Bioactive components from seaweeds: Cosmetic applications and future development

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Marine macroalgae biomass is often used for the production of ingredients in cosmetics. These ingredients can have one of the three main functions: (1) they are considered as additives which contribute to the organoleptic properties; (2) they are used for stabilisa-tion and preservation of the product; (3) or finally, they are bioactive compounds which fulfil a real cosmetic function and activity. This chapter presents the bioactivities of molecules or extracts used for cosmetic applications, and discusses some perspectives for the development of new compounds and specific extraction methods. Metabolites derived from seaweeds have been shown to be active in antiaging skin care, anticellulite treatment and slimming, as well as having antioxidant, photoprotective, moisturising, and whitening properties. Among the various classes of seaweed components, sul-phated polysaccharides, peptides, carotenoids, fatty acids, and phytohormones exhibit antiaging and antioxidant properties, while mycosporine-like amino acids, flavonoids have an antiphotoaging activity. Flavonoids (i.e. phlorotannins) are lipolytic agents which are isolated from macroalgae and which also inhibit melanogenesis. A better knowledge of algae genetics and the improvement of algae cultivation or co-cultivation will provide new opportunities for the development of bioactive compounds.

12.1 INTRODUCTION

The diversity of marine macroalgae (seaweeds) species and their widely ranging biochemical composition means that they represent a source of potential bioactive compounds for applications in the agri-food industry, cosmetics, pharmacology and, more recently, in the field of functional food and chemistry (Holdt & Kraan, 2011; Ioannou & Roussis, 2009, pp. 51; Mayer, Rodríguez, Berlinck, & Hamann, 2007). Macroalgae can be classified into three groups according to their pigmentation: Phaeophyceae (brown), Rhodophyceae (red) and Chlorophyceae (green). Seaweeds are the sources of mineral matter (11–55% dry weight, in the form of ash), polysaccharides (15–76% dry weight), proteins (1–50% dry weight), lipids (0.3–5% dry weight), phytohormones and pigments, as well as a wide variety of secondary metabolites (phenolic compounds, terpenoids and halogenated compounds, sulphur derivatives, and nitrogen derivatives). The biochemical composition varies greatly depending on the sampling site, the season of harvest and the environment (Cardozo, Guaratini, & Barros, 2007; Bourgougnon & Stiger-Pouvreau, 2012; Holdt & Kraan, 2011). Algae have been mainly exploited as a source of food in Asia where seaweed cultivation has become a major coastal economy, and as a source of technofunctional polysaccharides (agars, carrageenans and alginates).

Nowadays, there is a market trend in the cosmetic industry towards the development and manufacture of cosmetics with seaweed extracts. Seaweeds are rich in vitamins (A, B1, B2, B3 or PP, B5 or pantothenic acid, B6, B9 or folic acid, B12, C, D, E and K), essential amino acids, mineral macroelements and trace elements such as iodine (Ioannou & Roussis, 2009, pp. 51). Some examples of trade extracts are presented in Table 12.1. The main classes of actives in cosmetic care products are used for antiaging care, antiphotoaging, slimming care, photoprotection, moisturising and skin whitening. The presence of a particular compound not only means that these plants are of interest but also opens up the possibility of harvesting as well as cultivation and transformation under different conditions, leading to an enrichment of specific bioactive compounds. Cosmetic products not only have to comply with strict rules concerning the use of chemical substances (EU regulation No. 1223/2009 on cosmetic products) but must also satisfy consumer demand for products containing effective natural and nontoxic ingredients. Seaweed is used as a plant extract and there is no restriction for cosmetic use. In the first part of this article, we present an overview of macroalgae bioactive components or extracts derived from seaweeds for use in further cosmetic applications. We also discuss perspectives in marine biotechnology for the development of bioactive compounds and the use of some specific extraction methods is described. An improved knowledge of the genetics of algae and the cultivation of macroalgae will open up new strategies for the production of compounds of interest.

Table 12.1 Examples of Nomenclature INCI of Some Trade Seaweed Extracts (CosIng Database, 2014)

INCI Name	CAS No.	Description
Ecklonia laminaria extract	–	*Ecklonia laminaria* extract is the extract of the alga, *Ecklonia laminaria*. Skin conditioning.
Laminaria angustata extract	92128-82-0	*Laminaria angustata* extract is an extract of the alga, *Laminaria angustata*, Laminariaceae. Skin conditioning.
Laminaria digitata extract	90046-12-1	*Laminaria digitata* extract is an extract of the alga, *Laminaria digitata*, Laminariaceae. Skin protecting.
Algae extract	92128-82-0/ 68917-51-1	Algae extract is an extract of various species of algae; extract of the seaweed, *Fucus vesiculosus*, Furaceae. Emollient, humectant, masking, oral car, skin conditioning.

Continued

Table 12.1 Examples of Nomenclature INCI of Some Trade Seaweed Extracts (CosIng Database, 2014)—cont'd

INCI Name	CAS No.	Description
Fucus serratus extract	94167-02-9	*Fucus serratus* extract is an extract of the alga, *Fucus serratus* L., Fucaceae. Skin protecting.
Fucus vesiculosus extract	84696-13-9	*Fucus vesiculosus* extract is an extract of the dried thallus of the Bladderwrack, *Fucus vesiculosus* L., Fucaceae. Emollient, skin conditioning, smoothing, soothing.
Hydrolysed *Fucus vesiculosus* extract	84696-13-9/ 100085-36-7	Hydrolysed *Fucus vesiculosus* extract is a hydrolysed iodinated extract from the Bladderwrack, *Fucus vesiculosus* L., Furaceae. Skin conditioning, smoothing, soothing.
Hydrolysed *Fucus vesiculosus* protein	84696-13-9	Hydrolysed *Fucus vesiculosus* protein is the hydrolysate of the protein obtained from the Bladderwrack, *Fucus vesiculosus* L., Furaceae, derived by acid, enzyme or other method of hydrolysis. Skin conditioning.
Algae oligosaccharides	–	Algae oligosaccharides are oligosaccharides produced by the enzymatic degradation of agar that is obtained from *Gelidium* sp. and other algae. Skin conditioning.
Gelidium cartilagineum extract	94945-01-4	*Gelidium cartilagineum* extract is an extract of the alga, *Gelidium cartilagineum*, Gelidiaceae. Skin protecting.
Hydrolysed *Asparagopsis armata* extract	–	Hydrolysed *Asparagopsis armata* extract is the hydrolysate of *Asparagopsis armata* extract derived by acid, enzyme or other method of hydrolysis. Skin protecting.
Chondrus crispus extract	244023-79-8	*Chondrus crispus* extract is an extract of the carrageenan, *Chondrus crispus*, Gigartinaceae. Skin conditioning, viscosity controlling.
Chondrus crispus	–	*Chondrus crispus* is the material obtained from the whole alga, *Chondrus crispus*, Gigartinacea. Masking
Pelvetia canaliculata extract	223751-75-5	*Pelvetia canaliculata* extract is an extract of the alga, *Pelvetia canaliculata*, Fucaceae. Skin protecting.

Table 12.1 Examples of Nomenclature INCI of Some Trade Seaweed Extracts (CosIng Database, 2014)—cont'd

INCI Name	CAS No.	Description
Palmaria palmata extract	223751-74-4	*Palmaria palmata* extract is an extract of the alga, *Palmaria palmata*, Rhodymeniaceae. Skin protecting.
Sargassum muticum extract	–	*Sargassum muticum* extract is an extract of the alga, *Sargassum muticum*, Sargassaceae. Skin protecting.
Fucoxanthin	3351-86-8	Fucoxanthin is a carotenoid isolated from the alga, *Sargassum siliquastrum*. Skin conditioning.
Undaria pinnatifida extract	–	*Undaria pinnatifida* extract is an extract of the alga, *Undaria pinnatifida*, Alariaceae. Skin conditioning, skin protecting.
Codium tomentosum extract	223749-84-6	*Codium tomentosum* extract is an extract of the alga, *Codium tomentosum*, Codiaceae. Skin protecting.
Enteromorpha compressa extract	-	*Enteromorpha compressa* extract is an extract of the thallus of the alga, *Enteromorpha compressa*, Ulvaceae. Skin protecting.
Hydrolysed *Ulva lactuca* extract	97,281-59-9	Hydrolysed *Ulva lactuca* extract is the hydrolysate of *Ulva lactuca* extract derived by acid, enzyme or other method of hydrolysis. Skin conditioning.
Ulva ramulosa Callus culture extract	–	*Ulva ramulosa* Callus culture extract is the extract of a culture of the callus of *Ulva ramulosa*, Ulvaceae. Skin conditioning.
Kappaphycus alvarezii extract	–	Kappaphycus alvarezii extract is an extract of the alga, *Kappaphycus alvarezii*, Soleriaceae. Skin conditioning.
Jania rubens extract	–	Jania rubens extract is an extract of the seaweed, *Jania rubens*. Skin conditioning.
Halopteris scoparia extract	–	*Halopteris scoparia* extract is an extract of the alga, *Halopteris scoparia*, Stypocaulaceae. Skin conditioning.

INCI: international nomenclature of cosmetic ingredient.

12.2 METABOLITES OF INTEREST FOR COSMETICS

Several reviews have presented the detailed biochemical composition of marine macroalgae (Bourgougnon & Stiger-Pouvreau, 2012; Cardozo et al., 2007; Holdt & Kraan, 2011; Ioannou & Roussis, 2009, pp. 51; Mayer et al., 2007). Bioactive compounds are isolated by various methods depending on different factors: physicochemical properties, molecular size, and solubility. Phycocolloid applications have been described in previous reviews, as well as the benefits of different minerals and vitamins, so these aspects are not discussed further here.

12.2.1 Polysaccharides and Sulphated Polysaccharides

The different chemical structures of cell wall and storage polysaccharides have been previously described in a number of reviews (Bourgougnon & Stiger-Pouvreau, 2012; Holdt & Kraan, 2011; Kraan, 2012). Alginates, carrageenans and agars are used as stabilisers, thickeners and emulsifiers in various sticks, creams, lotions, soaps, shampoos, toothpastes, foams, and gels. Phaeophyceae contain alginates, laminarin, sargassan and fucans, the latter being classified into three groups: fucoidans, sulphated galactofucans and ascophyllans (Hemmingson, Falshaw, Furneaux, & Thompson, 2006; Logeart et al., 1997; Logeart, Prigent-Richard, Jozefonvicz, & Letourneur, 1997; Rocha et al., 2005). Fucoidan is a sulphated polysaccharide isolated from brown seaweed, which is characterised by a sulphated fucose backbone. Polysaccharides derived from Rhodophyceae are extremely variable, consisting of floridean starch (a glucan similar to amylopeptin), agars, carrageenans, xylans, galactans, sulphated galactans and sulphated rhamnans. Chlorophyceae contain sulphated galactans, xylans and ulvans. The chemical structures of cell wall and storage polysaccharides are still under investigation and these compounds make up a wide range of species-specific components with a high degree of seasonal and environmental variability.

12.2.2 Proteins and Amino Acids

One interesting feature of seaweeds is their richness in proteins and bioactive peptides. The composition and concentration of proteins varies with species, site and season of harvesting (Fitzgerald, Gallagher, Tasdemir, & Hayes, 2011). The protein fraction of brown algae is relatively low (1–24%

DW) compared with green (4–44% DW) and red macroalgae (5–50% DW) (Fitzgerald et al., 2011; Holdt & Kraan, 2011). These proteins include lectins and phycobiliproteins (Aneiros & Garateix, 2004). Most seaweeds contain all the essential amino acids and acidic amino acids, e.g. glutamic and aspartic acids (Fleurence, 2004). *Palmaria* and *Porphyra* species have been reported to enclose high amounts of glycine and arginine, the latter being a precursor of urea which is a component of the natural moisturising factor (NMF). Fleurence (2004) reports low levels of threonine, lysine, tryptophane, histidine and the sulphur-containing amino acids cysteine and methionine. However, threonine, valine, leucine, lysine, glycine and alanine contents are higher in brown seaweed. It is noteworthy that certain specific amino acids have much higher contents in some macroalgae: e.g. proline in *Ulva armoricana*, accounting for 5–10.5% of total amino acids, glycine in *Palmaria palmata*, arginine in *Chondrus crispus* and *Porphyra* sp., as well as alanine, glycine, arginine, leucine, valine, lysine and methionine in *Undaria pinnatifida* (Fleurence, 1999; Harnedy & FitzGerald, 2013; Holdt & Kraan, 2011). The carbohydrate-binding bioactive lectins found in *Ulva* sp., *Euchema* sp., and *Gracilaria* sp. give rise to biological activity by binding to specific cell glycoreceptors (Holdt & Kraan, 2011).

12.2.3 Phycobiliproteins

Phycobiliproteins are water-soluble and coloured components of the photosynthetic system in red macroalgae (Aneiros & Garateix, 2004; Chronakis, Galatanu, Nylander, & Lindman, 2000). Among this class of components, phycoerythrin makes up a large proportion of the red algal cell proteins (Chronakis et al., 2000; Wang, Sun, Fan, & Tseng, 2002). R-phycoerythrin, phycocyanin, and allophycocyanin are present in *Gracilaria gracilis* (Francavilla, Franchi, Monteleone, & Caroppo, 2013). R-phycoerythrin obtained through biotechnological processes is used as a natural dye, and represents an attractive alternative for reducing the use of synthetic pigments in the formulation of coloured creams and make up products (Harnedy & FitzGerald, 2011; Ruiz-Ruiz, Benavides, & Rito-Palomares, 2013).

12.2.4 Lipids

The main classes of lipids are present in seaweeds but at a low level compared to terrestrial plant. The lipids include liposoluble vitamins (A, D, E and K), fatty acids, triglycerides, phospholipids, glycolipids, sterols and carotenoids which have been previously reported (Holdt & Kraan, 2011). Each class is composed

of various molecules and the major compounds have been characterised. Fatty acids are precursors in the biosynthesis of eicosanoids, eicosapentaenoic and docosahexaenoic polyunsaturated ω-3 fatty acids. The nature of the fatty acids is highly variable, composed of saturated, monounsaturated and polyunsturated carbon chain. Thirty one fatty acids were identified in the red seaweed *G. gracilis* (Francavilla et al., 2013). Besides fatty acids, the unsaponifiable fraction contains carotenoids in red and green algae and fucoxanthine in brown algae, as well as tocopherols and sterols (Holdt & Kraan, 2011). Among the group of steroids, phytosterols form an important group and may have particular biological activities including anti-inflammatory and antioxidative effects (Lee, Lee, Jung, Kang, & Shin, 2003). However, the study of the biological activity of individual phytosterols is difficult because of the fact that pure phytosterols are expensive and scarcely available (Fernandes & Cabral, 2007). Fucosterol and fucosterol derivatives are present in brown algae, while desmosterol, cholesterol and cholesterol derivatives, campesterol and 24-ethylenecholesterol, are found in red seaweeds. Ergosterol and 24-ethylcholesterol have been reported in Chlorophyceae (Francavilla et al., 2013; Sánchez-Machado, López-Hernández, Paseiro-Losada, & López-Cervantes, 2004).

12.2.5 Pigments

Green lipid-soluble chlorophylls are present in all organisms that carry out photosynthesis. Carotenoids are coloured compounds involved in the photosynthetic apparatus and in the process of photoprotection by allowing the dissipation of excess heat energy and serving as direct quenchers of singlet oxygen or other reactive oxygen species (ROS) (Rastogi, Richa, Sinha, Singh, & Häder, 2010). These compounds are present in all species of macroalgae with seasonal variation. Zeaxanthin, α- and β-carotene, and lutein are found in red algae (Mikami & Hosokawa, 2013; Okai, Higashi-Okai, Yano, & Otani, 1996; Schubert, Garcia-Mendoza, & Pacheco-Ruize, 2006). β-carotene, zeaxanthin, violaxanthin and antheraxanthin are found in brown algae, along with fucoxanthin as well (Shang, Kim, Lee, & Um, 2011). In green algae, carotenoids consist of zeaxanthin, neoxanthin, antheraxanthin, violaxanthin, lutein, α- and β-carotene, siphonein and siphonaxanthin (Mikami & Hosokawa, 2013; Sánchez et al., 2012).

12.2.6 Phytohormones

The phytohormones include a number of "hormone-like" compounds, such as cytokinins, auxins, giberellins, betaïnes, abscisic acid (ABA), jasmonic acid, polyamine, brassinosteroids and rhodomorphin, which have been detected

by liquid chromatography in various seaweeds (Tarakhovskaya, Maslov, & Shishova, 2007). ABA, gibberellic acid, indole-3-acetic acid, indole-3-butyric acid (IBA), salicylic acid and kinetin riboside (KR) have been reported as being present in *Ulva* sp. and *Monostroma oxyspermum* (Gupta et al., 2011).

12.2.7 Terpenoids and Halogenated Compounds

Seaweeds produce a wide range of secondary metabolites, many of which exhibit a broad spectrum of activity (Da Gama, Pereira, Carvalho, Coutinho, & Yoneshigue-Valentin, 2002; Ioannou & Roussis, 2009, pp. 51). The ecological roles of these compounds have recently been investigated in studies that chiefly emphasise chemical mediation as a defence against herbivores (Gagnon, St-Hilaire-Gravel, Himmelman, & Johnson, 2006; Macaya, Rothäusler, Thiel, Molis, & Wahl, 2005). These compounds can also inhibit settlement or development of fouling organisms (including viruses, bacteria, fungi and other algae) (Bazes et al., 2006, 2008; De Nys & Steinberg, 2002; Hay, 1996; Hellio et al., 2001; Hellio, Bergé, Beaupoil, Le Gal, & Bourgougnon, 2002; Silkina, Bazes, Mouget, & Bourgougnon, 2012). Although a large body of evidence has been available for some time showing that algae are endowed with chemical defences, it has only recently emerged that many of these defences are induced following challenges by bioaggressors (Bourgougnon & Stiger-Pouvreau, 2012; Potin, Bouarab, Salaun, Pohnert, & Kloareg, 2002).

Macroalgae extracts show efficacious antifungal, antimicroalgal and antibacterial activities (Hirschfeld et al., 1973; König & Wright, 1997). Chlorophyceae contain cyclic and linear sesqui-, di-, and triterpenes while Rhodophyceae are characterised by a high structural diversity of halogenated secondary metabolites whose polyhalogenated monoterpenes exhibit a wide range of activities. As an example, red algae produced halogenated terpenoids such as halogenated monoterpene from *Plocanium costatum* (Figure 12.1).

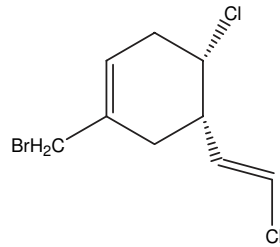

Figure 12.1 Chemical structure of halogenated monoterpene from *Plocanium costatum* (König, Wright, & de Nys, 1999).

Phaeophyceae differ from Rhodophyceae in having only minor halogenated hydrocarbons. Terpenes, phenolic compounds and meroterpenes make up the three major classes of secondary metabolites in brown seaweed (Kornprobst, 2014).

12.2.8 Phenolic Compounds, Polyphenols and Phlorotannins

In marine ecosystems, seaweeds of the upper intertidal zone are emerged for long periods during which they are exposed to strong, unfiltered UV radiation which induces the production of active oxygen species and free radicals. The production of phenolic compounds in marine algae has also been shown to be involved in various protection mechanisms such as against the oxidative or cytotoxic effects of UV damage. Phenolic compounds are secondary metabolites; hence, they are not directly involved in primary processes such as photosynthesis, cell division or reproduction of algae. Green and red seaweed have low contents of phenolic compounds compared to brown seaweeds (Hardouin et al., 2013; Mabeau & Fleurence, 1993) Phenolic compounds form a class of molecules divided into phloroglucinols (mono-, di-, tri-, tetra- and oligomeric) and phlorotannins, the latter being the most studied group in brown algae. Flavonoids are integral structural components of cell walls having an anti-UV function and acting as a chemical defence. Various compounds have been described, such as eckol, phlorofucofuroeckol A, dieckol (Figure 12.2), catechin and epigallocatechin (Heo et al., 2009; Rodríguez-Bernaldo de Quirós, Lage-Yusty, & López-Hernandez, 2010).

12.2.9 Mycosporine-like Amino Acids

The presence of mycosporine-like amino acids (MAAs) varies throughout the year due to the effect of insolation (Bedoux et al., in press; Bischof et al., 2006; Bourgougnon, Bedoux, Sangiardi, & Stiger-Pouvreau, 2011; Guinea, Franco, Araujo-Bazan, Rodriguez-Martin, & Gonzalez, 2012). MAAs are a family of secondary metabolites whose production is directly or indirectly related to the absorption of solar energy, and which protect marine organisms exposed to high UV radiation. MAAs have been detected in diverse organisms and especially in red macroalgae: *C. crispus*, *Palmaria* sp., *Gelidium* sp., *Porphyra* sp., *Gracilaria cornea*, *Asparagopsis* sp., *Desmarestia menziesii* (Karsten et Wiencke, 1999; Tsujino, Yade, & Sekikawa, 1980; Yuan, Westcott, Hu, & Kitts, 2009), *Grateloupia lanceola*, *Curdiea racovitzae* (Conde, Churio, & Previtali, 2000; Franklin, Kräbs, & Kuhlenkamp, 2001; Hoyer, Karsten, Sawall, & Wiencke, 2001; Huovinen, Matos,

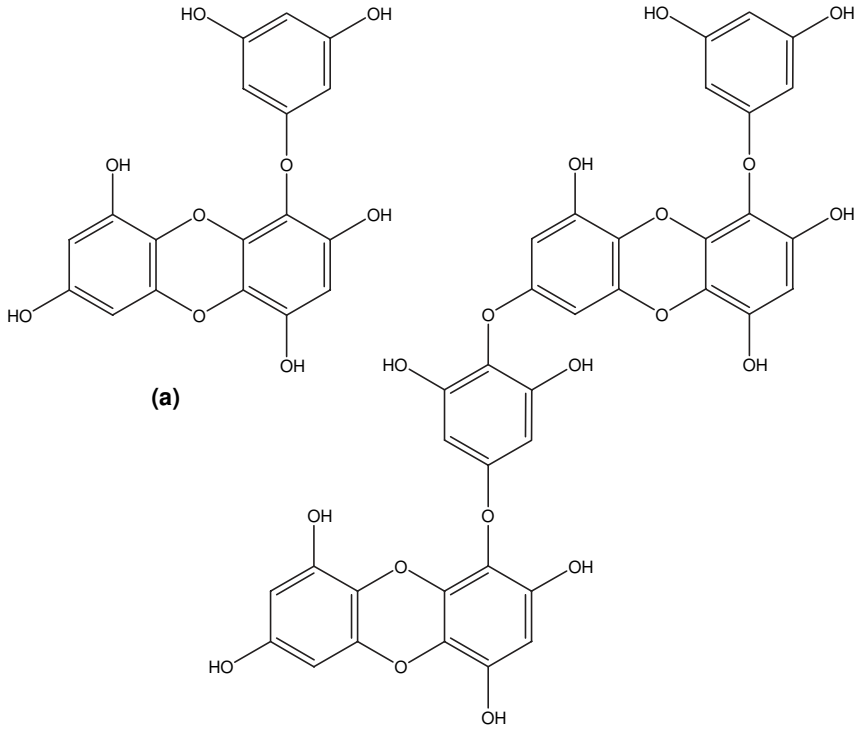

Figure 12.2 (a) Chemical structure of Eckol and Dieckol (Thomas & Kim, 2013).

Sousa Pinto, & Figueroa, 2006; Karentz, McEuen, Land, & Dunlap, 1991; Karsten, Sawall, & Wiencke, 1998; Peinado, Diaz, Figueroa, & Helbling, 2004; Sinha, Klisch, Gröniger, & Häder, 1998; Sinha, Klisch, Gröniger, & Häder, 2000), and more recently in *Solieria chordalis* (Bedoux et al., in press). Red macroalgae can contain up to 8 mg of MAAs per gram of dried matter (*C. racovitzae*). The content of MAAs is higher in summer and at a moderate depth (0–1 m) (Reef, Kaniewska, & Hoegh-Guldberg, 2009). The small intracellular compounds (<400 Da) of MAAs consist of a cyclohexenone or amino-cyclohexenimine ring linked to an amino acid, amino alcohol, or amino group, and are characterised by an absorption maximum between 320 and 360 nm. Generally, MAAs contain a glycine group on the C3 carbon and a second amino acid such as threonine, serine, taurine, and glutamate linked to the C1 carbon (Carreto & Carignan, 2011; Carreto, Carignan, & Montoya, 2001; Whitehead & Hedges, 2005; Yuan et al., 2009). MAAs may be potentially used in cosmetics and toiletries as UV protectors and activators of cell proliferation.

12.3 BIOLOGICAL ACTIVITIES AND SEAWEED COMPONENTS

Seaweeds have been described as having various activities as shown in Table 12.2. Molecules from brown macroalgae have antiaging, antiphotoaging, lipolytic and skin lightening (whitening) activities, while red seaweeds are characterized by antiaging, antiphotoaging, anti-UV and antioxidant activities.

12.3.1 Antiaging Care

The process of skin ageing is due to exogenous and endogenous factors. The genetic endogenous process is associated with a decrease in antioxidant status and cell proliferation capacity. Senescent cells express genes that produce degradative enzymes, growth factors and inflammatory cytokines. Exogenous factors include exposure to sunlight, pollution or nicotine, repetitive muscle movements, diet and medications (Farage, Miller, Elsner, & Maibach, 2008). Ageing of the skin occurs at several levels. The antioxidant defence system modulates the level of ROS that are produced during cellular respiration and energy metabolism. During skin ageing, cells lose their ability to regulate the generated ROS and suffer from oxidative stress. In the epidermis and dermis, a decrease in keratinocytes and melanocytes, as well as fibroblast proliferation and migration, leads to a decline of cellular activity and protein synthesis. Sulphated polysaccharides derived from macroalgae can have diverse biological and biochemical effects, including modulation of connective tissue proteolysis (Wijesinghe & Jeon, 2012b) and anti-inflammatory (Kang et al., 2011a; Senni et al., 2006), and can also act as free-radical scavengers and antioxidants for the prevention of oxidative damage in humans (Hu, Gen, Zhang, & Jiang, 2001; Rupérez, Ahrazem, & Leal, 2002; Zhang et al., 2004). Green algae, *Ulva lactuca* and *Codium tomentosum* (Chlorophyta) show antiaging, moisturising and lipolytic properties (Delaunay & Volle, 2011; Guglielmo & Montanari, 2008; Majmudar, 2012; Wang, Paul, & Luesch, 2013).

12.3.1.1 Sulphated Galactan and Sulfated Galactofucans

A fraction of the sulphated galactans was isolated from the red algae *Porphyra haitanensis* (Rhodophyta) by Zhang et al. (2004), using conventional hot-water extraction and ion-exchange cellulose chromatography. The 850 kDa-fraction was studied for *in vivo* antioxidant activity in ageing mice. Serum

Table 12.2 Examples of Seaweed used in Cosmetics, with Associated Metabolites and Activity

Macroalgae	Metabolites	Product Name	Activity	Manufacturer	Reference
Phaoephyceae					
Fucus vesiculosus	Fucoidan	–	Anticoagulant Antioxidant Skin fibroblast stimulation	–	Rupérez et al. (2002)
Fucus vesiculosus *Furcellaria lumbricalis*[a]	–	Topical cosmetic	Treating or preventing cellulite	Oriflame	Al-Bader, Davis, Laloeuf, and Rawlings (2013) (EP 2414047 B1)[b] Al-Bader et al. (2012)
Kjellmaniella crassifolia	Fucoidan		Antiaging Antiwrinkle	Takara Bio Inc.	Mizutani et al. (2010) (US 7678368 B2)
Padina pavonica	–	–	Keratinocytes differentiation Protein synthesis activation	Texinfine Patrinove	Gutierrez (1995) (EP 0655250 A1)
Laminaria digitata	Proteins (11%) Minerals (20%) Carbohydrates (69%)	Pheofiltrat	Lipolytic	Codif Int	Gedouin, Vallée, and Morvan (2006) (FR 2879098A1) Jang and Choung (2013)
Pelvetia canaliculata	Flanonoids Aminoacids Polyols Alginic acid Fucoidans	–	Antioxydant Collagen synthesis Stimulation Proteoglycans synthesis stimulation	–	Hupel, Lecointre, Meudec, Poupart, and Ar Gall (2011)
Ascophyllum nodosum	–	Algowhite	Tyrosinase inhibiting Anti-free-radical	Codif Int	http://www.codif-recherche-et-nature.com/
Hijikia fusiformis	Fucoxanthin	–	*In vivo* inducer of the Nrf2-ARE	–	Liu et al. (2011)

Continued

Table 12.2 Examples of Seaweed used in Cosmetics, with Associated Metabolites and Activity—cont'd

Macroalgae	Metabolites	Product Name	Activity	Manufacturer	Reference
Phaoephyceae					
Sargassum polycystum	Saponins, flavonoids, tannins, terpenoids, phenols, sugars, amino acids and amines	–	Antimelanogenesis or skin-whitening effect	–	Song et al. (2009) Chan et al. (2011)
Ascophyllum nodosum		Pheofiltrat	Skin conditioning regenerating and sebum regulating agent	Codif Int	http://www.codif-recherche-et-nature.com/
Saccharina longicruris	Galactofucan (1529 and 638 kDa)	–	Fibroblasts growth rate, synthesis of matrix metalloproteinase and collagen-I	–	Rioux et al. (2013)
Pelvetia wrightii	–	–	Anticellulite	–	Rozkin et al. (1991)
Ecklonia cava	Phlorotannins (dieckol)	–	Adipogenesis inhibitory effect	–	Ko et al. (2013)
Rhodophyceae					
Corallina pilulifera	–	–	Antiphotoaging	–	Ryu, Qian, Kim, Nam, and Kim (2009)
Corallina officinalis	Sulphated		Antioxidant		Yang, Liu, Wu, Chen, and Wang (2011)
Palmaria palmata	MAAs		Anti UV		Yuan et al. (2009)
Porphyra haitanensis	850 kDa sulphated galactans	–	*In vivo* antioxidant activity	–	Zhang et al. (2004)

Porphyra umbilicalis	MAAs		Anti-UVA Antioxydant		Zhang et al. (2004) Carreto and Carignan (2011)
Chlorophyceae					
Ulva lactuca	Clay and polysaccharide	Revertime	Antioxidant Antielastase Collagen synthesis Stimulation	Olmix	Demais et al. (2007) (EP 1786862 A1)
Ulva lactuca	Clay and lipopeptide	–	Antielastase Collagen synthesis Stimulation	Laboratoire Cosmétique de Lécousse	Delaunay and Volle (2011) (WO2011051591 A1)
Ulva lactuca	Fatty acids, keto-type C18 and keto-type C16	–	*In-vitro* and *in-vivo* Nrf2-ARE activation	–	Wang et al. (2013)
Ulva lactuca	Tripeptide composed of arginine–glycine–aspartic acid	–	Stimulation of collagen production via TGF-β, elastin, increase in the biosynthesis of collagen I	–	Guglielmo and Montanari (2008)
Codium tomentosum	–	–	Moisturizing	Mary Kay	Majmudar (2012) (US 8318178 B2)

[a]Red seaweed.
[b]Patent: skin care actives selected from the group consisting of glaucine, retinol, conjugated linoleic acid and caffeine.

malondialdehyde level was monitored as a marker of endogenous lipid peroxidation, along with the activities of the intracellular antioxidant enzymes superoxide dismutase (SOD), and glutathione peroxidase (GSH-Px), as well as total antioxidant capacity (TAOC). Treatment with the sulphated galactans fraction showed an effective inhibition of lipid peroxidation, inducing SOD and GSH-Px activities, and increasing the TAOC. Zhang et al. (2004) suggested that inhibition of lipid peroxidation might be attributed to the influence of sulphated galactans on the antioxidant enzymes and nonenzymatic defence system.

In the context of stimulating wound healing, galactofucan has been tested for its capacity to increase fibroblast cell migration and proliferation (Rioux, Moulin, Beaulieu, & Turgeon, 2013). Galactofucan (1529 and 638 kDa) was isolated from the brown seaweed *Saccharina longicruris*, subjected to depolymerisation and then added onto cultured dermal fibroblasts. Fibroblast growth rate and synthesis of matrix metalloproteinase and collagen-I were influenced according to the nature of the fractions (crude or depolymerised) and the molecular weight.

Furthermore, sulfated polysaccharides influence the migration and proliferation of fibroblasts, and studies have shown the capacity of these compounds for influencing growth factor modulation, stimulating oxidative phenomena, increasing skin thickness and elasticity, and inhibiting matrix metalloproteinases (Logeart, Letourneur, Jozefonvicz, & Kern, 1996; Senni et al., 2003; Senni et al., 2006).

12.3.1.2 Peptides

The role of proteins (elastin and collagen) and proteoglycans in the human skin network has been described by Gelse, Pöschl, and Aigner (2003). Several amino acids (serine, threonine and alanine) and amino acid derivatives (citrulline and pyrrolidone carboxylic acid) are components of the NMF in the *stratum corneum*. Over the last decade, the use of active peptides (less than 20 amino acids) in skin and hair care has attracted considerable attention in the industry. Up to the present, most active peptides have been synthesised using, for example, standard solid phase peptide synthesis methodology on Wang resin with a microwave synthesiser and Fmoc-protected amino acids as previously reported by Yang et al. (2013), or via classical chemical reaction using protected amino acids. Partial enzymatic hydrolysis of proteins (Hardouin et al., 2013) can also lead to oligopeptides. Although the use of L-amino acid ligase as a recombinant protein technology is able to produce peptides, this approach is not currently applied in the cosmetic field because

it implies the use of genetic modified organisms (Arai, Arimura, Ishikura, & Kino, 2013; Gorouhi & Maibach, 2009). Macroalgae are an important source of amino acids, amino acid derivatives, and peptides. Those have shown the ability to stimulate collagen production in skin. Furthermore, macroalgal protein hydrolysates from various seaweeds (*U. pinnatifida*, *Sargassum* sp., *Porphyra yezoensis*, *P. palmata* and *Enteromorpha prolifera*) demonstrate antioxidant activities (Harnedy & FitzGerald, 2013). A polypeptide from *U. lactuca*, called *Aosa* biopeptide, is used in cosmetic products; it is composed of glycine, arginine, lysine, valine and aspartic acid. The tripeptide composed of arginine–glycine–aspartic acid stimulates the production mechanism of collagen, via tissue growth factor, elastine, and produces an increasing biosynthesis of collagen I in human fibroblasts (Guglielmo & Montanari, 2008). Progress in biotransformation design implies that biopeptides from macroalgae could be used as a potential alternative source to synthetic ingredients and may contribute to antiaging. Enzymatic hydrolysis of algal proteins would allow the preparation of peptides that might lead to the development of skin bioactive compounds (Hardouin et al., 2013).

12.3.1.3 Keto-type C18 Fatty Acid

Naturally occurring molecules have been identified that are inducers of the nuclear factor E2-related factor 2 (Nrf2) antioxidant-response element (ARE) pathways. This defence system is induced by the cell to counteract oxidative stress. Wang et al. (2013) tested 30 macroalgae using an ARE-luciferase reporter gene assay and observed that *U. lactuca* extracts activated the reporter. After purification, three fatty acids, two keto-type C18 and one keto-type C16, showed *in vitro* and *in vivo* ARE activation. The electrophilic Mickael acceptor group appeared to be essential for the ARE activities.

12.3.1.4 Fucoxanthine

The carotenoid isolated from *Hijikia fusiformis* has been found to induce the Nrf2-ARE in mouse liver cells. We should mention that the electrophilic Mickael acceptor group is present in fucoxanthin (Liu, Chiu, & Hu, 2011). Zheng, Piao, Keum, Kim, and Hyun (2013) have demonstrated the ability of fucoxanthine to reduce apoptosis, protecting keratinocytes against oxidative damage by scavenging ROS.

12.3.1.5 Phytohormone Abscisic Acid

Phytohormones have shown potential inhibition of skin proteases and ROS. Systemic sclerosis (SSc) is a chronic inflammatory disease resulting in skin

fibrosis. The production of extracellular matrix (ECM) components, mainly type I collagen, is specifically upregulated in SSc fibroblasts causing thickening of the dermis. Bruzzone et al. (2012) have studied the effect of ABA on skin fibroblasts from SSc patients; ABA is reported to be an endogenous hormone in humans. ABA modifies some of the functions altered in SSc fibroblasts to a normal phenotype, suggesting that the skin of SSc patients could benefit from exposure to exogenous ABA.

12.3.2 Anticellulite and Slimming Care

Alterations of the skin of the thighs and buttocks, commonly referred to as cellulite, affect underlying adipose tissue of the hypodermis region. Adipose tissue contains collagen, reticulin and proteoglycan (Lotti, Ghersetich, Grappone, & Dini, 1990). Adipocytes produce triacylglycerols which represent the main component of adipose tissue in addition to cholesterol. Cellulite involves changes in the subcutaneous adipose layer biochemistry and in the structure of the supporting connective ECM together with the overlying dermal layer. These alterations include enhanced lipogenesis, decreased lipolysis and increased lipid storage within the adipocytes (Al-Bader et al., 2012; Hexsel & Soirefmann, 2011; Rosenbaum et al., 1998). Energy homeostasis is regulated by the chronobiology of adipocytes through the mechanisms of lipogenesis and lipolysis. Lipogenesis depends on α-adrenergic receptors on the adipocytes, cAMP production, antagonist cAMP phosphodiesterase, receptor adenosine A1, activation of the phosphodiesterase by insulin, and lipoprotein–lipase stimulation. The cAMP-dependent pathway is one of the mechanisms activating lipolysis in adipocytes (Carmen & Victo, 2006). Lipolysis is enhanced by β-receptors regulating cAMP production. Some topical treatments for cellulite include seaweed extracts, such as those used for increasing microcirculation flow, reducing lipogenesis and promoting lipolysis, which restore the normal structure of the dermis and subcutaneous tissue, and which scavenge free radicals or prevent their formation. The seaweeds most frequently used in anticellulite and slimming preparations are brown seaweeds, *Fucus vesiculosus*, *Furcellaria lumbricalis* (Al-Bader et al., 2012), *Laminaria digitata* (Jang & Choung, 2013) and *Pelvetia wrightii* (Rozkin, Levina, Efimov, & Usov, 1991). *Laminaria digitata* stimulates blood flow and aids the body in shedding excess fluids. In this way, seaweed can reduce the appearance of cellulite, but not the cellulite itself. Some constituents of macroalgae are lipolytic agents: flavonoids (Acheson et al., 2004; Kuppusamy & Das, 1992, Kuppusamy & Das, 1994; Ruckstuhl, Beretz, Anton, & Landry, 1979), quercetin (flavonoid belonging to the flavonols)

(Kuppusamy & Das, 1994) and phlorotannins (Ko et al., 2013). In the latter study, the potential inhibitory effect of extracts from five brown seaweed species was measured by adipogenesis assay according to the differentiation of 3T3-L1 preadipocytes into mature adipocytes by using the Oil-Red O staining protocol. The *Ecklonia cava* extract tested by Ko et al. (2013) showed evidence of an adipogenesis inhibitory effect on adipogenesis, compared to the results obtained from the other four brown seaweed extracts. Three phlorotannins were obtained by Ko et al. (2013) who observed their inhibitory effect on adipogenesis. Among the phlorotannins, dieckol exhibits potential adipogenesis inhibition and downregulates the expression of the peroxisome proliferator-activated receptor (PPAR) and other transcription factors implied in the expression of genes. PPAR is a protein which belongs to the family of nuclear receptors acting as a transcription factor of genes involved in lipid metabolism and adipogenesis. These results demonstrate the inhibitory effect of dieckol on adipogenesis through the activation of the AMP activated protein kinase signal pathway. Otherwise, Kang et al. (2011b) have shown that fucoxanthin isolated from *Petalonia binghamiae* has adverse effects.

12.3.3 Antioxidant—Photoprotection

Phenolic compounds are commonly characterized as being stress-induced compounds, and are involved in chemical protection mechanisms against biotic factors such as contamination due to bacteria and abiotic factors such as UV radiation and metal contamination (Llewellyn & Airs, 2010; Stengel, Connan, & Popper, 2011). Since phenolic compounds are produced in response to the generation of ROS, they exhibit anti-ROS properties (i.e. antioxidative) which ensure an efficient cytoprotective system. The antioxidant activity of seaweed phenols seems to depend on their structure and especially on the degree of polymerisation of phloroglucinol (Nakamura, Nagayama, Uchida, & Tanaka, 1996). The antioxidant and free-radical scavenging activities of phenols have essentially been identified in brown seaweeds (Ahn, Jeon, Kang, Shin, & Jung, 2004; Athukorala, Lee, Kim, & Jeon, 2007; Heo, Park, Lee, & Jeon, 2005; Park, Shahidi, & Jeon, 2004; Siriwardhana et al., 2008), and sometimes in red seaweeds (Cian, Martinez-Augustin, & Drago, 2012; Wang et al., 2010). In the short-wavelengths solar spectrum, the harmful effects of UV radiation (200–400 nm) are well documented (references in Pessoa, 2012; Rastogi et al., 2010; Talarico & Maranzana, 2000). All plant, animal and microbial organisms appear to be sensitive to UV radiation, but to a highly variable extent (Aiamla-or, Kaewsuksaeng,

Shigyo, & Yamauchi, 2010; Sinha et al., 2000; Srilaong, Aiamla-or, Soontornwat, Shigyo, & Yamauchi, 2011; Volkman & Gorbushina, 2006). Although sunlight-induced skin damage has been attributed mainly to the UV-B wavebands (285–320 nm), more recently, the important contribution of UV-A (320–400 nm) has been well demonstrated (Agar et al., 2004). UV radiation induces diverse effects such as the damaging of human skin (sunburn) and the formation of radical species, while causing the destruction of proteins, DNA and other biomolecules as well as leading to acute physiological stress (Torres et al., 2004). It can also lead to the proliferation of oncogenes which can mutate and cause cancer. Various natural substances extracted from plants could potentially have properties to protect against UV radiation. Macroalgae have developed mechanisms which counteract the damaging effects of UV-B and UV-A, by producing screen pigments such as carotenoids and phenolic compounds or UV-absorbing MAAs (Figueroa et al., 2003; Rosic, 2012). UV-absorbing compounds are bioactive compounds that can protect human fibroblast cells from UV-induced cell death and suppress UV-induced ageing in human skin. MAAs are UV-screen and antioxidant substances found in red algae, representing very efficient photoprotectors with high-energy dissipation and high photostability, but without generating oxidant photoproducts. Moreover, a product called Helioguard® 365 that contains MAAs has been commercialised (references in Bourgougnon et al., 2011; Bourgougnon & Stiger-Pouvreau, 2012; Richa et al., 2011).

12.3.4 Moisturising

The two external tissue layers of the skin surface are made up of dermis and epidermis. The epidermis is a multilamellar system whose outermost layer corresponds to the *stratum corneum* composed of corneocytes. Corneocytes contain keratin. Epidermis is mainly composed of keratinocytes, whereas dermis fibroblasts are embedded in an ECM composed of water, salts, proteins (fibrous collagen and elastin), adhesive glycoproteins and proteoglycans forming a colloidal gel. A core protein is linked to the polysaccharide fraction also called glycosaminoglycan (GAG) to form proteoglycan. Nonsulfated hyaluronic acid and sulphated GAGs represent more than 95% of the total mass of the molecule and are part of the skin's connective tissue giving elasticity and firmness. Proteoglycans act as a reservoir responsible for hosting most of the skin's water. The dermis ECM structure determines the physical characteristics of the tissue and the biological properties of its embedded cells (Esko, 1999). The moisturising properties of algae are due to the presence of several compounds

belonging to the group of NMFs (Watabe et al., 2013). Polysaccharides and oligosaccharides provide a high capacity for water storage, and these macromolecules can be linked to keratin through hydrogen bonds (Choi et al., 2013; Du, Bian, & Xu, 2013). *Mastocarpus* extract containing floridoside and isethionic acid has been shown to increase water retention of the stratum corneum (Deslandes & Bodeau, 2007).

12.3.5 Whitening

Melanin biosynthesis involves tyrosinase that catalyses the hydroxylation of L-tyrosine to 3,4-dihydroxyphenylalanine (L-DOPA) (Parvez et al., 2006). The inhibition of tyrosinase is the most common approach used to achieve skin whiteness. *Sargassum polycystum* extracts have been studied for their antimelanogenesis or skin-whitening effect by means of the cell-free mushroom tyrosinase assay (Song et al., 2009). The inhibition of cellular tyrosinase derived from melanin and melanogenesis was also assessed using kojic acid as a positive control. Ethanolic and ethyl acetate extracts, as well as the non-cytotoxic hexane fraction were found to reduce cellular tyrosinase activity while the water fraction showed only a small inhibitory effect according to the cell-free mushroom tyrosinase assay. The phytochemical composition of the active fraction includes saponins, flavonoids, tannins, terpenoids, phenols, sugars, amino acids and amines (Chan, Kim, & Cheah, 2011). Phenolic compounds are well-known components from brown seaweeds and this finding strengthens the role of these compounds in the inhibition of melanogenesis (Sabudak, Demirkiran, Ozturk, & Topcu, 2013). In addition, it has been reported that antioxidants may reduce hyperpigmentation and favour skin health (Ma et al., 2001).

12.4 FUTURE DEVELOPMENT

12.4.1 Seaweed Cultivation or Cocultivation for the Production of Actives

Out of the 16.8 million tons of seaweed produced in 2008, 93.8% were cultivated mainly in Asia (FAO, 2010). The versatility of seaweeds, whether used whole or for extraction in the hydrocolloid, pharmaceutical and cosmetics industries, has created a demand that cannot be satisfied by harvesting of wild stocks alone. The development of active ingredients from seaweed depends on the domestication of the species concerned. Indeed, it is imperative to know the biology of algae to be able to ensure high-quality culture, or even to enhance the content of a compound of interest.

In addition, the cultivation of seaweeds is essential in providing a sustainable and reproducible good-quality product (Guillemin et al., 2008). As the harvesting of wild populations of *Palmaria* is a seasonal activity, open-sea cultivation using a "Kuralon" string is a new technique producing a reliable crop that can be harvested as and when required (Edwards & Dring, 2011).

12.4.2 Specific Extraction Methods

Isolating a compound from seaweed first involves harvesting the algal raw material, storing (freeze drying), and then performing the extraction itself. Pretreatment of seaweed is of growing importance to achieve good extraction efficiency and the required selectivity. It is possible to obtain extracts with different compositions and yields by changing the extraction design. Therefore, depending on the type of compounds of interest, optimum extraction conditions can be utilised for selective isolation of specific groups of compounds. It is noteworthy that the extraction of target substances is carried out following an ecodesign strategy according to the six basic principles proposed by Chemat (2011). The algal raw material forms a variable but abundant and renewable resource. Moreover, reproducible cultivation techniques should be established to obtain a more standardised raw material (Edwards & Dring, 2011). The use of ecofriendly and nontoxic solvents coupled to efficient and sustainable extraction techniques is greatly encouraged (Anastas & Warner, 1998). The extract is not purified to an excessive degree in order to minimise the production of waste and, ultimately to move toward full use of the biomass. Moreover, the number of successive operations is limited as much as possible to maintain a simple and low-cost process. Finally, the extract is designed with a view to being incorporated as a natural ingredient into cosmetic products. This approach is expected to enhance the efficiency of the product. Xiao, Yuan, and Li (2013) report the isolation of fucosterol and phytol from the brown seaweeds *U. pinnatifida* and *Sargassum fusiforme* by microwave-assisted extraction coupled with high-speed countercurrent chromatography. Supercritical fluid extraction and subcritical water extraction are used for the extraction of lipids and antioxidants compounds, whereas fucoidan is obtained by ultrasound- and microwave-assisted extraction techniques (Herrero, Cifuentes, & Ibaňez, 2006). Fractions of fucoidan promote the proliferation of dermal fibroblasts, and protect the dermis elastic fibre network (Logeart et al., 1996; Senni et al., 2003; Senni et al., 2006). Different extraction procedures were compared by Hahn, Lang, Ulber, and Muffler (2012) as regards to the yield and chemical structure

of the fucoidan, as well as the extraction time. The use of ultrasound- and microwave-assisted extraction techniques allows high yields and a low extraction time without modifying the sulphate ester linkage. Microwave and ultrasound-assisted extraction are promising tools for establishing a more sustainable and efficient purification of fucoidan, and these techniques are competing with the enzyme-assisted release of sulphated polysaccharides. The enzyme-based technique appears to be advantageous for the large-scale production of fucoidan, but the economic efficiency of the process is dependent on the supply of the required enzymes.

12.4.3 Enzymatic Hydrolysis and Preparation of Cosmetic Actives

The cell wall consists of complex embedded polymers and it is a real challenge to carry out isolation of active oligosaccharides or peptides of high purity using water or aqueous organic solvent extraction processes. Extraction assisted by enzymatic hydrolysis is a promising soft technique to generate lower molecular weight oligosaccharide or peptide fractions, while also improving the extraction efficiency (quality and yield) of bioactive compounds derived from seaweeds. To obtain active peptides, sequential enzymatic digestion is recommended. Promising results have been obtained by several workers (Hardouin et al., 2013; Samarakoon & Jeon, 2012; Wijesinghe & Jeon, 2012a). The enzyme or multienzyme mixes tested in most studies are commercial preparations which are already used in the food industry. Moreover, the experimental conditions can be designed to conserve the native structure and function. Up to present, enzymatic degradation is hampered by the limited availability of the appropriate enzymes and demand for specific enzymes is already on the increase for the future development of bioactive extracts. Thus, the aim is to achieve a successful optimisation of heterologous carbohydrase or protease production, and the subsequent use of immobilised enzymes to control the degradation process is a promising approach. The purpose of obtaining natural antioxidants would be to supply a large-scale process for the production of water-soluble extracts (Heo et al., 2005; Heo, Jeon, Lee, Kim, & Lee, 2003, Wang et al., 2010).

12.4.4 Potential Antimicrobial Agents

Several cosmetic products are used for counteracting microbial colonisation (deodorants and antiperspirants), dental biofilm formation (toothpaste) and skin infection or inflammation (antiacne). Those products often contain synthetic antimicrobial agents listed in the Annex V (positive list) of the cosmetic regulation (EU cosmetic regulation No. 1223/2009). The exploration of

secondary metabolites from seaweeds could represent a new source of preservatives for cosmetics and has revealed important chemical relevant prototypes in the search for new agents (El Gamal, 2010; Ioannou & Roussis, 2009, pp. 51; Kornprobst, 2014; Mayer, 2002; Mayer & Hamann, 2004; Mayer et al., 2007). From 1960, up to the present, more than 15,000 novel compounds have been isolated from marine organisms (Cardozo et al., 2007).

12.5 CONCLUSION

Macroalgae represent a vegetative resource characterized by a high content of proteins, carbohydrates and minerals. Significant developments are taking place to introduce these marine plants in the field of cosmetic products, and there is growing public interest in the use of this natural resource for the production of industrially useful ingredients that may improve health and wellbeing. Seaweed extracts display a range of different activities in relation to antiaging, photoprotection, lipolysis, anti-inflammatory effects, moisturizing and whitening. Sulphated polysaccharide fractions and oligosaccharides, as well as peptides, keto-type fatty acids, fucoxanthin and phytohormones have been shown to have antiaging activities. Flavonoids and the particular class of phlorotannins, which are present in brown seaweeds, show lipolytic and anticellulite properties. Red seaweeds contain various MAAs, pigments and phenolic compounds which contribute to anti-photo-ageing and anti-free-radical activities. Green seaweeds, especially *U. lactuca* extracts, have been shown to counteract enzyme proteolysis of dermis components, while stimulating collagen biosynthesis. All these results have spurred great interest in the search for novel ingredients that might contribute to revealing new activities in the relevant applications. New strategies are being explored to monitor macroalgae growth and to study the biosynthesis and genetics of seaweeds, which will open up opportunities for developing new active compounds. However, it is important to study how the properties of the actives can be preserved in the formulations, and methods should be developed to enhance their bioavailability as functional cosmetics. Figure 12.3 presents a strengths–weaknesses–opportunities–threats (SWOT) diagram which shows that management of seaweed resources and the stability of actives are the main threats and weaknesses while the increased demand of consumer for natural product combined with the safety of seaweed extracts and the proved biological activities represent strengths and opportunities.

Figure 12.3 Strengths–weaknesses–opportunities–threats diagram related to the development of cosmetics containing seaweed actives.

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