

---

# Seaweeds for Food and Industrial Applications

---

Berna Kılınç, Semra Cirik, Gamze Turan,  
Hatice Tekogul and Edis Koru

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/53172>

---

## 1. Introduction

Marine macroalgae, or the term seaweeds, are plant-like organisms that generally live attached to rock or other hard substrata in coastal areas. The classification into divisions is based on various properties such as pigmentation, chemical nature of photosynthetic storage product, the organization of photosynthetic membranes, and other morphological features. Traditionally, they belong to four different groups, empirically distinguished since the mid-nineteenth century on the basis of color: **blue-green algae** (phylum: Cyanophyta, up to 1500 species), **red algae** (phylum: Rhodophyta, about 6000 species), **brown algae** (phylum: Ochrophyta, classes: Phaeophyceae, about 1750 species), and **green algae** (phylum: Chlorophyta, classes: Bryopsidophyceae, Chlorophyceae, Dasycladophyceae, Prasinophyceae, and Ulvophyceae, about 1200 species). However, each of these groups has microscopics, if not unicellular, representatives. All seaweeds at some stage in their life cycles are unicellular, as spores or zygotes, and may be temporarily planktonic. The blue-green algae are widespread on temperate rocky and sandy shores and have occasionally been acknowledged in seaweed floras. Seaweeds are found growing throughout the world oceans and seas none is found to be poisonous (Bold and Wyne, 1985; Guiry, 2009; Lobban and Harrison, 2000). Why seaweed is important? Most people don't realize how important marine macroalgae are, both ecologically and commercially. In fact, seaweeds are crucial primary producer in oceanic aquatic food webs. They are rich both in minerals and essential trace elements, and raw materials for the pharmaceutical and cosmetics industry (Chapman, 1970). Seaweed is a very versatile product widely used for food in direct human consumption. Its classified taxonomically as algae and they represent a food group that is not normally ingested in unprocessed form to any great extent in Western societies. Humankind is no strangers to the use of algae as a food source. Even if seaweeds have been used as a human food since ancient times, particularly in the region bounded by China, the

Korean Peninsula and Japan. But the commercial exploitation of this resource is only a few decades old, after World War II, when the focus was set on a possible insufficient protein supply due to the rapid increase of the world population. Today those countries are the largest consumers of marine algae as food. However, as nationals from these countries have migrated to other parts of the Earth, the demand for seaweed for food has followed them, for example, in some parts of the North and South America. Nowadays, seaweeds are major coastal resources which are valuable to human consumption and environment in many countries. Edible seaweeds were widely consumed, especially in Asian countries (e.g., Japan, China, Korea, Taiwan, Singapore, Thailand, Brunei, Cambodia, and Vietnam, but also in South Africa, Indonesia, Malaysia, Belize, Peru, Chile, the Canadian Maritimes, Scandinavia, South West England, Ireland, Wales, California, Philippines, and Scotland) as fresh, dried, or ingredients in prepared foods. Their photosynthetic mechanism is similar to that of land-based plants. They are generally more efficient in converting solar energy into biomass, mainly because of their simple cellular structure and being submerged in an aqueous environment with access to water, CO<sub>2</sub>, and other nutrients. Same time, macroalgae are considered as the food supplement for 21<sup>st</sup> century, because they contain proteins, lipids, polysaccharides, minerals, vitamins, and enzymes. In common, seaweeds are rich in vitamins A, E, C, and Niacin with similar content in red algae (Rhodophyta), brown algae (Ochrophyta) and green algae (Chlorophyta). The concentration of vitamins B<sub>12</sub>, B<sub>1</sub>, panthothetic acid, folic, and folinic acids are generally higher in greens and reds than in browns. The brown algae possess organic iodine in greater amounts. Marine algae are similar to oats in protein and carbohydrate values. The green and red algae appear higher in crude protein far tested about 2 to 4 %. All algae contain high content of carbohydrates (sugar and starches) in polysaccharide biochemical structure which is a natural nontoxic colloidal substance that has been used as mucilaginous material referred to as gel. The nutrients composition of seaweed vary and is affected by species, geographic area, season and temperature of water. These sea-vegetables are of nutritional interest as they are low calorie food, but rich in vitamins, minerals and dietary fibres. Seaweeds, which have traditionally been used by the Western food industry for their polysaccharide extractives 'alginate, carrageenan and agar' also contain compounds with potential nutritional benefits. Seaweeds have recently been approved in France for human consumption (as vegetables and condiments), thus opening new opportunities for the food industry. These seaweed ingredients must meet industrial and technical specifications and consumer safety regulations. It is also an ingredient for the global food and cosmetics industries and is used as fertilizer and as an animal feed additive. Total annual value of production is estimated at almost US\$ 6 billion of which food products for human consumption represent US \$ 5 billion. Total annual use by the global seaweed industry is about 8 million tonnes of wet seaweed. Seaweed can be collected from the wild but is now increasingly cultivated. It falls into three broad groups based on pigmentation; brown, red and green seaweed. Use of seaweed as food has strong roots in Asian countries such as China, Japan and the Republic of Korea, but demand for seaweed as food has now also spread to North America, South America and Europe. China is by far the largest seaweed producer followed by the Republic of Korea and Japan but seaweeds are today produced in all continents. Red and brown

seaweeds are also used to produce hydrocolloids; alginate, agar and carrageenan, which are used as thickening and gelling agents. Today, approximately 1 million tonnes of wet seaweed are harvested and extracted to produce about 55 000 tonnes of hydrocolloids, valued at almost US \$ 600 million (McHug, 2003).

## 2. Historical background on the use of seaweeds

The use of seaweed as food has been traced back to the fourth century in Japan and the sixth century in China. In 1750's, an English physician successfully used ash from kelp (Phaeophyceae) which is rich in iodine to treat goiter. Kelp was also used to treat obesity in 19 th. century, and agar was used as a laxative. Seaweeds were used as a source of iodine. And their crude extracts were used for clarification in brewing. Another hydrocolloid, carrageen, found initially in the red seaweed *Chondrus crispus* was known in Ireland since 1810. Alginic acid, a hydrocolloid found in all brown seaweeds, was discovered first by Charles Stanford in the 1880s. Development of a large scale alginate industry began in California and in Scotland in the late 1920s and early 1930s, respectively. *Laminaria japonica* was cultivated in China from the 1950s. The hydrocolloids have found increasing industrial and food applications in those years. Today China, Japan and the Republic of Korea are the largest consumers of seaweed as food. However, as nationals from these countries have migrated to other parts of the world, the demand for seaweed for food has followed them, as, for example, in some parts of the United States of America and South America. Increasing demand over the last fifty years outstripped the ability to supply requirements from natural (wild) stocks. Research into the life cycles of these seaweeds has led to the development of cultivation industries that now produce more than 90 percent of the market's demand. In Ireland, Iceland and Nova Scotia (Canada), a different type of seaweed has traditionally been eaten, and this market is being developed. Some government and commercial organizations in France have been promoting seaweeds for restaurant and domestic use, with some success. An informal market exists among coastal dwellers in some developing countries where there has been a tradition of using fresh seaweeds as vegetables and in salads. Various red and brown seaweeds are used to produce three hydrocolloids: agar, alginate and carrageenan. A hydrocolloid is a non-crystalline substance with very large molecules and which dissolves in water to give a thickened (viscous) solution. Alginate, agar and carrageenan are water-soluble carbohydrates that are used to thicken (increase the viscosity of) aqueous solutions, to form gels (jellies) of varying degrees of firmness, to form water-soluble films, and to stabilize some products, such as ice cream (they inhibit the formation of large ice crystals so that the ice cream can retain a smooth texture). Seaweeds as a source of these hydrocolloids dates back to 1658, when the gelling properties of agar, extracted with hot water from a red seaweed, were first discovered in Japan. Extracts of Irish Moss, another red seaweed, contain carrageenan and were popular as thickening agents in the nineteenth century. It was not until the 1930s that extracts of brown seaweeds, containing alginate, were produced commercially and sold as thickening and gelling agents. Industrial uses of seaweed extracts expanded rapidly after the Second World

War, but were sometimes limited by the availability of raw materials. In the 1950's, it was found that *Gracilaria* spp. treated with alkali produced higher strength gels. After several years, *Gracilaria* can be cultivated successfully on a commercial scale, it is now used more widely. Once again, research into life cycles has led to the development of cultivation industries that now supply a high proportion of the raw material for some hydrocolloids. Today, approximately 1 million tonnes of wet seaweed are harvested and extracted to produce the above three hydrocolloids. Total hydrocolloid production is about 55 000 tonnes, with a value of US \$ 585 million. Alginate production (US \$ 213 million) is by extraction from brown seaweeds, all of which are harvested from the wild; cultivation of brown seaweeds is too expensive to provide raw material for industrial uses. Agar production (US \$ 132 million) is principally from two types of red seaweed, one of which has been cultivated since the 1960-70s, but on a much larger scale since 1990, and this has allowed the expansion of the agar industry. Carrageenan production (US \$ 240 million) was originally dependent on wild seaweeds, especially Irish Moss, a small seaweed growing in cold waters, with a limited resource base. However, since the early 1970s the industry has expanded rapidly because of the availability of other carrageenan-containing seaweeds that have been successfully cultivated in warm-water countries with low labour costs. Today, most of the seaweed used for carrageenan production comes from cultivation, although there is still some demand for Irish Moss and some other wild species from South America. Seaweed meal, used as an additive to animal feed, has been produced in Norway, where its production was pioneered in the 1960s. It is made from brown seaweeds that are collected, dried and milled. Drying is usually by oil-fired furnaces, so costs are affected by crude oil prices. Approximately 50 000 tonnes of wet seaweed are harvested annually to yield 10 000 tonnes of seaweed meal, which is sold for US \$ 5 million. Fertilizer uses of seaweed date back at least to the nineteenth century. Early usage was by coastal dwellers, who collected storm-cast seaweed, usually large brown seaweeds, and dug it into local soils. The growth area in seaweed fertilizers is in the production of liquid seaweed extracts. These can be produced in concentrated form for dilution by the user. Several can be applied directly onto plants or they can be watered in, around the root areas. There have been several scientific studies that prove these products can be effective. In 1991, it was estimated that about 10 000 tonnes of wet seaweed were used to make 1 000 tonnes of seaweed extracts with a value of US \$ 5 million. However, the market has probably doubled in the last decade because of the wider recognition of the usefulness of the products and the increasing popularity of organic farming, where they are especially effective in the growing of vegetables and some fruits. Cosmetic products, such as creams and lotions, sometimes show on their labels that the contents include "marine extract", "extract of alga", "seaweed extract" or similar. Usually this means that one of the hydrocolloids extracted from seaweed has been added. Alginate or carrageenan could improve the skin moisture retention properties of the product. Pastes of seaweed, made by cold grinding or freeze crushing, are used in thalassotherapy, where they are applied to the person's body and then warmed under infrared radiation. This treatment, in conjunction with seawater hydrotherapy, is said to provide relief for rheumatism and osteoporosis (De Roeck-Holtzauer, 1991).

### 3. Sources of seaweed

A seaweed may belong to one of several groups of multicellular algae: the red algae, brown algae and green algae,. As these three groups are not thought to have a common multicellular ancestor, the seaweeds are a polyphyletic group. In addition, some tuft-forming blue green algae (Cyanobacteria) are sometimes considered as seaweeds — "seaweed" is a colloquial term and lacks a formal definition. Two specific environmental requirements dominate seaweed ecology. These are the presence of seawater (or at least brackish water) and the presence of light sufficient to drive photosynthesis. Another common requirement is a firm attachment point. As a result, seaweeds most commonly inhabit the littoral zone and within that zone more frequently on rocky shores than on sand or shingle. Seaweeds occupy a wide range of ecological niches. The highest elevation is only wetted by the tops of sea spray, the lowest is several meters deep. In some areas, littoral seaweeds can extend several miles out to sea. The limiting factor in such cases is sunlight availability. The deepest living seaweeds are some species of red algae. A number of species such as *Sargassum* have adapted to a fully planktonic niche and are free-floating, depending on gas-filled sacs to maintain an acceptable depth. Others have adapted to live in tidal rock pools. In this habitat seaweeds must withstand rapidly changing temperature and salinity and even occasional drying

#### 3.1. Red seaweeds

Red seaweeds have had a more diverse evolution than the green and the brown. Many species cannot stand desiccation and dominate the inter-tidal rock pools. Others tolerate desiccation, such as the purple laver which can often be seen stretched out like a dry black film over mussle beds on rocky beaches. Red seaweeds such as *Polysiphonia lanosa* are epiphytes, these are plants that grow on other plants for physical support. In this case the epiphyte benefits from the host's buoyancy lifting it closer to the sunlight. The red colour of the seaweeds is due to the larger amount of red phycoblin pigments overriding the green pigment chlorophyll. The main biomass of red algae worldwide is provided by the Corallinaceae and Gigartinaceae. The red algae *Gelidium*, *Gracilaria*, *Pterocladis* and other many red algae are used in the manufacture of the important agar, used widely as a growth medium for microorganism and other biotechnological and food applications. Another important red seaweed alga is *Eucheuma* used in the production of Carrageenan, an important product used in cosmetics, food processing and industrial uses, as well as a food source. Some of the most significant caargeenan species include *Betaphycus gelatinae*, *Eucheuma denticulatum*, and several species of the genus *Kappaphycus* including *K. alvarezii* (Lobban and Harrison, 1994).

#### 3.2. Brown seaweeds

*Laminaria* sp. 'kombu', *Undaria* sp. 'wakame', *Hizikia fusiforme* 'hiziki' is edible and an important resource Asia countries especiaqlly China and Japan. They are consumed raw, boiled or dried material with sweetened green beans, jelly, crushed ice, and coconut milk in Southern Vietnam (Tsutsui et. al., 2005). *Laminaria* sp. was in plentiful supply in Japan, mainly from the northern island of Hokkaido, where several naturally growing species were available.

*Undaria* sp. has been harvested from natural resources for many years in the China, Japan and Korean region. Another algae *Cladosiphon okamuranus* 'mozuku' as salad in Okinawa-Japan (Thoma, 1997; Zhang et al., 2007; Zhu et al., 2009). *Sargassum* sp. is known as horsetail and it is eaten as soup or dressed with soybean sauce, or after being processed in Korea (Madlener, 1997) and in Hawaii (Novaczek, 2001). In the Pacific region, *Rosenvingea* sp. or slippery cushion, *Turbinaria* or spiny leaf are eaten as soup or omelet *Colpomenia* sp. or paperly sea bubble as chop soup, stew or salad. *Hydroclatharus* sp. or sea colander, *Dictyota* sp. or brown, *Padina* or sea fan ribbon weeds as a food dressing, soup or stew (Novaczek, 2001).

### 3.3. Green seaweeds

Green seaweeds are found on both sandy and rocky beaches. Many can tolerate low salinity and will colonise areas where rivers meet the sea. The green colour of the seaweed is due to the green pigment chlorophyll required for the photosynthesis of light. Using only chlorophyll means that green seaweeds require good levels of light and therefore will not thrive in shadowed areas or too any depth. It does give them an advantage, the ability to live higher up shore without competition from the red or brown seaweeds. The green seaweeds *Ulva* sp., *Enteromorpha* sp., *Monostroma* sp., *Caulerpa* sp., *Codium* sp., are commonly known as source of food. In Asia countries especially Japan, dried fronds of edible *Monostroma* sp. and *Enteromorpha* sp are being known as 'aonori-green laver-ele ele-lulua-lumi boso'. These algae are eaten by humans as edible raw, dried, or cooked. They used in preparation of 'nori-jam' soup (Lobban and Harrison, 1994; Novaczek, 2001).

## 4. Nutritional composition of edible seaweeds

Proximate composition (moisture, ash, protein and oil content), total dietary fibre content and physicochemical properties of three brown and two red edible Spanish seaweeds, namely: *Himanthalia elongata* (sea spaghetti), *Bifurcaria bifurcata*, *Laminaria saccharina* (sweet kombu), *Mastocarpus stellatus* and *Gigartina pistillata* were studied. Ashes (24.9–36.4%) were high in all samples. Protein content ranged from 10.9 to 25.7%, being much higher for *Laminaria* (25.7%) followed by the red seaweeds (15.5–21.3%). Minor components were lipids (0.3–0.9%) in all samples except for *Bifurcaria* (5.6%). In conclusion, these seaweeds can be estimated as a good source of food fibre, protein and minerals for human consumption (Gómez-Ordóñez et al., 2010). Mineral content was determined in several brown (*Fucus vesiculosus*, *Laminaria digitata*, *Undaria pinnatifida*) and red (*Chondrus crispus*, *Porphyra tenera*) edible marine sea vegetables. Seaweeds contained high proportions of ash (21.1–39.3%) and sulphate (1.3–5.9%). In brown algae, ash content (30.1–39.3%) was higher than in red algae (20.6–21.1%). Edible brown and red seaweeds could be used as a food supplement to help meet the recommended daily intake of some essential minerals and trace elements (Rupérez, 2002). Sea spaghetti (*Himanthalia elongata*), Wakame (*Undaria pinnatifida*), and Nori (*Porphyra umbilicalis*), on fatty acid composition, amino acid profile, protein score, mineral content and antioxidant capacity in low-salt meat emulsion model systems. The addition of seaweeds caused an increase in  $\omega$ -3 polyunsaturated fatty acids (PUFA) and a decrease in the  $\omega$ -6/ $\omega$ -3 PUFA ratio. In general, addition



of seaweeds to products increased the concentrations of K, Ca, Mg and Mn. The presence of Nori caused an increase in levels of serine, glycine, alanine, valine, tyrosine, phenylalanine and arginine, whereas Wakame and Sea Spaghetti produced no significant changes in amino acid profiles in the model systems. López-López *et al.*, 2009). The nutritional compositions of 34 edible seaweed products of the *Laminaria* sp., *Undaria pinnatifida*, *Hizikia fusiforme* and *Porphyra* sp. varieties were analyzed. The marine macroalgae varieties tested demonstrated low lipid contents with  $2.3 \pm 1.6$  g/100 g semi-dry sample weight(s.w.) and proved to be a rich source of dietary fibre ( $46.2 \pm 8.0$  g/100 g s.w.). The pure protein content of seaweed products varied widely ( $26.6 \pm 6.3$  g/100 g s.w. in red algae varieties and  $12.9 \pm 6.2$  g/100 g s.w. in brown algae varieties). All essential amino acids were detected in the seaweed species tested and red algae species featured uniquely high concentrations of taurine when compared to brown algae varieties (Dawczynski *et al.*, 2007). The total lipid, protein, ash and individual fatty acid contents of edible seaweeds that had been canned (*Saccorhiza polyschides* and *Himanthalia elongata*) or dried (*H. elongata*, *Laminaria ochroleuca*, *Undaria pinnatifida*, *Palmaria* sp. and *Porphyra* sp.) Total lipid content ranged from  $0.70 \pm 0.09$  to  $1.80 \pm 0.14$  g/(100 g dry weight). The four most abundant fatty acids were C16:0, C18:1 $\omega$ 9, C20:4 $\omega$ 6 and C20:5 $\omega$ 3. Unsaturated fatty acids predominated in all the Brown seaweeds studied, and saturated fatty acids in the red seaweeds, but both groups are balanced sources of  $\omega$ 3 and  $\omega$ 6 acids. Ash content ranged from  $19.07 \pm 0.61$  to  $34.00 \pm 0.11$  g/(100 g dry weight), and protein content from  $5.46 \pm 0.16$  to  $24.11 \pm 1.03$  g/(100 g dry weight) (Sanchez-Machado, *et al.*, 2004).

## 5. Edible seaweed in foods

Red macro-algae (*Gracilaria* spp.) are used as a fresh food in Hawaii. Species commonly marketed include *G. coronopifolia*, *G. parvispora*, *G. salicornia* and *G. tikvahiae*, however, these seaweeds have a short postharvest life of about 4 days (Paul and Chen, 2008). Seaweeds are a rich source of phytochemicals having anti-oxidant and antimicrobial properties. Presence of fibres and minerals helps in improving the mineral content reduce the salt content. The adding of seaweeds or their extracts to food products will help in reducing the utilization of chemical preservatives (Gupta and Abu-Ghannam, 2011). Edible seaweeds contain various bioactive compounds with potential health benefits and their use as functional ingredients opens up new prospects for food processing, meat product formulations included. Seaweeds basically contain high proportions of polysaccharides along with various other potentially beneficial compounds such as good-quality protein and essential fatty acids, particularly long-chain n-3 polyunsaturated fatty acids (PUFAs). Alginates are the most abundant ionic polysaccharides present in brown seaweeds (Fernández-Martín *et al.*, 2009). Some seaweed polysaccharides are used by food industry as texture modifiers because of their high viscosity and gelling properties. In Asia seaweeds have been used for centuries in salads, soups and as low calorie dietetic foods. The dietary fibre which constitutes 25-75 % of the dry weight of marine algae and represents their major component, is primarily soluble fibre. (Jiménez-Escrig and Sánchez-Muniz, 2000). In particular, miyeok (*Undaria pinnatifida*) is often served in soup, salad, and sidedishes.

Gamma irradiation at 10 kGy is sufficient to sterilize freeze-dried miyeokguk without significant deterioration in the sensory quality, and thus, the freeze-dried and irradiated miyeokguk at 10 kGy fulfills the microbiological requirements as space food (Song *et al.*, 2012). The sausages were produced with two types of carrageenan (i- and j-) in four levels (0%, 1%, 2% and 3%). Carrageenan had a better effect on such characteristics as pH, weight loss and lipid oxidation of the sausages, as well as, on sensory attributes. The carrageenan level of 3% negatively affected the firmness of the sausages. Carrageenan added at levels up to 2% had a positive effect on the physicochemical and microbiological characteristics of the lowfat fermented sausages. (Koutsopoulos *et al.*, 2008). Cultivated *Ulva rigida* was utilized by using marination technology. Fresh and boiled (at 100°C for 2 min.) *Ulva rigida* were marinated with two different formulations by using 2 % lemon salt and 2 % vinegar. The marination of *Ulva rigida* were made at room temperature for 20 days. Marinated fresh and boiled *ulva rigida* by using lemon salt and vinegar can be an alternative for human foods (Kılınç *et al.*, 2011). Breads were made by using *Lemna minor* (Tekogul *et al.*, 2011) and *Ulva rigida* (Turan *et al.*, 2011). The shelf-life of breads by using *Ulva rigida* were determined as unacceptable on day 5 at room temperature whereas on day 10 at 4°C. When compared with control groups, the shelf-life of breads containing *Ulva rigida* were determined longer shelf-life. Breads prepared with *Ulva rigida* extended the shelf-life of breads for 2 days in two different storage period. *Lemna minor* extended the shelf-life of breads. The shelf-life of breads with *Lemna minor* were extended the acceptable limit on day 8 at room temperature whereas on day 12 at 4 °C. But control group extended this acceptable limit on day 3 at room temperature, on day 8 at 4 °C (Tekogul *et al.*, 2011).

### 5.1. Fermented seaweed

Brown edible seaweeds as a sole source of nutrition for the growth of lactic acid bacteria. Growth kinetics of lactic acid bacteria (LAB; *Lactobacillus plantarum*) was studied using three species of edible Irish brown seaweeds *Himanthalia elongata*, *Laminaria digitata* and *Laminaria saccharina*. The results of this study present an indication of the potential of fermentation of seaweeds using LAB with a possibility towards the development of a range of functional foods (Gupta *et al.*, 2011). Low molecular weight polysaccharides from seaweed as prebiotics. *Gelidium* seaweed showed significant increase in bifidobacterial populations. Agar and alginate bearing seaweeds indicate prebiotic potential (Ramnani *et al.*, 2012). Brown macroalgae contain high concentration of mannitol and laminarian. *Clostridium acetobutylicum* ferments these seaweed extract substrates to butanol. Seaweed fermentation exhibited triaunic growth: glucose-mannitol- laminarin. Butanol yields in seaweed and pure glucose fermentations were comparable (Huesemann *et al.*, 2012).

### 5.2. Seaweeds used as fertilizer and biogas production

Seaweed are used as a fertilizer which is suitable for use in organic agriculture (López-Mosquera *et al.*, 2011). Energy-rich methane can be harnessed from seaweed deposits by anaerobic digestion. However, the high heavy metal content in the seaweed and its digestates limits their use as fertilisers. The efficient utilisation of seaweed for biogas



production, and the partial heavy metals mobilisation to enable the metal removal for improved fertiliser quality (Nkemka and Murto, 2012). The red alga *Chondracanthus squarulosus* was cultured under semi-controlled conditions to evaluate growth (biomass production) with agricultural fertilizers (ammonium nitrate, ammonium sulphate and urea) vs. analytical grade inorganic salts; sodium nitrate (analytical grade) and seawater were used as controls (Pacheco-Ruiz *et al.*, 2004).

## 6. Conclusion and outlook

Seaweeds are being studied on the use of many industrial applications such as food, cosmetics, chemistry, paint, medicine, etc., at nowadays. In Western countries has traditionally concentrated on the extraction of compounds used by pharmaceutical, cosmetics, and food industries (Wijesinghe and Jeon, 2012a). Biologically active compounds of seaweeds (phlorotannins, carotenoids, alginic acid, fucoidan, peptides) have been demonstrated to play a significant role in prevention of certain degenerative diseases such as cancer, inflammation, arthritis, diabetes and hypertension. Therefore, seaweed derived active components, whose immense biochemical diversity looks like to become a rich source of novel chemical entities for the use as functional ingredients in many industrial applications such as functional foods, pharmaceuticals and cosmeceuticals (Wijesinghe and Jeon, 2012b). Commercially available varieties of marine macroalgae are commonly used to as 'seaweeds' Conventional, macroalgae can be classified as brown algae (Phaeophyta), red algae (Rhodophyta), and green algae (Chlorophyta), depending on their nutrient and chemical composition. Red and brown algae are mainly used as human food sources. The protein content of seaweed species varies greatly and demonstrates a dependence on such factors as season and environmental growth conditions. For example, the protein content of brown algae species, e.g., *Laminaria japonica*, *Hizikia fusiforme* or *Undaria pinnatifida*, is relatively low with 7–16 g/100 g dry weight (d.w.) (Jurković *et al.*, 1995; Kolb *et al.*, 1999; Rupérez and Saura-Calixto, 2001). On the other hand, red algae, e.g., *Palmaria palmata* (Dulse) and *Porphyra tenera* contain 21–47 g protein/100 g d.w. (Fleurence, 1999; Rupérez and Saura-Calixto, 2001). The protein in algae contains all essential amino acids (EAA) and all EAA are available throughout the year although seasonal variations in their concentrations are known to occur (Galland-Irmouli *et al.*, 1999). For example, the proportion of EAA is 45–49% in *Hizikia* sp. and *Eisenia bicyclis* (Arame). In both these brown algae varieties, Ecological factory is the first limiting EAA, followed by Lys (Kolb *et al.*, 1999). The EAA contents of some species (e.g., *Porphyra* sp.) can be compared with those of soy and egg protein (Fleurence, 1999; Galland-Irmouli *et al.*, 1999). In addition to, high concentrations of Arg, Asp and Glu peptides are found in many macroalgae species (Fleurence, 1999). The fat content of marine macroalgae accounts for 1–6 g/100 g d.w. (Fleurence *et al.*, 1994; Jurković *et al.*, 1995; Herbreteau *et al.*, 1997). In some brown algae varieties, such as *Hizikia* sp. and *Eisenia bicyclis* (Arame), only 0.7–0.9 g/100 g d.w. of fat content were found (Kolb *et al.*, 1999). Brown seaweeds are rich in fucose rich sulfated polysaccharides fucoidans (Wijesinghe and Jeon, 2012a). Polysaccharides produced by marine seaweeds form the basis of an economically important and expanding global industry. Key products are agars, agaroses, algin, and carrageenans.

These are used on ingredients in food, pharmaceuticals and diverse consumer products and industrial processes (Renn, 1997). Red algae (e.g., *Porphyra* sp.) have high concentrations of eicosapentaenoic acid (C20:5,  $\omega$ -3, EPA), with 48.0–51.0% of total fatty acid methyl esters (FAME), and marginal concentrations of arachidonic acid (C20:4,  $\omega$ -6, ARA), with 2.1–10.9% of total FAME and, linoleic acid (C18:2,  $\omega$ -6, LA), with 1.3–2.5% of total FAME (Fleurence *et al.*, 1994; Takagi *et al.*, 1985). In contrast, brown algae (e.g., *Laminaria* sp., *Undaria* sp., *Hizikia* sp.) have high concentrations of oleic acid (C18:1,  $\omega$ -9, OA) with 4.1–20.9% of total FAME, LA with 4.0–7.3% of total FAME as well as  $\alpha$ -linolenic acid (C18:3,  $\omega$ -3, ALA) with 3.6–13.8% of total FAME but low concentrations of EPA with 5.9–13.6% of total FAME (Fleurence *et al.*, 1994; Takagi *et al.*, 1985). Interestingly, in *Porphyra* sp., *Laminaria* sp., and *Undaria* sp., the concentrations of docosahexaenoic acid (C22:6,  $\omega$ -3, DHA) and docosapentaenoic acid (C22:5,  $\omega$ -3, DPA) were below the detection limit (less than 0.1% of total FAME (Fleurence *et al.*, 1994; Takagi *et al.*, 1985). The types and abundance of carbohydrates vary strongly between algae species. Typical carbohydrates in red algae varieties consist of floridean starch ( $\alpha$ -1.4-binding glucan), cellulose, xylan, and mannan. The water-soluble fibre fraction is formed by sulfur-containing galactans, e.g., agar and carrageen (Jiménez-Escrig and Sánchez-Muniz, 2000; Van den Hoek *et al.*, 1993). The typical carbohydrates in brown algae varieties consist of fucoidan, laminaran ( $\beta$ -1.3-glucan), cellulose, alginates, and mannitol. Brown algae fibres are mainly cellulose and insoluble alginates. Alginates are Ca, Mg, or Na salts of alginic acid (1.4-linked polymer of  $\beta$ -*D*-mannuronic acid and  $\alpha$ -*L*-guluronic acid). The amorphous, slimy fraction of brown algae fibres consists mainly of water-soluble alginates and/or fucoidan. Main reserve polysaccharides of Phaeophyta are laminaran ( $\beta$ -1.3-glucan) and mannitol (Kolb *et al.*, 1999; Dawczynski *et al.*, 2007). The typical algae carbohydrates are not digestible by the human gastrointestinal tract and, therefore, they are dietary fibres. The content of total dietary fibre ranges from 33–50 g/100 g d.w. (Jiménez-Escrig and Cambrodon, 1999, Lahaye, 1991). Accordingly, the fibre content of seaweed varieties is higher than those found in most fruits and vegetables. The human consumption of algal fibre has been proven to be health-promoting and its benefits are well documented in the scientific literature. The consumption of this dietary fibre has been related to the following health promoting effects: **1)** its consumption promotes the growth and protection of the beneficial intestinal flora (Fujii *et al.*, 1992, Goni *et al.*, 2001), **2)** its consumption, in combination with high glycemic load foods, reduces the overall glycemic response, macroalgae fibre acts as a hypoglycaemic (Goni, Valdivieso, & Garcia-Alonso, 2000), **3)** its consumption greatly increases stool volume (Jiménez-Escrig & Sánchez-Muniz, 2000) and **4)** its consumption reduces the risk of colon cancer (Guidel-Urbano & Goni, 2002). In addition, seaweeds varieties are rich sources of vitamin C, vitamin B-complex, e.g., folic acid and B<sub>12</sub>, and vitamin A precursors, such as  $\beta$ -carotene (McDermid and Stuercke, 2003, Takenaka *et al.*, 2001; Watanabe *et al.*, 2002). Because the seaweed species are rich in beneficial nutrients, in countries such as China, Japan, and Korea, they have been commonly utilised in human alimentation (since ancient times) (Lahaye, 1991). For example, Japanese people consume more than 1.6 kg algae (d.w.) per year *per capita* (Fleurence, 1999). In addition to their importance as traditional the Asian foods, macroalgae species are utilised industrially as a source of hydrocolloids, such as agar, carrageen, and alginate (Jiménez-Escrig & Sánchez-Muniz, 2000). Over the past few decades, the consumption of seaweed products has increased

in European countries. Currently, approximately 15–20 edible algae strains are being commonly marketed for consumption in Europe. These seaweed varieties differ greatly in their quality, colour, consistency, and nutrient content. Nowadays, for this reason the studies of algology evaluate and compares the nutrient and chemical contents of many commercially available seaweed products which were locally purchased in European food stores and speciality shops (Herbreteau *et al.*, 1997; Dawczynski *et al.*, 2007).

## Author details

Berna Kılınc<sup>1</sup>, Semra Cirik<sup>2</sup>, Gamze Turan<sup>2</sup>, Hatice Tekogul<sup>2</sup> and Edis Koru<sup>2</sup>

1 Ege University Fisheries Faculty, Dept. Of Fisheries and Seafood Processing Technology, Bornova, Izmir, Turkey

2 Ege University Fisheries Faculty, Dept. of Aquaculture Algae Culture Laboratory, Bornova, Izmir, Turkey

## References

- [1] Bold, H. C. & Wyne, M. J. (1985). *Introduction to the algae: Structure and Reproduction*, Second Edition, New Jersey, Prentice-Hall, Inc., USA, , 720.
- [2] Chapman, V. J. (1970). *Seaweeds and Their Uses*, Chapman & Hall. London, , 334.
- [3] Dawczynski, C, Schubert, R, & Jahreis, G. (2007). Amino acids, fatty acids, and dietary fibre in edible seaweed products, *J. of Food Chemistry*, , 103
- [4] De Roeck-holtzhauer, J. (1991). Uses of Seaweeds in Cosmetics. *In: Seaweed Resources in Europe: Uses and Potential*. M. G. Guiry andn G. Blunden (editors). John Wiley and Sons, Ltd. England, , 83-93.
- [5] Fujii, T, Kuda, T, Saheki, K, & Okuzumi, M. (1992). Fermentation of water-soluble polysaccharides of brown algae by human intestinal bacteria *in vitro*, *Nippon Suisan Gakk*, , 58, 149-152.
- [6] Fleurence, J, Gutbier, G, Mabeau, S, & Leray, C. (1994). Fatty acids from 11 marine macroalgae of the French Brittany coast, *Journal of Applied Phycology*, , 6, 527-532.
- [7] Fleurence, J. (1999). Seaweed proteins: Biochemical, nutritional aspects and potential uses, *Trends in Food Science and Technology*, , 10, 25-28.
- [8] Fernández-martín, F, López-lópez, I, & Cofrades, S. Jiménez Colmenero F. ((2009). Influence of adding Sea Spaghetti seaweed and replacing the animal fat with olive oil or a konjac gel on pork meat batter gelation. Potential protein/alginate association. *Meat Science*, , 83, 209-217.

- [9] Galland-irmouli, A. V, Fleurence, J, Lamghari, R, Luçon, M, Rouxel, C, & Barbaroux, O. (1999). Nutritional value of proteins from edible seaweed *Palmaria palmata* (Dulse), *Journal of Nutritional Biochemistry*, , 10, 353-359.
- [10] Guiry, M. (2009). *Seaweed site, seaweed web site*, National University of Ireland, Galway, URL.: <http://www.seaweed.ie/algae/seaweeds.html>.
- [11] Goni, I, Valdivieso, L, & Garcia-alonso, A. (2000). Nori seaweed consumption modifies glycemic response in healthy volunteers, *Nutrition Research*, , 20, 1367-1375.
- [12] Goni, I, Guidel-urbano, M, Bravo, L, & Saura-calixto, F. (2001). Dietary modulation of bacterial fermentative capacity by edible seaweeds in rats, *Journal of Agriculture and Food Chemistry*, , 49, 2663-2668.
- [13] Gómez-ordóñez, E, Jiménez-escrig, A, & Rupérez, P. (2010). Dietary fibre and physicochemical properties of several edible seaweeds from the northwestern Spanish coast. *Food Research International*, , 43, 2289-2294.
- [14] Gupta, S, & Abu-ghannam, N. (2011). Recent developments in the application of seaweeds or seaweed extracts as a means for enhancing the safety and quality attributes of foods. *Innovative Food Science and Emerging Technologies*, , 12, 600-609.
- [15] Gupta, S, Abu-ghannam, N, Scannell, A, & Growth, G. M. and kinetics of *Lactobacillus plantarum* in the fermentation of edible Irish brown seaweeds. *Food and Bioproducts Processing*, , 89, 346-355.
- [16] Herbreteau, F, Coiffard, L. J. M, Derrien, A, & De Roeck-holtzhauer, Y. (1997). The fatty acid composition of five species of macroalgae, *Botanica Marina*, , 40, 25-27.
- [17] Huesemann, M. H, Kuo, G, Urquhart, A, Gill, G. A, & Roesijadi, G. (2012). Acetone-butanol fermentation of marine macroalgae. *Bioresource Technology*, , 108, 305-309.
- [18] Jurkovic, N, Kolb, N, & Colic, I. (1995). Nutritive value of marine algae *Laminaria japonica* and *Undaria pinnatifida*, *Die Nahrung*, , 39, 63-66.
- [19] Jiménez-escrig, A, & Sánchez-muniz, F. J. (2000). Dietary fibre from edible Seaweeds:Chemical structure, physicochemical properties and effects on cholesterol metabolism, *Nutrition Research*, , 20, 585-598.
- [20] Kolb, N, Vallorani, L, & Stocchi, V. (1999). Chemical composition and evaluation of protein quality by amino acid score method of edible brown marine algae Arame (*Eisenia bicyclis*) and Hijiki (*Hijikia fusiforme*), *Acta Alimentaria*, , 28, 213-222.
- [21] Koutsopoulos, D. A, Koutsimanis, G. E, & Bloukas, J. G. (2008). Effect of carrageenan level and packaging during ripening on processing and quality characteristics of low-fat fermented sausages produced with olive oil. *Meat Science*, , 79, 188-197.
- [22] Kiliñç, B, Turan, G, & Tekogul, H. (2011). Kültürü Yapılan Deniz Yosunu (*Ulva Rigida*) ile Farklı Formülasyonlarda Marinat Üretimi ve Duyusal Değerlendirmesi", *16. Ulusal Su Ürünleri Sempozyumu*, 25-27 Ekim, sf. 272-273, Antalya. Lahaye, M. (1991). Marine

algae as sources of fibers: Determination of soluble and insoluble dietary fiber contents in some sea vegetables, *Journal of Science and Food Agriculture*, , 54, 587-594.

- [23] Lobban, S. C, & Harrison, J. P. (1994). *Seaweed Ecology and Physiology*, Cambridge University Press, 386 p.
- [24] López-lópez, I, Bastida, S, Ruiz-capillas, C, Bravo, L, Larrea, M, Sánchez-muniz, F, Cofrades, S, & Jiménez-colmenero, F. (2009). Composition and antioxidant capacity of low-salt meat emulsion model systems containing edible seaweeds. *Meat Science*, , 83, 492-498.
- [25] Lobban, S. C. (2000). *Seaweed Ecology and Physiology*, Cambridge University Press, The Edinburgh Building, Cambridge CB2 2RU, UK, ISBN-0521403340., 359.
- [26] López-mosquera, M. E, Fernández-lema, E, Villares, R, Corral, R, Alonso, B, & Blanco, C. (2011). Composting fish waste and seaweed to produce a fertilizer for use in organic agriculture. *Procedia Environmental Sciences*, , 9, 113-117.
- [27] Madlener, J. C. (1977). *Seavegetable Book*, Carlsson N. Potter, Inc., New York, USA, 288 p.
- [28] Mchug, J. D. (2003). *A Guide to the Seaweed Industry*, FAO Fisheries Technical Papers Rome-Italy, 9-25104-958-0(441), 105.
- [29] Mcdermid, K. J, & Stuercke, B. (2003). Nutritional composition of edible Hawaiian seaweeds, *Journal of Applied Phycology*, , 15, 513-524.
- [30] Novaczek, I. (2001). *A guide to the Common and Edible and Medicinal Sea Plants of the Pacific Island*, University of the South Pacific, 40pp.
- [31] Nkemka, V. N, & Murto, M. (2012). Exploring strategies for seaweed hydrolysis: Effect on methane potential and heavy metal mobilisation. *Process Biochemistry*. In press.
- [32] Pacheco-ruiz, I, Zertuche-González, J.A., Arroyo-Ortega, E., Valenzuela-Espinoza, E. ((2004). Agricultural fertilizers as alternative culture media for biomass production of *Chondracanthus squarulosus* (Rhodophyta, Gigartinales) under semi-controlled conditions. *Aquaculture*, , 240, 201-209.
- [33] Paull, R. E, & Chen, N. J. Postharvest handling and storage of the edible red seaweed *Gracilaria*. *Postharvest Biology and Technology*, , 48, 302-308.
- [34] Ramnani, P, Chitarrari, R, Tuohy, K, Grant, J, Hotchkiss, S, Philp, K, Campbell, R, Gill, C, & Rowland, I. (2012). In vitro fermentation and prebiotic potential of novel low molecular weight oligosaccharides derived from agar and alginate seaweeds. *Anaerobe* , 18, 1-6.
- [35] Renn, D. (1997). Biotechnology and the red seaweed polysaccharide industry: status, needs, and prospects. *Trends in Biotechnology*, , 15, 9-14.
- [36] Rupérez, P. (2002). Mineral content of edible marine seaweeds. *Food Chemistry*, , 79, 23-26.

- [37] Rupérez, P, & Saura-calixto, F. (2001). Dietary fibre and physicochemical properties of edible Spanish seaweeds, *European Food Research Technology*, , 212, 349-354.
- [38] Sa'nchez-Machado D.I., Lo'pez-Cervantes, J., Lo'pez-Herna'ndez, J., Paseiro-Losada, Fatty acids, total lipid, protein and ash contents of processed edible seaweeds. *Food Chemistry*, 85: 439-444., 2004.
- [39] Song, B. S, Park, J. G, Kim, J. H, Choi, J. I, Ahn, D. H, Hao, C, & Lee, J. W. (2012). Development of freeze-dried miyeokguk, Korean seaweed soup, as space food sterilized by irradiation. *Radiation Physics and Chemistry*, , 81, 1111-1114.
- [40] Tekogul, H, Turan, G, & Kiliñ, B. (2011). Su Mercimeđi (*Lemna Minor*) Katkılı Bayatlamayan Ekmek Üretimi, 16. *Ulusal Su Ürünleri Sempozyumu*, Ekim, sf. 274, Antalya., 25-27.
- [41] Turan, G, Tekogul, H, Kiliñ, B, & Cirik, Ş. (2011). Demir Deposu Kültür Deniz Marulu (*Ulva Rigida*) İle Hazırlanan Yosunlu Ekmeklerin Duyusal Olarak Deđerlendirilmesi ve Raf Ömrü Tespiti, 16. *Ulusal Su Ürünleri Sempozyumu*, Ekim, sf.275, Antalya, 25-27.
- [42] Thoma, T. (1997). *Cultivation of the brown alga, Cladosiphon okamuranus 'okinawa-Mozuku' in Seaweeds Cultivation and Marine Ranching*, Ohno, M. & Cricthely, A. (Eds) JICA, Yokosuka, , 51-56.
- [43] Takenaka, S, Sugiyama, S, Ebara, S, Miyamoto, E, Abe, K, & Tamura, Y. (2001). Feeding dried purple laver (Nori) to vitamin B<sub>12</sub>-deficient rats significantly improves vitamin B<sub>12</sub>-status, *British Journal of Nutrition*, , 85, 699-703.
- [44] Tsutsui, I, Huybh, Q. N, Nguyen, H. D, Arai, S, & Yoshida, T. (2005). *The Common Marine Plants of Sothern Vietnam*, Japan Seaweed Association, Kochi, 250 pp.
- [45] Watanabe, F, Takenaka, S, Kittaka-katsura, H, Ebara, S, & Miyamoto, E. (2002). Characterization and bioavailability of vitamin B<sub>12</sub>-compounds from edible algae, *Journal of Nutritional Science and Vitaminology*, , 48, 325-331.
- [46] Wijesinghe, W. A. J. P, & Jeon, Y. J. ((2012a). Biological activities and potential industrial applications of fucose rich sulfated polysaccharides and fucoidans isolated from brown seaweeds: A review. *Carbohydrate Polymers*, , 88, 13-20.
- [47] Wijesinghe, W. A. J. P, & Jeon, Y. J. extraction (EAE) of bioactive components: A useful approach for recovery of industrially important metabolites from seaweeds: A review. *Fitoterapia*, , 83, 6-12.
- [48] Zhang, X. C, Zheng, L. H, Liu, S. W, Tang, X. R, & Wang, J. F. (2004). Introduction to new economical seaweed, *Cladosiphon okamuranus*, *Period. Ocean. Univ. China*, , 34, 807-810.
- [49] Zhu, Q, & Zhang, X. A., K.K.I.U. ((2009). Ultrastructure Of Sporophyte of *Cladosiphon okamuranus* Tokida (Ectocarpales, Phaeophyceae), *Bangladesh J. Bot.*, , 38(2), 177-180.