



Dietary fibre and physicochemical properties of several edible seaweeds from the northwestern Spanish coast

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ABSTRACT

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%). Total dietary fibre content ranged from 29.3 to 37.4% of which 39.1–74.7% was soluble. For brown algae, the soluble fibre contained uronic acids from alginates and neutral sugars from sulphated fucoidan and laminarin. For red seaweeds, the main neutral sugars corresponded to sulphated galactans (carrageenan or agar). Insoluble fibres (7.4–22.7%) were essentially made of cellulose with an important contribution of Klason lignin especially in brown seaweeds (9.5–10.8%). Regarding the main physicochemical properties, swelling and water retention capacity were high in all samples, while oil retention was low, related to the hydrophilic nature of fibre polysaccharides. In conclusion, these seaweeds can be estimated as a good source of food fibre, protein and minerals for human consumption.

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1. Introduction

While marine algae have traditionally formed part of the Oriental diet, especially in Japan, China and Korea (Nisizawa, Noda, Kikuchi & Watanabe, 1987; Murata, & Nakazoe, 2001; FAO, 2002); their major use in Western countries has traditionally concentrated on the extraction of compounds used by pharmaceutical, cosmetics, and food industries as source of phycocolloids, thickening and gelling agents (production of agar, alginate, carrageenan, etc) (Mabeau & Fleurence, 1993; Jiménez-Escrig & Goñi, 1999; Jiménez-Escrig & Sánchez-Muniz, 2000). However, in recent decades there has been an increase in direct consumption of marine algae as food in Western countries and most recently as components of functional foods (Shahidi, 2009) because of their especial nutritional properties. Although varying from one type to another, edible marine algae, sometimes referred to as seaweeds, are known for their richness in polysaccharides, proteins (Fleurence, 1999), minerals and vitamins (Mabeau & Fleurence, 1993; Rupérez & Saura-Calixto, 2001; Rupérez,

Ahrazem, & Leal, 2002) and their low lipid content (1–3% algal dry weight) (Jiménez-Escrig, & Goñi, 1999; Dawczynski, Schubert, & Jahreis, 2007) with high concentrations of certain long-chain polyunsaturated fatty acids (Bocanegra, Bastida, Benedí, Ródenas, & Sánchez-Muniz, 2009).

The consumption of seaweeds is subject to specific regulation (Mabeau & Fleurence, 1993) and the details of their chemical composition and variations among species are required to obtain authorisation for its use in human nutrition. France has been the first European country to establish a specific regulation concerning the use of seaweeds for human consumption (Mabeau & Fleurence, 1993). Currently, in Spain seaweeds are considered as novel foods and for the purposes of controlling the maximum limit of contaminants they have been included in the canned vegetables group (RD, 2420/78); but there are no specific regulations for seaweed and derived products and their consumption is limited.

Seaweeds contain large amounts of polysaccharides, most of which are not digested by humans, whose gastrointestinal tract does not produce the required degradation enzymes; therefore, they can be regarded as dietary fibres. From a nutritional point of view, seaweeds are interesting because of their high content in dietary fibre (33–75%) (Jiménez-Escrig & Goñi, 1999; Jiménez-Escrig & Sánchez-Muniz, 2000), particularly rich in the soluble fractions (50–85% of total dietary fibre content); which in red seaweeds (Rhodophyta) are mostly composed of sulfated galactans, such as agar and carrageenans. In brown seaweeds (Phaeophyta), soluble dietary fibre polysaccharides

Abbreviations: EDTA, ethylene-diamine-tetra-acetic acid; SDF, soluble dietary fibre; IDF, insoluble dietary fibre; TDF, total dietary fibre; NS, neutral sugars; UA, uronic acids; KL, Klason lignin; GLC, gas-liquid chromatography; FID, flame ionization detector; SC, swelling capacity; WRC, water retention capacity; ORC, oil retention capacity; ANOVA, analysis of variance.

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are alginates, fucans, and laminarans; the insoluble fibres are essentially made of cellulose (Jiménez-Escrig & Sánchez-Muniz, 2000). This dietary fibre content can be calculated as non-starch polysaccharides plus lignin (Rupérez & Saura-Calixto, 2001) according to the AOAC dietary fibre method (Prosky, Asp, Schweizer, DeVries, & Furda, 1988).

Dietary fibre from different algal sources is known for the capacity to lower serum cholesterol levels (Jiménez-Escrig & Sánchez-Muniz, 2000; Ginzberg, Cohen, Sod-Moriah, Shany, Rosenshtrauch, & Arad, 2000) and the potential to be used as natural antioxidants by the food industry (Jiménez-Escrig, Jiménez-Jiménez, Pulido, & Saura-Calixto, 2001; Rupérez, Ahrazem, & Leal, 2002). These properties of seaweed polysaccharides seem to be due to their ability to disperse in water, retain cholesterol and related physiologically active compounds and inhibit lipid absorption in the gastrointestinal track, and also due to the antioxidant bioactivity of sulphated polysaccharides and polyphenols (Rupérez et al., 2002; Díaz-Rubio, Pérez-Jiménez, & Saura-Calixto, 2009).

These properties confer on the seaweed the potential to be used in food technology for the acquisition of low-calorie food (Kadam & Prabhasankar, in press; Murata & Nakazoe, 2001; Sakata, 1995) and might be important in body weight control, as well as in prevention of gastrointestinal (Lahaye & Kaeffer, 1997) and cardio-vascular (Bocanegra et al., 2009) diseases.

Several edible Spanish seaweeds which are commonly used in the oriental diet are known world-wide by their Japanese names as Kombu (*Laminaria* spp.), Wakame (*Undaria pinnatifida*) and Nori (*Porphyra* spp.). They are a good source of food ingredients and new dietary fibre-rich products (Rupérez & Saura-Calixto, 2001). Indeed, many other brown and red types of seaweed are present in the Spanish coasts and the details of their chemical composition and physicochemical properties are required in order to fulfill the increasing demand for Spanish seaweed products. The aim of the present study was to evaluate the nutritional composition, namely dietary fibre, of several brown and red Spanish seaweeds, which are not so commonly consumed, and their physicochemical properties (swelling, water and oil retention capacity) that are mainly responsible for their physiological effects.

2. Materials and methods

2.1. Raw material

Brown seaweeds (Phaeophyta) *Himantalia elongata* (L.) S.F. Gray (sea spaghetti; Fucales, Himantaliaceae), *Bifurcaria bifurcata* R. Ross (Fucales, Cystoseiraceae) and *Laminaria saccharina* (L.) J.V. Lamouroux (sweet Kombu; Laminariales, Laminariaceae); and red seaweeds (Rhodophyta) *Mastocarpus stellatus* (Stackhouse) Guiry (Gigartinales, Gigartiniaceae) and *Gigartina pistillata* (S.G. Gmelin) Stackhouse (Gigartinales, Gigartiniaceae) were obtained from a local supplier (Porto-Muiños, Cambre, Coruña, Spain). All the seaweeds were collected during spring–summer 2008 and 2009, except for *L. saccharina* which was cultured under sea natural conditions. In the supplier industry, seaweeds were cleaned from ephyphytes and sand, washed with tap running water, air-dried at 50 °C and milled to less than 1.0 mm particle size. The milled seaweed samples were stored in sealed plastic bags at 2 °C several months until analysis. Residual moisture content was determined by drying at 105 °C in an oven to constant weight.

2.2. Chemical analysis

2.2.1. Protein, oil and ashes

Protein content was determined with a Leco FP-2000 Instrument. In brief, powdered samples were weighed (50–100 mg) into ceramic boats and loaded into the FP-2000, where they were combusted in the pure oxygen environment of the furnace. After passing through a thermo-

electric cooler to drop out water, an aliquot from the combustion gasses was taken. Gasses were scrubbed, and all nitrogen-containing materials were reduced to N₂, and detected by a thermal-conductivity cell. An air blank was carried out and the instrument calibrated with EDTA. Protein was calculated as nitrogen × 6.25.

Oil was extracted from 1 g (dry weight) seaweed sample with 50 mL petroleum ether in a Soxhlet system (Tecator). For ashes, seaweed samples were incinerated in a furnace at 550 °C for 16 h and weighed.

2.2.2. Dietary fibre

Soluble and insoluble dietary fibre fractions were determined according to the AOAC enzymatic-gravimetric method (Prosky et al., 1988), omitting α-amylase and amyloglucosidase treatment for brown seaweeds, because they contain negligible amounts of starch (Goñi, Valdivieso, & Gudiel-Urbano, 2002). After the enzymatic treatment the samples were dialysed against water for 48 h. Soluble dietary fibre (SDF) dialysates were then hydrolysed with 1 M sulphuric acid (100 °C, 1.5 h). In order to quantify a precipitate which appeared after the hydrolysis, the hydrolysates were centrifuged and the insoluble residue obtained was washed with distilled water to almost neutral pH and then dried at 60 °C in an oven to constant weight.

Insoluble dietary fibre (IDF) residues obtained after enzymatic treatment and centrifugation were hydrolysed with 12 M sulphuric acid (30 °C, 1 h) and 1 M sulphuric acid (100 °C, 1.5 h). The residual material was dried (105 °C, overnight) and quantified as Klason lignin (KL).

Neutral sugars (NS) from the hydrolysates of fibre fractions (SDF and IDF) were identified and quantified by gas–liquid chromatography (GLC) as alditol acetates with inositol as internal standard. A Shimadzu gas chromatograph model GC-14A equipped with a flame ionization detector (FID), an automatic injector (AOC-14) and a Hewlett-Packard HP-Chem Station with an HP-Deskjet 600 printer were used. The column was a Supelco SP-2330 capillary fused silica, 30 m × 0.32 mm i.d., 0.2 μm film thickness. The oven, injector and detector temperatures were: 240 °C (isothermal), 270 °C, and 270 °C, respectively. The split ratio was 1:10 and the carrier gas (nitrogen) head column pressure was 0.75 kg/cm².

Uronic acids (UA) in the hydrolysates were quantified colorimetrically by the Scott method, with galacturonic acid as standard and 3,5-dimethylphenol as the reagent (Scott, 1979), and corrected for incomplete recovery of uronic acids (26.9 g/100 g) from alginate hydrolysis (Rupérez et al., 2002).

Soluble dietary fibre was calculated as NS, plus UA, plus the residue (resistant to the hydrolysis), and insoluble dietary fibre was calculated as NS, plus UA, plus KL.

2.3. Physicochemical properties

Swelling and water retention capacity in seaweed samples were assessed following the experimental protocol used in a European collaborative study (Robertson, De Monredon, Dysseleer, Guillon, Amadó & Thibault, 2000). In addition oil retention capacity was measured.

2.3.1. Swelling capacity (SC)

The dry powdered sample (500 mg) was weighed in a 10 mL measuring cylinder (0.1 mL graduations) and 10 mL distilled water, containing 0.02% sodium azide as bacteriostatic was added. Then, it was stirred gently to eliminate trapped air bubbles and left on a level surface at room temperature overnight (18 h) to allow sample to settle. The volume (mL) occupied by the sample was measured and SC was expressed as mL/g of dry sample.

2.3.2. Water retention capacity (WRC)

Thirty millilitres of distilled water, containing 0.02% sodium azide was added to 500 mg of dry powdered samples in a 50 mL centrifuge tube. The sample was stirred and left at room temperature for 18 h.

After centrifugation at 3,000×g for 20 min, the supernatant was discarded, the residue was weighed and WRC calculated as g water/g of dry sample.

2.3.3. Oil retention capacity (ORC)

The same protocol as above was followed, but using commercial virgin olive oil (0.4°) instead of water. ORC was expressed as g olive oil retained/g of dry sample.

2.4. Statistical analysis

All determinations were performed at least in triplicate, the data were expressed as means ± standard deviations, and reported on a dry matter basis.

One-way analysis of variance (ANOVA) was carried out to assess for any significant differences between the means. Differences between means at the 5% ($P < 0.05$) level were considered significant.

3. Results and discussion

3.1. Proximate composition (moisture, ashes, protein and oil content)

Moisture contents were very similar in all samples (see Table 1) with the lowest value for *Laminaria* (6.64% dry weight) and the highest for *Gigartina* (9.86% dry weight).

3.1.1. Ash

Ashes contents were high and ranged from 24.99% (*Mastocarpus*) to 36.41% (*Himanthalia*) (Table 1). Similar values have been reported by other authors for red and brown seaweeds (Mabeau & Fleurence, 1993; Rupérez & Saura-Calixto, 2001; Cofrades, López-López, Solas, Bravo, & Jiménez-Colmenero, 2008; Sánchez-Machado, López-Cervantes, López-Hernández, & Paseiro-Losada, 2004). This high ash content is a general feature of seaweeds, and these values are generally much higher than those of terrestrial vegetables other than spinach (Rupérez, 2002). Besides, they vary between species, between geographical locations and between seasons (Ito & Hori, 1989; Kaehler, & Kennish, 1996). Inorganic anion profile of these five seaweeds has been determined by ion chromatography and reported recently by our group (Gómez-Ordóñez, Alonso & Rupérez, 2010). Brown seaweeds are characterized by higher chloride content up to 33.7–36.9% ash dry weight, while red seaweeds are characterized by higher sulphate content (45–57% ash dry weight). Besides chloride and sulphate, small amounts of fluoride, nitrate and phosphate and trace amounts of nitrite and bromide are found in all the seaweeds (Gómez-Ordóñez et al., 2010). Related to their mineral content, these seaweeds may serve as food supplement to help meet the recommended daily intakes of some minerals and trace elements, as well as in other seaweeds studied previously (Rupérez, 2002).

3.1.2. Protein

For brown seaweeds, the contents ranged from 10.9 to 25.7% (Table 1), while being much higher for *Laminaria* (25.7%) followed by the red ones (15.5–21.3%), within the values reported for other authors (Fleurence, 1999; Sánchez-Machado, Lopez-Cervantes et al., 2004).

Table 1

Moisture, ashes, protein and oil content (% dry weight) in edible Spanish seaweeds.

Seaweed	Moisture	Ashes	Protein	Oil
<i>Himanthalia</i>	9.08 ± 0.02 ^{ac}	36.41 ± 0.15 ^a	14.08 ± 0.21 ^a	0.94 ± 0.07 ^a
<i>Bifurcaria</i>	8.73 ± 0.04 ^a	34.31 ± 0.21 ^b	10.92 ± 0.10 ^b	5.67 ± 0.32 ^b
<i>Laminaria</i>	6.64 ± 0.06 ^b	34.78 ± 0.08 ^c	25.70 ± 0.11 ^c	0.79 ± 0.07 ^a
<i>Mastocarpus</i>	8.86 ± 0.04 ^a	24.99 ± 0.12 ^d	21.30 ± 0.18 ^d	0.39 ± 0.02 ^c
<i>Gigartina</i>	9.86 ± 0.07 ^c	34.56 ± 0.47 ^{bc}	15.59 ± 0.28 ^e	0.57 ± 0.06 ^a

Data are mean values of triplicate determinations ± standard deviation.

Means with different letters in each column differ significantly ($P < 0.05$).

Sánchez-Machado, López-Cervantes, et al. (2004) have reported lower protein content (5.46 % dry weight) in *H. elongata* dried seaweeds, and also lower values than their respective canned seaweeds (10.95 % dry weight), than those reported here. According to Fleurence, most brown seaweeds industrially exploited (*Laminaria digitata*, *Ascophyllum nodosum*, *Fucus vesiculosus* and *H. elongata*) have a protein content lower than 15%, (dry weight), except for *U. pinnatifida* (Wakame) and in the present study *L. saccharina*. The favourable conditions of the cultured *L. saccharina* could be responsible for this higher protein content; red seaweeds such as *Porphyra* spp. (Nori) are relatively high in proteins (Rupérez & Saura-Calixto, 2001; Sánchez-Machado, López-Cervantes, et al., 2004). These levels may vary according to the species, geographic area, season or environmental conditions (Ito & Hori, 1989). Indeed, protein content seems to be subject to large variations during the year, with the maximum concentration during winter and the beginning of spring, and the minimum concentration during summer and early autumn period (Galland-Irmouli et al., 1999; Denis et al., 2010). Nevertheless, seaweeds, especially the red seaweeds appear to be an interesting potential source of food proteins.

3.1.3. Oil

Lipid content was very low in all seaweed samples (0.3–0.9%), except for *Bifurcaria* (5.6%, Table 1), but this fell within the ranges reported previously (Jiménez-Escrig & Goñi, 1999; Rupérez & Saura-Calixto, 2001). Studies from lipid extracts of *B. bifurcata* have shown that this species contains a rich array of acyclic diterpens (geranylgeraniol and derived diterpenes) (Valls, Piovetti, Banaigs, Archavlis, & Pellegrini, 1995; Culioli, Di Guardia, Valls, & Piovetti, 2000) and their content can vary between 4.5 and 6.6 mg/g algal dry weight from different coastal locations (Ireland, Spain, and France) (Daoudi et al., 2001). Also, high levels of fucosterol have been reported in *Bifurcaria* and in some brown seaweed (Sánchez-Machado, López-Hernández, Paseiro-Losada, & López-Cervantes, 2004).

3.2. Dietary fibre

Soluble, insoluble and total dietary fibre contents of brown and red seaweeds are shown in Table 2. The total dietary fibre content (TDF, 29.3 to 37.4% dry weight) was slightly lower than previously reported (33–50% algal dry weight; Rupérez & Saura-Calixto, 2001). Besides higher TDF values (50.3% dry weight) have been reported for *H. elongata* (Cofrades et al., 2008) than those reported here, yet these values were still higher than levels reported in most higher plants and terrestrial foodstuffs (Mabeau & Fleurence, 1993; MacArtain, Gill, Brooks, Campbell, & Rowland, 2007).

Also, seaweeds showed higher levels of SDF than IDF as is already known (Jiménez-Escrig & Sánchez-Muniz, 2000; Rupérez & Saura-Calixto, 2001), the opposite of which usually happens in land plants (Anderson & Bridges, 1988). The ratio of SDF to TDF ranged from 39.1 to 74.7%, being higher for red seaweeds, due to their higher SDF content. Slightly lower values of this ratio (43.1–64.9 %) were reported previously for red algae *Chondrus crispus*, and Nori (Rupérez & Saura-Calixto, 2001). Besides, there were statistical

Table 2

Soluble, insoluble and total dietary fibre (% dry weight) in edible Spanish seaweeds.

Seaweed	SDF	IDF	TDF
<i>Himanthalia</i>	23.63 ± 0.48 ^a	13.51 ± 0.45 ^a	37.14 ± 0.86 ^a
<i>Bifurcaria</i>	14.64 ± 0.68 ^b	22.79 ± 0.97 ^b	37.42 ± 0.78 ^a
<i>Laminaria</i>	17.12 ± 0.84 ^c	13.11 ± 0.56 ^a	30.23 ± 0.85 ^b
<i>Mastocarpus</i>	22.85 ± 0.19 ^a	8.85 ± 0.67 ^c	31.70 ± 0.23 ^c
<i>Gigartina</i>	21.90 ± 0.22 ^a	7.41 ± 0.12 ^c	29.31 ± 0.34 ^b

Data are mean values of triplicate determinations ± standard deviation.

Means with different letters in each column differ significantly ($P < 0.05$).

SDF = soluble dietary fibre; IDF = insoluble dietary fibre; TDF = total dietary fibre.

Table 3
Soluble and insoluble dietary fibre fractions (% dry weight) in edible Spanish seaweeds.

Seaweed	SDF			IDF		
	NS	UA	Residue	NS	UA	KL
<i>Himanthalia</i>	5.14 ± 0.75 ^a	12.65 ± 0.95 ^a	5.84 ± 0.22 ^a	3.31 ± 0.64 ^a	0.71 ± 0.03 ^a	9.54 ± 0.40 ^a
<i>Bifurcaria</i>	2.35 ± 0.25 ^b	7.67 ± 0.69 ^b	4.62 ± 0.45 ^b	7.04 ± 0.27 ^b	4.43 ± 0.87 ^b	10.83 ± 0.84 ^b
<i>Laminaria</i>	2.15 ± 0.15 ^b	9.64 ± 0.74 ^c	4.91 ± 0.32 ^{ab}	5.89 ± 0.75 ^{bc}	2.14 ± 0.33 ^c	3.89 ± 0.12 ^c
<i>Mastocarpus</i>	19.00 ± 0.35 ^c	2.35 ± 0.28 ^d	0.09 ± 0.03 ^c	5.18 ± 0.24 ^{ac}	0.62 ± 0.24 ^a	3.45 ± 0.90 ^c
<i>Gigartina</i>	19.48 ± 0.34 ^c	1.27 ± 0.25 ^d	0.25 ± 0.12 ^c	4.73 ± 0.29 ^a	0.21 ± 0.09 ^a	3.24 ± 1.13 ^c

Data are mean values of triplicate determinations ± standard deviation.

Means with different letters in each column differ significantly ($P < 0.05$).

SDF = soluble dietary fibre; IDF = insoluble dietary fibre; NS = neutral sugars; UA = uronic acids; KL = Klason lignin.

significant differences in SDF values between brown and red seaweeds, except for *Himanthalia* with the highest value (23.63%, Table 2) followed by the red ones (21.9–23.1%). This difference in the amount of SDF is related to differences in polysaccharide solubility and composition between brown and red seaweeds. In this way, sulphated polysaccharides in red seaweeds, with a higher proportion in the soluble fraction of dietary fibre, turn up to be more soluble than the polysaccharides of brown algae due to their ability to form viscous gels in the intestinal track (Jiménez-Escrig & Sánchez-Muniz, 2000). For brown seaweeds, the AOAC method for dietary fibre analysis presented some difficulties and after dialysis of the soluble fibre two fractions could be distinguished: a soluble fraction and a sulphuric acid-insoluble residue, this sulphuric acid-insoluble residue ranged 24–31% of the total soluble fibre in the different seaweed tested (Table 3). The higher fraction corresponded to uronic acids (7.6–12.6% dry weight) that came from alginates and the acid-insoluble residue was probably composed of alginic acid. In comparison, only 1.2–2.3% of uronic acids were quantified in the soluble fibre of red seaweeds (Table 3).

Also, soluble fibre in brown seaweeds is composed of neutral glucans, like laminarin and sulphated fucoidans (Lahaye & Kaeffer, 1997). Neutral sugar contents determined by GLC are shown in Table 4. The main sugars detected in brown seaweed were fucose, glucose and galactose, respectively, which possibly corresponded to sulphated fucoidan and laminarin. For red seaweeds the main neutral sugar identified by GLC in SDF was galactose in both algae (Table 4) due to sulphated galactans like agar and carrageenans, as described in this type of algae (Jiménez-Escrig & Goñi, 1999). These values in neutral sugars of SDF were much higher in red seaweeds (19–19.4%; Table 3) than in brown seaweeds (2.15–5.14%; Table 3), and corresponded with values reported previously (Rupérez & Saura-Calixto, 2001).

Insoluble fibre (7.4–22.7% dry weight; Table 2) was composed of neutral sugars (3.3–7.04%), residual uronic acids (0.21–4.43%) from alginates in brown seaweeds and varying amounts of Klason lignin (Tables 2 and 3). The main neutral sugars determined by GLC were

glucose and fucose for brown seaweeds and galactose and glucose for the red ones (Table 5). Insoluble fibres are essentially made of cellulose, plus residual polysaccharides. KL was high, especially in *Bifurcaria* (10.83%) and *Himanthalia* (9.54%), most probably due to protein and other compounds resistant to protease treatment. There were statistically significant differences between IDF in brown and red seaweeds, with the highest value for *Bifurcaria* (22.79%; Table 2) and the lowest values for the red ones (7.41 and 8.85%). Various amounts of polyphenols (Jiménez-Escrig et al., 2001) and other compounds usually are associated to Klason lignin (Pinelo, Arnous, & Meyer, 2006) in brown algae that might be responsible for their higher IDF content. Thus, the highest value for IDF of *B. bifurcata* (IDF = 22.7%, Table 2) may be related to the higher KL content (KL = 10.8%, Table 3).

3.3. Physicochemical properties

The physiological effects of dietary fibre are related to their physicochemical properties. The water associated with fibre is an important consideration when studying the effects of fibre in the diet. Such water will influence the metabolic activity of fibre along the gut. The swelling, water and oil retention capacity of the brown and red seaweed samples are shown in Table 6. SC and WRC of the seaweed samples ranged from 7.2 to 11.4 mL/g dry weight and 4.9 to 10.2 g/g dry weight, respectively, with no statistically significant differences between the two groups (brown and red seaweed). Both *Bifurcaria* (brown alga) and *Mastocarpus* (red alga) with the higher IDF values in each group (Table 2), also showed the lowest (ANOVA one-way, $P < 0.05$) SC and WRC values, indicating the possible relationship between insoluble fibre and water retention capacity. The SC and WRC of the seaweed samples were not only similar to those of *Fucus*, *Kombu*, *Wakame*, *Chondrus* and *Nori* (5.7–10.5 mL/g and 5.1–10.9 g/g dry weight, respectively) reported previously (Rupérez & Saura-Calixto, 2001), but also comparable to those of some soybean by-products (dietary fibre concentrates) as okara (10.54 mL/g and 8.87 g/g dry weight, respectively) also with an important contribution in

Table 4
Neutral sugars determined by GLC (% dry weight) in soluble dietary fibre from edible Spanish seaweeds.

Neutral sugars	Brown seaweeds			Red seaweeds	
	<i>Himanthalia</i>	<i>Bifurcaria</i>	<i>Laminaria</i>	<i>Mastocarpus</i>	<i>Gigartina</i>
Rhamnose	0	0	0.05 ± 0.01	0	0
Fucose	2.37 ± 0.45 ^a	1.16 ± 0.29 ^b	1.18 ± 0.07 ^b	0.06 ± 0.01 ^c	0.11 ± 0.02 ^c
Arabinose	0	0	0.06 ± 0.01	0	0
3,6-Anhydro-Gal [*]	0	0	0	0.05 ± 0.02	0
Xylose	0.17 ± 0.04 ^{ac}	0.14 ± 0.10 ^{ab}	0.10 ± 0.02 ^b	0.43 ± 0.06 ^d	0.19 ± 0.02 ^c
Mannose	0.21 ± 0.04 ^a	0.25 ± 0.09 ^a	0.22 ± 0.05 ^a	0.82 ± 0.02 ^b	0.68 ± 0.15 ^c
6-O-Me-Gal [*]	0	0	0	0.26 ± 0.03	0
Galactose	0.56 ± 0.08 ^a	0.50 ± 0.10 ^a	0.49 ± 0.03 ^a	16.79 ± 2.23 ^b	17.75 ± 1.53 ^c
Glucose	1.84 ± 0.23 ^a	0.30 ± 0.07 ^b	0.08 ± 0.01 ^c	0.58 ± 0.07 ^d	0.75 ± 0.04 ^e
Total sugar	5.14 ± 0.75 ^a	2.35 ± 0.25 ^b	2.15 ± 0.15 ^c	19.00 ± 0.35 ^d	19.48 ± 0.34 ^d

Data are mean values of triplicate determinations ± standard deviation.

Means with different letters in each row differ significantly ($P < 0.05$).

^{*} Tentatively identified as 3,6-anhydrogalactose and 6-O-methylgalactose by their retention times.

Table 5

Neutral sugars determined by GLC (% dry weight) in insoluble dietary fibre from edible Spanish seaweeds.

Neutral sugars	Brown seaweeds			Red seaweeds	
	<i>Himanthalia</i>	<i>Bifurcaria</i>	<i>Laminaria</i>	<i>Mastocarpus</i>	<i>Gigartina</i>
Rhamnose	0	0	0.02 ± 0.01	0	0
Fucose	0.29 ± 0.08 ^{ab}	3.53 ± 0.69 ^c	0.37 ± 0.05 ^a	0	0.03 ± 0.01 ^b
Arabinose	0	0	0	0	0
Xylose	0.05 ± 0.03 ^a	0.12 ± 0.02 ^b	0.07 ± 0.01 ^c	0.21 ± 0.03 ^d	0.04 ± 0.01 ^a
Mannose	0.14 ± 0.06 ^{ab}	0.18 ± 0.04 ^a	0.07 ± 0.01 ^c	0.08 ± 0.01 ^{bc}	0.58 ± 0.17 ^d
6-O-Me-Gal*	0	0	0	0.09 ± 0.02	0
Galactose	0.12 ± 0.06 ^a	0.26 ± 0.07 ^a	0.13 ± 0.02 ^a	3.72 ± 0.89 ^b	3.46 ± 1.09 ^b
Glucose	2.70 ± 0.47 ^a	3.11 ± 0.53 ^b	6.19 ± 0.51 ^c	1.08 ± 0.25 ^d	0.59 ± 0.12 ^e
Total sugar	3.31 ± 0.64 ^a	7.04 ± 0.27 ^b	6.83 ± 0.09 ^b	5.18 ± 0.24 ^c	4.73 ± 0.29 ^c

Data are mean values of triplicate determinations ± standard deviation.

Means with different letters in each row differ significantly ($P < 0.05$).

* Tentatively identified as 6-O-methylgalactose by its retention time.

total indigestible fraction (41.6% dry weight, Espinosa-Martos & Rupérez, 2009). Moreover, SC was comparable to other vegetable food samples such as pea hulls, apple pulp or citrus pulp (10 mL/g dry weight), and higher than those for pea (5.26 mL/g) and chickpea (4.28 mL/g) (Tosh & Yada, 2010). Reported WRC values of the IDF of chickpeas, peas and lentils (10.1–13.4 g/g) (Tosh et al., 2010) were slightly higher than those obtained in the present work for brown and red seaweeds. However, values of WRC are difficult to compare with each other, because they depend on the experimental conditions (temperature, pH, time, centrifugation) as well as on sample preparation and particle size, being the temperature the factor with major influence (Wong & Cheung, 2000; Carvalho et al., 2009).

Fleury and Lahaye (1991) reported that the physicochemical properties of powdered seaweed could be assumed to reflect those of the fibre present. These properties could be related to the hydrophilic nature of the charged polysaccharides of SDF: alginates and fucans (see uronic acid content, Table 3) in brown seaweeds, and agar and carrageenan (see neutral sugar content, Tables 3 and 4) in red seaweeds; although protein is also closely associated with cell wall polysaccharides (Fleury & Lahaye, 1991; Carvalho et al., 2009). In this study, the total contents of protein and TDF in the seaweed samples were up to 48.3–55.9% dry weight, so the physicochemical properties of the brown and red seaweeds might be mainly determined by these two chemical components. These properties confer on the fibre the ability to absorb and hold water, and these polysaccharides can be potentially beneficial in gut health, contributing to water binding, faecal bulking and decreasing transit time, which is a positive factor in preventing colon cancer (Goñi, Gudiel-Urbano, Bravo, & Saura-Calixto, 2001).

Oil retention capacity was low and similar in all seaweed samples (1.22–1.67 g/g dry weight, Table 6). There were statistically significant differences between brown and red seaweeds, with slightly lower values for the red ones, indicating that the nature of their constituents was much more hydrophilic than lipophilic. In view of these results, this hydrophilic nature might work more clearly in the sulphated galactans in red seaweeds than in the polysaccharides

Table 6

Physicochemical properties of edible Spanish seaweeds.

Seaweed	Swelling capacity (mL/g dry weight)	Water retention capacity (g/g dry weight)	Oil retention capacity (g/g dry weight)
<i>Himanthalia</i>	10.97 ± 0.62 ^a	7.26 ± 0.13 ^a	1.61 ± 0.07 ^a
<i>Bifurcaria</i>	7.75 ± 0.73 ^b	4.89 ± 0.12 ^b	1.65 ± 0.11 ^a
<i>Laminaria</i>	10.20 ± 0.37 ^a	8.93 ± 0.52 ^c	1.67 ± 0.11 ^a
<i>Mastocarpus</i>	7.20 ± 0.42 ^b	5.42 ± 0.06 ^b	1.22 ± 0.04 ^b
<i>Gigartina</i>	11.43 ± 0.63 ^a	10.22 ± 0.67 ^d	1.32 ± 0.03 ^b

Mean values of triplicate determinations ± standard deviation.

Means with different letters in each column differ significantly ($P < 0.05$).

(alginate, laminarans and fucans) in the brown ones. Reported ORC values of soybean (0.23 g/g) and okara (0.20 g/g) (Espinosa-Martos & Rupérez, 2009) are lower than those found in the brown and red seaweeds tested in the present work.

4. Conclusion

All the brown and red seaweeds selected from the Spanish northwestern Atlantic coast were a good source of dietary fibre, minerals and protein. The study of their physicochemical properties, together with their chemical composition, reveals their suitability to be a good source of food fibre for human consumption. Yet further studies are necessary (e.g. polysaccharides, fatty acids and amino acids composition) to improve our knowledge about the nutritional value of these marine algae, traditionally consumed in Japan.

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