Trends in Food Science & Technology Volume 19, Issue 1, January 2008, Pages 31-39

In the search of new functional food ingredients from algae

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Introduction

The economic, cultural and scientific development of our society has given rise to important changes in our food habits and life-style. For example, diets in developed countries are highly caloric, rich in saturated fats and sugars, while the consumption of complex carbohydrates and dietetic fiber is low. This fact, together with a decrease in physical activity, has given rise to an increase of obesity problems, and along with it, a raise in the incidence of heart diseases, diabetes and hypertension in the population (Geslain-Lanéelle, 2006).

The increasing number of scientific papers published for the last two decades correlating diet and some chronic diseases has shown the extraordinary possibilities of foods to support, or even to improve, our health ([Palanca et al., 2006] and [Roche, 2006]). As a consequence, nowadays, there is a huge interest among consumers and food industry on products that can promote health and well-being (Sloan, 1999). These foods have been generically named functional foods.

The concept of functional food as a mean to protect consumer's health was developed at the beginning of the 1980s in Japan, as a way to reduce the high health costs derived from a population with high life expectations (Arai, 1996). In Europe, in the second half of the 1990s, a working group coordinated by the European Section of the International Life Science Institute (ILSI) and supported by the European Commission, was created to promote inside the IV Framework Program the action FUFOSE (Functional Food Science in Europe) to stimulate the scientific study on functional foods. From this project a definition for functional food was generated. Namely, a food can be considered “functional” if, besides its nutritious effects, it has a demonstrated benefit for one or more functions of the human organism, improving the state of health or well-being or reducing the risk of disease (Diplock *et al.*, 1999). In this definition it is necessary to emphasize three important and new aspects: (a) the functional effect is different that the nutritious one; (b) the functional effect must be demonstrated satisfactorily; and (c) the benefit can consist in an improvement of a physiological function or in a reduction of risk of developing a pathological process. Besides, the functional foods must have a series of additional characteristics as, for instance, the need of effectiveness in their beneficial action at the normal consumed doses.

In the future, functional foods will be regulated by the new guideline approved in December 2006, by the European Union (Regulation (CE) 1924/2006 of the European Parliament and of the Council, December

20, 2006: nutrition and health claims made on foods). In this regulation the nutritional allegations and/or healthy properties of the new products are regulated, including their presentation, labeling and promotion.

The beneficial action exercised by functional foods (see Table 1 for some examples) is due to a component or a series of ingredients that either are not present in the analogous conventional food or are present at lower concentrations. These ingredients are called *functional ingredients*. Thus, foods were initially enriched with vitamins and/or minerals, such as vitamin C, vitamin E, folic acid, zinc, iron, and calcium (Sloan, 2000). Later, the approach changed to enrich foods with several micronutrients such as ω3 fatty acids, linoleic acids, phytosterols, soluble fiber (inulin and fructooligosaccharides, called prebiotics), etc., trying to promote consumers health or to prevent different diseases ([Hasler, 1998], [Sloan, 2002] and [Unnevehr and Hasler, 2000]). Also, foods can be changed to contain or enriched with viable microorganisms that can benefit human health; these products are called probiotics and are able to improve the activity in the intestinal tract and the immune system, among other functions. Usually the microorganisms added to the food are lactic acid bacteria including *Lactobacillus acidophilus*, *Lactobacillus johnsonii*, *Lactobacillus reuteri*, *Lactobacillus casei shirota*, etc. (Sanders, 1999).

Table 1.

Some examples of functional foods and functional ingredients together with their possible effect on human health (according to Hasler, 2002)

Functional food	**Functional ingredients**	**Possible health effect**
Chocolate	Flavonoids (procyanidins)	Reduce LDL cholesterol
Green tea	Catechins	Reduce risk of certain types of cancer
Tomatoes and processed tomato products	Lycopene	Reduce risk of certain types of cancer
Red wine	Polyphenolic compounds	Reduce risk of certain heart diseases
Fatty fish	(n-3) Fatty acids	Reduce risk of certain heart diseases
Fermented dairy products	Probiotics	Support intestinal tract health, boost immunity
Cruciferous	Glucosinolates, indoles	Reduce risk of certain types of cancer
Lamb, turkey, beef, dairy	Conjugated linoleic acids (CLA)	Reduce breast cancer
Cranberry juice	Proanthocyanidins	Reduce urinary tract infections

Functional food	Functional ingredients	Possible health effect
Fortified margarines	Plant sterol and stanol esters	Reduce total and LDL cholesterol
Fortified juice	Soluble fiber	Reduce total and LDL cholesterol
Garlic	Organosulfur compounds	Reduce total and LDL cholesterol

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Algae are photosynthetic organisms, which possess reproductive simple structures. These organisms constitute a total of 25–30,000 species, with a great diversity of forms and sizes, and that can exist from unicellular microscopic organisms (microalgae) to multicellular of great size (macroalgae). Algae can be a very interesting natural source of new compounds with biological activity that could be used as functional ingredients. In fact, some algae are organisms that live in complex habitats submitted to extreme conditions (for example, changes of salinity, temperature, nutrients, UV–vis irradiation), therefore, they must adapt rapidly to the new environmental conditions to survive, producing a great variety of secondary (biologically active) metabolites, which cannot be found in other organisms (Carlucci, Scolaro, & Damonte, 1999). Also, considering their great taxonomic diversity, investigations related to the search of new biologically active compounds from algae can be seen as an almost unlimited field.

Besides its natural character, other important aspects related to the algae are their easy cultivation, their rapid growing (for many of the species) and the possibility of controlling the production of some bioactive compounds by manipulating the cultivation conditions. In this way, algae and microalgae can be considered as genuine natural reactors being, in some cases, a good alternative to chemical synthesis for certain compounds. Moreover, one of the least studied aspects, which is one of the research lines of our group, is the development of more appropriate, fast, cost-effective and environmental-friendly extraction procedures able to isolate the compounds or compounds of interest from these natural sources.

Objective

At present, one of the principal research lines in Food Science and Technology is the extraction and characterization of new functional ingredients of natural origin. In our laboratory, we have studied for years different natural sources of functional ingredients including plants, spices, etc. ([Cifuentes et al., 2001], [Ibañez et al., 1999], [Ibáñez et al., 2001] and [Señoráns et al., 2001]). Recently, we have started a new line of investigation in which different algae and microalgae are being studied as possible natural sources of functional ingredients ([Herrero et al., 2004] and [Herrero et al., 2005]), combining their use with clean extraction technologies based on sub- and supercritical fluids (Jaime *et al.*, 2005; Mendiola *et al.*, 2005).

The objectives of this review paper are first to present the results obtained of a detailed bibliographical search about the composition of different algae and, secondly, to discuss their possibilities as new sources of functional ingredients. The information provided on the different algae does not refer in many cases to the same constituents since it has been taken from different research papers with different objectives. Nevertheless, we believe the information provided can be useful to many research groups considering the huge interest in the search for new natural sources of functional ingredients.

Chemical composition of different algae

The species of algae described in this work are macroalgae (namely, *Sargassum vulgare*, *Undaria pinnatifida*, *Himanthalia elongata*, *Chondrus crispus*, *Porphyra sp.*, *Cystoseira spp.* and *Ulva spp.*) and have been selected considering their potential as natural sources of new functional ingredients. Also, an important factor to consider here was the low toxicity of the selected varieties, assuming that any hypothetical new functional ingredient obtained from them could be used for the future development of new functional foods.

S. vulgare

S. vulgare belongs to the group of brown algae that have been traditionally consumed in the East countries. The different species present good nutritional values as sources of proteins, carbohydrates, minerals and vitamins. According to the study done by Marinho-Soriano, Fonseca, Carneiro, and Moreira (2006) on the chemical composition of *S. vulgare*, the major components of this type of algae were carbohydrates (67.80%); according to the above mentioned study, the synthesis of carbohydrates seemed to be favored by both, intensity of light and temperature while decreasing the nitrogen and proteins content. The percentage of lipids in this type of macroalgae was very low (0.45%); on the other hand, *S. vulgare* had a high percentage of fiber (7.73%) and proteins (15.76%). In a study developed by Dietrich *et al.* (1995), it was demonstrated that *S. vulgare* contained also polysaccharides with potential antiviral action formed principally by alginic acid, xylofucans and two species of fucans.

According to Barbarino and Lourenco (2005), proteins of *S. vulgare* had a high nutritional value since they contained all the essential amino acids in significant amounts. Although in general, algae do not contain valuable quantities of the essential amino acid methionine, *S. vulgare* presented high levels of this amino acid (1.7%). Also, although practically all the species of algae are rich in phenylalanine, tyrosine and treonine, *S. vulgare* presented as main amino acids leucine (8.2%), alanine (6.8%), glutamic (17.4%) and aspartic acid (10.6%).

H. elongata, *U. pinnatifida*, *Porphyra sp.* and *C. crispus*

Porphyra sp. and *C. crispus* belong to the group of red algae while *H. elongata* and *U. pinnatifida* are brown algae. Nowadays, these macroalgae are very interesting to consumers and food industry due to their low content in calories and high content in vitamins, minerals and dietetic fiber.

The algae, *H. elongata* (dehydrated and canned), *U. pinnatifida* and *Porphyra sp*. (dehydrated), have been studied by Sanchez-Machado, Lopez-Cervantes, Lopez-Hernandez, and Paseiro-Losada (2004). These authors showed the valuable protein content of these algae (as high as 24%, given as gram of protein per 100 g of alga) and the low percentage of lipids (about 1% in all cases). Interestingly, although these algae showed a low lipid content, they possessed a high level of polyunsaturated fatty acids (PUFAs) as can be seen in Table 2 (Sanchez-Machado, Lopez-Cervantes, Lopez-Hernandez, & Paseiro-Losada, 2004). Thus, these algae seemed to be an interesting source of some polyunsaturated ω3-fatty acids, as for example, the eicosapentaenoic acid (EPA), given as C20:5 ω3. These ω3-fatty acids have demonstrated their effect on the reduction of coronary diseases (Simopoulos, 2004). Besides, Kamat *et al.* (1992) have demonstrated that some fatty acids from algae can have certain antiviral activity. According to Le Tutour *et al.* (1998), the use of an extract containing soluble lipids from *H. elongata* increased synergically the antioxidant effect of vitamin E, in a percentage as high as 45%.

Table 2.

Fatty acids profile of different algae canned and dehydrated according to Sanchez-Machado, Lopez-Cervantes, Lopez-Hernandez, and Paseiro-Losada (2004)

Fatty acids	**Canned**	**Dehydrated**		
	Himanthalia elongata	***Himanthalia elongata***	***Undaria pinnatifida***	***Porphyra sp.***
C14:0	9.57 ± 0.81	5.85 ± 0.35	3.17 ± 0.31	0.53 ± 0.21
C16:0	36.73 ± 2.16	32.53 ± 1.61	16.51 ± 1.35	63.19 ± 1.93
C16:1 ω7	3.00 ± 0.38	2.79 ± 0.25	3.70 ± 0.88	6.22 ± 0.70
C16:2 ω4	Tr	Tr	Tr	Tr
C16:3 ω4	0.06 ± 0.01	4.38 ± 1.33	2.31 ± 1.94	1.56 ± 0.51
C18:0	0.59 ± 0.07	0.68 ± 0.15	0.69 ± 0.08	1.23 ± 0.10
C18:1 ω9	22.64 ± 1.80	19.96 ± 2.01	6.79 ± 0.90	6.70 ± 1.16
C18:1 ω7	–	–	–	1.29 ± 0.68
C18:2 ω6	5.80 ± 0.21	4.39 ± 0.34	6.23 ± 0.32	1.17 ± 0.13
C18:3 ω3	6.77 ± 0.79	8.79 ± 0.71	11.97 ± 1.75	0.23 ± 0.16
C18:4 ω3	1.94 ± 0.43	3.53 ± 0.56	22.60 ± 2.48	0.24 ± 0.35
C20:1 ω9	–	–	–	4.70 ± 0.26
C20:4 ω6	9.78 ± 2.27	10.69 ± 1.30	15.87 ± 1.68	6.80 ± 1.18

Fatty acids	Canned	Dehydrated		
	Himanthalia elongata	***Himanthalia elongata***	***Undaria pinnatifida***	***Porphyra sp.***
C20:4 ω3	0.35 ± 0.19	0.88 ± 1.80	0.70 ± 0.14	0.07 ± 0.02
C20:5 ω3	2.77 ± 0.80	5.50 ± 1.78	9.43 ± 0.69	6.03 ± 0.95
Saturated fatty acid	46.89 ± 3.03	30.06 ± 2.11	20.39 ± 1.73	64.95 ± 2.24
Monounsaturated	25.64 ± 2.18	22.75 ± 2.26	10.50 ± 1.78	18.91 ± 2.81
PUFAs	27.47 ± 4.73	38.16 ± 7.84	69.11 ± 9.01	16.10 ± 3.31
PUFAs ω6	15.58 ± 2.48	15.08 ± 1.64	22.10 ± 2.00	7.97 ± 1.31
PUFAs ω3	11.83 ± 2.21	18.70 ± 4.84	44.70 ± 5.05	7.20 ± 1.48
Ratio ω6/ω3	1.32	0.81	0.49	1.21

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H. elongata also presented high levels of α-tocopherol, as demonstrated by Sánchez-Machado, López-Hernández, and Paseiro-Losada (2002); for example, the content of α-tocopherol in *H. elongata* dehydrated (33.3 μg/g dry weight) was considerably higher than in *H. elongata* canned (12.0 μg/g dry weight), which clearly indicates the important effect of the processing on this compound. Other compounds that could be found in these algae were sterols (Sanchez-Machado, Lopez-Hernandez, Paseiro-Losada, & Lopez-Cervantes, 2004). Thus, the algae *H. elongata*, *U. pinnatifida* and *Porphyra sp.*, contained ethylenecholesterol, with relative small variations in their content, what seems to indicate a much lower effect of the conditions of conservation on this compound (dehydrated or canned for *H. elongata*). The predominant sterol for the brown algae (*H. elongata* and *U. pinnatifida*) was fucosterol (1706 μg/g of dry weight and 1136 μg/g of dry weight, respectively), and for the red alga (*Porphyra sp*.) was demosterol (337 μg/g of dry weight). Cholesterol, in general, was present at very low quantities, except in *Porphyra sp*. that can contain up to 8.6% of the total content of sterols as cholesterol.

Algae present in general high fiber contents (see Table 3). Thus, in red algae the soluble fraction was principally composed of sulphated galactans such as agar or carrageenans, while in brown algae, the soluble fraction was principally composed of alginates, fucans and laminarin; in both cases, the insoluble fraction was basically formed of cellulose (Sanchez-Machado, Lopez-Cervantes, Lopez-Hernandez, Paseiro-Losada, & Simal-Lozano, 2004).

Table 3.

Uronic acid contents in the total dietary fiber fractions from some algae according to Sanchez-Machado, Lopez-Cervantes, Lopez-Hernandez, Paseiro-Losada, *et al.* (2004)

Fatty acids	Canned	Dehydrated		
	Himanthalia elongata	***Himanthalia elongata***	***Undaria pinnatifida***	***Porphyra sp.***
Total dietary fiber (g/100 g dry weight)	53.3 ± 3.5	32.6 ± 0.4	42.7 ± 1.8	40.5 ± 2.8
β-d-mannuronic acid (%)	78.2 ± 1.4	75.6 ± 1.8	78.3 ± 2.7	Not determined
α-l-guluronic acid (%)	21.8 ± 1.4	24.4 ± 1.8	21.7 ± 2.7	Not determined

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Folates act as vitamins cofactors and are essential for the synthesis of purines and pyrimidines, as well as for the production of methionine from homocysteine. They also play an important role in neural tube defects. It has been demonstrated in animal studies that low levels of folic acid can increase the risk of suffering cancer. Interestingly, red and brown algae can also contain high levels of folic acid and folate derivatives including 5-metil-tetrahydro-folate, 5-formyl-tetrahydro-folate and tetrahydro-folate. Thus, amounts as high as 150 µg of total folic acid per 100 g of dry algae had been detected in *U. pinnatifida* (Rodriguez-Bernaldo de Quiros, Castro de Ron, Lopez-Hernandez, & Lage-Yusty, 2004). *U. pinnatifida* is a brown alga that is consumed preferably in some regions of the coast of Australia and New Zealand. This alga also contained high levels of sulphated polysaccharides (sulphated fucans or fucoidans) that present potential antiviral activity (Hemmingson, Falshaw, Furneaux, & Thompson, 2006).

Volatile compounds have also been identified in samples of *U. pinnatifida* cultured in different conditions (Shin, 2003). Namely, a total of 127 volatile compounds were identified including 4 organic acids, 34 aldehydes, 19 alcohols, 34 ketones, 8 esters, 12 hydrocarbons, 5 sulfur-containing compounds, and 11 more of different nature.

The brown alga *U. pinnatifida* and the red alga *C. crispus* could be used as a food supplement to help meeting the recommended daily intake of some minerals, macro elements (Na, K, Ca, Mg, ranging from 8.1 to 17.9 mg/100 g), and trace elements (Fe, Zn, Mn, Cu ranging from 5.1 to 15.2 mg/100 g) according to Ruperez (2002). In this regard, some studies have been directed to demonstrate the effect of the consumption of *U. pinnatifida* on the bones calcification in rats (Yamaguchi, Hachiya, Hiratuka, & Suzuki, 2001); however, the results obtained were not conclusive in favor of the consumption of this alga. Another study investigated the effect of fiber from *U. pinnatifida* on the cardiovascular diseases (hypertension and hypercholesterolemia) (Ikeda *et al.*, 2003). In the same study (Ikeda *et al.*, 2003), authors discuss that the possible preventive effect of this alga on cerebrovascular diseases could be partially due to its content in fucoxanthin, which could protect of ischemic neuronal cells death. Other authors claimed that fucoxanthin from algae could increase the metabolism, helping to control the weight and reducing the obesity in animal studies (Maeda, Hosokawa, Sashima, Funayama, & Miyashita, 2005).

In a recent study (Amano, Kakinuma, Coury, Ohno, & Hara, 2005), the usefulness of a mixture of several brown algae (*Eisenia bicyclis* ('Arame'), *Hizikia fusiformis* ('Hijiki'), and *U. pinnatifida* sporophylls ('Mekabu')) and the red alga *Porphyra yezoensis* ('Susabinori') was investigated for the reduction of lipid levels in blood and thrombosis prevention. This effect was associated to the presence of polysaccharides in all the algae. In this study, a group of rats were fed using a cholesterol-rich diet containing this mixture of algae (9–10% w/w) for 28 days. Serum total cholesterol, LDL cholesterol, free cholesterol, and triglyceride levels were significantly reduced to 49.7%, 48.1%, 49.0% and 74.8%, respectively, of those of the control. Nevertheless, HDL cholesterol did not present significant changes, while platelet aggregation also decreased significantly (Amano *et al.*, 2005).

Fatty acids and sterols content determined in red alga *C. crispus* showed that the main fatty acids were palmitic, palmitoleic, oleic, arachidonic and eicosapentanoic acids (Tasende, 2000). These five fatty acids represent more than 78% of the total fatty acids content, showing that unsaturated fatty acids are present in a much greater quantity (>80%) than saturated fatty acids. The major sterol was cholesterol (>94%), containing smaller amounts of 7-dehydrocholesterol and stigmasterol and minimum amounts of campesterol, sitosterol and 22-dehydrocholesterol (Tasende, 2000).

The red alga *Porphyra sp.*, contained sulphated polysaccharides (porphyrans) that have been shown to present potential apoptotic activities (Kwon & Nam, 2006).

Cystoseira spp.* and *Ulva spp.

Cystoseira spp. belongs to the group of brown algae, while *Ulva spp*. belongs to the group of green algae. These two macroalgae are good natural sources of proteins, carbohydrates, minerals and vitamins, while containing low levels of lipids.

Cystoseira spp. possesses, among their more significant compounds, different types of terpenes. Terpenes containing aryl groups have been attracting more and more attention because they present a broad spectra of pharmacological activities, and combine valuable curative properties with practically no harmful side effects. A very comprehensive review on arylterpenes in algae was carried out by Kukovinets and Kislitsyn (2006). The existing information about terpenes contents in algae can be summarized as follows.

The more representative diterpenes are of types 1–3 (see Fig. 1), which exhibit antimicrobial activity, and were isolated from the marine alga *Cystoseira spinosa* var. *Squarrosa*. On the other hand, brown algae *Cystoseira usneoides*, which contained usneoidone E, exhibited antiviral and antitumor activity (Kukovinets & Kislitsyn, 2006). The marine algae *Cystoseira josteroides* and *Sargassum macrocarpum* are good sources of zosterdiol A, zosterdiol B, zosteronol and zosteronediol and of a new toluquinol derivative with antibacterial properties. Prenyldiketones (see Fig. 2) were found in important amounts in the marine alga *Cystoseira spp*. (Kukovinets & Kislitsyn, 2006). However, no biological activity of these compounds has been reported so far.

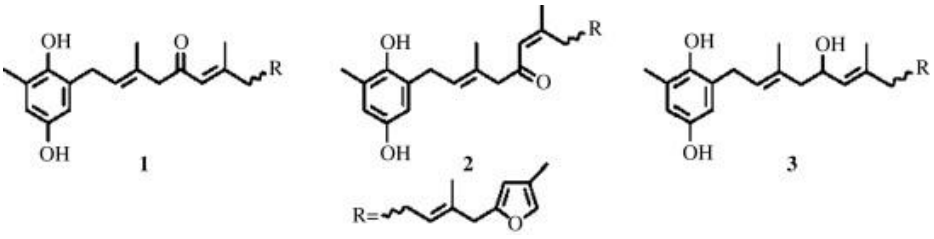

Fig. 1. Diterpenes of alga *Cystoseira spinosa* var. *Squarrosa*. Modified from Kukovinets and Kislitsyn (2006).

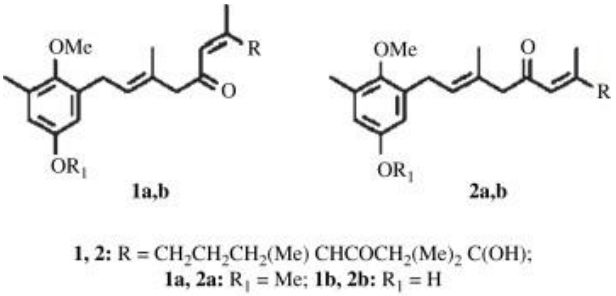

Fig. 2. Diterpenes from alga *Cystoseira spp.* Modified from Kukovinets and Kislitsyn (2006).

Antimicrobial activity of several extracts of the alga *Cystoseira barbata* has also been investigated (Ozdemir, Horzum, Sukatar, & Karabay-Yavasoglu, 2006). Namely, hexane, methanol, dichloromethane and chloroform extracts were tested for their antimicrobial activities against four Gram-positive bacteria, four Gram-negative bacteria and *Candida albicans* ATCC 10239 yeast (Ozdemir *et al.*, 2006). Hexane extracts showed higher antimicrobial activity than methanol, dichloromethane and chloroform extracts. The volatile oils of these algae did not remarkably inhibit the growth of tested microorganisms. In these volatile oils authors identified hydrocarbon compounds such as docosane (7.61%) and tetratriacontane (7.47%), among others.

According to the investigation carried out by Kapetanovic *et al.* (2005), the main sterols in the green alga *Ulva lactuca* were cholesterol and isofucosterol, while in the brown alga *Cystoseira adriatica*, the principal sterols were cholesterol and stigmast-5-en-3 beta-ol, containing the latter a very low concentration of fucosterol (Kapetanovic *et al.*, 2005).

Sulphated polysaccharides have been identified in the brown alga *Cystoseira canariensis* (Ramazanov, Jimenez del Rio, & Ziegenfuss, 2003). These sulphated polysaccharides comprise a complex group of macromolecules with a wide range of important physiological properties able to regulate the bioactivity of growth factors and cytokines such as the basic fibroblast growth factor, interferon, various enzymes and transforming growth factor (Ramazanov *et al.*, 2003).

The antifungal and anti-aflatoxinogenic activity of the brown alga *Cystoseira tamariscifolia* has also been studied against pathogenic and toxigenic strains of yeasts and moulds (Zinedine, Elakhdari, Faid, & Benlemlih, 2004). Namely, antimicrobial effect of different alga extracts (using methanol, ethanol, diethyl ether, hexane, chloroform and water) was investigated. Results from inhibitory tests showed that only ethanolic extracts present antimicrobial activity against moulds and yeasts. The growth of two types of yeasts, *C. albicans* HSZ02 and *C. albicans* IP4872, was completely inhibited by a concentration of 50 and 100 ppm of ethanolic extract of this alga. The growth of the species *Sacharomyces cerevisiae* S326 was affected by 25 ppm of ethanol extract. For moulds, the growth of *Penicillium cyclopium* strain IP1231-80 was inhibited by 50 ppm while the growth of all *Aspergillus* strains used was inhibited by 100 ppm of the same extract. The ethanolic extract of *C. tamariscifolia* showed also aptitude to reduce the production of aflatoxin B1 by *Aspergillus parasiticus* NRRL2999. Results showed that the reduction on aflatoxin B1 biosynthesis was, respectively, about 25.4%, 37.6%, 75.8%, and 96.3% by 10, 25, 50, and 100 ppm of the ethanolic extract.

Contents of proteins, ashes, humidity and carbohydrates were determined for different macroalgae (De Padua, Fontoura, & Mathias, 2004). It was observed that *Ulva oxysperma* and *Ulva spp* showed high mineral levels and low calories, while *U. oxysperma* presented lower protein levels than *Ulva spp*. (De Padua *et al.*, 2004). As an example, composition of *U. oxysperma* was determined to be the following: humidity (16–20%), ash (17–31% dry base), proteins (6–10% dry base), lipids (0.5–3.2% dry base), fibers (3–12% dry base), and carbohydrates (46–72% dry base); which corresponded to 192–270 kcal/100 g (wet base). On the other hand, *U. lactuca* (15–18% dry base) and *Ulva fasciata* (13–16% dry base) revealed a content slightly higher of proteins, but a similar energetic content (250–272 and 225–239 kcal/100 g, respectively) (De Padua *et al.*, 2004).

Discussion on the potential of some algae as natural sources of functional ingredients

One of the main objectives of the functional food science is to identify the beneficial interactions among a food, or specific ingredient, and one or more functions of the organism, obtaining, if possible, definitive proofs about the mechanisms involved in the interaction. This primary objective must be based on investigations *in vitro* or *ex vivo* in cellular lines or culture tissues, later in animal models and finally they must be corroborated in studies of observation or intervention in human (clinical trials).

The rigorous design of a functional food needs to know the biological activity at molecular level of their components and the bases of the disease (or diseases) considered as target. The recent branch of science that studies interactions between genes and food ingredients is called Nutritional Genomic or Nutrigenomic ([Palanca et al., 2006] and [Roche, 2006]). Theoretically, we might manage to select a diet according to our genome with the objective to reduce the genetic risk of suffering certain diseases or to find on the market products designed specifically for “difficult days”, for some sports competitions, etc. (Marriott, 2000).

The principal guideline to follow in the design of a new functional food is to increase as much as possible the benefit/risk ratio, acting simultaneously on both: trying to increase to the maximum the benefit and to

reduce to the minimum the risk. Increasing the benefit implies to look for a physiological wide effect, assuring that existing bioavailability and that the mentioned bioavailability are going to be kept along all the useful life of the food. In order to reduce the risk it is necessary to carry out toxicity studies, to use the functional ingredient in a minimal effective doses and to use as functional ingredients products naturally found in foods or natural sources.

The composition of the different algae described above shows that these organisms can be an interesting natural source of functional ingredients (see Table 4). Thus, in general all of them present good nutritional values that make them good candidates as source of proteins, carbohydrates, fiber, minerals, vitamins and, besides, they present a low content in lipids. Although, logically, the toxicological aspects associated with some of their components must be taken into account here. It is interesting to mention that their content in proteins, carbohydrates, lipids, fiber, metabolites, etc. can be influenced by the growing parameters (water temperature, salinity, light and nutrients), concluding that algae can be considered as a magnificent bioreactor able to provide different types of compounds at different quantities.

Table 4.

Some examples of algae together with their functional ingredients and possible effect on human health

Algae	**Functional ingredients**	**Possible health effect**
Sargassum vulgare	Alginic acid, xylofucans	Antiviral activity
Himanthalia elongate	PUFAs	Reduce risk of certain heart diseases
	α-Tocoferol	Antioxidant activity
	Sterols	Reduce total and LDL cholesterol
	Soluble fiber	Reduce total and LDL cholesterol
Undaria pinnatifida	PUFAs	Reduce risk of certain heart diseases
	Sterols	Reduce total and LDL cholesterol
	Soluble fiber	Reduce total and LDL cholesterol
	Folates	Reduce risk of certain types of cancer
	Sulphated polysaccharides	Antiviral activity
	Fucoxanthin	Preventive effect on cerebrovascular diseases
		Increase the metabolism
Phorphira spp.	PUFAs	Reduce risk of certain heart diseases
	Sterols	Reduce total and LDL cholesterol

Algae	Functional ingredients	Possible health effect
	Soluble fiber	Reduce total and LDL cholesterol
Chondrus crispus	PUFAs (n-3) fatty acids	Reduce risk of certain heart diseases
	Sterols	Reduce total and LDL cholesterol
	Soluble fiber	Reduce total and LDL cholesterol
	Sulphated polysaccharides (porphyrans)	Apoptotic activities
Cystoseira spp.	Terpenes	Valuable curative properties
	Sterols	Reduce total and LDL cholesterol
	Sulphated polysaccharides	Regulate the bioactivity of growth factors and cytokines
Ulva spp.	Sterols	Reduce total and LDL cholesterol

Algae have mainly been used in west countries as raw material to extract alginates (from brown algae) and agar and carragenates (from red algae). However, from the description given above it is concluded that algae also contain multitude of bioactive compounds that might have antioxidant, antibacterial, antiviral, anticarcinogenic, etc. properties. Some of them are outlined later due to their special interest as possible functional ingredients.

Thus, the main part of the described algae presents a high fiber content in which the soluble fraction is composed principally of sulphated galactans as agar or carragenates (in red algae) and of alginates, fucans and laminarin (in brown algae). Consumption of dietetic fiber has a positive influence on several aspects related to health, reducing the risk of suffering colon cancer, constipation, hypercholesterolemia, obesity and diabetes. Besides, many constituents of the dietetic fiber show antioxidant activity as well as immunological activity (Suzuki *et al.*, 2004). In this sense, *U. pinnatifida* (wakame) showed some positive effect on several cardiovascular diseases (hypertension and hypercholesterolemia) (Ikeda *et al.*, 2003); this alga contains basically dietetic fiber, being its principal component alginate. This alginic acid has demonstrated to reduce hypertension in hypertensive rates (Ikeda *et al.*, 2003).

Another family of compounds of great interest, and that are common to many of the algae described in this work, are polysaccharides with potential antiviral action. For example, *S. vulgare* contains alginic acid, xylofucans and two species of fucans (Dietrich *et al.*, 1995), whereas *U. pinnatifida* (brown alga) contains high levels of sulphated polysaccharides, specifically, sulphated fucans (fucoidans) (Hemmingson *et al.*, 2006) and sulphate of galactofucan (Thompson & Dragar, 2004). These compounds have demonstrated a powerful antiviral activity against herpes type 1 virus (HSV-1), HSV-2, and cytomegalovirus in humans (HCMV). The fucoidans, moreover, might be used also as anticoagulant and antithrombotics agents (Lee, Hayashi, Hashimoto, Nakano, & Hayashi, 2004), and they have

demonstrated, in studies *in vivo*, to have an antitumoral effect in rats with mammary carcinogenesis (Maruyama, Tamauchi, Hashimoto, & Nakano, 2003). On the other hand, the red alga *Porphyra sp*. contains a sulphated polysaccharide called porphyran that has demonstrated some potential apoptotic activity (evaluated using AGS cells from a human gastric cancer) inducing the death of the carcinogenic cells (Kwon & Nam, 2006).

Among the most relevant compounds found in the algae, antioxidants are probably the substances that have attracted major interest. Algae, as photosynthetic organisms, are exposed to a combination of light and high oxygen concentrations what induces the formation of free radicals and other oxidative reagents. The absence of structural damage in the algae leads to consider that these organisms are able to generate the necessary compounds to protect themselves against oxidation. In this respect, algae can be considered as an important source of antioxidant compounds that could be suitable also for protecting our bodies against the reactive oxygen species formed e.g., by our metabolism or induced by external factors (as pollution, stress, UV radiation, etc.). In algae there are antioxidant substances of very different nature, among which vitamin E (or α-tocopherol) and carotenoids can be highlighted within the fat-soluble fraction, whereas the most powerful water-soluble antioxidants found in algae are polyphenols, phycobiliproteins and vitamins (vitamin C).

In brown algae the principal tocopherol is α-tocopherol (0.052 mg/g in *H. elongata*), this compound is highly stable to heat and acids, and unstable to alkali, UV radiation and oxygen. α-Tocopherol has antioxidant activity because it fixes free radicals, thanks to the presence of a phenol group in its structure. Carotenoids are a family of compounds of importance also due to their high antioxidant activity and its great structural diversity. There are numerous studies that associate the antioxidant activity of different algae with the carotenoids contents. In this regard, a type of carotenoids called xantophylls obtained from *U. pinnatifida* have demonstrated some activity against cerebrovascular diseases (Ikeda *et al.*, 2003).

Algae are also a magnificent source of polyunsaturated fatty acids, as the eicosapentanoic acid (EPA) described in *H. elongata*, *U. pinnatifida* and *Porphyra sp*. These ω3 fatty acids have demonstrated their effect on the reduction of coronary diseases, thrombosis and arteriosclerosis (Simopoulos, 2004).

Other compounds of great importance that can be found in most of the algae described in this work are sterols. Diverse clinical studies have demonstrated that diets with sterols (from plants) might help to reduce cholesterol levels in blood. Additionally, they have antiinflammatory, antibacterial, antifungicidal, antiulcerative and antitumoral activity ([Dunford and King, 2000], [Kamal-Eldin et al., 1998] and [Sanchez-Machado et al., 2004c]).

In summary, in this work a bibliographical revision has been carried out on the composition and biological activity of some algae discussing their possibilities as natural sources of functional ingredients. Thus, it is possible to conclude that these organisms show a high potential as natural sources of ingredients with many different biological activities. However, once their usefulness is demonstrated, it will be necessary to approach other new aspects related to e.g., production of ingredients at industrial scale, algae growing, ingredients extraction, purification, etc. In this regard, the development of environment-friendly extraction

processes to isolate the compound (or compounds) of interest in a fast, cost-effective and non-aggressive way will be one of the main topics for new developments. It is foreseeable that this line of investigation (i.e., the search of new functional ingredients from natural sources) will be one of the hot challenges in Food Science and Technology that, basically, tries to give response to the social demand of new functional foods with scientifically demonstrated health properties.

Acknowledgements

This work has been financed by Ministerio de Educación y Ciencia (Project AGL2005-06726-C04-02) and by Comunidad de Madrid (Project ALIBIRD, S-505/AGR-0153). MP would like to thank CSIC for a I3P grant.

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