5 Marine Algae and Their Importance

Sarah Constance Motshekga, Lesego Tabea Temane, Jonathan Tersur Orasugh, and Suprakas Sinha Ray

Abstract

Simple, non-flowering marine algae are a diverse group that range in size from unicellular (2 μm to 30 m) to multicellular forms (kelps up to 70 m). They are crucial for the formation of habitats and as a food source in the marine environment. Alga is the oldest member of the plant world, with origins going back several million years. They support life in the marine ecosystem by creating food webs, producing oxygen, and acting as the largest primary producer in the marine environment. They also act as habitats for many creatures. Algae are a major primary producer in the marine ecosystem and contribute more than 90% of the world's photosynthesis. They are made up of many kinds of big macroalgae and tiny algae. Photosynthetic organisms called marine algae (also known as seaweeds) inhabit the seas and oceans. They are acknowledged as having a number of advantages and serving as a source of several significant bioactive chemicals. We discuss facts about marine algae, including their taxonomy, distribution, and significance, in this chapter. Because it doesn't need land, irrigation infrastructure, additional nutrients, or fertilizers, marine algae have an advantage over terrestrial-based crops developed for biofuels. Farms that cultivate macroalgae for human and animal consumption are widespread around the world, whereas biofuel-focused farms are still in the experimental phase. For scientists conduct-

S. C. Motshekga
Department of Chemical Engineering, University of South Africa, Roodepoort, South Africa

L. T. Tersur · J. T. Orasugh (✉) · S. S. Ray
DST-CSIR National Centre for Nanostructured Materials, Council for Scientific and Industrial Research, Pretoria, South Africa

Department of Chemical Sciences, University of Johannesburg, Doorfontein, Johannesburg, South Africa
e-mail: JOrasugh@csir.co.za

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ing studies in this field, the information presented in this review provides a scientific basis on marine algae.

Keywords

Anaerobic digestion · Brown algae · Dietary fibers · Marine algae · Red algae

5.1 Introduction

Marine algae are photosynthetic plant-like organisms that are found in aquatic environments, mainly in the sea; but some species are also found in rivers, lakes, and even wastewater. Algae have the ability to adapt to a wide range of environmental conditions such as temperature, salinity, pH, moisture, and different light intensities, which describes their distribution worldwide (Anbuchezhian et al. 2015). Algae are a very large and diverse group of more than 30,000 species which range from unicellular to multicellular types. They have different characteristics in which even their color, size, habitat, and nutrition are quite different (Pooja 2014). Algae are considered the primary producers of the aquatic environment due to the key role they play in the productivity of many nutrients and the marine food chain at large (Anbuchezhian et al. 2015; Pooja 2014; Hasan and Rina 2009). They are also considered the fastest-growing species that are largely productive, chemically unique, and biologically active, which gives a broad scope for their characteristics. They use different mechanisms to fix the atmospheric carbon dioxide and effectively utilize the nutrients that could be converted into biomass (Hasan and Rina 2009). Algae, like higher plants, exhibit inherent cellular mechanisms for using solar energy (light) for the photosynthesis process. Algae are classified into two major types: macroalgae (seaweed) and microalgae (Pooja 2014; Hasan and Rina 2009).

Macroalgae are large-size algae that are visible to the naked eye and are multicellular photoautotrophic organisms which in addition to being primary producers they also play a crucial role in the structuring and preservation of the marine ecosystem. Macroalgae differ in various aspects such as size (some species can grow up to tens of meters), morphology, ecophysiology, and longevity. They play a huge role in the marine ecosystem in that they also hold fast to the sediment and prevent coastal erosion; while other species have gas-filled-like structures to help in buoyancy. Based on their pigmentation, macroalgae are classified into three classes which are green algae (Chlorophyta), brown algae (Phaeophyta), and red algae (Rhodophyta) (Anbuchezhian et al. 2015; El Gamal 2010). Their growth rate could be more than 30 times faster than terrestrial plants and the oil content in macroalgae is also 30 times more than conventional crops. The oil derived from macroalgae is of better quality and the algal source is sulfur free and entirely biodegradable. Macroalgae are a prospective source of fuel for the production of biodiesel, bioethanol, biomethane, and biohydrogen due to their water content that is rich in lipids, protein, and carbohydrates (Godvin Sharmila et al. 2021). The percentage of lipids in macroalgae is very low, hence, macroalgae are more considered for natural sugars and the carbohydrates which they contain in large quantities for the production of biogas or alcohol-based fuel. The algae chemical composition can vary depending on the season of harvest, site of collection, environmental conditions, growth habitat, and time (Godvin Sharmila et al. 2021). In recent years, macroalgae have received more attention owing to their various health-promoting properties that can decrease the risks of many ill-health. In most Asian countries, hundreds of marine macroalgae are mainly used for human nutrition. Furthermore, macroalgae have also found use in water treatment and in agriculture as natural fertilizers, therefore improving the quality of the soil and agricultural products and limiting the use of chemical fertilizers. Due to their capacity to reduce carbon dioxide emissions, these aquatic organisms are further exploited as sustainable feedstock for biofuel production. The use of macroalgae as a source of renewable energy has been explored for years with constant improvement being done in this area (Anbuchezhian et al. 2015; Pooja 2014; Hasan and Rina 2009; Warner et al. 2015).

Unlike macroalgae, microalgae are microscopic organisms that are also found in freshwater and marine environment. They are highly diverse organisms with the ability to generate a wide range of useful chemicals and metabolites. Microalgae are unicellular microorganisms, which can exist individually, in chains or in groups. Their size ranges from a few micrometers to a few hundred micrometers depending on the type of species. Microalgae have a rapid growth rate compared to their terrestrial counterparts (Bajhaiya et al. 2017). A typical microalgae species can be evaluated by its ability to transform solar energy into biomass production and subsequently the formation of metabolites. Microalgae are photosynthetic autotrophic organisms, which are capable of producing complex compounds by using the available simple substances in their environment (Bajhaiya et al. 2017). Due to their ability to utilize carbon dioxide and solar energy to generate products without needing organic carbon, photosynthetic microalgae are attractive and a potential alternative to microbial factories that use bacteria and fungi. It is estimated that there are about 200,000 to 800,000 species of microalgae, with about 50,000 species identified. These aquatic microorganisms have developed a defense mechanism to survive in harsh and unfavorable environments because they are found in ever-changing climate conditions that unfortunately lead them to produce a wide range of chemical compounds with novel properties and various biological activities. The production of these chemical compounds varies from species to species, and no single species produce the same compound as they are depending on factors such as life cycle, environmental conditions, seasons, etc. By producing natural bioactive compounds, microalgae are a good natural substitute for the chemical synthesis of certain bioactive compounds that are of commercial interest (Mobin et al. 2019). In addition, these chemical compounds are physiologically active substances and offer high-value bioproducts for commercial use. Microalgae are classified based on their various characteristics that include their pigmentation, morphology, photosynthetic membranes, and storage arrangements. Microalgae species are divided into four groups, namely diatoms (Bacillariophyceae), green algae (Chlorophyceae), blue-green algae (Cyanophyceae), and golden algae (Chrysophyceae) (Rajkumar et al. 2014).

In this chapter, we go over some information concerning marine algae, such as their taxonomy, distribution, and importance. Marine algae have an advantage over terrestrial-based crops created for biofuels because it doesn't require land, irrigation infrastructure, additional nutrients, or fertilizers. Worldwide, there are many farms that grow macroalgae for human and animal consumption, but biofuel-focused farms are still in the experimental stage. The data offered in this review offers a scientific foundation on marine algae for researchers working in this area.

5.2 Properties of Marine Algae

Studies have demonstrated the positive effects that bioactive substances taken from marine algae have on human health. However, the commercialization of these high-value compounds has been restricted because of the poor bioactive chemical extraction yield, regulatory approval standards, and the high production costs. To guarantee the safety, effectiveness, and quality of the substances derived from marine algae, it is also necessary to address potential side effects, allergic reactions, heavy metal contamination, and toxins. Here are a few of the effects that bioactive substances derived from marine algae have.

We understand that most marine algae's primary structure is polysaccharide in nature though in conjunction with other chemical compounds in their diverse percentages as per the source of the algae.

Most of the compositional monosaccharide configuration, molecular weight (MW), backbone, as well as structure–function correlation of polysaccharide-based three main species of algae (red, brown and green algae) are summarized in Table 5.1.

5.3 Microalgae Harvesting Methods

Microalgae harvesting is crucial for the extraction of useful algal biomass for further processing and for end-product applications. Harvesting is the process of removing water from the microalgae culture, hence, the aim of harvesting is to generate slurry with around 2–7% algal suspension (total solid matter). There are four main methods of microalgae harvesting: centrifugation, floatation, filtration, and sedimentation (gravity settling), which have been extensively explored for both pilot and large-scale harvesting of algal biomass (Cassini et al. 2017). A pre-treatment method such as flocculation may be necessary for improving the harvesting yield. To increase the effectiveness of the harvesting method, the combination of two or more of these methods is often utilized. Selection of a harvesting method largely depends on several factors such as density and size of the microalgae and the desired final products (Fu et al. 2017; Balasubramaniam et al. 2021). An effective harvesting is a key to a good economical yield of the overall process. There is typically no best method when it comes to harvesting, as each method has its own

Table 5.1 The monosaccharide composition, molecular weight, backbone, polysaccharide type, and structure-function relationship of polysaccharide-derived from three main species of algae (red, brown, and green algae)

Species	Polysaccharide type	Molecular weight (Da)	Monosaccharide	Backbone	Biological activities	Ref
Red algae						
Mastocarpus stellatus	Carrageenan	1248 k	Gal:Glc:Xyl:Man = 87.8:5.4:4.4:2.4	β-1,3-Gal and α-1,4-Gal	Anticoagulant	Youssouf et al. (2017) and Gómez-Ordóñez et al. (2014)
Chondrus armatus	Carrageenan	88 k	Gal	β-1,3-Gal and α-1,4-Gal	Antiviral	Kalitnik et al. (2013)
Nemalion helminthoides	Sulfated mannan	43.8 k	Man:Xyl:Sulphate = 1:0.01:0.64	α-1,3-Man	Immunomodulatory	Pérez-Recalde et al. (2014)
Ahnfeltiopsis flabelliformis	Sulfated galactan	–	Gal:3,6-AnGal:Glc:Xyl:SO_3Na = 34.9:15.0:2.0:2.1:18.7	β-1,3-Gal and α-1,4-Gal	Anticoagulant	Kravchenko et al. (2014)
Porphyra haitanensis	porphyran	277 k	Gal	β-1,3-Gal	Antitumor	Wang and Zhang (2014)
Gracilaria fisheri	Sulfated galactan	–	Gal	β-1,3-Gal and α-1,4-Gal	Antioxidant	Imjongjairak et al. (2016)
Cryptonemia seminervis	Sulfated galactan	51.6 k	Gal, trace in Glc, Ara	β-1,3-Gal and α-1,4-Gal	Anti-metapneumovirus	Mendes et al. (2014)

(continued)

Table 5.1 (continued)

Species	Polysaccharide type	Molecular weight (Da)	Monosaccharide	Backbone	Biological activities	Ref
Gelidium crinale	Sulfated galactan	300–600 k	Gal	α-1,3-Gal and α-1,4-Gal	Antiinflammatory	Assreuy et al. (2012)
Brown algae						
Alaria marginata	Galactofucan	–	Fuc:Gal:Xyl = 47.5:47.3:5.2	→3)-α-l-Fuc-(2,4-SO_3^-)-(1→	Anticancer	Usoltseva et al. (2016)
Hizikia fusiforme	–	–	Fuc:Gal:Xyl:Glc = 1.00:0.50:0.24:0.21	–	Immunomodulatory	Jeong et al. (2015)
Cystoseira sedoides	Fucoidan	642 k	Fuc and Uronic acid	α-1,3 or α-1,4-Fuc	Antiinflammatory	Hadj Ammar et al. (2015)
Coccophora langsdorfii	Fucoidan	–	Fuc	α-1,3 and α-1,4-Fuc	Anticancer	Imbs et al. (2016)
Eisenia bicyclis	Laminaran	19–27 k	Glc	β-1,3 and β-1,6-Glc	Anticancer	Wozniak et al. (2015)
Scytothamnus australis	Sulfated fucan	–	Fuc:Xyl:Glc = 40.8:1.5:1	α-1,3-Fuc	Anti-HSV1	Wozniak et al. (2015)
Sargassum fusiforme	Laminaran	27.6 k	Glc:Gal = 1.13:0.38	β-1,3-Glc, β-1,6-Glc	–	Jin et al. (2014)
Laminaria japonica	Laminaran	–	Man:Ara:Glc:Gal:Fuc = 3.27:8.61:4.23:12.12:46.93	–	Antioxidant	Cheng et al. (2011)

Species	Polysaccharide type	Molecular weight (Da)	Monosaccharide	Backbone	Biological activities	Ref
Green algae						
Enteromorpha linza	Rhamnan sulphate	108.4 k	Rha:Xyl:Man:Glc:Gal = 3.6:1.0:0.31:0.28:0.19	1,4-Rha	Antioxidant	Wang et al. (2013)
Codium divaricatum	Sulphated galactan	37.9 k	Gal:Glc = 97.8:2.16	1,3-β-Gal	Anti-coagulant	Li et al. (2015)
Capsosiphon fulvescens	Ulvan	–	Rha:Xyl:Man = 45.0:44.1:10.2	4)-β-Xyl-(1→4)-α-Rha-(1→	Anticoagulant	Synytsya et al. (2015)
Ulva armoricana	Ulvan	140–500 k	Rha:Gal:Glc:Xyl = 40.0:6.7:26.2:4.4	–	Antiviral	Hardouin et al. (2016)
Ulva pertusa	Ulvan	28.2 k	–	–	Antiradiation	Shi et al. (2013)
Monostroma angicava	Rhamnan sulphate	88.1 k	Rha	α-1,2-Rha, α-1,3-Rha	Anticoagulant	Li et al. (2017)
Gayralia oxysperma	Rhamnan sulphate	109 k	Rha:Xyl:Glc = 76.0:17.3:4.4	α-1,3-Rha	Antitumor	Ropellato et al. (2015)

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Gal galactose, *Glc* glucose, *Xyl* xylose, *Man* mannose, *3,6-AnGal* 3,6-anhydro-D-galactose, *Ara* arabinose, *Fuc* fucose, *Rha* rhamnose

Table 5.2 Comparison of microalgal harvesting methods

Method	Advantages	Disadvantages
Flocculation	Simple and low cost High yield of biomass harvesting	Potential contamination of harvested algal biomass by chemical coagulants Synthetic coagulants negatively influence biochemical compounds (proteins, lipids, carbohydrates)
Floatation	Simple to operate	High maintenance cost Small air bubbles are energy intensive Requires flocculants
Filtration	Reliable and can handle even the delicate cells	High maintenance cost Slow process High operational costs Membrane fouling or clogging
Centrifugation	Easy, rapid, and efficient Can handle most algal types	High energy input High maintenance cost Internal damage of cells
Sedimentation	Simple, cost-effective Low energy input	Often slow and produce low yield Suited for dense algal cultures

advantages and disadvantages (Table 5.2). For macroalgae, manual harvesting works well or often times the use of mechanical techniques is used.

5.3.1 Flocculation

Flocculation is considered to be an inexpensive harvesting method in which the addition of flocculants causes the microalgae cells to agglomerate by forming larger particles known as flocs. Chemical and bio-flocculants are the two types of flocculants available. The flocculants could either be cationic polymers or multivalent cations (Cassini et al. 2017). Iron and aluminum salts are chemical flocculants that are of low cost, readily available, and used widely in industries. And the biopolymer bio-flocculant being used is chitosan. Several factors such as the type of microalgae, cell concentration, type of flocculant, flocculant dosage, pH, charge density, growth phase, salinity, the presence of algal organic matter, etc., could affect the flocculation process, thus the selection of an appropriate flocculant is imperative (Balasubramaniam et al. 2021). Various mechanisms such as bridging, surface charge neutralization, electrostatic patching neutralization or sweeping may be used to explain the flocculation process. Flocculation is often used with the combination of a filter compressor (Branyikova et al. 2018).

5.3.2 Floatation

Floatation is the separation process where microalgal cells float on the surface of water using air or gas bubbles to the solid particles. Harvesting involves the pumping of air bubbles from underneath the sedimentation tank to aid gravitational separation where the generated bubbles will attach and carry the solid particles to the collection area. Sometimes a chemical coagulant is added to allow the floatation process in increasing the harvested biomass, or an adjustment of pH is carried out to enhance the separation (Mustafa et al. 2021). The four main types of floatation techniques used in the harvesting of algal biomass are dissolved-air, electro-floatation, dispersed air, and ozone floatation (Mustafa et al. 2021). The dissolved air floatation method uses tiny air bubbles with a size range of 10–100 μm, which forces or pushes the solid microalgae cells to rise to the surface where they may be collected using the skimming method. This makes the dissolved air method time and energy-consuming, while the dispersed air floatation method uses air bubbles with a diameter of 700–1500 μm created from strong mechanical agitators. Although this method uses less energy, it has substantial maintenance costs. The floatation technique is economically feasible due to the operational costs, simple to operate and a high yield of biomass harvesting (Balasubramaniam et al. 2021).

5.3.3 Filtration

Filtration is the dewatering process used after flocculation to enhance the harvesting efficiency. The process separates the alga biomass from the liquid culture medium by passing through specific filters such as porous membranes, screens or microstrainers. Porous membranes are typically used for microalgae with low density and also performed on a small scale. The pressure difference throughout the filter is crucial to separate the solid particles and the liquid which can either be by gravity or vacuum. The few available filtration methods are conventional filtration, microfiltration, and ultrafiltration. The conventional process is convenient for harvesting large microalgae (Balasubramaniam et al. 2021). Membrane filtration could be used to meet the requirements of both dewatering and thickening of the microalgae harvesting. However, this procedure for algal biomass harvesting always suffers from clogging or membrane fouling, especially with high biomass concentrations that could be time-consuming, increase operational costs, and reduce the effectiveness of the process. The drawbacks of the filtration process of microalgae harvesting include high maintenance cost, slow operation, and high operation (Mustafa et al. 2021).

5.3.4 Centrifugation

Centrifugation of the microalgae is the separation of the algal biomass from the culture media using centrifugal force to separate the solids according to their cell size and density difference. This method is preferred over other harvesting techniques because it is reliable and rapid for all microalgae species, not time-consuming and can harvest almost all microalgae without the use of any flocculants or chemicals. Due to the ability of this process to harvest large amount of the microalgae biomass, it is commonly used for saturated fatty acids, pharmaceuticals, and other high-value products (Balasubramaniam et al. 2021). As a result, the effectiveness of the entire process depends on the rotating speed used to separate solids that are suspended in a liquid, which enables it to harvest the majority of the algal biomass from the culture media. However, this process is also time-consuming and costly due to the high amount of energy input required. Furthermore, there is a chance that the mechanical spinning of the microalgal cells could be destroyed under the high shear and gravitational forces. One of the benefits of using the centrifugation methods is that it is effective and does not use chemicals that can contaminate the end-product. Centrifugation is often done at a laboratory or pilot scale (Mustafa et al. 2021).

5.3.5 Sedimentation

Sedimentation is the initial step of separating the microalgae from water. Harvesting of microalgae using this method yields a wet and large amount of sludge, which results from the slow settling and poor velocity. Factors that could influence the success of this method are the weight of the microalgae, sedimentation velocity, light intensity, temperature, time, and size. Sedimentation method works effectively in the combination of the flocculation process, which enhances the microalgal removal and settling. The method is also cost-effective, simple and requires low energy input (Mustafa et al. 2021). However, the process is slow and produces a low yield of microalgal harvest, especially when the microalgae culture did not go through the process of flocculation.

5.4 Bioactive Compounds from Marine Algae and Their Biological Activity

Marine algae produce various bioactive compounds that have been used in a wide range of applications ranging from nutritional supplements to bioactive substances for health benefits. The content and key compositions of the bioactive compounds in marine algae vary from species to species, and no species produces the same compounds. These bioactive compounds include and are not limited to polysaccharides, vitamins, minerals, proteins, and lipids. Research has shown that these bioactive compounds have numerous health-promoting benefits such as antimicrobial, anti-inflammatory, anticancer, and antibiotic effects. Figure 5.1 gives a summary of the bioactive compounds and their properties. Both macroalgae and microalgae contain more of the bioactive compounds, although this section will focus more on microalgae (Hakim and Patel 2020).

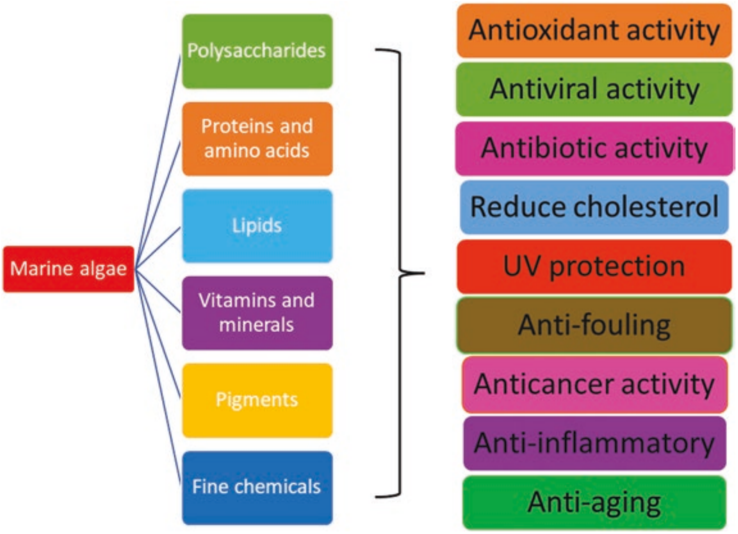

Fig. 5.1 Summary of bioactive compounds and some of their properties

5.4.1 Polysaccharides

Polysaccharides are long chains of carbohydrates (cellulose, starch, or glycogen) made up of smaller carbohydrates that are commonly used in the human body for cellular structure and energy. Fructose, glucose, xylose, and galactose make up the majority of polysaccharides, whereas sulfate, protein, and uronic acid are only present in trace levels. Marine algae produce a wide range of polysaccharides with varying value and largely depends on their degree of purity, availability, and use (Mahata et al. 2022). With the right conditions, around 15–55% of the dry biomass weight of marine algae can be extracted as polysaccharides. Among the available polysaccharides, sulfate polysaccharides are the most significant algal polysaccharides from the biological activity perspective and a significant source of bioactive natural compounds with properties such as antithrombotic, antitumor, antimicrobial, antimutagenic, anti-inflammatory, immunomodulatory, and antiviral effects. The polysaccharides are also promising therapeutics for atherosclerosis due to their properties, abundant availability, cost-effective, and minimal toxicity (Øverland et al. 2019).

5.4.2 Proteins and Amino Acids

Marine algae can have a protein concentration that ranges from 6 to 52% of their dry weight. However, the protein content contained in microalgae are up to 71% of their dry weight, although these amounts are strongly impacted by the environmental conditions, including temperature, salinity, light, pH, mineral content, CO_2 supply, population density, growth phase physiological status, the season, and the species (Hakim and Patel 2020; Øverland et al. 2019). Because of this high protein content, microalgae are promising to be used as a protein source in food industries. Essential amino acids determine the quality of food proteins. Although glutamine and aspartic acid are the two most abundant amino acids in microalgae, the algae can also accumulate large concentrations of other amino acids such as alanine, arginine, valine, leucine, lysine, threonine, isoleucine, and glycine. The properties of flavor development are observed in glutamine and asparagine. Because microalgae can produce practically all amino acid compounds, they are preferred to other sources of protein in protein-rich diets (Hakim and Patel 2020; Mahata et al. 2022). In addition, genetically modified microalgae are capable of producing a variety of proteins effectively.

5.4.3 Lipids

Marine macroalgal species contain a very low lipid content; however, most microalgae are rich in oil content. Because microalgae have a high lipid content, they could substitute fish oil in aquaculture and for human consumption. Microalgal lipids are abundant in essential long-chain polyunsaturated fatty acids (PUFAs), such as omega-3 and omega-6 oil, which are needed because humans and many other animals cannot produce them on their own. They are also beneficial for functional components of the cell membranes. The bioactive chemicals of prostaglandins and thromboxane, which are required for the maintenance of cholesterol and triglycerides in the body as well as for protection against some diseases including dermatitis and osteoarthritis, are produced by PUFAs, which benefit both human and animal health (Mobin et al. 2019). Omega fatty acids have drawn a lot of interest because of their role in growth, nutrition and therapeutic and pharmaceutical use. For human consumption, marine fish like salmon and cod are currently the main source of these bioactive compounds. However, the quantity and composition of algal lipids differ depending on the species, region, season, temperature, salinity, amount of light, or a combination of these factors. Phospholipids, which are frequently used in the cosmetics industry as wetting agents, emulsifiers, solubilizers, and liposomes, are another component of microalgae that is abundant (Mahata et al. 2022). They also have medicinal usefulness due to their anti-inflammatory and antithrombotic properties. About 10% to 50% of the total lipids in marine microalgae can be phospholipids.

5.4.4 Vitamins and Minerals

Micronutrients such as vitamins and minerals are crucial for the human body metabolism, just like macronutrients like protein, fat, and carbohydrates. They all co-exist in biochemical pathways where they eventually take part in a number of biological processes, including boosting immunity, promoting growth and development and repairing cell damage. Moreover, a lack of vitamins can cause a number of illnesses, such as rickets, beriberi, and scurvy. Vitamins can be found in abundance in marine microalgae (Mahata et al. 2022). These aquatic microorganisms are capable of producing all the vitamins that are produced by higher plants. Spirulina sp., for example, has large amounts of vitamins A and B complex, which have a direct effect on how the brain and cells operate, as well as how well they prevent illness. Compared to soybeans and cereals, microalgae accumulate more vitamins, but this varies depending on algal species, season, alga growth stage, and environmental parameters. In addition, the growth and maintenance of the body depend on a variety of minerals, including calcium, phosphate, potassium, magnesium, sodium, iron, zinc, and copper. Although an inadequate potassium diet might result in convulsions, a calcium and phosphate deficit results in bone abnormalities (Mobin et al. 2019). Magnesium, iron, copper, and zinc all play important roles in maintaining healthy bones, eyesight, and energy levels. These elements, which could be used in the diet of humans or animals, are fortunately present in marine microalgae. Macroalgae also possess a high mineral content, which has traditionally been given to farm animals as a mineral supplement (Mobin et al. 2019; Øverland et al. 2019).

5.4.5 Pigments

The presence of pigments within microalgae cells gives them their characteristic colors. The two main types of pigments are water-soluble and fat-soluble. Carotenoids and chlorophylls are fat-soluble pigments, whereas phycobilin is a water-soluble pigment. These high-value compounds made from microalgae have potential uses in medicine as antioxidants, immunological boosters, neuroprotectants, and vitamin precursors. Algal pigments have been proposed as a potential anti-aging ingredient for skin care products (Mahata et al. 2022). Marine microalgae and cyanobacteria have the ability to generate up to 8% of the fluorescent proteins called phycobiliproteins. Based on their long-wavelength absorption maxima, the phycobiliproteins can be divided into four main classes: allophycocyanin (650–660 nm), phycocyanin (610–625 nm), phycoerythrin (490–570 nm), and phycoerythrocyanin (560–600 nm). Due to their widespread usage in immunity assays, phycocyanin and phycoerythrin are the two most well-known phycobiliproteins. Carotenoids are naturally occurring, lipophilic (fat-soluble) pigments created by starving microalgae. In addition, marine Spirulina species, *Porphyridium* species, and *Chlorella protothecoides* are abundant in natural pigments that may be used as food additives, antioxidants, food identifiers, and therapeutic substances (Mahata et al. 2022).

5.4.6 Marine Algae-Based Fine Chemicals

5.4.6.1 Carotenoids

Carotenoids are a significant group of pigments that are fat-soluble and are potent antioxidants that are essential for oxygen photosynthesis. Carotenoids cannot distribute the energy they acquire from the sun directly to the photosynthetic pathway; hence, they can only pass it from one chlorophyll molecule to the other. Carotenoids typically make up 0.1 to 2% of the dry weight of the majority of algae. Only a few of the 400 known carotenoids, such as β-carotene and astaxanthin are of great commercial significance. Other carotenoids are of less significance (lutein, zeaxanthin, lycopene, and bixin). The physico-chemical characteristics of the aquatic environment, including water temperature, salinity, light, and nutrient availability, might affect the carotenoid composition of microalgae (Surget et al. 2017). The majority of environmental factors change seasonally, which might eventually promote or impede the formation of carotenoids.

5.4.6.2 Antioxidants

Antioxidants are abundant in microalgal biomass, which has potential uses in human and aquatic diet, cosmetics, and medicine. Applications of antioxidants in health has sparked interest due to the free radicals and oxidation used in many physiological functions. Due to the harsh environmental conditions that microalgae have adapted to, they experience a significant amount of oxygen and radical stresses. As a result, their bodies have developed various and effective defence mechanisms to prevent the accumulation of free radicals and reactive oxygen species. This process shields microalgae from cell-damaging activities (Surget et al. 2017). Astaxanthin is one of the strong antioxidants.

5.4.6.3 Phenols

Phenols are a significant class of natural products produced by microalgae as secondary metabolites. These substances have biological and antioxidant properties and they are crucial for algal cell defense against biotic and abiotic stress. The basic functions of algae, such as photosynthesis, cell division, and reproduction, are not directly affected by these substances. Purified phenolic compounds have properties that include antioxidant, anti-radical, UV protection, metal chelation, and antifouling. However, the antioxidant properties are the primary bioactivity linked to phenolic chemicals (Surget et al. 2017). Some algal phenolic compounds have reportedly been linked to anti-inflammatory activity, including rutin, hesperidin, morin, caffeic acid, catechol, catechin and epigallocatechin gallate, a phenolic compound that may be able to combat free radicals.

5.4.6.4 Minerals

The high mineral concentration of microalgae is well known. Spirulina, a microalga, has ash in excess of 6.7% of its dry weight. The general mineral content is greatly influenced by the ambient growing conditions, including season, temperature, physiological status, geographic variances, etc. (Øverland et al. 2019).

5.5 The Importance of Marine Algae

5.5.1 Edible and Poisonous Algae

For long years, people have grown algae and consumed it as food. Dried microalgae not only have a lot of provitamin A but also have other elements such as proteins, minerals, vitamins, and antioxidants. The micronutrients in minerals are iodine, iron, zinc, copper, selenium, molybdenum, fluoride, manganese, boron, nickel, and cobalt. The macronutrients in minerals are sodium, calcium, magnesium, potassium, chlorine, sulfur, and phosphorus (Thomas 2002). Thousands of tons of consumable algae and algal-derived products are produced annually around the world for use as dietary supplements, food additives, functional foods, and pharmaceuticals (Suter 2011). As a sort of brown algae, edible seaweed is a vegetable of the sea that both marine life and people consume in a variety of ways. Asian cuisines, notably those of Japan and Korea, have traditionally harvested and consumed edible seaweed that is low in calories and high in nutrients (Veluchamy and Palaniswamy 2020).

Seaweed is primarily recognized as a source of iodine because it has a proportion of iodine that exceeds the minimal dietary needs. Brown algae have the highest iodine content, with dry kelp containing between 1500 and 8000 ppm and dry rockweed (Fucus) containing between 500 and 1000 ppm (Cole and Sheath 1990). In dried seaweeds, red and green algae (Fig. 5.2) typically have lesser levels (between 100 and 300 ppm), yet they still have large concentrations compared to all other terrestrial plants. Very little amounts of seaweed could meet the current 150 μg/day recommendation for daily adult needs. Even green and red algae, such as the purple nori used in Japanese cuisine, give 100–300 μg of iodine per gram. Just 1 g of dried brown algae provides between 500 and 8000 μg (Hoek et al. 1995).

According to studies, the thyroid gland is the principal tissue that uses iodine in the human body, and it adjusts quickly to greater iodine consumption (it is a component of thyroid hormones). Due to the extremely low iodine content of the soil, plants, and animals that are used as common food sources, large percentages of the world's population receive insufficient amounts of iodine. To ensure that proper quantities are reached, iodine is frequently added to table salt in many nations. A few emerging nations, nevertheless, are still catching up and experiencing the negative effects of inadequate iodine intake. China is home to the most people who have a history of consuming little iodine, followed by India (Kandale et al. 2011).

Seaweed is one of the richest plant sources of calcium, second only to iodine, although compared to dietary needs, its calcium concentration is far inferior to that of iodine. Usually between 4 and 7% of the dry matter of seaweeds is calcium. One gram of dried seaweed has 70 mg of calcium (7%), which is less than the 1000 mg recommended daily intake. Even yet, this is more than a serving of the majority of items without a milk base (Kandale et al. 2011).

Along the oceanic coasts of the world, sea lettuce, a type of edible green seaweed, grows. It has long been a staple diet for people as well as water creatures like manatees and sea slugs. Spirulina, a marine alga, contains a remarkable amount of

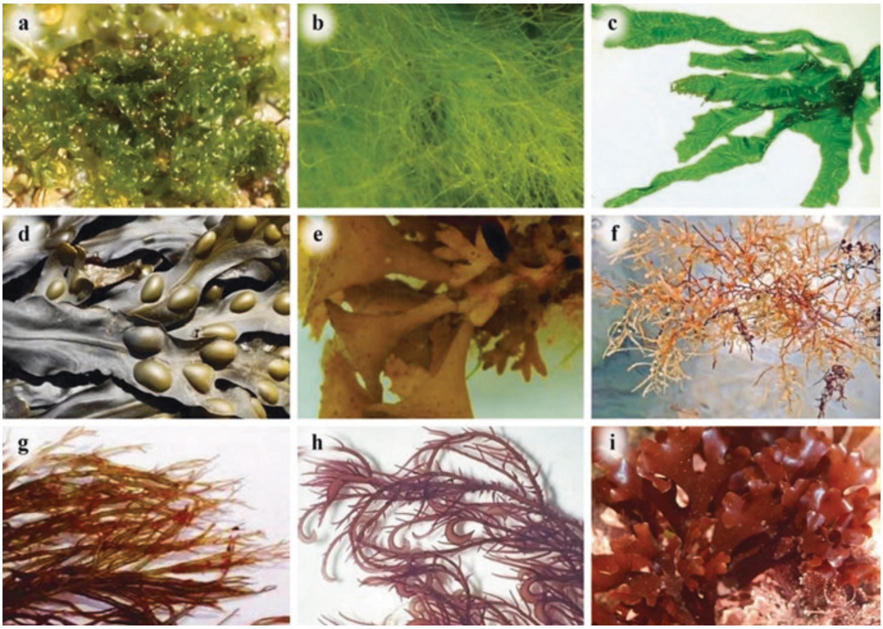

Fig. 5.2 Different seaweeds images such as green, brown, and red. (**a**) Ulva reticulata Forsskål; (**b**) Chaetomorpha linum (O.F.Müller) Kützing; (**c**) Ulva lactuca f. fasciata (Delile) Hering; (**d**) Fucus vesiculosus Linnaeus; (**e**) Turbinaria turbinata (Linnaeus) Kuntze; (**f**) Sargassum natans (Linnaeus) Gaillon; (**g**) Gracilaria edulis (SGGmelin) PCSilva; (**h**) Hypnea musciformis (Wulfen) J.V.Lamouroux; (**i**) Chondrus crispus Stackhouse. (Reproduced with copyright permission from Pradhan et al. (2022), Elsevier 2022)

protein, of which 90% is easily digestible. Spirulina is a microalga that may offer a promising source of protein for people who are undernourished or suffer from protein insufficiency (Suter 2011).

High quantities of unsaturated fatty acids are found in the oils from certain algae. For instance, the triglyceride pool of Parietochloris incisa has a very high amount of arachidonic acid, up to 47% of the total. Docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) are long-chain, necessary omega-3 fatty acids that can be found in some types of algae that are popular among vegetarians and vegans (Bigogno et al. 2002). Oleic and alpha-linoleic acids are found in significantly larger concentrations in green algae, whose fatty acid composition is most similar to that of higher plants. Red algae are rich in EPA, which is primarily found in animals, particularly fish (Kandale et al. 2011).

Alginate, agar, and carrageenan, gelatinous compounds together known as hydrocolloids or phycocolloids, are gelatinous substances that are extracted from seaweeds through harvesting or cultivation. As food additives, hydrocolloids have come to economic prominence. The food sector takes advantage of their emulsifying, water-retention, and gelling abilities, among other physical qualities. Agar is a food additive that is used in molded foods, confectionary, meat and poultry items, desserts, and beverages. Carrageenan is a preservative that is used in dairy products, baked goods, salad dressings and sauces, dietetic foods, and meat and fish products (Kandale et al. 2011). Chemical dyes and coloring agents can also be replaced with the natural pigments produced by algae (Bigogno et al. 2002).

Edible algae are a rich source of dietary fiber, minerals, and proteins (Kuda et al. 2002). Between 32% and 50% of the dry matter in seaweed is made up of fiber. The soluble fiber fraction makes up 51–56% of the total fibers in red (agars, carrageenans, and xylans) and green (ulvans) algae and 67–87% in brown algae (laminaria, fucus, and others). In general, soluble fibers are thought to reduce cholesterol and have hypoglycemic properties (Kandale et al. 2011).

Marine algae are another popular source of antioxidants (Nagai and Yukimoto 2003). Eisenia bicyclis (arame) (Cahyana et al. 1992) and fucoxantinein Hijikia fusiformis (hijiki) (Yan et al. 1999) contain phylopheophytin, one of several active antioxidant substances from brown algae. The amount of protein in seaweed varies. Brown algae have a low dry matter content (5–11%), whereas some species of red algae have a dry matter content (30–40%) that is comparable to legumes. Green algae, which are still rarely harvested, have up to 20% of their dry matter in protein, which is a significant amount. A microalga called spirulina is well recognized for having a very high concentration, or 70% dry matter (Kandale et al. 2011).

These algae are typically boiled, steam-treated, dried, and stored while in process. According to Jiménez-Escrig et al., a brown alga called Fucus had 98% less ability to scavenge radicals after being dried at 50 °C for 48 h. In addition, these dried goods are reconstituted with 20 to 40 times their original volume of water before consumption. Agars are used in the food business and for lab media culture. They are made from red seaweeds like Gracilaria (Jiménez-Escrig et al. 2001).

But certain algae can actually be dangerous to people. For instance, eating tropical fish that have consumed alga like Gambierdiscus or Ostreopsis can have devastating effects on humans and induce the ciguatera sickness. Fish-eating algae with the names Heterosigma and Dictyocha (classes of Raphidophyceae and Dictyochophyceae, respectively) are also suspected. Arsenic poisoning can occur if some seaweeds are consumed since they contain significant amounts of the toxic metal. Brown algae called hizoka contain enough arsenic to be used as rat poison (Britannica E 2022).

5.5.2 Anticancer Activity of Marine Algae

Recently, researchers have been more interested in bioactive substances with anticancer characteristics that were derived from marine algae. According to studies, -carotene, an antioxidant also obtained from marine algae, is extremely beneficial in the early phases of cancer treatment. Another biomolecule that is obtained from marine algae and has anti-inflammatory and antioxidant characteristics is phycocyanin. In both developed and developing nations, cancer is recognized as one of the top causes of mortality. The growth in the average global life expectancy has made it a significant health issue and a burden for the majority of public healthcare systems everywhere (Yao et al. 2022). GLOBOCAN estimates that there are 18.1 million new instances of cancer worldwide, affecting people of all sexes and ages, while 9.6 million people died from cancer in 2018 (Bray et al. 2018). By 2030, it is anticipated that there will be 13.1 million cancer-related deaths worldwide (Rashid et al. 2019). Oncology has made considerable strides in recent years, developing cancer treatments like surgery, radiation, chemotherapy, molecule-targeted therapeutics, and cell-based therapies (Miller et al. 2016; Halim et al. 2019; Wang et al. 2022). However, there are still issues that make it difficult to use and render these cancer therapies ineffective. For instance, chemotherapy, the most popular cancer treatment, also harms or kills healthy cells, causing significant side effects in the patients. To improve the quality of life for cancer patients, it is imperative to find novel anti-cancer chemicals that target cancer cells while having less of an impact on normal cells. Discovering molecules that can aid in the prevention and treatment of cancer has increasingly relied on natural products (Özyalçin and Sanlier 2020; Tang et al. 2020).

Over a hundred Marine algal polysaccharides (MAPs) have been examined through in vitro and in vivo animal studies over the course of the last ten years, indicating the excellent anti-cancer effects of MAPs in a wide spectrum of cancer cell lines. Numerous MAPs effectively stop the growth of tumor cells and harm cancer cells without having any negative side effects, addressing the main problems with traditional chemotherapy. According to recent research, MAPs primarily combat cancer by preventing cancer cells from proliferating, causing cancer cells to undergo apoptosis and cell cycle arrest, preventing tumor tissues from forming new blood vessels or metastasizing, scavenging reactive oxygen species (ROS), triggering an immune response, and controlling the gut microbiota (Yao et al. 2022).

5.5.2.1 MAPs Inhibit the Proliferation of Cancer Cells

Through direct cytotoxicity, MAPs prevent and destroy cancer cells and reduce colony development in cancer cells. The red alga *Gracilariopsis lemaneiformis* (*Gp. lemaneiformis*) has been shown to have antitumor properties, and its polysaccharides of ganoderma lucidum (PGL) has been shown to have potent anticancer properties. PGL is known as a neutral polysaccharide with a linear structure made up of repeating units of the disaccharide agarobiose and is composed of 3,6-anhydro-L-galactose and D-galactose. In a study, Khang and colleagues looked at the ability of the human gastric cancer cell line MKN45, the lung cancer cell line A549, and the cervical carcinoma cell line HeLa to proliferate after the addition of PGL. The CCK-8 assay findings for cell viability showed that PGL had the most pronounced anticancer effect on A549 lung cancer cells. In addition, trypan blue staining's results on cell proliferation matched up with the results of the cell viability test. Furthermore, they discovered that PGL hindered cell proliferation, decreased cell viability, and changed cell shape, and that these effects were time- and concentration-dependent. In an effort to better understand the molecular mechanism of the PGL-induced antitumor phenotype, they calculated the gene expression values by Cufflinks and the distribution, and 758 differentially expressed genes were observed (Kang et al. 2016a).

Nikolova et al. carried out research to demonstrate a cell-specific effect of a recently isolated extracellular polysaccharide from the red microalga Porphyridium sordidum in an effort to shed some light on the effectiveness of polysaccharides on normal and cancer cells. The xylose:glucose and galactose:manose:rhamnose in the red microalga Porphyridium sordidum had a molar ratio of 1:0.52:0.44:0.31. As we look more closely at the isolated polysaccharide's anti-proliferative effects. MDA-MB231 high metastatic and MCF-7 low metastatic cancer cell lines, together with one normal cell line (MCF10A), were examined. Polysaccharide concentrations of 10, 25, 50, 75, or 100 g/mL were applied to the cells during 24 and 48 h. The 3-(4,5-dimethylthiazol-2-yl)-5-(3-carboxymethoxyphenyl)-2-(4-sulfophenyl)-2H-tetrazolium (MTS) test assay was used to examine the effects of polysaccharide on cell proliferation. The results revealed that polysaccharides could not significantly alter cell viability 24 h after incubation, but that 48 h later, cell survival appeared to be dose- and cell-type-dependent. Furthermore, the combination of 200 V/cm electroporation and the application of 75 g/mL polysaccharide caused changes in cell morphology and a 40% reduction in the viability of MDA-MB231 cells, whereas control cells (MCF10A) maintained their normal morphology and vitality (Nikolova et al. 2019).

In a study against colorectal cancer, Choi and colleagues examined the sulfated glucuronorhamnoxylan polysaccharide (abbreviated SPS-CF) that was isolated from the green alga Capsosiphon fulvescens. At 500 μg/mL, the SPS-CF treatment caused a dose-dependent reduction of the proliferation of HT-29 human colon cancer cells by up to 40%. Figure 5.3e demonstrates that, in comparison to untreated control cells, the cell viability was dose-dependently reduced to 93, 90, 80, and 64% at doses of 0, 50, 100, 200, and 500 μg/mL, respectively. Although the treatment of 200 and 400 mg/kg SPS-CF intraperitoneally had no effect on the change in mice body weight (Fig. 5.3b), it considerably slowed the growth of colon tumors when compared to control mice (mice treated with phosphate-buffered saline) (Fig. 5.3a). Following 14 days of treatment, the average tumor volumes were 2822 mm^3 for the SPS-CF 200 mg/kg/day group, 2691 mm^3 for the SPS—CF 400 mg/kg/day group, and 3561 mm^3 for the control group (Fig. 5.3c). The 400 mg/kg dose resulted in a roughly 20% reduction in tumor weight when compared to the control group (Fig. 5.3d) (Choi et al. 2019).

Three human cancer cell lines (Fig. 5.4), including HepG2 (hepatocellular carcinoma), MCF7 (human breast cancer), and Hela, were tested for the cytotoxic effects of an ulvan isolated from the green seaweed Ulva lactuca (cervical cancer) in a study by Thanh et.al. The figure shows the ulvan's cytotoxic effects against the HepG2, MCF7, and Hela cancer cell lines at different concentrations (0.8, 4, 20, and 100 μg/mL). According to the study, the percentage of cell viability decreased as ulvan concentration grew, reaching zero at a concentration of 100 μg/mL (Thanh et al. 2016).

At a concentration of 200 μg/mL, fucoidan derivatives from the brown alga Saccharina cichorioides were discovered to exhibit inhibitory activity on the development and colony-forming capacity of HT-29 human colorectal cancer cells (Anastyuk et al. 2017), while HT29 and HCT-116 human colorectal cancer cells

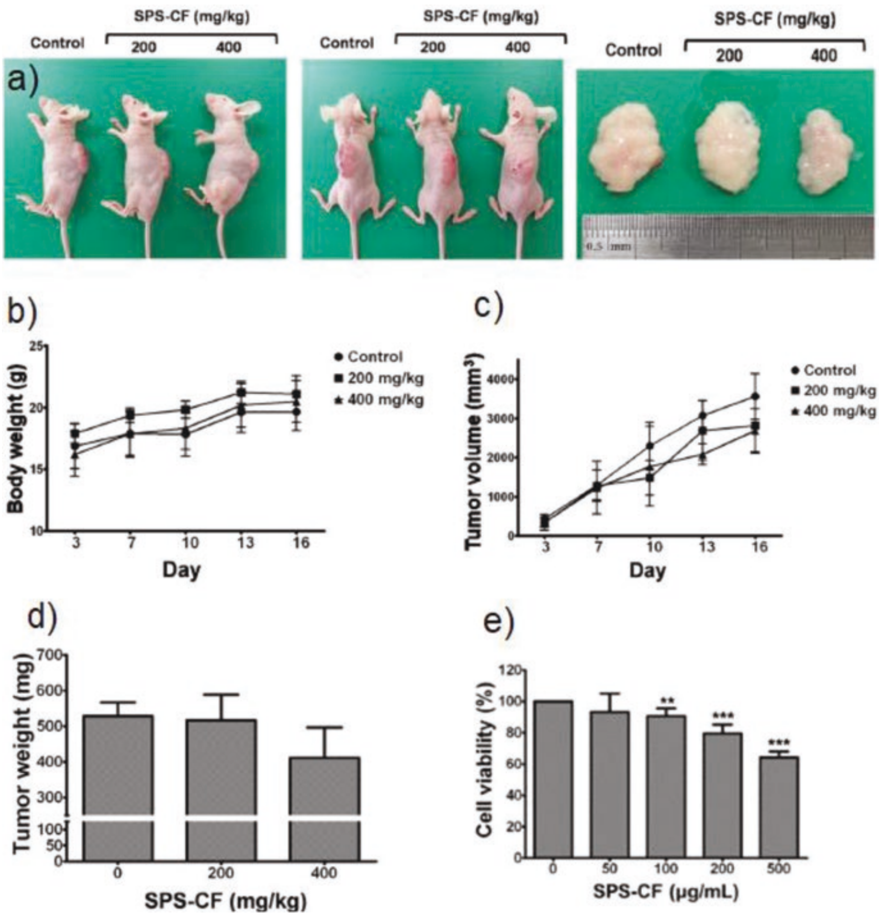

Fig. 5.3 In vivo efficacy of SPS-CF against human colon cancer xenografts. (**a**) Tumor size in the tissues of SPS-CF treated mice maintained smaller tumor sizes compared with the control group. (**b**) The average body weight of each group was expressed as the means ± SD ($n = 4$ per group). (**c**) The average tumor volume of each group was measured using a caliper and expressed as the means ± SD ($n = 4$ per group). (**d**) The average tumor weight of each group was expressed as the means ± SD ($n = 4$ per group). (**e**) Effects of SPS-CF on the cell viability and cell cycle in HT-29 cells—Inhibitory effects of SPS-CF on the growth of HT-29 cells were determined by MTT assay. (Reproduced with copyright permission from Choi et al. (2019), Elsevier 2019)

showed signs of being inhibited by polysaccharides from Fucus evanescens. At a concentration of 200 g/mL, the polysaccharides F1 and F3 inhibited the colony growth of HCT116 cells by 28 and 32%, respectively, although they only had a small impact on the colony growth of HT-29 cells (16 and 27%, respectively) (Hmelkov et al. 2018).

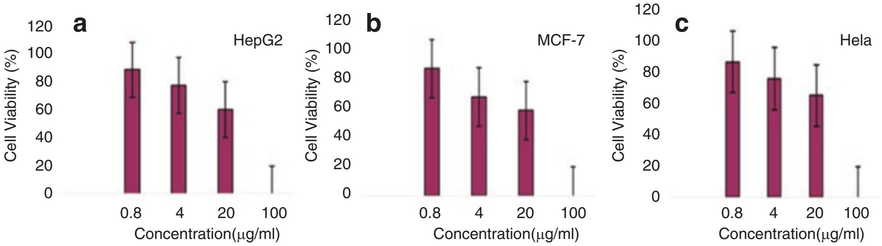

Fig. 5.4 Cytotoxic effect of the ulvan at various concentrations against (a) HepG2, (**b**) MCF7, and (**c**) Hela cancer cell lines. The data shown are the mean ± SD of triplicate assays, and the experiment was repeated three times. (Reproduced with copyright permission from Thanh et al. (2016), Elsevier 2016)

5.5.2.2 MAPs Induce Apoptosis in Cancer Cells

Organisms eliminate unneeded or diseased cells from their bodies through a physiological process known as apoptosis, often known as programmed cell death. It takes part in a variety of pathogenic conditions, such as cancer. Cell shrinkage, membrane blebbing, nuclear condensation, and the creation of an apoptotic body are all characteristics of apoptosis. When cell division and apoptosis are out of balance, tumors develop. Exploring new medications that can cause cancer cells to die by inducing apoptosis is desirable because apoptosis is thought to be a controlled and regulated process (Kandeel et al. 2018). MAPs are powerful anti-cancer agents with a strong therapeutic potential against a range of malignancies, as they can control cancer cell apoptosis and promote cancer cell death, according to extensive research conducted over the past few decades. In a concentration-dependent manner (0 mg/L, 20 mg/L, 80 mg/L, and 320 mg/L), a study found that polysaccharides extracted from the brown alga Laminaria japonica (LJP) strongly triggered apoptosis (mostly late apoptosis) in HONE1 human nasopharyngeal cancer cells. Where after LJP treated for 72 h, HONE1 apoptosis was dominated by late apoptosis, and HONE1 apoptosis in different concentrations of LJP was listed as following: 0 mg/L (8.81 ± 1.25) % (Fig. 5.5a), 20 mg/L (18.58 ± 2.43) % (Fig. 5.5b), 80 mg/L (32.24 ± 2.49)% (Fig. 5.5c), 320 mg/L (49.51 ± 1.89%)% (Fig. 5.5d) (Zeng et al. 2017).

In Caco-2 human epithelial colorectal adenocarcinoma cells, FHs 74 Int normal human small intestine cells, HepG2 human hepatocellular carcinoma cells, and Fa2N-4 human hepatocytes, degraded -carrageenan from Kappaphycus alvarezii promoted the morphological hallmarks of apoptosis. In cells treated with -carrageenan, the morphological signs of apoptosis, such as cell detachment, membrane blebbing, chromatin condensation, nuclear disintegration, and the production of apoptotic bodies, were seen (Zainal Ariffin et al. 2014). In addition, MCF-7 human breast adenocarcinoma cells and HCT-15 human colon adenocarcinoma cells were both induced to undergo apoptotic morphological alterations and cell-mediated death by fucoidan isolated from the brown alga Sargassum polycystum. When cells were left untreated with F2, the nuclei in the control cells fluoresced uniformly

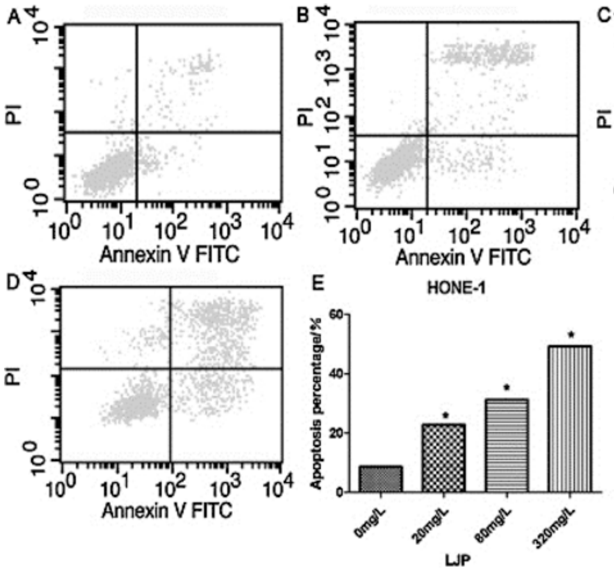

Fig. 5.5 LJP significantly induced apoptosis of HONE1 cells. Flow cytometry was used to detect the apoptosis of NPC cells. HONE1 apoptosis in different concentrations of LJP was detected, and HONE1 apoptosis in different concentrations of LJP was listed as following: (**a**) 0 mg/L (8.81 ± 1.25) %, (**b**) 20 mg/L (18.58 ± 2.43) %, (**c**) 80 mg/L (32.24 ± 2.49) %, (**d**) 320 mg/L (49.51 ± 1.89%) %. (**e**) The differences of apoptosis rate between the LJP group and the control group were statistically significant ($P < 0.01$), and so was the differences between groups in different concentration ($P < 0.01$). (Reproduced with copyright permission from Zeng et al. (2017), Elsevier 2017)

green, indicating that the cells were healthy and their nuclei were intact (Fig. 5.6i and iia). The number of apoptotic cells, however, significantly increases in the MCF-7 and HCT-15 cells treated with F2 at IC_{50} and 100 μg/mL doses (Fig. 5.6i and iib and c). This demonstrates nuclear condensation and fragmentation. These findings made it abundantly evident that cells containing DNA and nuclei displayed uniform bright green, while cells exhibiting early apoptotic yellow staining and late apoptotic reddish or orange staining were identified (Palanisamy et al. 2018).

In a different experiment, polysaccharides from the red alga Porphyra haitanensis (PHP) caused apoptosis in SGC-7901 human gastric cancer cells, with a definite apoptosis peak in the concentration range of 10–500 μg/mL, showing a clear apoptosis peak in Fig. 5.7. The rate of apoptosis increased as PHP concentration increased. The ratio of apoptosis to PHP concentration was strongly associated. The apoptosis rate was 19.65% when PHP concentration was 500 g/mL, which was substantially higher than the control group (Chen and Xue 2019). Although Yu et al. investigated the anticancer activity of Auricularia polytricha polysaccharides (APPs) against A549 human lung cancer cells and its underlying mechanisms, they discovered that cells treated with lower concentrations of APPs moderately accumulated in the G0/G1 phase of the cell cycle when compared to the control group (43.25% for control; 50.35% for 25 μg/mL APPs) (Yu et al. 2014). The cleaved poly

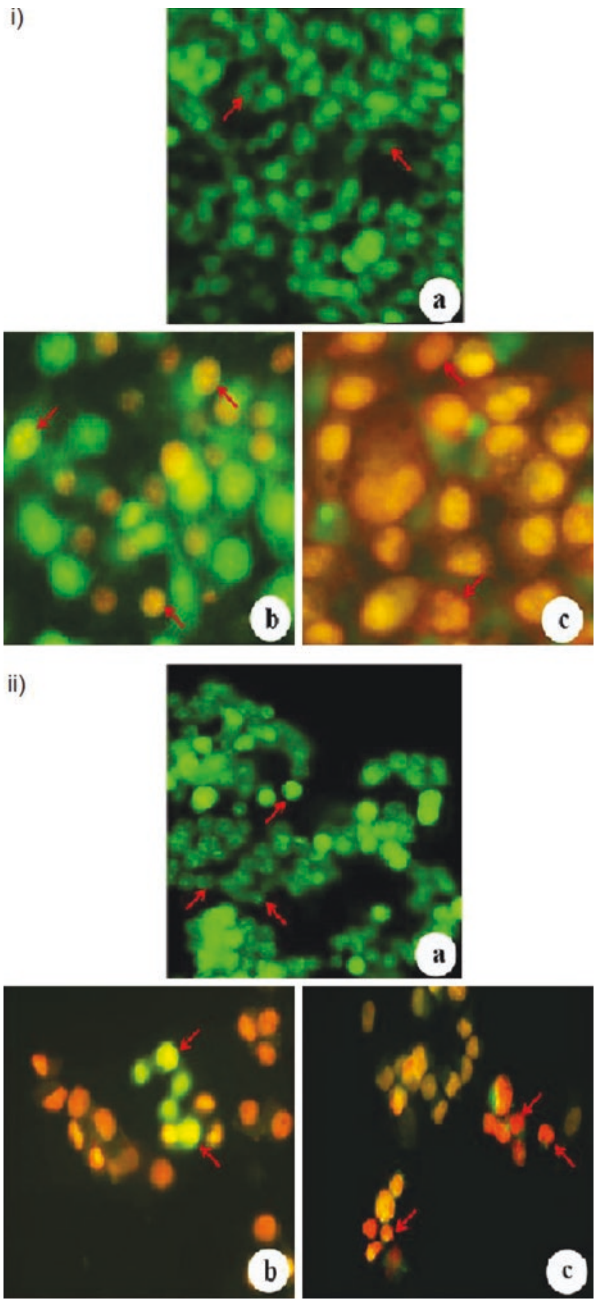

Fig. 5.6 Effect of fraction 2 on apoptosis morphological changes of breast and colon cancer cell lines under fluorescence microscope after 24 h of incubation. (*i*) Breast cancer (MCF-7) cell lines; (**a**) control, (**b**) IC50 concentration (20 μg/mL), (**c**) maximum concentration (100 μg/mL). (*ii*) Colon cancer (HCT-15) cell lines; (**a**) control, (**b**) IC50 concentration (50 μg/mL), (**c**) maximum concentration (100 μg/mL). (Reproduced with copyright permission from Palanisamy et al. (2018), Elsevier 2018)

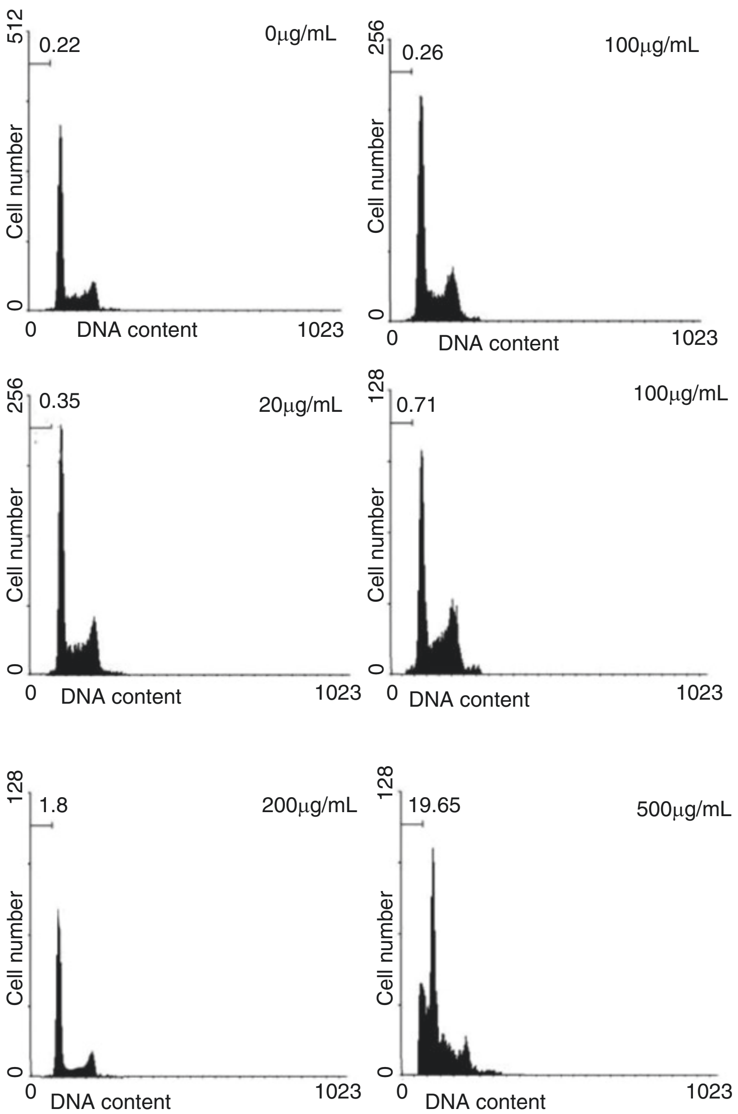

Fig. 5.7 Apoptosis rate of SGC-7901 cells treated by PHP with different concentrations for 48 h. (Reproduced with copyright permission from Chen and Xue (2019), Elsevier 2019)

(ADPribose) polymerase (PARP) level was dramatically increased by the sulfated glucuronorhamnoxylan polysaccharide isolated from the green alga *Capsosiphon fulvescens*, and DNA fragmentation was induced. These effects were seen in HT-29 human colon cancer cells in a study by Choi et al. (2019).

5.5.3 Antioxidants Property of Marine Algae

Antioxidants are defined as the quantity of free radicals eliminated or neutralized by antioxidant compounds. Numerous studies have demonstrated their versatility as food additives. They shield living things from reactive oxygen species (ROS), which can damage lipids, DNA, and proteins and cause a number of chronic diseases, including diabetes, atherosclerosis, rheumatoid arthritis, cancer, and Alzheimer's (Sato et al. 2019). The majority of algal colorants are well-known for having antioxidant effects. As a result, in recent years, interest in these natural antioxidants as sources of antioxidants has increased (Marinho et al. 2019).

Carotenoid is one of the algae pigments whose antioxidant properties have received the most attention. Numerous health advantages of carotenoids, including the preservation of cognitive function, have been demonstrated (Johnson 2012; Devore et al. 2013); for skin protection (Stahl and Sies 2012); in older adults' resulting in mineral density increase and decrease in their rheumatoid arthritis symptoms (Rodriguez-Amaya 2019) and as a provitamin source (Pérez-Gálvez et al. 2020). The removal of electrons from carotenoids or the formation of carotenoid-radical adducts are two methods by which antioxidants scavenge free radicals (FRs). This characteristic appears to have therapeutic potential for a number of disease states, including the treatment of cardiovascular disease, macular degeneration, breast, prostate, gastrointestinal system, and lung malignancies (Pérez-Gálvez et al. 2020).

Fucoxanthin is one of the most common xanthophyll carotenoid pigments. Fucoxanthin can protect tissue when there is a lack of oxygen because all other carotenoids are unable to quench active radical species (D'Orazio et al. 2012; Xia et al. 2013; Tavares et al. 2020). Fucoxanthin, which has been shown to have a variety of health-promoting benefits including anti-obesity, anti-cancer, and UV protection capabilities, is primarily found in brown algae (Holdt and Kraan 2011). Several other studies have also demonstrated fucoxanthin's potent capacity to scavenge free radicals (Marinho et al. 2019; Peng et al. 2011; Koduvayur Habeebullah et al. 2018).

The most significant provitamin A source among the carotenoids is beta-carotene, which is followed by alpha-carotene and beta-cryptoxanthin. Strong antioxidant properties of astaxanthin allow it to prevent oxidation of low-density lipoprotein caused by azo-compound (Wang et al. 2012). Codium fragile, a digestible seaweed that is a mainstay of the Japanese diet, is rich in siphonaxanthin [19-(trans-Δ2-dodecenoate)] (10). Siphonaxanthin is a dietary ingredient that reduces the viability of human leukemia HL-60 cells 2014 (Sugawara et al. 2014); (Batista et al. 2019). In addition, it is anti-angiogenic. Their research revealed that siphonaxanthin is a significant bioactive carotenoid with a lot of potential for use in the medical or food industries.

Another family of color compounds with anti-inflammatory, antimutagenic, and antioxidant characteristics is the chlorophyll pigment family (Tumolo and Lanfer-Marquez 2012; Chen and Roca 2018; Nwoba et al. 2019). Studies on chlorophyll claim that it transforms into derivatives such pheophorbides and pheophytins, which are absorbed at a rate akin to some carotenoids both during digestion and after absorption to the intestines (Pérez-Gálvez et al. 2020; Chen and Roca 2018, 2019).

Research is continuing to gain a better understanding of the metabolic processes, the mechanisms of oxidation, and the absorption of chlorophyll (Pérez-Gálvez et al. 2020).

Antioxidant activity can also be impacted by chlorophyll's shape and arrangement. According to studies, chl a is a more potent antioxidant than chl b (Fernandes et al. 2017; Saldarriaga et al. 2020). In addition, by substituting the central magnesium ion with copper, metallo-chlorophyll or copper chlorophyllins are produced, which have a better antioxidant capacity and provide a stable food coloring ingredient (Viera et al. 2019). According to the research by Cho et al. (Cho et al. 2011), pheophorbide gives Ulva prolifera's chlorophyll outstanding antioxidant potential, including DPPH and hydroxyl radical scavenging action. On the other hand, Phormidium autumnale has 200 times the antioxidant power of alpha-tocopherol (Hsu et al. 2013).

The results of recent efforts to incorporate algae into novel food formulations have been positive. According to a study by Batista et al. (Batista et al. 2019), adding microalgae such as *Arthrospira platensis*, *Chlorella vulgaris*, *Tetraselmis suecica*, and *Phaeodactylum tricornutum* to wheat crackers significantly increased antioxidant activity. Chlorophyll has the power to halt degenerative diseases in their tracks, according to reports (Dashwood 2021). However, the antioxidant properties of chlorophylls are fragile and easily broken down into chemicals (Indrasti et al. 2018). The microencapsulation technology has been used to preserve chlorophyll. According to studies, the antioxidant quality was both conserved and boosted by the microencapsulated Spirulina in pasta and the kale chlorophyll in whey protein (Zen et al. 2020; Zhang et al. 2020).

According to Pan-utai and Iamtham (2019), phycobiliprotein pigments have a variety of health-promoting qualities and may be used as food coloring or additives. Numerous investigations on the antioxidant activity of phycobiliproteins (PBPs) have been done recently (Pleonsil et al. 2013; Thangam et al. 2013; Sonani et al. 2015). These studies showed how well PBPs can bind and lessen ferrous ions. Phycoerythrin's antioxidant function has a stronger reducing power and a lower ability to chelate than phycocyanin or allophycocyanin. On the other hand, the chelating and lowering properties of phycocyanin and allophycocyanin are comparable. For the phycobiliproteins, it is discovered that the antioxidant activity of phycoerythrin > phycocyanin > allophycocyanin is dose-dependent (Sonani et al. 2015). They have also shown that Caenorhabditis elegans can age more slowly due to phycoerythrin's antioxidant properties. However, preservation methods may have an impact on the antioxidant activity of PBPs (Tello-Ireland et al. 2011).

Cyanosarcina sp., *Phormidium* sp., *Scytonema* sp., and *Leptolyngbya* sp. provided phycobiliproteins that were extremely thermostable and had significant antioxidant activity (Pumas et al. 2011). A gastrointestinal digestion of the phycoerythrin from Bangia fusco-purpurea can produce certain peptides that have considerable antioxidant activity, according to a study by Wu et al. (2015). On the basis of this, PE can be applied to the creation of functional foods. In addition, research into the phycoerythrin from *Grateloupia filicina*'s possible health advantages revealed that PE shielded astrocytes from hydrogen peroxide's oxidative damage (Jung et al.

2016). In addition, cytoprotective against damage caused by hydrogen peroxide was the phycoerythrin found in dulse (*Palmaria* sp.) (Sato et al. 2019).

Numerous health benefits of phycocyanin, including anticancer, antioxidant, anti-inflammatory, and hepatoprotective qualities, have been documented in addition to its nutritional value and abundance of important amino acids (Bertolin et al. 2011; Park et al. 2018; Osman et al. 2019). According to Abdel-Daim et al. (2015), the multiple health advantages associated to phycocyanin are the outcome of this antioxidant property. Spirulina platensis-derived phycocyanin showed dose-dependent antioxidant activity (Wu et al. 2016). In addition, they noticed that phycocyanin is light-sensitive at normal temperatures and that its thermal stability is compromised at temperatures higher than 45°C. But, it has been claimed that sodium chloride can successfully stabilize phycocyanin and maintain its effectiveness. Along with its antioxidant abilities, phycocyanin is also known to have anti-lipid peroxidation characteristics. Strong anti-lipid peroxidation activity was shown by the extract of Geitlerinema sp. (Renugadevi et al. 2018).

A powerful antioxidant, allophycocyanin (APC) is a naturally occurring pigment (Bertolin et al. 2011). Contrary to phycoerythrin, the elimination of ROS is accomplished by the responses of antioxidant proteins expressed by the antioxidant genes rather than through direct oxidation-reduction reactions (Kim et al. 2018). Allophycocyanin has excellent therapeutic potential, according to a study. Human erythrocytes' oxidative stress could be successfully reversed by APC and selenium-containing APC, and an oxidant's ability to promote lipid oxidation was also prevented (Zhang et al. 2011). Furthermore, they demonstrated that how Se-APC can stop the production of intracellular reactive oxygen species. The ability of APC to reduce free radical production has been noted by researchers to have potential applications in the treatment of illnesses. Allophycocyanin from Palmaria palmata has stronger antioxidant activity than PE and exhibited cytoprotective effects on human neuroblastoma SH-SY5Y cells (Sato et al. 2019).

The amount of polyphenols in various kinds of algae varies. Compared to most other algae, brown algae have more content of polyphenols. Algal polyphenols are anti-diabetic, anti-Alzheimer's, anti-allergy, anti-aging, and lower the risk of cardiovascular and cancer disorders, according to studies (Rodrigo et al. 2011; Stagos et al. 2012; Cha et al. 2016; Peñalver et al. 2020). Algal polyphenols are sufficiently powerful that they could replace synthetic antioxidants in the food sector (Hermund et al. 2018). Due to its effects on various enzymes as catalase, glutathione peroxidase, superoxide dismutase, and free radical elimination, polyphenols have a substantial antioxidant capacity (Gómez-Guzmán et al. 2018; Sanchez et al. 2019).

Phlorotannins, polyphenols derived from brown algae, have numerous health advantages, including lowering the risk of cancer, metabolic, and neurological diseases (Gómez-Guzmán et al. 2018). Like other tannins, they are present in soluble form in the cytoplasm or the intercellular spaces of cell organelles (Generalić Mekinić et al. 2019). Numerous phenolics also function as a type of chemical defense against bacteria, grazers, and fouling organisms. As a result, polyphenols have significant pharmacological and nutraceutical value and may be included in functional meals to help with weight management or digestion (Holdt and Kraan

2011; Generalić Mekinić et al. 2019; Le Lann et al. 2016). Phlorotannin from *Sirophysalis trinodis*, also known as *Cystoseira trinodis*, was isolated from *Sargassum muticum* and demonstrated antioxidant and antiproliferative action in breast cancer cells (Namvar et al. 2013; Sathya et al. 2017). Phlorotannin is said to have ten times the antioxidant activity of any known biological molecule (Lomartire et al. 2021). They could potentially be included in skin care products and other cosmetic applications (Bedoux et al. 2014). A study on the health advantages of algae species revealed that frequent consumption of food high in phlorotannins decreased the risk of hypercholesterolemia and cardiovascular disease (Namvar et al. 2012). With so many beneficial components present in algae, it is difficult not to include algae in your regular diet. For greatest health benefits, Machu et al.'s (Machu et al. 2015) recommendation is to consume algae directly as food rather than as a supplement.

Strong antioxidant capabilities are present in algal anthocyanins, and they are comparable to those of alpha-tocopherol, quercetin, and catechin (Alappat and Alappat 2020). According to a study by Kongpichitchoke et al. (2015), algal anthocyanin plays a crucial part in the electron transfer route by providing unpaired electrons from free radicals with electron donations. The substance had a variety of qualities, including those that were anticancer, anti-diabetic, anti-inflammatory, anti-obesity, and lowered fasting sugar (Alappat and Alappat 2020; Pojer et al. 2013; Sarikaphuti et al. 2013; Bontempo et al. 2015; Lee et al. 2017; Lin et al. 2017; Strugała et al. 2019).

5.5.4 Anti-Obesity Properties of Marine Algae

Metabolic disorders like dyslipidemia, hyperglycemia, and hypertension are associated with obesity. The burden of obesity is primarily derived from its associated chronic disorders, including type II diabetes mellitus, cancer, lung diseases, and cardiovascular diseases (Adams et al. 2006; Finucane et al. 2011). The etiology of the relationship between obesity and chronic diseases is still being studied. It is interesting to note that chronic low-grade inflammation has been connected to the development of obesity and disorders that are related to it (Greenberg and Obin 2006; Osborn and Olefsky 2012).

The effects of the Sabah brown seaweed Sargassum polycystum on body weight and blood plasma levels in rats given a high-fat diet supplemented with various doses of the seaweed powder were examined by Awang and colleagues. To supplement their high-fat diets, the low dose group (LDG), medium dosage group (MDG), and high dosage group (HDG), respectively, received supplements of 2.5, 5.0, and 10.0% seaweed powder. When compared to the control group, they discovered that the HDG (10.0% seaweed treatment diet) had the greatest effect in preventing weight gain, followed by the MDG (5.0% seaweed treatment diet) and LDG (2.5% seaweed treatment diet) (Awang et al. 2014). Another study by Kang et al. found that *Plocamium telfairiae* extract (PTE) had the best inhibitory effect on lipogenesis in adipocytes among the red algae extracts examined and was therefore chosen as a possible anti-obesity treatment. Over the course of 14 weeks, the body weight was assessed once each week (Fig. 5.8). In comparison to mice fed a normal diet, mice fed a high-fat intake had a higher body weight at 14 weeks. However, compared to the mice who received the high-fat dose alone, the body weights of the mice treated with PTE (100 mg/kg) also experienced a considerable drop (Kang et al. 2016b).

Li et al. evaluated the impact of diet-induced obesity in C57BL/6J mice on the development of siphonaxanthin-rich green algae (Codium cylindricum). A low-fat diet (LF; 7% fat, w/w), a high-fat diet (HF; 35% fat, w/w), or a high-fat diet supplemented with 1% or 5% green algal powder (1GA or 5GA) were given to the mice over the course of 78 days. The findings demonstrated that the 5GA group's body weight and perirenal white adipose tissue (WAT) were significantly lower than those of the HF group. In addition, the green algae's dietary fiber's inhibitory effect on fat absorption was cited as a contributing factor in the lowering of WAT (Li et al. 2018).

Ben Abdallah Kolsi and colleagues studied the effects of Cymodocea nodosa sulfated polysaccharide (CNSP) on lipase activity in vitro and in vivo to high-fat diet (HFD)-rats on body weight, lipid profile, and liver-kidney functions. In comparison to untreated HDF-rats, the treatment of CNSP causes obese rats' body weight to drop and their intestinal and serum lipase activity to be inhibited. In HFD-rats, this decrease in lipase activity causes an increase in high-density lipoprotein cholesterol (HDL-C) levels and a decrease in total cholesterol (T-Ch), triglycerides (TG), and low-density lipoprotein cholesterol (LDL-C) (Kolsi et al. 2015)

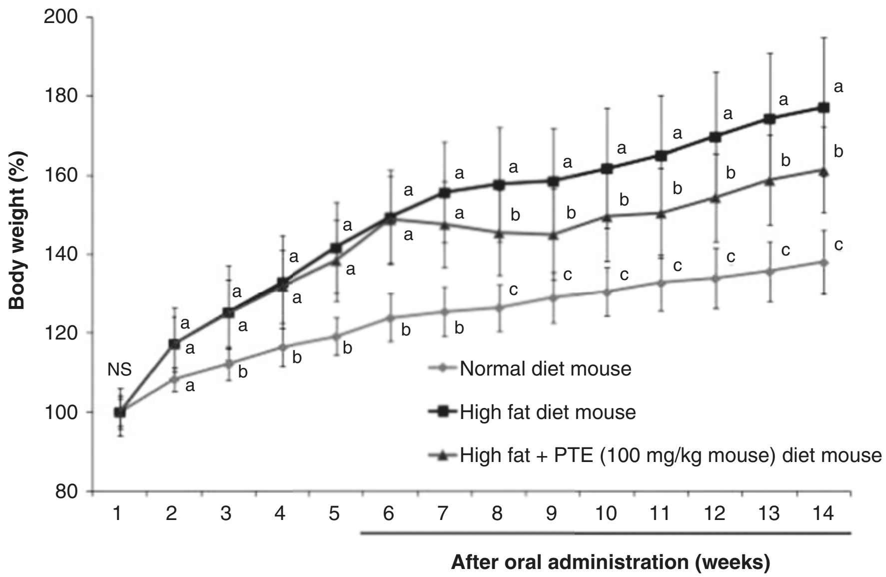

Fig. 5.8 Body weight gain of mice fed experimental diets for 14 weeks. The results are expressed as mean ± standard error (n = 10). (Reproduced with copyright permission from Kang et al. (2016b), Elsevier 2016)

5.5.5 Anti-Diabetic Properties of Marine Algae Anti-Obesity Properties of Marine Algae

The aberrant metabolism of glucose that occurs in diabetes mellitus is partly brought on by peripheral tissue resistance to the action of insulin. Polyuria, polydipsia, and polyphagia are the identifying signs. The most serious chronic disease that is becoming more and more prevalent in an aging and fat world is diabetes mellitus. Hyperglycemia is one of the multiple disorders that makes up diabetes mellitus. Diabetes mellitus is primarily divided into type 1 diabetes, which is insulin-dependent, and type 2 diabetes, which is not insulin-dependent (type 2 diabetes). Type 2 diabetes, which is the most common type of diabetes, is in particular a growing global health concern (Zimmet et al. 2001). The onset of type 2 diabetes and its accompanying consequences, such as micro- and macro-vascular illnesses, are significantly influenced by hyperglycemia (Baron 1998). Therefore, avoiding or curing diabetic complications and increasing the quality of life for diabetic patients depend on good blood glucose level management (DeFronzo 1999).

Currently, treatment options for type 2 diabetes include insulin and a number of oral anti-diabetic medications, including sulfonylureas, metformin, rosiglitazone, -glucosidase inhibitors, and thiazolidinediones. However, these treatments have either a meager efficacy or major adverse effects based on the mechanism of action, such as hypoglycemia, flatulence, weight gain, and worsening of gastrointestinal issues. As a result, interest in complementary therapies and the therapeutic use of natural diabetes medications, particularly those made from herbs, has grown recently (Chang et al. 2006; Jung et al. 2007). This is due to the fact that plant sources are typically thought to be less hazardous and to have less adverse effects than manufactured ones (Lee and Jeon 2013).

Chinese traditional medicine has used marine algae as a treatment for diabetes among alternative medicines because they include a number of biologically relevant compounds (Brown et al. 2014). Table 5.3 lists numerous Marine algal compounds with specific anti-diabetic characteristics, such as phloroglucinol (23), eckol (24), dieckol, phloroeckol, and phlorofucofuroeckol A. (Lee and Jeon 2013). The anti-diabetic activities of other algal chemicals like bromophenol (Zhao et al. 2018) and fucosterol (Unnikrishnan et al. 2015) are also well documented. Several isolated carotenoids from algae, including astaxanthin (7) and fucoxanthin (1), have anti-diabetic properties. For instance, the brown alga fucoxanthin (1), which is widely distributed, has significant potential as a functional food that fights diabetes and obesity (Miyashita and Hosokawa 2017). Similar results have been seen with astaxanthin (7), a reddish carotenoid pigment that is frequently present in *Haematococcus pluvialis* (Chlorophyta), which has a notable anti-diabetic impact.

Astaxanthin (7) oral treatment was shown by Wang et al. (2012) to greatly reduce postprandial hyperglycemia and postprandial area under the curve (AUC). There is anti-diabetic action in the Ecklonia species extract. These mainly contained phlorotannins and shown anti-diabetic action with an IC_{50} value of 10.7 μM. With IC_{50} values for the phlorofucofuroeckol A and dieckol at 1.37 μM and 1.61 μM, respectively, in comparison to the reference medication acarbose (IC_{50} = 51.65 μM)

Table 5.3 Marine algal compounds with specific anti-diabetic characteristics

Active compounds	Species	Anti-diabetic action	Ref.
Fucoxanthin (**1**)	*Eisenia bicyclis*	PTP 1B inhibition, Aldose reductase	Jang et al. (2018)
Eckol (**24**), dieckol, and 7-phloroeckol		Inhibition α-amylase and α-glucosidase	Abdelsalam et al. (2019)
Dieckol	*Ecklonia cava*	α-Glucosidase inhibitor	Lee et al. (2009a)
	Ecklonia cava	Postprandial hyperglycemia-lowering effect	Lee et al. (2012a)
	Ecklonia cava	Glucose uptake effect in skeletal muscle	Guan (2011)
	Ecklonia cava	PTP 1B inhibition	Moon et al. (2011)
	Ecklonia cava	Protective effect against diabetes complication	Lee et al. (2010)
Fucodiphloroethol G	*Ecklonia cava*	α-Glucosidase inhibitor	Lee et al. (2009a)
6,6′-Bieckol	*Ecklonia cava*	α-Glucosidase inhibitor	Lee et al. (2009a)
7-Phloroeckol	*Ecklonia cava*	α-Glucosidase inhibitor	Lee et al. (2009a)
	Ecklonia cava	PTP 1B inhibition	Moon et al. (2011)
Phloroglucinol	Ecklonia stolonifera	α-Glucosidase inhibitor	Moon et al. (2011)
	Eisenia bicyclis	PTP 1B inhibition	Moon et al. (2011)
Dioxinodehydroeckol	Ecklonia stolonifera	α-Glucosidase inhibitor	Moon et al. (2011)
	Eisenia bicyclis	PTP 1B inhibition	Moon et al. (2011)
Diphlorethohydroxycarmalol	*Ishige okamurae*	α-Glucosidase inhibitor	Heo et al. (2009)
	Ishige okamurae	Postprandial hyperglycemia-lowering effect	Heo et al. (2009)
	Ishige okamurae	Protective effect against diabetes complication	Heo et al. (2010)
Eckol	*Ecklonia stolonifera*	α-Glucosidase inhibitor	Moon et al. (2011)
	Eisenia bicyclis	PTP 1B inhibition	Moon et al. (2011)
Octaphlorethol A	*Ishige foliacea*	Glucose uptake effect in skeletal muscle	Lee et al. (2012b)

(continued)

Table 5.3 (continued)

Active compounds	Species	Anti-diabetic action	Ref.
Polyphenolic-rich extract	Ascophyllum nodosum	α-Glucosidase inhibitor	Nwosu et al. (2011)
Phlorotannin-rich extract	Ascophyllum nodosum	Postprandial hyperglycemia-lowering effect	Roy et al. (2011)
	Fucus vesiculosus	Postprandial hyperglycemia-lowering effect	Roy et al. (2011)
Polyphenolic-rich extract	Ecklonia cava	Glucose uptake effect in skeletal muscle	Kang et al. (2010)
Dieckol-rich extract	Ecklonia cava	Improvement of insulin sensitivity	Lee et al. (2012c)
Polyphenolic-rich extract	Ishige okamurae	Improvement of insulin sensitivity	Min et al. (2011)
Phlorofucofuroeckol A	*Ecklonia stolonifera*, *Ecklonia cava*	α-amylase inhibitor PTP 1B inhibition ACE inhibitor α-glucosidase inhibitor	Machu et al. (2015) and de Jesus Raposo et al. (2013)
Diphlorethohydroxycarmalol	*Ishige okamurae*	α-glucosidase inhibitor (IC50 = 0.16 ± 0.01 mM) α-amylase inhibitor (IC50 = 0.53 ± 0.018 mM)	Motshakeri et al. (2014)
Extract of *Sargassum hysterix*	*Sargassum hysterix*	α-amylase inhibitor (IC_{50} = 0.58 ± 0.01 mg/mL) α-glucosidase inhibitor (IC_{50} = 0.59 ± 0.02 mM)	Gotama and Husni (2018)
Pheophytin-A	*Eisenia bicyclis*, *Ecklonia stolonifera*	Aldose reductase Inhibition (fucosterol IC_{50} HLAR = 18.94, HRAR = 144)	Jung et al. (2013)
Bromophenols	*Symphyocladis latiuscula*	Phosphatase 1B (PTP1B), glucosidase, −amylase, and aldose reductase	Abdelsalam et al. (2019)

(Abdelsalam et al. 2019). They also showed that eckol (24) had higher alpha-glucosidase activity than dioxinodehydroecko (IC_{50} = 34.60 µM and phloroglucinol, IC_{50} = 141.18 µM) and lower IC_{50} (IC50 = 22.78 µM) than both of these compounds.

The brown alga Ishige okamurae has recently been demonstrated to contain numerous phlorotannins, including diphlorethohydroxycarmalol, octaphlorethol A, and phluroglucinol 6-6-bieckol, which may have anti-diabetic potential (Yang et al. 2019). The therapy of Sargassum polycystum extract displayed a hypoglycemic effect on streptozotocin-induced type 2 in diabetic rats, according to a study by Motshakeri et al. (2014). They discovered that this edible alga's ethanol and aqueous extract dramatically lowered the glycemic index of diabetic rats by 27% and 35%, respectively. The activity of the alpha-amylase and alpha-glucosidase enzymes has been reported to be inhibited by a number of compounds identified in Eisenia bicyclis, including eckol (24), dieckol, 7-phloroeckol, and fucosterol (Abdelsalam et al. 2019; Jung et al. 2013).

5.5.6 Antiviral Application of Marine Alga

The utilization of marine algae as source material for the synthesis/isolation of bioactive antiviral materials has been explored for centuries though their adoption within the last two decades has been intensified among researchers and industrialists (Tassakka et al. 2021).

The pharmacology of a number of marine natural products have antiviral action against the human immunodeficiency virus type 1 (HIV-1), dengue virus, SARS-CoV-2 virus (Abdelsalam et al. 2019), hepatitis B virus, influenza virus, and West Nile virus.

In an interesting study, red marine alga "*Halymenia durvillei* (Rhodophyta)" extracts as natural antiviral medication have been utilized effectively to inhibit SARS-CoV-2 virus (Tassakka et al. 2021). The authors extracted 37 compounds along with their identifications. As per their report, in contrast, cholest-5-En-3-Ol (3.Beta.)- had a high fitness score in molecular docking studies both in the monomer and dimer state compared to the N3 inhibitor and remdesivir affinity scores, suggesting the potential of compounds 1-2 tetradecandiol and E,E,Z-1,3,12-nonadecatriene-5,14-diol for therapeutic purposes. These natural substances may work well for the treatment of COVID-19 infection as they have competitive affinity scores against the 3CL-Mpro (Tassakka et al. 2021). In light of the encouraging findings that demonstrated the potential of *H. durvillei* as a substitute treatment in treating COVID-19 infection, they recommended that the ADME (absorption, distribution, metabolism, and excretion) and pharmacokinetic studies should also be utilized to evaluate the ability of the natural compounds as oral pharmaceuticals (Tassakka et al. 2021).

A group of researchers have proposed in their report the Four identified marine sulfated glycans have been found to have antiviral properties against enveloped (the herpesvirus human cytomegalovirus) and non-enveloped (adenovirus) DNA viruses (Zoepfl et al. 2021). These include a sulfated galactan from the red alga *Botryocladia occidentalis*, a sulfated fucan from the sea urchin *Lytechinus variegatus*, and a sulfand a sulfated fucan and a fucosylated chondroitin sulfate from *Isostichopus badionotus*, a sea cucumber. According to this study's authors, all four new glycans prevented viral entrance and attachment, most likely through interacting with virions. The antiviral profiles of the sulfated fucans, which both lack anticoagulant activity, imply that their activities are due to other physicochemical factors as well as their potential conformational shapes in solution and when interacting with virion proteins, rather than just their sulfation content or negative charge density. Exploring the connections between glycan structure and antiviral activity is made possible by the structural and chemical characteristics of these marine sulfated glycans (Zoepfl et al. 2021).

In another study, four marine red alga Rhodomela confervoides-based ureidobromophenols with great antioxidant properties have been identified where Compound 1 featured a bromophenol but also butyric acid units fixed to the same N-atom of ureido moiety and the other isolated ureidobromophenols have strong anti-DPPH as well as anti-ABTS properties (Li et al. 2021). The authors made note of the possibility that the seaweed functional food ingredients or dietary food supplements in the food business can benefit from the ureidobromophenols, isolated from marine algae, which have antioxidant properties.

The antiviral property of diterpenes extracted from marine algae "*Dictyota menstrualis*" against HIV-1 virus has been demonstrated by Pereira et al. (2004) in their work. The antiviral performance was credited to the solubility of the algae (*Dictyota menstrualis*) "CH_2Cl_2/MeOH" against the replication of the HIV-1virus as per their in vitro studies. Two diterpenes, (6R)-6-hydroxydichotoma-3,14-diene-1,17-dial (Da-1), and (6R)-6-acetoxi-dichotoma-3,14-diene-1,17-dial (AcDa-1), were shown to have antiretroviral action. The culture media of HIV-1-infected PM-1 cells was supplemented with Da-1 or AcDa-1 at various points after infection or during virus adsorption/penetration. The findings suggested that the chemicals had an impact on a preliminary stage of the viral replication cycle. Each diterpene was tested for its ability to prevent virus binding and entry into host cells, but no inhibitory impact was found (Pereira et al. 2004). The viral protease coding sequence was amplified from total cellular DNA to examine provirus DNA synthesis and integration into the host genome. Infected cells treated with the diterpenes did not contain any proviral DNA. The recombinant HIV-1 reverse transcriptase (RT) was evaluated in vitro in the presence of each diterpene to examine the impact of the diterpenes on the reverse transcription of the viral genomic RNA. The RNA-dependent DNA-polymerase activity of HIV-1 RT was dose-dependently suppressed by Da-1 and AcDa-1. Together, their findings show that both diterpenes impede HIV-1 RT and, as a result, virus replication (Pereira et al. 2004).

Seeing this is not an exhaustive discussion though inclusive, we have presented few instances based on available literature where it is clearly shown that the active compounds in marine algae are responsible for their antiviral activity though there is a great need for more exploitation in this area.

5.5.7 Antibacterial/Antifungal Application of Marine Algae

The antibacterial and antifungal characteristics of diverse marine algae have been exploited by humans for centuries without proper documentation; however, researchers/industrialists have beamed light on marine algae utilization as source material for the preparation of diverse antibacterial and well as antifungal agents within the recent decades (de Felício et al. 2015).

In this vein, the antibacterial efficacy of silver chloride nanoparticles synthesized from marine algae (*Sargassum plagiophyllum*) has been reported (Stalin Dhas et al. 2014). The destruction of *E. coli* bacterial cells as presented in Fig. 5.9 was reported by these group of researchers (Stalin Dhas et al. 2014).

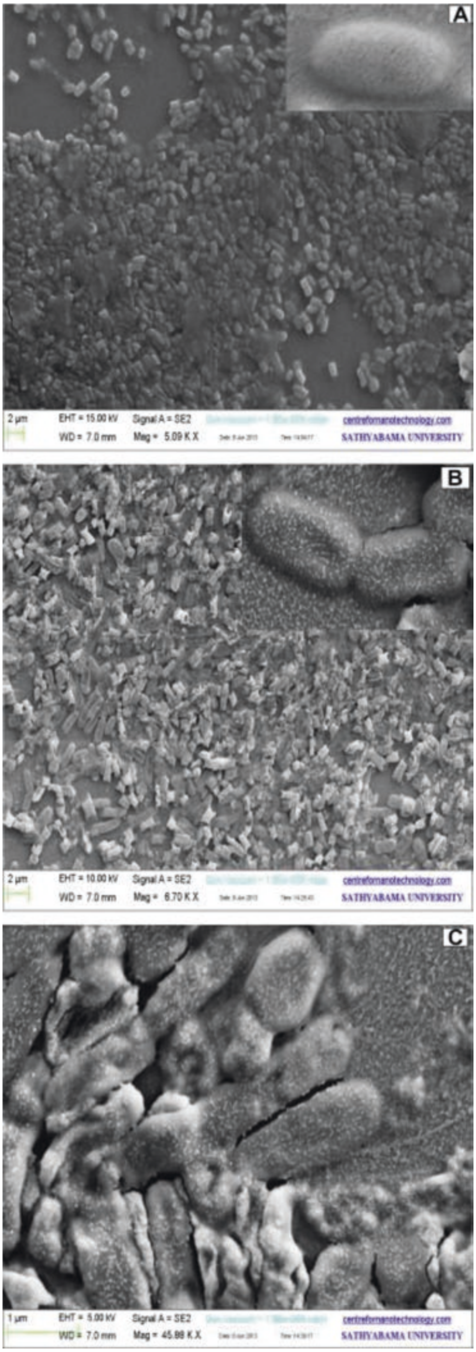

Fig. 5.9 Morphological analysis of *E. coli* using FESEM before (**a**) and after (**b** and **c**) treatment with silver chloride nanoparticles (20 µg/mL). Inset: figure shows individual bacterial cells before and after treatment. (Reproduced with copyright permission from Stalin Dhas et al. (2014), Elsevier 2014)

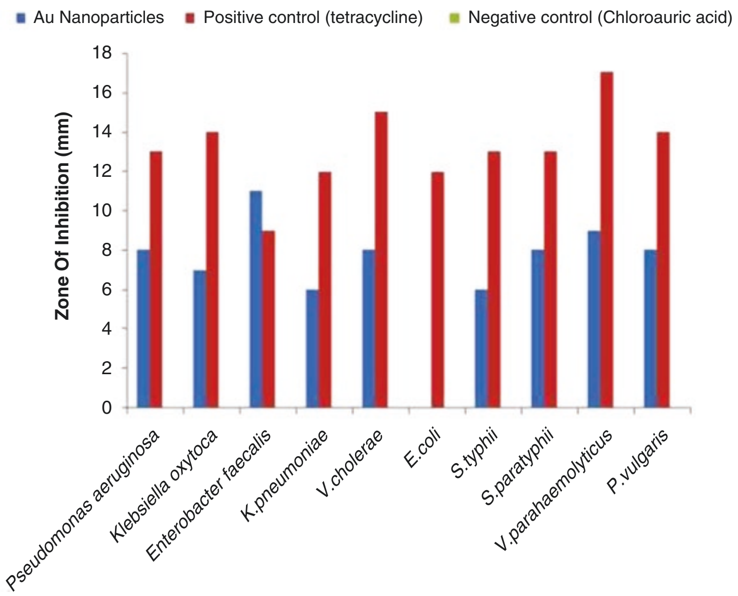

Fig. 5.10 Antibacterial activity of gold nanoparticles synthesized by the reduction of gold chloride with the *S. marginatum* biomass against some selected bacterial pathogens. (Reproduced with copyright permission from Arockiya Aarthi Rajathi et al. (2012), Elsevier 2012)

In another study, the antimicrobial activity of brown marine algae synthesized Au nanoparticles has been demonstrated (Rajathi et al. 2012), even as the authors showed as depicted in Fig. 5.10 that the nanoparticles demonstrated the highest antibacterial activity against *E. faecalis* (~11 mm) and the minimal zone of inhibition against *K. pneumoniae* was recorded, and it was higher than that of the positive control tetracycline (6 mm). *E. coli* did not exhibit any inhibition (0 mm) (Rajathi et al. 2012). They also noted that the green technique to nanoparticle synthesis produced highly efficient nanoparticles against gram-negative bacteria. Au nanoparticles' antibacterial properties complied with an antibacterial activity's method of action.

In another report, Ma et al. (2021) have demonstrated three 5-hydroxyepicycloneroadiol oxide (1) and 4-hydroxyepicyclonerodiol oxide (2), and one new naturally occurring halogenated trichothecane derivative, trichodermol chlorohydrin (3), sesquiterpenes from the marine-alga-epiphytic fungus Trichoderma hamatum Z36-antibacterial 7's activity (Ma et al. 2021). According to their research, *Amphidinium carterae*, *Chattonella marina*, and *Prorocentrum donghaiense* were used to test the effects of compounds 1 through 3 on different marine phytoplankton species. All of the isolates have the ability to stop *C. marina* from growing, as demonstrated in Table 5.4. When compared to 2 and 10-cycloneren-3,5,7-triol, 1 had a greater impact on *P. donghaiense* and less of an impact on *C. marina*. These variations could be related to cyclization of the side chain moiety and variation (C-4 or C-5) of the hydroxy group. The antibacterial activity of these isolates was further

Table 5.4 Antimicroalgal and antibacterial activities of 1–3

Compd	IC_{50} (µg/mL)			Inhibitory zone diameter (mm) at 40 µg/disk			
	A. carterae	*C. marina*	*P. donghaiense*	*V. anguillarum*	*V. harveyi*	*V. parahaemolyticus*	*V. splendidus*
1	na	55	35	10	8.5	7.7	7.7
2	na	24	na	9.0	7.7	8.0	6.7
3	97	26	35	0	0	7.0	0
$K_2Cr_2O_7$	1.4	1.1	1.1				
Chloramphenicol				30	40	35	40

Reproduced with copyright permission from Ma et al. (2021), Elsevier 2021
na no activity at 100 µg/mL

tested against *Vibrio anguillarum*, *Vibrio harveyi*, *Vibrio parahaemolyticus*, and *Vibrio splendidus* (Table 5.4). All four bacteria are capable of being inhibited by compounds 1 and 2; however, compound 3 only exhibits sporadic activity against *V. parahaemolyticus*. Despite the chlorine atom's presence in 3, it doesn't appear to be able to enhance the antibacterial activity. None of the isolates, taken collectively, perform better than positive controls.

At present, literature on the application of marine algae-derived bioactive compounds and their utilization as antibacterial or antifungal agents is vast; we will refer readers interested in further reading to the review article by Mayer et al. (2022).

5.5.8 Marine Algae Application in Cosmetics

During growth, algae generate a large number of secondary metabolites. Due to their specific characteristic, they have been recognized as a significant natural source of these bioactive chemicals with a wide range of biological activity in cosmetic compositions.

For the purpose of enhancing biological effects in skin, many cosmetics that incorporate algae or even algal extracts have been produced. However, the majority of these studies, which are usually contained in patents, do not specify the specific biocompounds or underlying mechanisms behind each cosmetic performance. In addition, it is unclear if the overall effect of algal extract in cosmetic products is a result of many chemicals working together or if each bioactive acts independently.

To make it easier to identify biocompounds for the creation of novel cosmetic products with commercial applications, not only the active components' characterisation but also the profiles of algal extracts might be examined.

To assess the true commercial potential of algae for the manufacturing of industrial cosmetics, stability, compatibility, and even toxicity, research must be taken into account.

Sandolera and colleagues looked into the marine GABA and its derivative GABA-alanine, both of which are made by the cultured red microalga *Rhodosorus marinus*, and found that its mechanism of action involves the suppression of TRPV1 expression in healthy human astrocytes in vitro. The treatment of "sensitive skin, atopia, dermatitis, and psoriasis" could therefore be accomplished with these chemicals (Scandolera et al. 2018).

Secondary metabolites generated from algae are renowned for their beneficial effects on the skin (Pangestuti and Kim 2011). The cosmetics industry has been funding the research and development of new products that contain ingredients or extracts from natural sources due to a global trend toward products that are viewed as healthful, environmentally sustainable, and obtained ethically.

Algae are naturally exposed to oxidative stress, and they develop a number of effective defense mechanisms against reactive oxygen species and free radicals. They also produce substances that can protect cosmetics from the damaging effects of UV radiation by acting similarly to the organic and inorganic filters currently on the market (Sousa et al. 2008). For instance, growing *C. vulgaris*, Nostoc, or

Spirulina platensis in the presence of UV light results in an increase in the production of both chlorophyll and carotenoids (Sharma and Sharma 2015). In addition, due to their antioxidant capabilities, these compounds may aid in preventing the oxidation of oil in formulations, particularly in emulsions with a significant quantity of oily phase (Sharma and Sharma 2015).

By encouraging the expression of heme oxygenase-l (HO-l), a molecule that stops the formation of heme on the skin by eliminating heme catabolites, fucus vesiculosus extract helps to diminish the appearance of dark circles on the skin area around the eye. In topical preparations, the extract's anti-inflammatory and antioxidant capabilities may help diminish fine lines and wrinkles while also helping to lessen the appearance of eye bags and eye puffiness. Moreover, utilizing cosmetics and sunscreens could delay or even prevent skin aging (Sun and Chavan 2017).

Inhibiting some inflammatory processes and accelerating the healing process, as well as preserving skin hydration, are all possible effects of particular secondary metabolites of specific microalgae (Kim et al. 2008).

Red microalgae extracts are also used in anti-aging creams, anti-irritant peelers, skin care, sun protection, hair care, emollient, revitalizing, and regeneration products (Sun and Chavan 2017; Borowitzka 2013; Sanghvi and Martin Lo 2010; Arad and Yaron 1992).

In cosmetic compositions, algae are primarily used as thickening, water-binding, and antioxidant agents. However, each species may have made more than one contribution, as shown in Table 5.5 (Hasan and Rina 2009).

These were listed in accordance with the category of cosmetic product to help people understand how algae affects cosmetics.

5.5.8.1 Sunscreen

Frequently used UV filters that shield the skin against a variety of harms, such as photoaging, sunburn, photodermatoses, and skin cancer (Nohynek et al. 2010; Peres et al. 2016; Pereira et al. 2015; Mercurio et al. 2015). Some types of algae produce compounds with specific chemical structures that not only absorb UV light but also prevent the production of melanin (Hagino and Saito 2010).

Chlorogloeopsis spp. extract helps keratinous tissue by protecting it from UVA and UVB damage (which causes the creation of free radicals), preventing photoaging, wrinkle formation, and skin sagging (O'Connor et al. 2011).

Isochrisis algae could block UV transmission with a profile similar to that of a formulation with solely organic and inorganic filters and an SPF of 15. In addition, nannochloropsis algae proved excellent at blocking UVA and UVB transmission. In addition, compared to a commercial formulation, the incorporation of cyanobacteria in sunscreen formulation produced higher UVB-UVA absorption (290 to 400 nm) and good visible spectrum absorption (400–650 nm) (Huner et al. 2004).

The cyanobacterium Nostoc sp. R76DM also makes amino acids that are similar to mycosporine and absorb UV light (MAAs). The antioxidant and reactive oxygen species (ROS) scavenging ability of MAAs palythine, asterina, porphyra, and palythene was dose-dependent in vitro (Rastogi et al. 2016). Although these MAAs were used in the development of no cosmetic product.

Table 5.5 Studies of the use of algae in cosmetics

Algae	Form of use in the formulation	Extraction Solvent	Percentage in formulation (%)	Galenic form	Cosmetic effect	Ref
Genus *Porphyra* and *Wakame* *Spirulina* sp. *Chlorella* sp.	Protein and peptides (dry powder)	Organic solvents	0.01–10	Skin lotion Milky lotion Skin cream Body soap Shampoo Rinse Bath agents	Gloss and moisture on the skin Smoothness, moisture and gloss on the hair	Hagino and Saito (2010)
Coccoid and *Filamentous*	Extract	–	0.1–2.5	Emulsion Lotion Powder product	Enhancing skin barrier and collagen formation Anti-aging effect	Einarsson et al. (2014)
Phaeodactylum tricornutum	Extract	Isopropanol or polar Solvent (Ethanol) with later use of Aqueous-Ethanolic and Heptane	0.1–10	Cream Emulsion Emulsion-Gel	Protecting the skin from the adverse effects of UV exposure Preventing and/or delaying the appearance of skin aging effects	Nizard et al. (2007)
Fucus vesiculosus	Extract	Polar solvents	0.1–10	Liquid Crystal Cream	Reduce the appearance of dark circles Stimulates collagen	Sun and Chavan (2017)
Chlamydocapsa sp.	Lipsomal Extract	–	3.0	Cream Hydrogel Hair mask	Prevent or delay skin aging Avoid loss of the barrier function Reduce transepidermal water loss (TEWL)	Stutz et al. (2012)
Genus *Spirulina*, *Donaliela*, *Hematococcus*, *Nannochloropsis*, *Tetraselmis*	Cell algae	–	1.0–20	Gel, Emulsion (Water/Oil and Oil/Water)	Sunscreen	Lotan (2012)
Cyanobacteria	Extract	Methanol and acetone	0.001–25	Cream	Sunscreen	Huner et al. (2004)

(continued)

Table 5.5 (continued)

Algae	Form of use in the formulation	Extraction Solvent	Percentage in formulation (%)	Galenic form	Cosmetic effect	Ref
Chlorogloeopsis spp.	Extract	Water	0.05–20	Sun Creams and lotions, Shampoo lipsticks	Photoaging, wrinkle, sagging skin, sunscreen, and prevent sun damage to the hair and nail	O'Connor et al. (2011)
Genus *Prototheca*, *auxenochlorella*, *Chlorella* or *Parachlorella*	Cell algae or extract	Water	1.0–90	Cream, soap, lotion, Shampoo, facial wash	Sun protection, hydration, anti-aging, exfoliant to skin or hair	Schiff-Deb and Sharma (2015)

5.5.8.2 Moisturizers

Cosmetics have the power to maintain or enhance the skin's natural protective barrier, maintaining a healthy appearance. They are recommended in atopic dermatitis situations as well as when a client develops dry skin conditions, such as when there has been a change in the filagrin gene, which produces the skin's natural moisturizing factor (NMF) (Ramos-e-Silva et al. 2013; Chaves et al. 2014).

Some proteins including their hydrolyzates from the *Porphyra* genus, *Spirulina* species, and *Chlorella* species have a strong affinity for skin and hair, retaining moisture and having the right viscosity (Hagino and Saito 2010). Products for skin and hair care, body soap or bath products, creams, shampoos, rinses, hair restorers, solutions for permanent waves, shampoos, and rinses all contain cosmetics containing algal peptides (Hagino and Saito 2010).

When compared to the control, skin gloss and moist feel actions in cosmetics containing Porphyra were higher. Cosmetics for hair care that contain spirulina give a moisturizing sensation, gloss, smooth combing, and good sensory qualities. (Hagino and Saito 2010).

As a non-toxic, non-irritating, and non-sensitizing substance that promotes antistatic and emollient actions in moisturizing creams, squalene, which is derived from the Thraustochytriales plants Schizochytrium, Aurantiochytrium, and Thraustochytrium, is used in cosmetics to stimulate ideal skin properties (Pora et al. 2018; Kaya et al. 2011).

5.5.8.3 Anti-Aging Products

Cosmetics used to counteract environmental and intrinsic (smoking, UV radiation, and environmental circumstances) factors that promote aging of the skin (natural physiological changes or genetically determined). For instance, they could lessen the effects of aging and boost the consumer's self-esteem, resulting in a higher standard of living (Mukherjee et al. 2011).

Phloroeckol and tetrameric phloroglucinol, two antioxidant substances chemically categorized as phlorotannins, were discovered in the brown macroalga *Macrocystis pyrifera* recently. The anti-diabetic and antioxidant properties of these phlorotannins may help to delay the aging process of the skin (Leyton et al. 2016).

To increase collagen stimulation, anti-aging treatments can contain extracts of *Monodus* sp., *Thalassiosira* sp., *Chaeloceros* sp., and *Chlorococcum* sp. (Zanella et al. 2018).

Chlorella vulgaris extracts increase the production of collagen in the skin, promoting tissue regeneration and the prevention of stretch marks. Arthrospira extracts could heal the indications of early skin aging and prevent the development of wrinkles (Kim et al. 2008; Spolaore et al. 2006). Numerous vital vitamins, minerals, and fatty acids, such as omega-3 and -6, which are well recognized to promote skin health and cell regeneration, are contained in brown macroalgae's makeup (Kim et al. 2008).

Free radicals may activate metalloproteinase (MMP), harming skin fibroblasts' collagen, cell membranes, and nuclei. It may be possible to prevent UV-induced skin issues such as stratum corneum thickening, rough texture, wrinkles, and flaccidity by using a green algae extract to decrease MMP activity and increase the amount of collagen and elastin in the fibroblast (Shih and Shih 2009).

In this regard, extracts of Coccoid and Filamentous, two blue-green algae found in saline hot water, also contain unidentified biocompounds that have the potential to stop skin photoaging. In addition, by promoting keratinocytes' terminal differentiation and the expression of crucial skin barrier genes, they may improve skin barrier performance (Einarsson et al. 2014). In addition, it promotes the synthesis of new collagen to speed up skin regeneration and stop the aging process (Einarsson et al. 2014).

Extracts from *Phaeodactylum tricornutum* may increase the activity of the proteasome in skin cells, notably keratinocytes, fibroblasts, or melanocytes. In additionto improving skin elasticity and firmness, this extract can shield the skin from the damaging effects of UV radiation. It might prevent wrinkles from forming or lessen the depth of existing wrinkles (Nizard et al. 2007).

In products for the skin and even hair protection, extracts of the snow algae *Chlamydocapsa* sp. are applied topically to function primarily in oxidative reactions, such as photoaging. In addition, it could lessen transepidermal water loss (TEWL), prevent the development of wrinkles brought on by exposure to UV rays, cold, or dryness, and shield against the loss of the barrier function brought on by environmental exposure (Stutz et al. 2012).

5.5.8.4 Whitening

Cosmetics that block the tyrosinase enzyme prevent excessive skin pigmentation and promote whitening (Babitha and Kim 2011). *Nannochloropsis oculata*'s pure extract, which contains the anti-tyrosinase zeaxanthin, was trademarked for use in creams (Babitha and Kim 2011).

5.5.8.5 Hair Care

For formulations to stop hair loss, extracts of *Monodus* sp., *Thalassiosira* sp., *Chaeloceros* sp., as well as *Chlorococcum* sp. are suggested because they could alter melanogenesis in human skin and hair, enhancing and promoting keratinocyte differentiation, melanocyte proliferation, and the growth of human hair and hair follicles (Zanella et al. 2018).

Skin and hair can be softened and made more flexible by cosmetic formulations for sun protection and anti-aging that comprise species of the microalgae *Chlorella* genus, which mostly consist of intact microalgal cells and contain oil derived by dry weight (Brooks and Franklin 2013).

Finally, taking into account the current market, alguronic acid appears as a new topical cosmetic product capable of enhancing skin appearance and health. It is made of a combination of polysaccharides extracted from biomass of the cyanobacteria *Chlorella protothecoides* (UTEX 31) and Parachlorella, which are grown in the dark under heterotrophic conditions (Im et al. 2012). Further research to support the product's effect is not yet available, though. We therefore propose additional research on bioactive chemicals to enhance the biological activities of algae, taking into account that the use of algae in cosmetics is a promising topic for the cosmetics sector.

5.5.9 Others

There exist several other applications of marine algae in niches such as antifouling, anti-coagulants (Li et al. 2017), and so on: the list is unending seeing that there is a current drive by researchers/industrialists toward the utilization of these materials for advanced uses.

5.5.10 Potential Uses of Marine Algae

5.5.10.1 Potential Use in Dermatology

Algae Against Acne Vulgaris

Many teens and young adults suffer with acne vulgaris, sometimes known as acne, which is a prevalent skin problem. It is distinguished by pimples, blackheads or whiteheads, greasy skin, and even scars. Years of acne can leave lifelong scars, deformity, and negative impacts on physiological development (Leyden 1995). Acne has a complicated and multifaceted etiology. Although acne is typically thought of as an inflammatory condition, it can also be caused by germs, hair follicle keratinization, and sebum release (Farrar and Ingham 2004). Acne is typically caused by *Staphylococcus epidermidis, S. aureus, Pseudomonas aeruginosa,* and *S. aureus (*Yamaguchi et al. 2009*)*. Traditional treatments for acne vulgaris caused by bacterial overgrowth include clindamycin and erythromycin. Nevertheless, widespread use of antibiotics has resulted in bacterial resistance. In addition, antibiotics may irritate and induce skin allergies. Therefore, the bioactive substances produced from sea algae may be a secure, all-natural substitute. It has been observed that macroalgae extracts contain antibacterial and antifungal properties (Pérez et al. 2016). When extracts from different marine algae were tested for their ability to kill skin-related bacteria, some potent antibacterial chemicals were discovered. In addition, some macroalgal extracts have anti-inflammatory properties and have the capacity to control collagen and growth factor levels, which may help to treat acne and hasten skin restoration (Lee et al. 2009b).

5.5.10.2 Algae Protects Skin from UV Radiation Injury

In recent years, photoaging brought on by excessive sun exposure has become a major issue. Fig. 5.11 illustrates the method by which UV promotes the creation of reactive oxygen species (ROS) (Pallela et al. 2010); this is essential for maintaining homeostasis and cell signaling. However, the concentration of ROS will increase

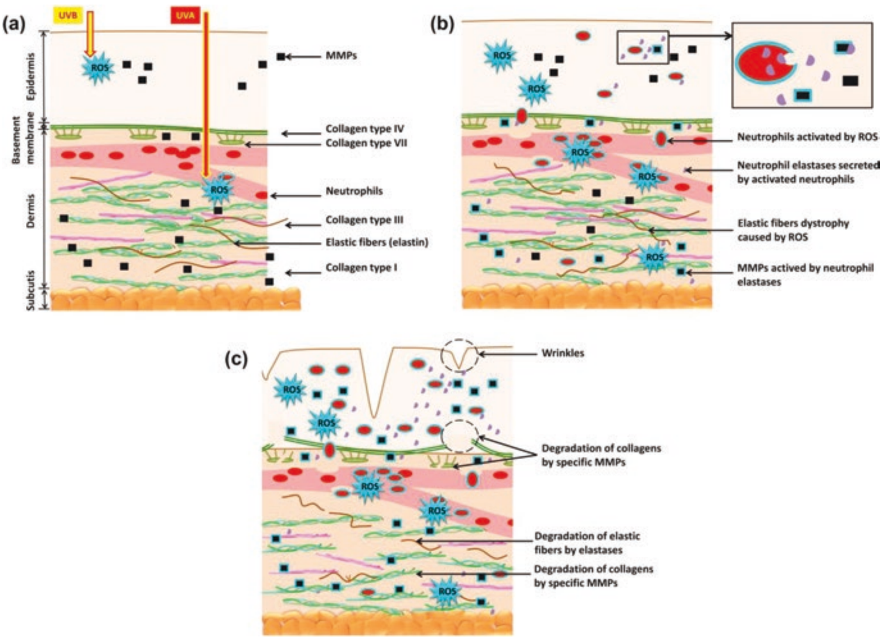

Fig. 5.11 The mechanism of photoaging: (**a**) The amount of ROS increased by UV exposure: UVB usually reach the epidermis, while UVA can penetrate the epidermis, and reach the dermis. When skin is exposed to UV radiation, the concentration of ROS will rise due to the skin antioxidant defenses. (**b**) The damage caused by ROS: When expose to UV radiation, ROS proliferates quickly, and neutrophils will be activated by high concentrations of ROS. Then ROS cause elastic fibers dystrophy and activated neutrophils secrete neutrophil elastases which activate matrix metalloproteinases (MMPs). (**c**) The damage caused by MMPs: The degradation of collagen is caused by MMPs, and the degradation of elastic fibers is caused by elastases, leading to collagen-support reduce and loss of skin elasticity, finally promote winkle formation and accelerate skin aging. (Reproduced with copyright permission from Wang et al. (2017), Elsevier 2017)

quickly when skin is subjected to unfavorable conditions, such as UV irradiation or high temperatures, and a high concentration of ROS may harm cell structure. Collagen and elastin in the dermis support the epidermis and help keep skin supple and elastic. High quantities of ROS will cause neutrophils to become activated when exposed to UV irradiation (Fig. 5.11a). Once elastic fiber dystrophy is brought on by ROS, active neutrophils produce neutrophil elastases, which in turn activate matrix metalloproteinases (MMPs) (Fig. 5.11b) (Chen et al. 2012). Elastic fiber breakdown is likewise a result of elastases, whereas collagen degradation is a result of MMPs. The skin begins to lose its elasticity and develop wrinkles when exposed to excessive UV light. MMP buildup is therefore bad for skin (Fig. 5.11c). To combat photoaging, marine organisms, particularly macroalgae, create a wide range of well-known photoprotective and anti-photoaging chemicals (Pallela et al. 2010). In addition to absorbing UV-A and UV-B rays, macroalgal bioactive compounds also have the ability to scavenge ROS that have formed and prevent the synthesis of MMPs.

5.5.10.3 Algae for Melanoma Treatments

A relatively frequent malignant tumor is skin cancer. Basal cell carcinoma, squamous cell carcinoma, and melanoma are the three primary kinds of skin cancer. Non-melanoma skin cancers include basal cell and squamous cell carcinomas. The most dangerous and prevalent type of skin cancer is melanoma, which is produced by melanocytes. The majority of melanomas range in color from brown to black, but they can also have more aggressive features including pink, red, or flesh color, as well as itchiness or bleeding. Skin cancer is brought on by both environmental and hereditary causes, such as pale skin, UV exposure, and numerous benign naevi (Garbe and Leiter 2009). Overexposure to UV radiation is the main risk factor for skin cancer. Repeated exposure to UV radiation can result in skin cancer, according to a number of experimental animal studies (Chiang et al. 2015; Wang et al. 2015; Cordeiro-Stone et al. 2016). Thus, wearing sunscreen and limiting your exposure to UV radiation are excellent ways to avoid skin cancer. Additional therapies are also required, such as surgery, chemotherapy, radiation therapy, and targeted therapy. The most often prescribed chemotherapy medications typically have higher cytotoxicity and side effects, which can injure other body organs, lower quality of life, and worsen medical conditions. For instance, autoimmune-mediated adverse effects such as colitis, hypophysitis, hepatitis, and iridocyclitis may appear in patients receiving CTLA-4 antibody therapy for metastatic melanoma (Kähler and Hauschild 2011). Treatment for metastatic melanoma with vemurafenib may result in facial palsy (Klein et al. 2013). There is an urgent need to research more suitable and efficient skin cancer treatments.

Marine algae have been shown to contain antitumor and cytotoxic substances, such as polysaccharides from *Sargassum fusiforme* that have anti-liver cancer activity (Fan et al. 2017). Spatane diterpinoids isolated from brown marine algae *Stoechospermum marginatum* can effectively inhibit malignant melanoma growth (Velatooru et al. 2016). Ascophyllan derived from brown seaweed *Ascophyllum nodosum* exhibits in vivo anti-metastatic activity on B16 melanoma cells (Abu et al.

2015). The anti-melanoma mechanisms of bioactive compounds derived from macroalgae usually rely on activating the caspase cascade such as caspase-3, -6, -9, and reducing the expression of cyclin-dependent kinase (cdk2, cdk4) and matrix metalloprotease family.

5.6 Challenges and Ways Forward

Compared to terrestrial biomass, the estimated costs for marine algae are now many times higher, but with better yields, scale, and operations, algae may eventually become cost-competitive with terrestrial crops (Warner et al. 2015). About 50 countries presently undertake seaweed cultivation, which has been expanding quickly (traditionally in Japan, the Republic of Korea, and China). Also gathered in 2014 were 27.3 million tons of aquatic plants, including seaweed, for a total value of $5.6 billion (Hasan and Rina 2009). The expense of upkeep for marine sensors, charging for autonomous underwater vehicles, charging for transport vessels, etc., may be another obstacle in the growth or production of marine algae.

The cost of production for marine algae is very high in comparison to conventionally cultivated crops: this eventually results in high final product cost. Simpler cultivation approaches, cheaper technologies for marine-based sensors, underwater vehicles, etc. should be adopted to cut the production cost of these essential marine algae.

Again, we must remember that there is limited or rare awareness of the general public to/on the importance of marine algae and the nutritional as well as medicinal value. It is very difficult to make people accept marine algae as an alternative food source as well as medicines seeing the general populace is accustomed with land cultivation food products. The way forward in this regard is to sensitize the general public via the Internet, televisions, radios, and other available media outlets on the authenticity, importance, as well as potential of marine algae important attributes and their potential to replace most conventionally cultivated agro-products and pharmaceuticals.

The improvement of microalgae's growth and yield is one of the primary obstacles to expanding biotechnological applications of these organisms. The balance between actively dividing and dying cells determines the growth rate of a microalgal population. This "performance index" is primarily influenced by how well cells adapt to their culture environment and how expensive it is to regulate internal activities energetically. The latter is based on the strains' physiological adaptability and how well their ecophysiological requirements match the surroundings. The "Photosynthetic Regulation Biotechnology" and the genetic engineering of strains are two of the most promising paths forward for increasing biomass or the creation of intriguing chemicals.

To maximize the fitness of farmed species and reduce production costs, the functional biodiversity of microalgae must be thoroughly investigated. In addition, the mass culturing conditions now in use must be reconsidered. For the reasons already covered in the regulated vs. uncontrolled environmental characteristics, indoor culturing systems would be preferred to outdoor systems (Barra et al. 2014). In addition, we advise using local microalgal species and saltwater from which the species has been isolated, i.e., growing plants close to aquatic habitats. This method could lower the cost of cultivation, permit the use of recently separated species and strains, and possibly also offer significant flexibility in the selection of species that have similar ecophysiological requirements. This might help address the potential decrease of growth efficiency brought on by sustained cultivation.

In addition, given that ammonium is digested more quickly than nitrate and thus allows for an increase in production efficiency, we advise using it as a nitrogen source to boost biomass production (see above). For the reasons described in the preceding sections, we propose using a sinusoidal-shaped intra-diel light–dark cycle as opposed to a quadratic distribution. Through a program of light variation frequency, turbulence, which reproduces coastal habitats, can be used to cultivate coastal species. We suggest using lighting technologies that enable control of the photon flux density and spectrum composition to better optimize photosynthetic productivity (Barra et al. 2014). To boost growth yield and lower production costs, green radiation may be eliminated from the light spectrum for several microalgal groups (such as diatoms or chlorophytes) (Wondraczek et al. 2013). We propose that genetic engineering should focus on the photophysiological response system, entering the field of "photosynthetic regulatory biotechnology," since the impact of light fluctuations on the physiology and growth of autotrophs is significant (Costa et al. 2013). However, when microalgae go through photophysiological pathway change, there is a strong possibility of developing a productive strain with a modest growth rate.

Diatoms, which include many coastal species, may be the ideal model to cultivate for biotechnological purposes due to their enormous variety and numerous ecological idiosyncrasies (see previous). To successfully cultivate diatom species for biotechnological applications, ecophysiological and process engineering researchers must communicate more effectively. Many diatom species thrive on benthic substrates, at least during one stage of their life cycle. In addition, they have sexual reproduction (Reed and Stewart 1988), which enables frequent gene recombination processes and significant physiological flexibility (Brunet et al. 2013). By adjusting the growth conditions, we could readily regulate their photophysiological reactions and biochemical pathways to boost the synthesis of specified compounds.

5.7 Conclusion and Future Prospect

The current study provides a succinct overview of marine algae with particular emphasis on marine algae in general: the chapter details the distribution of marine algae. Macroalgae are significant sources of the extraction of natural components, it can be said after summing the studies looking into the usage and composition of marine algae. These algae can be harvested and are used extensively in medicine and nutrition throughout the world. In addition, the biomass could be used to make adsorbents for water treatment filters or as a source of biofuel.

Marine algae if utilized efficiently can be a source material for many advanced materials for important applications. Thus, a variety of antioxidants, such as carotenoids, tocopherol, ascorbic acid, chlorophyll derivatives, phlorotannins, polyphenols, mycosporine-like amino acids, etc., can be produced using synthetic means. With careful investigation/research into these wonderful materials is highly essential to discover other beneficial antioxidants of high value for diverse applications.

As well as being a significant source of minerals, vitamins, proteins, fibers, and polyunsaturated fatty acids, marine algae are also known to include other nutrients. As was already noted, other studies have also shown their advantageous impacts on consumption. There is therefore a need to dig more into these valuable materials for better materials supplements (minerals, vitamins, proteins, fibers, etc.) as an awaited answer to diverse biomedical challenges.

Marine algae are projected as biorefinery to be a major source of industrially important chemicals for advanced materials synthesis like proteins, carbohydrates, polymers, oils, fats, aromatics, etc. Marine algae are underutilized at present though there is a new drive into their application by both researchers and industrialists globally: come on, let us make maximum use of marine algae.

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