EJEAFChe
Electronic Journal of Environmental, Agricultural and Food Chemistry

ISSN: 1579-4377

NUTRITIONAL VALUE OF SEAWEEDS

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KEYWORDS

antioxidant, carotenoids, polyphenols, minerals, fibers

ABSTRACT

In the Far East and Pacific, there has been a long tradition of consuming seaweeds as sea vegetables, while in Western countries the principal use of seaweeds has been as source of phycocolloids (alginate, carrageenan and agar), thickening and gelling agents for various industrial applications, including uses in foods. In addition, seaweeds constitute an interesting source of compounds with health protective effects. This paper is a short review on the biochemical composition and the nutritional value of seaweeds.

INTRODUCTION

In Asia, seaweeds have been consumed as a vegetable since the beginning of time. On average, the Japanese eat 1.4 kg per person per year. This ancient tradition and everyday habit has made possible a large number of epidemiological researches showing the health benefits linked to seaweed consumption (Teas 1981, Hiqashi et al. 1999, Funahashi et al. 1999). France was the first european country to establish a specific regulation concerning the use of seaweeds for human consumption as non–traditional food substances. Currently, 12 macroalgae (6 brown algae, 5 red algae, 2 green algae) and two microalgae are authorized as vegetables and condiments (table 1).

Table 1. Seaweeds authorized in France for human consumption

Phyllum	Name
Brown seaweeds	Ascophyllum nodosum Fucus vesiculosus Fucus serratus Himanthalia elongata Undaria pinnatifida
Red seaweeds	Porphyra umbilicalis Palmaria palmata Cracilaria verrucosa Chondrus crispus
Green seaweeds	Ulva spp. Enteromorpha spp.
Microalgae	Spirulina sp. Odontella aurita

These seaweeds must meet safety regulations in terms of toxicological and bacteriological criteria (Table 2). This regulation, in addition to the potential nutritional properties of seaweds, allows the food industry to include seaweeds as raw or semi-processed materials in the formulation of seafood products. This paper reports data about the nutritional properties of edible seaweeds.

Table 2. Quality criteria applied to edible seaweeds sold in France

Criteria	Limit
Toxic minerals (mg/kg dry matter)	Inorganic Arsenic < 3.0 Lead < 5.0 Cadmium < 0.5 Tin < 5.0 Mercury < 0.1 Iodine < 5.0
Bacteria (colony-forming unit /g)	Aerobes < 100 Fecal coliforms < 10 Clostridium perfringens < 1 Anaerobes < 100

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Polysaccharides and dietary fibres

Seaweeds contain large amounts of polysaccharides, notably cell wall structural polysaccharides that are extraded by the hydrocolloid industry: alginate from brown seaweeds, carrageenans and agar from red seaweeds. Other minor polysaccharides are found in the cell wall : fucoidans (from brown seaweeds), xylans (from certain red and green seaweeds), ulvans in green seaweeds. Seaweeds also contain storage polysaccharides, notably laminarin (β-1,3- glucan) in brown seaweeds and floridean starch (amylopectin- like glucan) in red seaweeds. When faced with the human intestinal bacteria, most of these polysaccharides (agars, carrageenans, ulvans and fucoidans), are not digested by humans and therefore can be regarded as dietary fibres (Lahaye et al 1990, Lahaye et al 1991). Water-soluble and water-insoluble fibres have been associated with different physiological effects. Many viscous soluble polysaccharides (pectins, guar gum, etc.) have been correlated with hypocholesterolemic and hypoglycemic effects, whereas water-insoluble polysaccharides (cellulose) are mainly associated with a decrease in digestive tract transit time (Southgate, 1990). Among polysaccharides, fucoïdans were particularly studied as they showed interesting biological activities (anti-thrombotic, anti-coagulant, anti-cancer, anti-proliferative, anti-viral, and anti-complementary agent, anti-inflammatory). These properties open up a wide field of potential therapeutic applications, some of which are already the subject of patents concerning notably the anti-coagulant and anti-thrombotic properties (Charreau et al. 1995, Nasu et al 1997, Angstwurm et al. 1997). As for xylans and laminarans, they are completely and rapidely degraded by intestinal bacteria, alginates are only partly degraded and lead to a substantial production of short chain fatty acids.

Minerals

Seaweeds draw from the sea an incomparable wealth of mineral elements, macro-elements and trace elements. The mineral fraction of some seaweeds accounts for up to 36% of dry matter. The brown seaweeds have traditionally been used for treating thyroid goitre (Suzuki et al. 1965). The link between iodine and the thyroid hormones was established soon afterwards. Despite the fact that this raw material source of iodine has been abandoned (except in China), *Fucus vesiculosus* is still registered in the European pharmacopoeia for its high iodine content. As concerns iodine, laminaria is the main source as it contains 1500 to 8000 ppm dry weight (fucals contain 500 to 1000 ppm dry weight of iodine). Seaweeds are also one of the most important vegetable source of calcium. Calcium content may be as high as 7 % of the dry weight in macroalgae and up to 25 to 34 % in the chalky seaweed lithotamne. Seaweed consumption may thus be usefull in the case of expectant mothers, adolescants and elderly that all exposed to a risk of calcium deficiency. Despite hight contents, the linkage of certain minerals with anionic polysaccharides (alginate, agar or carrageenan) might limit their absorption. For instance, the strong affinity of divalent cations (particularly calcium) for carboxylic polysaccharides (alginates)

probably limits their availability. In contrast, the weakness of the linkages between polysaccharides and iodine allows rapid release of this element.

Table 3: Dietary fibre contents of seaweeds and some terrestrial plants

	Fibre (% dry weight)		
	Soluble	**Insoluble**	**Total**
Phaeophyceae			
Wakame (Undaria pinnatifida)	30.0	5.3	35.3
Sea spaghetti (Himanthalia elongata)	25.7	7.0	32.7
Konbu breton (Laminaria digitata)	32.6	4.7	37.3
Chlorophyceae			
Sea lettuce (Ulva lactuca)	21.3	16.8	38.1
Ao nori (Enteromorpha spp.)	17.2	16.2	33.4
Rhodophyceae			
Nori (Porphyra tenera)	17.9	6.8	34.7
Terrestrial plants			
Apple	5.9	8.3	14.2
Cabbage	16.8	17.5	34.3
Wheat Bran	8.0	77.0	85.0
Sugar beet pulp	25.0	50.0	75.0

Proteins and amino acids

The protein content of brown seaweeds is generally small (average: 5-15 % of the dry weight), whereas higher protein contents are recorded in green and red seaweeds (on average 10-30 % of the dry weight). In some red seaweeds, such as Palmaria palmata (dulse) and Porphyra tenera (nori), proteins can represent up to 35 and 47% of the dry matter, respectively. These levels are comparable to those found in high-protein vegetables such as soybeans (in which proteins represents 35 % of the dry mass) . The protein levels of Ulva spp. are in the range 15-20 % of the dry weight. Except for Undaria pinnatifida, which contains 11-24 % proteins, other brown seaweeds (Laminaria digitata, Ascophyllum nodosum, Fucus vesiculosus and Himanthalia elongata) have a low protein content. Spirulin, a freshwater micro-alga, is well-known for its high protein content (70% of dry matter).

The digestibility in vivo of algal proteins is not well documented, and available studies about their assimilation by humans have not provided conclusive results. However, several workers have described a high rate of algal protein degradation in vitro by proteolytic enzymes such as pepsin, pancreatin and pronase (Fujiwara-Arasaki 1979, Ryu et al. 1982). Comparable results are observed with proteins from green and brown seaweeds. However, for these seaweeds, the high phenolic content might limit protein availability in vivo and thus moderate in vitro figures. This situation is probably not found for the green and red seaweeds, which possess low levels of phenols and a higher protein content.

Among the algal proteins, it is worth noting the occurance of phycobiliproteins in red and blue algae (blue phycocyanin in Spirulin, phycoerythrin in red algae) (Boussiba et Richmond 1979, Fan-jie et al. 1984). These compounds are made up of biline (tetrapyrolic open core) linked in a covalant way to a proteic chain. Recent studies showed that phycobiliproteins present antioxidant properties, which could be beneficial in the prevention or treatment of neuro-degenerative diseases caused by oxidative stress (Alzeimer's and Parkinson's) as well as in the cases of gastric ulcers and cancers (Gonzales et al. 1999, Padula et Boiteux 1999, Remirez et al. 1999).

Lipids and fatty acids

Lipids represent only 1-5 % of algal dry matter and show an interesting polyunsaturated fatty acid composition particularly regarding with omega 3 and omega 6 acids which play a role in the

prevention of cardio-vascular diseases, osteoarthritis and diabetes. The green algae show interesting levels of alpha linolenic acid (ω3 C18:3). The red and brown algae are particularly rich in fatty acids with 20 carbon atoms: eicosapentanoïc acid (EPA, ω3 C20 :5) and arachidonic acid (AA , ω6 C20 :4). Spirulin provides an interesting source of gamma linolenic acid (GLA) (20 to 25 % of the total lipidic fraction), which is a precursor of prostaglandins, leucotriens and thromboxans involved in the modulation of immunological, inflammatory and cardio-vascular responses. Spirulin thus provides an interesting alternative to the other known sources of GLA : onagre oil, blackcurrant pips and borage oil (Renaud et al 1999, Fleurence et al. 1994). Besides fatty acids, unsaponifiable fraction of seaweeds was found to contain carotenoids (such as B-carotene, lutein and violaxanthin in red and green seaweds, fucoxanthin in brown seaweeds), tocopherols, sterols (such as fucosterol in brown seaweeds), and terpenoids (Jensen 1969, Piovetto et Peiffer 1991, Haugan et Liaaen-Jensen 1994). Lipidic extracts of some edible seaweeds showed antioxidant activity and a synergistic effect with the tocopherol (Le Tutour 1990).

Micronutrients

Vitamins

Vitamin B12

Algae are a source of vitamins from group B. For instance, seaweeds contain vitamin B12, which is particularly recommended in the treatment of the effects of ageing, of chronic fatique syndrome (CFS) and anaemia. Among the edible seaweeds, Spirulin is richest in vitamin B12. Daily ingestion of one gramme of Spirulin would be enough to meet the daily requirements in B12 (Watanabe et al. 1999).

Vitamin C

Algae provide a worthwhile source of vitamin C (Qasim et Barkati 1985). The levels of Vitamin C average between 500 to 3000 mg/kg of dry matter for the green and brown algae (a level comparable with that of parsley, blackcurrant, and peppers), whereas the red algae contains vitamin C levels of around 100 to 800 mg/ kg. Vitamin C is of interest for many reasons : it strengthens the immune defence system, activates the intestinal absorption of iron, controls the formation of conjunctive tissue and the protidic matrix of bony tissue, and also acts in trapping free radicals and regenerates Vitamin E.

Vitamin E

Due to its antioxidant activity, vitamin E inhibits the oxidation of the low-density lipoproteins. It also plays an important part in the arachidonic acid chain by inhibiting the formation of prostaglandins and thromboxan. The brown seaweeds contain higher levels of vitamin E than green and red seaweeds. Among the brown algae, the highest levels are observed in the Fucaceae, *Ascophyllum* and *Fucus sp*., which contain between 200 and 600 mg of tocopherols / kg of dry matter. Brown algae contain alpha, beta and gamma tocopherol while the green and red algae only contain the alpha tocopherol. It was shown that the gamma and alpha tocopherols increase the production of nitric oxide and nitric oxide synthase activity (cNOS) and also play an important role in the prevention of cardio-vascular disease (Solibami et Kamat 1985).

Polyphenols

Algal polyphenols, also called phlorotannins, differ from terrestrial plant polyphenols. Polyphenols from terrestrial plants derived from gallic and ellagic acid, whereas the algal polyphenols derived from phloroglucinol units (1,3,5-trihydroxybenzine). Phlorotannins constitute an extremely heterogeneous group of molecules (struture and polymerisation degree heterogeneity) providing a wide range of potential biological activity. Highest contents are found in brown seaweeds, where phlorotanin range from 5 to 15 % of the dried weight (Ragan et Craigie 1973, Mc Innes et al 1984, Glombitza et Keusgen 1984). Antioxidant activity of polyphenols extracted from brown and red seaweeds has already been demonstrated by in vitro assays (Nakamura et al 1996). However, on the contrary of terrestrial plants polyphenols, little is known about the role of phlorotannin in preventing diseases linked to oxidative stress.

Carotenoids

Carotenoids are powerful antioxidants. Recent studies have shown the correlation between a diet rich in carotenoids and a diminishing risk of cardio-vascular disease, cancers (β-carotene, lycopene), as well as opthalmological diseases (lutein, zeaxanthin). Brown seaweeds are particularly rich in carotenoids especially in fucoxanthin, β-carotene, violaxanthin . The main carotenoids in the red algae are the β-carotene and α-carotene and their dihydroxylated derivatives : zeaxanthin and lutein. The carotenoid composition of the green algae is similar to that of higher plants : the main carotenoids present are the β-carotene, lutein, violaxanthin, antheraxanthin, zeaxanthin and neoxanthin. A lot of studies demonstrated the antioxidant properties of the algal carotenoids and the role they play in preventing many pathologies linked to oxidative stress (Okuzumi et al 1993,. Yan et al 1999).

CONCLUSIONS

In adddition to their technological properties, seaweeds exhibit original and interesting nutritional properties. From a nutritional standpoint, the main properties of seaweeds are their high mineral (iodine, calcium) and soluble dietary fibre contents, the occurence of vitamin B12 and specific components such as fucoxanthin, fucosterol, phlorotannin. If more research is needed to evaluate the nutritional value of marine algae, seaweeds can be regarded as an under-exploited source of health benefit molecules for food processing and neutraceutic industry.

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