.2, 8.3, and 8.4).

Table 8.1 Antibacterial activity of some algae species

Bioactive compound/Microalgae	Targeting bacteria	References
Ambiguine I isonitrile/*Fischrella* sp.	*E. coli* ESS K-12, *Staphyloccocus albus*, *Bacillus subtilis*	[86]
Skeletonema costatum	*Vibrio spp.*	[71]
Carbamidocyclophanes/*Nostoc* sp.	*Staphylococcus aureus*	[12]
γ-lactone malyngolide 14/*Lyngbya majuscule*	*Mycobacterium smegmatis* and *Streptococcus pyogenes*	[15]
Norbietane diterpenoid (20-nor-3a-acetoxyabieta-5,7,9,11,13-pentaene)/*Microcoleus lacustris*	*S. aureus*	[35]
Noscomin/*Nostoc commune*	*Bacillus cereus, Staphylococcus*	[51]
	epidermidis, Escherichia coli	
Phenolic compound/*Nostoc muscorum*	*B. subtilis, B. cereus, E. coli, Salmonella typhi, S. aureus*	[24]
Cycloeudesmol/*Chondria oppositiclada*	*S. aureus, Candida albicans*	[27]
Hapalindole T/*Fischerella* sp.	*S. aureus, Pseudomonas*	[3]
	P. aeruginosa, S. typhi, E. coli	
Euglena viridis	*Pseudomonas, Aeromonas, E. coli, Edwarsiella*	[18]
Padina pavonica	*Enterococcus faecalis, S. epidermidis*	[21]
Ulva fasciata, Chaetomorpha aerea	*Klebsiella pneumonia, P. aeruginosa, S. aureus*	[90]
Ulva Lactuca	*B. subtilis, B. pumilus*	[77]
Cystoseira sp., Gelidium latifolium		

Table 8.2 Antiprotozoan activity of some algae species

Bioactive compounds/Microalgae	Targeting protozoans	References
Ascosalipyrrolidinones/*Ascochyta salicorniae*	*Plasmodium falciarum*	[74]
Viridamide A/*Oscillatoria nigro*	*Trypanosoma cruzi*, *Leishmania exicana, Plasmodium falciparum*	[95]
Virdis		
Symplocamide A/*Symploca* sp.	*T. cruzi, Leishmania donovani, P. falciparum*	[60]
Venturamides/*Oscillatoria* sp.	*P. falciparum*	[61]
Snyderol sesquiterpene/*Laurencia obtuse*	*Plasmodium falciarum*	[104]
Ambigol C/*Fischerellambigua*	*T. rhodesiense, P. falciparum*	[112]
Amphidinium sp.	*Trichomonas foetus*	[109]
Dinophysis fortii, *Prorocentrum lima*	*T. foetus*	[9]
n-hexane, dichloromethane/*Bostrychia tenella*	*T. cruzi* trypomastigotes, *Leishmania amazonensis* promastigotes	[19]

Table 8.3 Antiviral activity of some algae species

Bioactive compounds/ Microalgae	Targeting protozoans	References
Spirulan/*Spirulina* sp.	HIV-1 and HIV-2 (inhibits reverse transcriptase) HSV, influenza	[96]
Nostoflan/*Nostoc flagilliforme*	HSV-1 (HF), HSV-2 (UW-268), human cytomegalovirus (Towne), influenza (NWS), adenovirus (type 2), Coxsackie (Conn-5)	[96]
Cyanovirin-N/*Nostoc ellipsosporum*	HIV-1 (interacts with high mannose groups of envelope glycoproteins, gp120 and blocks its interaction with target cell receptors) HIV-2, HSV-6, Mesles virus	[96]
	Simian immunodeficiency virus, feline immunodeficiency virus	
Tribromo 4,5-dihydroxybenzyl methyl ether/*Symphyocladia latiuscula*	Wild-type HSV-l, APr HSV-I, and TK-HSV-l	[79, 78]
Sulfoquinovosyl diacylglycerol/*Ishige okamurai*	HSV-2	[107]
Dollabelladiene 147, 10,18-diacetoxy – 8-hydroxy	HSV-1and HIV-1	[6, 47]
2,6-dollabeladiene 148/*Dictyota pfaffi*		
8,80-bieckol 151 and 8400-bieckol 152/	HIV-1 reverse transcriptase and protease	[30]
Venustatriol 302, thyrsiferol 303 and thyrsiferyl 23-acetate	Vesicular stomatitis	[88]
	Vesicular stomatitis Indiana virus, HSV-l	
304/*Laurencia venusta*		

Table 8.4 Antifungal activity of some algae species

Bioactive compounds/Microalgae	Targeting fungus	References
Ulva lactuca, Cystoseira sp., Gelidium latifolium	*Candida albicans, Microsporum gypseum, Aspergillus niger*	[77]
Padina pavonica	*Candida spp.*	[21]
Chlamydomonas reinhardtii	*A. niger, Aspergillus fumigatus*	[32]
Trentepohlia umbrina	*A. niger*, *Trichoderma barsianum*	[94]
Amphidinium sp.	*A. niger*	[109]
Dinophysis fortii, *Prorocentrum lima*	*A. niger*	[9]

8.6 Natural Compounds

A number of chemical functional groups from algae have been reported to be bacterial inhibitors, including polysaccharides, phlorotannins, peptides, fatty acids, terpenes, and halogenated furanones, as described in the following sections.

8.6.1 Polysaccharides

Fucoidan- and laminarin-like algal polysaccharides have shown antibacterial activity against *E. coli* and *S. aureus* and have been used as oral drugs. They also prevent the adhesion of the biofilm forming *Helicobacter pylori* in gastric mucosa [8, 39, 53, 113]. In Ireland, ultrasound-assisted extraction was used to obtain laminarin from the brown seaweeds *Ascophyllum nodosum* and *Laminaria hyperborean*; the laminarin was shown to be a significant growth inhibitor of *E. coli*, *Listeria monocytogenes*, *S. aureus,* and *Salmonella typhimurium* [53]. Hot and cold water extraction was used to obtain polysaccharides from the brown seaweed *Dictyopteris membranacea* and red seaweed *Pterocladia capillacea;* these extracts showed antibacterial activity against Gram-negative *Pseudomonas fluorescens* and *E. coli* and Gram-positive bacteria *B. cereus* and *S. aureus* [2].

Spirulan and Ca-spirulan are the most important anticancer polysaccharides isolated from *Spirulina* spp.; they also showed effective and broad-spectrum activity against HIV-1, HIV-2, and influenza viruses. These sulfated polysaccharides inhibit the reverse transcriptase activity of HIV-1 (like azidothymidine) [26]. Another acidic polysaccharide, nostoflan from *Nostoc flagelliforme*, exhibits potent virucidal activity against HSV-1 [56].

8.6.2 Proteins and Peptides

Lectins are a diverse group of proteins that are found in algae, plants, animals, bacteria, and viruses [5]. They have various biological functions in humans, such as blood-protein regulation, carbohydrate binding, cell adhesion, and immune defense [65].

Lectins extracted from the red algae *Solieria filiformis* have demonstrated inhibitory effects against both Gram-negative and Gram-positive pathogenic bacteria [44]. The inhibition of bacterial growth is thought to occur by the binding of lectin with mannan, which is a linear polymer of the saccharide monomer mannose that arises on the cell surface of Gram-negative bacteria. Mannan acts as a hapten upon binding with a large lectin molecule, producing an immune response. However, it does not seem to inhibit the growth of Gram-positive *S. aureus* or *B. subtilis*, probably due to inappropriate lectin-polysaccharide binding sites on the cell surfaces of these species [100].

In another study, enzymatic hydrolysis was used with trypsin-extracted antibacterial peptides (>10 kDa mass) from *Saccharina longicruris*. Food spoilage from *S. aureus* was inhibited at concentrations of 0.31 to 2.5 mg/mL, indicating that the hydrolysate could be used as a potential agent for food preservation [7].

8.6.3 Fatty Acids

Antibacterial fatty acids, including 13-octadeadienoic acid and cyclopentaneacetic acid, have been obtained by ethanol extraction from *Sargassum vulgare* and by diethyl ether extraction from *Sargassum fusiforme.* Morphological variations were observed in *S. aureus* and *K. pneumonia* cells treated with these seaweed extracts. Transmission electron microscopy showed that the cell walls of both organisms were punctured, resulting in cell wall rupture, protoplasm shrinking, cytoplasmic vacuolation, cytoplasmic seepage, chromatin sprinkling, cell size reduction, and outer cell shape alteration [23]. In another study, long-chain fatty acids extracted from the green microalga *Planktochlorella nurekis* demonstrated antibacterial activity against *Campylobacter jejuni*, *E. coli, Salmonella enterica,* and *Lactobacillus johnsonii* [14].

8.6.4 Phlorotannins

The antibacterial activity of phlorotannins is reportedly due to the inhibition of oxidative phosphorylation. Phlorotannins could bind with bacterial proteins, such as cell membranes and enzymes, thus triggering bacterial cell lysis. Phloroglucinol compounds caused bacteriolysis of *Vibrio sp.* when tertiary structures, such as methyl- or acetyl-vinyl, were present [54]. Phlorotannins isolated from *Sargassum thunbergii* algae showed activity against *Vibrio parahaemolyticus* by destroying its cell wall and cell membrane, thus causing membrane permeability destruction and cytoplasm leakage [110].

Lee et al. extracted a wide range of solvents from brown seaweed, *Eisenia bicyclis* (Arame) and investigated them against antibiotic-resistant *Propionibacterium*-related acne. The phlorofucofuroeckol compound (phlorotannin with an alcohol substituent) showed the most potent antibacterial activity, including antimicrobial activity against MRSA [59].

8.6.5 Terpenes

A number of terpene compounds isolated from algae, such as diterpene-benzoate bromophycolides, have the ability to inhibit bacterial growth. Lane et al. extracted bromophycolides (diterpene-benzoate macrolides) from the Fijian red alga *Callophycus serratus* with methanol, dichloromethane, and water. The extracts significantly inhibited MRSA and vancomycin-resistant *Enterococcus faecium* [58].

8.7 Conclusion

Antimicrobial drug resistance is a serious concern, with limited or no treatment options for infections that are emerging globally. Antimicrobial agents may be derived from bacteria and fungi or chemically synthesized. However, resistance to these agents has led to the need for alternative natural sources. Algae are a potential alternative source for antimicrobial agents due to their diversity and ubiquitous nature, along with their ability to produce secondary metabolites that exhibit antimicrobial (i.e., antibacterial, antifungal, antiviral, antimalarial, and antiprotozoan) activities. Algae and their synthesized products have an ability to survive and adapt to a wide range of habitats, even when their environmental conditions are altered or stressed.

To date, there has been quite limited research into these microorganisms, and they predominantly remain an "untapped" resource. Thus, there is obviously a need for further study of the compounds described in this chapter for the treatment and prevention of various diseases, as well as an ongoing search for other undiscovered metabolites. Various technologies are available to assist in the systematic identification and purification of these natural products, which—when combined with in vivo experiments—could lead to novel antimicrobial agents.

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