CHAPTER 2

Nutritional and Digestive Health Benefits of Seaweed

Niranjan Rajapakse[*,1] and **Se-Kwon Kim**[†,‡]

Contents

Abstract

Seaweed is a famous delicacy in some parts of the Asia and also a well-known source of important food hydrocolloids, such as agar, alginates, and carrageenan. In addition to the food value of seaweed,

[*] Faculty of Agriculture, Department of Food Science and Technology, University of Peradeniya, Peradeniya, Sri Lanka
[†] Marine Bioprocess Research Center, Pukyong National University, Busan, Republic of Korea
[‡] Department of Chemistry, Pukyong National University, Busan, Republic of Korea
[1] Corresponding author: Niranjan Rajapakse, *E-mail address:* n_rajapakse@yahoo.com

Advances in Food and Nutrition Research, Volume 64
ISSN 1043-4526, DOI: 10.1016/B978-0-12-387669-0.00002-8

© 2011 Elsevier Inc.
All rights reserved.

several health benefits have also been reported to be present in this valuable food source. It is presumed that the unique features of the marine environment, where the seaweeds are grown, are mainly responsible for most of its properties. Among the functional effects of the seaweed, nutritional and health-related benefits have been widely studied. Compared to the terrestrial plants and animal-based foods, seaweed is rich in some health-promoting molecules and materials such as, dietary fiber, ω-3 fatty acids, essential amino acids, and vitamins A, B, C, and E. In this chapter, the nutritive value of seaweed and the functional effects of its soluble fiber are discussed with a special reference to the digestive health promotion of human.

I. SEAWEED AS A FOOD

Seaweed, also called as algae, is taxonomically classified under four groups namely: red algae (rhodophyta), brown algae (phaeophyta), green algae (chlorophyta), and blue-green algae (cyanophyta). Macroalgae, which include above three groups of seaweed other than blue-green algae, have a long history of utilization as direct or processed food across the globe. In Asian countries, seaweed is directly used for several culinary purposes, whereas in the west, it is exclusively used for the extraction of important food hydrocolloids including agar, carrageenan, and alginates. Availability almost throughout the year and relatively easy collection potential make macroalgae an inexpensive food source. With the advancement of biological and marine sciences, identification and large-scale culturing of edible micro algae (blue-green algae) have also become a reality, and later they have been introduced into different food applications.

Seaweed is a rich source of nutrients included in Asians traditional cuisine and is being extensively explored for its other merits as a food. Apart from its proven nutritional properties, bioactive molecules found in seaweeds have attracted the interest of health conscious societies, as seaweed is regarded as a remarkable marine medicinal food.

II. INTERVENTION OF SEAWEED TO ENHANCE HUMAN NUTRITION

Acquirement of a good mental and physical health through optimum nutrition is a key to wellness of humans. The nutrients in our daily diet or those synthesized in the human body using the precursor molecules play a vital role in regulating the bodily functions, essential for normal growth and development. Carbohydrates, proteins, lipids, and vitamins are provided to the human body through different food sources. Like most of the terrestrial plants, marine algae are also a rich source of above nutritional elements. In comparison with many common vegetables, high levels of fiber, minerals, ω-3 fatty acids, and moderate concentrations of lipids and proteins available in most of the edible seaweed help it to be considered as an important food source for human nutrition. However, the available amounts of the above nutrients may vary basically depending on the variety, season, and the area of production (Murata and Nakazoe, 2001).

A. Carbohydrates

Seaweed contains a large amount of carbohydrate as structural, storage, and functional polysaccharides, and the total carbohydrate content may ranges from 20% to 76% of dry weight (Holdt and Kraan, 2011) depending on the species. Though the carbohydrate content in seaweed is considerably high, its greater portion is available as polysaccharide dietary fiber, which is not taken up by the human body. Therefore, seaweed is not a good source of carbohydrate in terms of bioavailability. Little, but absorbable, forms of carbohydrate present in seaweed comprise glucose, mannose, and galactose.

B. Proteins

In general, seaweed protein is rich in glycine, arginine, alanine, and glutamic acid, and contains all the essential amino acids, the levels of which are comparable to those of the FAO/WHO requirements of dietary proteins (Anonymous, 2006). However, when compared with the other protein-rich food sources, seaweed is appeared to be limiting with lysine and cystine. With respect to the protein level and amino acid composition, the amino acid score and the essential amino acid index were higher in red seaweed than those in brown and green seaweeds (Holdt and Kraan, 2011). The amino acid score of the proteins in some red seaweed such as *Porphyra* spp. and *Undaria* spp. was 91 and 100, respectively, the same as that in animal-derived foods (Murata and Nakazoe, 2001). Red seaweed contains the highest protein content, which is comparable in quantitative terms to legumes at 30–40% of dry matter, and brown and green seaweeds contain only 15% and 30%, respectively (Murata and Nakazoe, 2001). A comparative study carried out with several red and brown seaweeds revealed that protein content of red seaweed species *Porphyra palmate* and *Porphyra tenera* ranged from 21% to 47% and that in brown seaweeds *Laminaria japonica* and *Undaria pinnatifida* ranged from 7% to 16% (Marsham *et al.*, 2007). Therefore, most of the edible red seaweeds can be considered as a good source of protein to be included in the diet.

However, aspartic and glutamic acid that exhibit interesting properties in flavor development are less in red seaweed compared to that in brown seaweed. In addition, the blue-green alga, *Spirulina*, is well known for its very high protein content which is close to 70% of the dry matter. The *in vivo* digestibility of seaweed proteins is not well documented. However, the extractability and the *in vitro* digestibility of seaweed protein attain more than 80% irrespective of the species (Fleurence, 1999).

C. Lipids

Seaweed has a very little lipid content, ranging from 1% to 5% of dry matter (Khotimchenko, 2005). Neutral lipids and glycolipids are the major lipid classes in all seaweeds, and the proportion of essential fatty acids in seaweed is higher than that in land plants. Seaweed synthesizes higher amounts of polyunsaturated fatty acids (PUFAs) especially under the cool climates, and the total lipid content is elevated during the hot seasons (Narayan *et al*., 2006). However, the content and the composition of fat can be greatly varied depending on the type of seaweed.

PUFAs in seaweeds contain substantial amount of ω-3 fatty acids as the major component. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are the two important fatty acids of marine origin belonging to ω-3 fatty acids that are responsible for a number of health benefits in the human body. α-Linolenic acid is the precursor of both EPA and DHA and is not synthesized in mammalians. However, α-linolenic acid can be converted into EPA and DHA upon consumption by the human. The major PUFA in most seaweed is EPA and the content of which can be even closer to 30% of the total fatty acid content. Though the red seaweed is rich in EPA and ω-6 fatty acids such as arachidonic acid, as a whole, all seaweeds are a balanced source of ω-3 and ω-6 acids. Therefore, seaweed is a good source of health-promoting PUFA compared to the other foods derived from plant and animal sources. The amount of phospholipids in seaweed is about 4–10% of the total lipid. Moreover, phospholipids in the diet act as an emulsifier and ease the digestion and absorption of fatty acids enhancing the nutritive value of the food. Moreover, seaweed contains many essential fatty acids, which may add to their efficacy as a part of a balanced diet.

D. Vitamins

Seaweed contains several vitamins both water soluble such as B and C and lipid soluble such as A and E at varying levels. Brown seaweed, *U. pinnatifida*, contained 14.5 mg/100 g of vitamin E and that was much higher than the vitamin E content (10 mg/100 g) in peanut (Anonymous, 2004). This high vitamin E content helps to protect PUFA in seaweed and to maintain their nutritional benefits. Red and brown seaweeds are rich in carotenes (provitamin A) and vitamin C, and their amounts may range from 20 to 170 ppm and 500 to 3000 ppm, respectively. They are also considered as good sources of vitamin B_{12}, which is not found in most land plants but present in a few vegetables in considerable amounts (Bender, 1980).

E. Minerals

Generally, seaweed contains high ash content indicating appreciable amounts of minerals. Mineral content of seaweed can account for up to 36% of its dry mass and mineral macronutrients include sodium, calcium, magnesium, potassium, chlorine, sulfur, and phosphorus whereas the micronutrients include iodine, iron, zinc, copper, selenium, molybdenum, fluoride, manganese, boron, nickel, and cobalt. Among these minerals, calcium holds 4–7% of dry matter. At 7% calcium, a typical daily portion size of seaweed (8 g dry weight) provides 560 mg of calcium which is a considerable amount compared to its recommended daily allowance (800–1000 mg) (Anonymous, 2004). In seaweeds, calcium is available as calcium phosphate, and that is more bioavailable than the form of calcium in milk, which is calcium carbonate.

Seaweed is a primary source of iodine, and in some seaweed, iodine content exceeds its dietary minimum requirement (150 μg/day). The highest iodine content is found in brown algae (1500–8000 ppm), and in most instances, red and green algae have lower contents. Iodine amount in the seaweed remains comparatively high than that in the land plants. Since animal- and plant-derived foods are very low in iodine, seaweeds can be considered as the best inexpensive food to fulfill the iodine requirement of human.

Interestingly, seaweed contains considerably high amounts of iron and copper compared to food sources renowned to contain those minerals such as, meat and spinach (Holland *et al.*, 1993). In addition, a normal portion size of brown seaweed, which includes species such as *Laminaria* and *Undaria*, provides more than 50% of the recommended daily allowance of magnesium. Therefore, seaweed can be used as a food supplement to fulfill most of the important mineral requirements of the body.

III. DIETARY FIBER IN SEAWEED HELPS TO AMELIORATE DIGESTIVE HEALTH

Dietary fiber, a group of non-starch carbohydrates basically of plant origin found in various vegetables, fruits, grains, nuts, and root crops, is an essential part of a healthy diet. Since the dietary fiber is not digested by the digestive enzymes, it cannot perform a direct nutritional effect in the human body. However, dietary fiber indirectly supports the human nutrition by involving in some important functions to promote the digestive health during its passage through the gastrointestinal track. These functions include reduction of incidences of colorectal cancers, suppression of bowel inflammations and related abdominal disorders, facilitation of bowel movement, and growth promotion of health-promoting gut microflora.

In comparison to the fiber content of the foods derived from terrestrial plants, seaweed has similar or even higher levels of dietary fiber. The average total dietary fiber content in seaweed can be varied from 36% to 60% based on its dry matter (Lahaye, 1991; Rasmussen and Morrissey, 2007). Nearly, 55–70% of its total dietary fiber is represented by the soluble fiber fraction which mainly comprises agar, alginates, and carrageenan at varying amounts depending on the type of seaweed (Table 2.1) and the growing conditions. In addition, some other important sulfated polysaccharides such as fucoidans, laminarin, porphyran, and ulvan are also available at relatively low quantities in seaweed. *U. pinnatifida*, *Chondrus*, and *Porphyra* have the highest content of soluble dietary fiber, and *Fucus* and *Laminaria* have the highest content of insoluble dietary fiber among the other common seaweed used in the food industry (Fleury and Lahaye, 1991). The recommended average daily intake of dietary fiber in the United States and in the United Kingdom is about 25–30 g and more than 18 g, respectively. The typical daily portion size of the seaweeds consumed in Asian cuisines on dry matter basis is about 8 g (MacArtain *et al*., 2007). Therefore, 12–15% of daily dietary requirement of fiber can be fulfilled by adding seaweed in the diet. This is considerably a large amount compared to that of other food sources on weight-for-weight basis.

TABLE 2.1 Different types of soluble fiber available in seaweed

Soluble fiber (hydrocolloid)	Source
Agar	Red seaweeds (*Gracilaria, Gelidium, Pterocladia*)
Carrageenans	Red seaweeds (*Eucheuma, Chondrus, Hypnea, Gigartina*)
Alginate	Brown seaweeds (*Macrocystis, Laminaria, Ascophyllum*)
Fucoidan	Brown seaweeds (*Laminaria religiosa, Nemacystus decipiens*)
Laminarin	Brown seaweeds (*Laminaria japonica, Saccharina latissima*)
Porphyran	Red seaweeds (*Porphyra* spp.)
Ulvan	Green seaweeds (*Ulva lactuca, Enteromorpha* spp.)

A. Reduces the risk of colorectal cancer

Colorectal cancer, which is characterized by neoplasia in the colon, rectum, or vermiform appendix, is the third most commonly diagnosed cancer in the world. More than half of the deaths of colorectal cancer are reported from the developed regions of the world. Several studies suggested that diets high in red and processed meat, as well as those low in fiber, are associated with an increased risk of colorectal cancer (Chao *et al.*, 2005; Wakai *et al.*, 2007). Dietary fiber has been hypothesized to involve in reducing the risk of colorectal cancer through several protective mechanisms including dilution of fecal carcinogens, reduction of transit time of feces through the bowel, production of short chain fatty acids which promote anticarcinogenic action, and binding of carcinogenic bile acids (Lipkin *et al.*, 1999).

Soluble fiber in seaweed can bind with water 20 times of their own volume exhibiting strong hydrocolloidal properties of its network structure. Therefore, seaweed added to the diet can enhance water binding to the food pellet in the gut and facilitate stool bulking, and decrease transit time in the colon, that act as positive factors to prevent colon cancer (Brownlee *et al.*, 2005). The viscous indigestible masses of fiber in the gut trap toxins and other cancerous material in the digested food, and those are then expelled through the feces. Thereby, they help to protect the surface membrane of the digestive tract against potential carcinogens. Studies carried out using the laboratory animal models revealed that some seaweed fibers are effective in controlling chemically induced gut cancer. Different diets consisting 0.05–0.2% seaweed powders of *Eisenia bicyclis*, *Laminaria angustata*, and *P. tenera* were tested in intestinal tumor-induced rats with potent intestinal carcinogen, 1,2-dimethylhydrazine, and after 20 days, the tumor incidence was clearly reduced at varying degrees (Yamamoto and Maruyama, 1985). Moreover, porphyran showed appreciable antitumor activity against Meth-A fibrosarcoma in rats (Noda, 1993). Development of colorectal epithelium into carcinoma is associated with a progressive inhibition of apoptosis and it further contributes to tumor growth. A study was carried out to determine apoptosis-inducing activity of fucoidan in cultured HT-29 and HCT116 human colon cancer cells and revealed that fucoidan can reduce the viability of tested cells in a dose-dependent manner through the inhibition of both tumor necrosis factor and caspase-induced cell signaling (Kim *et al.*, 2010).

B. Suppresses gastrointestinal inflammation

Seaweed polysaccharide fiber in the diet has shown to be effective in suppressing inflammation in the stomach and reducing the risk of gastroduodenal ulcers. Most of the soluble types of fiber in algae help to develop a viscous layer next to the epithelial margin of the upper digestive tract displaying a protective and coating effect against the digestive enzymes and low pH environment. Therefore, the chances of inflammating the epithelial layer either by chemicals or pathogenic microorganisms are minimized. In addition, some seaweed dietary fiber contributes to regenerate the damaged mucous membrane. Clinical trials showed that sodium alginate promotes the regeneration of mucous membrane in the stomach, suppresses inflammation, and eradicates colonies of *Helicobacter pylori* in the mucous membrane (Khotimchenko *et al.*, 2001). In support of the above observations, the effects of alginic acid and its derivatives for the treatment of gastritis and gastroduodenal ulcers were also studied and positive results were obtained.

Other than the reparative and sheathing effects of these polysaccharides, some agaro-oligosaccharides suppressed the production of proinflammatory cytokines and enzymes associated with the production of nitric oxide in the tissues of the digestive track, controlling the inflammatory reactions at cellular level (Enoki *et al.*, 2003).

C. Encourages the action of probiotics

Though the seaweed fiber is not digested by the enzymes in the upper digestive track (stomach and duodenum) of humans, it is partially degraded by the microflora in the colon, the lower segment of the digestive system. The colonic microflora is a complex and co-existing microbial ecosystem of potentially pathogenic and beneficial bacteria associated with gut lymphoid tissue. Probiotics, potentially health-promoting bacteria in the gut lymphoid tissue, and prebiotics, the fermentable substrates of such bacteria including dietary fiber, play a key role in promoting digestive health and in nutrition by salvaging nutrient and energy producing end metabolic products, like short chain fatty acids. Dietary modulation of the intestinal microflora can be achieved via either oral administration of probiotics or prebiotic compounds. Fermentation of fiber from brown seaweed with human fecal bacteria has indicated that probiotics follow their original fermentation pathways as exhibited with prebiotics from some other non-seaweed food sources (Mabeau and Fleurence, 1993). This fermentable fiber stimulates the growth of bifidobacteria and lactobacilli, which are the most important probiotic genera in humans, and maintains a more favorable balance among the colonic microflora.

Laminarin, a less viscous phycolloid amply found in *Laminaria* and *Saccharina*, has shown its capability to promote higher production of butyric acid through bacterial fermentation (Deville *et al.*, 2004). Butyrates are important energy-yielding metabolites for the colonial epithelial cells and account for about 70% of the energy requirement of the colon (Reilly *et al.*, 2008). Prebiotic effects of laminarin studied in animal models reported that 1% dietary supplementation resulted in an increase in

Bifidobacterium counts in the cecum of rats compared to a control diet, but there was no significant difference in *Lactobacillus* counts (Kuda *et al*., 2005). Studies carried out on seaweed extracts found that fucoidan also functions as a good prebiotic. Several other studies have also confirmed the positive dietary effects of alginates encouraging the growth of beneficial microbial fauna in fecal matter (Wang *et al*., 2006).

Laminarin and fucoidan may offer a dietary means to modulate the gut environment and immunity, and thereby reducing the risk of pathogenic microorganisms in the gut. Inclusion of brown seaweed, *Ascophyllum nodosum*, to the diet of weanling pigs resulted in lower numbers of *Escherichia coli* in the small intestine (Dierick *et al*., 2009). Moreover, sodium alginate seemed to demonstrate a strong antibacterial element by decreasing enterobacteriaceae, enterococci, and lecithinase negative clostridia, indicating a potentially beneficial shift in the microbial ecosystem in the gut.

IV. NUTRITION-RELATED OTHER HEALTH BENEFITS OF SEAWEED

In addition to the above discussed nutrients, diverse amount of phenolic molecules has been identified from seaweed and is classified under different groups of phytochemicals. Those molecules virtually do not play the roles of nutrients and proven to have different bioactive properties associated with enhancing physical fitness to refrain from diseases or to exert therapeutic effects against certain illnesses. However, the medicinal effects of such molecules are not discussed in this chapter. Non-communicable diseases such as diabetes, obesity, and cardiovascular dieses have a strong relationship with dietary habits and nutritional profiles of the food. Therefore, next few sections of this chapter address the nutrition-related several health effects of seaweed fiber, other than previously mentioned, and its contribution to enhance digestive health.

A. Reduction of obesity by bringing down the caloric value of the diet

Dietary obesity and obesity-related diseases are among the widely occurring nutritional health problems in most of the developed nations in the Western world. Seaweed fiber in the diet helps to control weight gain in different ways. Adding considerable amount of seaweed to the diet enables to keep the dieter feel fuller quickly and to reduce the appetite dramatically for further eating. Moreover, most of the dietary fiber in seaweed is not taken up by the human body and provides a low caloric value to the diet. In addition, this soluble fiber forms a viscous mass in the gut and traps digestive enzymes and some other nutrients, slowing down the digestibility of food and the absorption of nutrients in the intestine. A recent study carried out with a drug developed using alginic acid revealed that volunteers who were 25–30% overweight significantly decreased their body weight after treating with the drug (Zee, 1991). In addition to the dietary fiber, polyphenols in the seaweed extracts of *Ascophyllum* and *A. nodosum* inhibited α-amylase and α-glucosidase activities (Nwosua *et al*., 2011).

B. Reduction of lipid absorption and cardiovascular diseases

Reduction of the risk of cardiovascular diseases by consuming seaweed is suggested due to its modifying effects on the gastrointestinal tract such as emulsification of bile acid and interfering with lipid micelle formation, dilution of lipase concentration, binding with cholesterol, and slowing down of lipid absorption. Studies carried out using rats reported that alginic acid leads to a decrease in the concentration of cholesterol and is often coupled with an increase in the fecal cholesterol content and a hypocholesterolemic response (Dumelod *et al*., 1999). Moreover, porphyran significantly lowered the artificially enhanced level of hypertension and blood cholesterol in rats conserving cardiac health (Noda, 1993).

C. Influence on glycemic control

Dilution and slowing down the action of carbohydrases in the gut by seaweed fiber would have a positive impact on regulating the blood glucose level. Therefore, control of starch digestion in the diet can help to control blood glucose in type II diabetes. Five grams of sodium alginate administered daily to type II diabetic patients was found to prevent a postprandial increase of glucose and insulin, and to slow down gastric transit (Torsdottir *et al*., 1991). Hydrolysates of agar resulted in agaro-oligosaccharides possessing an activity against α-glucosidase (Chen *et al*., 2005). Moreover, *Ascophyllum* extracts at 50 mg/ml completely inhibited amylase activity. A meal supplemented with 5% alginates from brown seaweed decreased glucose absorption balance over 8 h in pigs, and much similar studies have been done on rats and humans (Vaugelade *et al*., 2000). The above findings suggest that seaweed fiber has an effective influence in inhibiting starch digestive enzymes at a very low level and maintains glycemic control *in vivo*.

Taking all the above discussed dietary functions of seaweed into consideration, it can be concluded that seaweed is a potential food to be added to the diet to enhance the human nutrition and digestive health.

REFERENCES

Anonymous (2004). Functional, health and therapeutic effects of algae and seaweed. Institut de Phytonutrition electronic database. Version 1.5. Beausoleil: France.

Anonymous (2006). Food and Nutrition Board, Recommended Dietary Allowances, 12th edn National Academy Press, Washington, DC.

Bender, A. E. (1980). Dictionary of Nutrition and Food Technology. Butterworths, London.

Brownlee, I. A., Allen, A., Pearson, J. P., Dettmar, P. W., Havler, M. E., Atherton, M. R., and Onsoyen, E. (2005). Alginate as a source of dietary fiber. *Crit. Rev. Food Sci. Nutr.* **45**, 497–510.

Chao, A., Thun, M. J., and Connell, C. J. (2005). Meat consumption and risk of colorectal cancer. *JAMA* **293**(2), 172–182.

Chen, H. M., Zheng, L., and Yan, X. J. (2005). The preparation and bioactivity research of agaro-oligosaccharides. *Food Technol. Biotechnol.* **43**, 29–36.

Deville, C., Damas, J., Forget, P., Dandrifosse, G., and Peulen, O. (2004). Laminarin in the dietary fibre concept. *J. Sci. Food Agric.* **84**, 1030–1038.

Dierick, N., Ovyn, A., and De Smet, S. (2009). Effect of feeding intact brown seaweed Ascophyllum nodosum on some digestive parameters and on iodine content in edible tissues in pigs. *J. Sci. Food Agric.* **89**, 584–594.

Dumelod, B. D., Ramirez, R. P., Tiangson, C. L., Barrios, E. B., and Panlasigui, L. N. (1999). Carbohydrate availability of arroz caldo with λ-carrageenan. *Int. J. Food Sci. Nutr.* **50**, 283–289.

Enoki, T., Sagawa, H., Tominaga, T., Nishiyama, E., Komyama, N., Sakai, T., Yu, F. G., Ikai, K., and Kato, I. (2003). Drugs, foods or drinks with the use of algae-derived physiologically active substances. US Patent 0,105,029.

Fleurence, J. (1999). Seaweed proteins: Biochemical, nutritional aspects and potential uses. *Trends Food Sci. Technol.* **10**, 25–28.

Fleury, N. and Lahaye, M. (1991). Chemical and physicochemical characterization of fibers from *Laminaria digitata* (Kombu Breton)—A physiological approach. *J. Sci. Food Agric.* **55**, 389–400.

Holdt, S. L. and Kraan, S. (2011). Bioactive compounds in seaweed: Functional food applications and legislation. *J. Appl. Phycol.* **23**, 543–597.

Holland, B., Brown, J., and Buss, D. H. (1993). Fish and Fish Products: Third Supplement to 5th Edition of McCance and Widdowson's The Composition of Foods. Royal Society of Chemistry, Cambridge.

Khotimchenko, S. V. (2005). Lipids from the marine alga *Gracilaria verrucosa*. *Chem. Nat. Comp.* **41**, 285–288.

Khotimchenko, T. S., Kovalev, V. V., Savchenko, O. V., and Ziganshina, O. A. (2001). Physical-chemical properties, physiological activity, and usage of alginates, the polysaccharides of brown algae. *Russ. J. Mar. Biol.* **27**(1), S53–S64.

Kim, E. J., Park, S. Y., Lee, J. Y., and Park, J. H. (2010). Fucoidan present in brown algae induces apoptosis of human colon cancer cells. *BMC Gastroenterol.* **10**, 96.

Kuda, T., Yano, T., Matsuda, N., and Nishizawa, M. (2005). Inhibitory effects of laminaran and low molecular alginate against the putrefactive compounds produced by intestinal microflora in vitro and in rats. *Food Chem.* **91**, 745–749.

Lahaye, M. (1991). Marine-algae as sources of fibers: Determination of soluble and insoluble dietary fiber contents in some sea vegetables. *J. Sci. Food Agric.* **54**, 587–594.

Lipkin, M., Reddy, B., Newmark, H., and Lamprecht, S. A. (1999). Dietary factors in human colorectal cancer. *Annu. Rev. Nutr.* **19**, 545–586.

Mabeau, S. and Fleurence, J. (1993). Seaweed in food products: Biochemical and nutritional aspects. *Trends Food Sci. Technol.* **4**, 103–107.

MacArtain, P., Gill, C. I. R., Brooks, M., Campbell, R., and Rowland, I. R. (2007). Nutritional value of edible seaweeds. *Nutr. Rev.* **65**(12), 535–543.

Marsham, S., Scott, G. W., and Tobin, M. L. (2007). Comparison of nutrition chemistry of a range of temperate seaweed. *Food Chem.* **100**(4), 1331–1336.

Murata, M. and Nakazoe, J. (2001). Production and use of marine algae in Japan. *Jpn. Agric. Res. Q.* **35**, 281–290.

Narayan, B., Miyashita, K., and Hosakawa, M. (2006). Physiological effects of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)—A review. *Food Rev. Int.* **22**, 291–307.

Noda, H. (1993). Health benefits and nutritional properties of nori. *J. Appl. Phycol.* **5**, 255–258.

Nwosua, F., Morrisa, J., Lunda, V. A., Heather, D. S., Rossa, A., and McDougall, G. J. (2011). Anti-proliferative and potential anti-diabetic effects of phenolic-rich extracts from edible marine algae. *Food Chem.* **126**(3), 1006–1012.

Rasmussen, R. S. and Morrissey, M. T. (2007). Marine biotechnology for production of food ingredients. *In* ''Advances in Food and Nutrition Research'', (S. L. Taylor, Ed.), Vol. 52, pp. 237–292. Elsevier, New York.

Reilly, P., O'Doherty, J. V., Pierce, K. M., Callan, J. J., O'Sullivan, J. T., and Sweeney, T. (2008). The effects of seaweed extract inclusion on gut morphology, selected intestinal microbiota, nutrient digestibility, volatile fatty acid concentrations and the immune status of the weaned pig. *Animal* **2**, 1465–1473.

Torsdottir, I., Alpsten, M., Holm, G., Sandberg, A. S., and Tolli, J. (1991). A small dose of soluble alginate-fiber affects postprandial glycemia and gastric-emptying in humans with diabetes. *J. Nutr.* **121**, 795–799.

Vaugelade, P., Hoebler, C., Bernard, F., Guillon, F., Lahaye, M., Duee, P. H., and Darcy-Vrillon, B. (2000). Non-starch polysaccharides extracted from seaweed can modulate intestinal absorption of glucose and insulin response in the pig. *Reprod. Nutr. Dev.* **40**, 33–47.

Wakai, K., Date, C., Fukui, M., Tamakoshi, K., Watanabe, Y., Hayakawa, N., Kojima, M., Kawado, M., Suzuki, K., Hashimoto, S., Tokudome, S., Ozasa, K., *et al*. (2007). Dietary fiber and risk of colorectal cancer in the Japan collaborative short study. *Cancer Epidemiol. Biomarkers Prev.* **16**(4), 668–675.

Wang, Y., Han, F., Hu, B., Li, J. B., and Yu, W. G. (2006). In vivo prebiotic properties of alginate oligosaccharides prepared through enzymatic hydrolysis of alginate. *Nutr. Res.* **26**, 597–603.

Yamamoto, I. and Maruyama, H. (1985). Effect of dietary seaweed preparations on 1,2-dimethylhydrazine induced intestinal carcinogenesis in rats. *Cancer Lett.* **26**(3), 241–251.

Zee, S. (1991). Body weight loss with the aid of alginic acid. *Med. Arh.* **45**(3–4), 113–114.