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Nutritional value of selected macroalgae

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Abstract Macroalgae are traditionally used in human and animal nutrition. Their protein and fiber content have been widely studied and differ according to the species, their geographic origin and their seasonal conditions. In addition to their value for human nutrition, seaweeds have multiple therapeutically applications (e.g., weight control, hypocholesterolemic, antioxidant and antitumor activities, others) and, in general, contribute and promote human health. In the archipelago of the Azores, the consumption of seaweeds is widespread and accepted as a common practice in some islands. This work is aimed at providing information on the protein and fiber content of the locally consumed species, to promote this regional food product that can be potentially profitable from the biotechnology and commercial perspective, and also benefit public health, particularly, taking into account the low level of marine pollution in the Azores archipelago. Protein and fiber content of eight seaweeds (*Porphyra* sp., *Osmundea pinnatifida*, *Pterocladiella capillacea*, *Sphaerococcus coronopifolius*, and *Gelidium microdon,* Rhodophyta; *Cystoseira abies-marina* and *Fucus spiralis*, Phaeophyta; *Ulva compressa*, Chlorophyta) were determined using the Kjeldahl method and the Weende method, respectively. The protein content ranged from 6.81 to 26.62 of dry weight for *C. abies-marina* and *U. compressa*, respectively. Fiber content was generally higher as compared with that in seaweeds from other origins and ranged from 33.82 to 63.88 for *O. pinnatifida* and *F. spiralis*, respectively.

Keywords Fiber · Protein · Seaweeds

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Introduction

In recent years, the number of studies on macroalgae, their chemical composition, physiological and technological properties has grown exponentially, and these organisms have become a focus of commercial interest as potential ingredients of the so-called functional or health-promoting foods, as the use of macroalgae has grown exponentially during the last decade (Sekmokienė et al. 2007). When combined with its texture properties, the use of algae as a functional nutrient seems worthy for exploration (MacArtain et al. 2007). Presently, seaweed-based food additives are commonly used in the preparation of fast food. In this context, virtually every one eats some processed seaweeds every day (Dhargalkar and Verlecar 2009). Edible macroalgae are rich in resistant protein and dietary fiber (Mamatha et al. 2007). Protein content differs according to species being generally low in brown

seaweeds (3±15% of the dry weight) as compared with green or red ones (10±47% of the dry weight; Fleurence 1999).

Like vegetables, such as cabbage, wheat bran and sugar beet pulp (Burtin 2003), average, macroalgae may provide up to 12.5% of a person's daily fiber needs in an 8 g serving intake (MacArtain et al. 2007). The consumption of dietary fibers and plant cell walls containing such fiber components protects human organisms against a number of chronic diseases (e.g., colon cancer, Guidel-Urbano and Goni 2002). Soluble fibers ingestion may exert prebiotic effects probably due to the growth of bifidobacterium (Hoebler et al. 2000). In combination with high-glycemic-intake foods, soluble fibers reduces the overall glycemic response (Goni et al. 2000), namely the reduction of blood cholesterol, and the modulation of blood glucose (Brennan 2005).

Traditionally, the Azoreans have gathered seaweeds either to eat or for chemically material extraction. The brown seaweed *Fucus spiralis* is a local delicacy; the swollen reproductive parts of the frond (the receptacles) are picked and eaten fresh. The red seaweed *Porphyra* sp. is collected, then fried or incorporated into soups or omelets. The red seaweeds *Laurencia* and *Osmundea* are pickled in vinegar with onions, and eaten with fried fish. The commercial harvesting of *Pterocladiella capilacea* and *Gelidium microdon* is a small-scale family business. The algae are gathered, dried, and then exported for agar extraction (Neto et al. 2005; personal observations).

With the current trend for consumers to embrace organically grown natural foods from clean environments, seaweeds should receive an increasing acceptance from the public. There is currently no legislation in Portugal regarding the use of specific seaweed as food products and in the Archipelago of the Azores coastal water bodies are in excellent environmental conditions, according to the parameters of the Water Frame Directive (Neto et al. 2009). Attending to this, in the present investigation we evaluate the protein and fiber contents of selected seaweeds common at the Azorean shores that may be potentially profitable from the biotechnology and commercial perspectives.

Materials and methods

Algae sampling and preparation

The studied Azorean seaweeds (*Ulva compressa* Linnaeus from Clorophyta; *Cystoseira abies-marina* (S.G. Gmelin) C. Agardh and *Fucus spiralis* Linnaeus, from Phaeophyta; *Osmundea pinnatifida* (Hudson) Stackhouse, *Porphyra* sp. C. Agardh, *Pterocladiella capillacea* (S.G. Gmelin) Santelices & Hommersand, *Gelidium microdon* Kützing and *Sphaerococcus coronopifolius* Stackhouse, from Rhodophyta) were collected in the littoral zone (37° 40′ N and 25° 31′ W) of São Miguel Island (Azores, Portugal), during January and February of 2007. In the laboratory, algae were washed in distillate water, air-dried, kept in an air-tight container and frozen to −20°C until further analyses. Previous to analytical procedures, seaweeds were defrosted and dried during 48 h at 65°C until constant weight and then homogenized with liquid nitrogen (ULTRA-TURRAX T50), re-dried at 60°C and stored in a desiccator.

Determination of crude protein

The organic nitrogen content of the dried macroalgae was quantified using a modified Kjeldahl procedure (AOAC 1990) in a VELP Scientifica UDK 132 apparatus. The digestion was performed with sulfuric acid (H_2SO_4), 96%, for 75 min at 420°C, plus 75 min at 370°C, then distilled with acid boric solution (2%) and titrated with HCl 0.1 M. Estimation of the crude protein content was calculated multiplying the organic nitrogen by a factor of 6.25.

Determination of crude fiber

The fiber determination of the dried macroalgae was performed using a modified Weende procedure (AOAC 1990) in a VELP Scientifica *Dosi-Fiber* apparatus. Acid hydrolysis was done with sulfuric acid (H_2SO_4) 0.128 M and the basic hydrolysis with potassium hydroxide (KOH) 0.223 M. The cold extraction was performed with acetone; the sample was then dried (1 h at 105°C) until reach a constant weight, cooled in a desiccator, weighted (W_1), dried back in a muffle at 550°C for 3 h and reweighted (W_2) after cooling in a desiccator. The crude fiber percentage was calculated following the equation: $\%\text{crude fiber} = 100 \times (W_1 - W_2/W_0)$ (initial weight 1–1.5 g).

Results

The yield of samples moisture varied between 9.75% for *O. pinnatifida* and 28.59% for *G. microdon* (Table 1).

The crude protein content varied within the studied species (Table 2), being the highest in *U. compressa* (26.62%) followed by *Porphyra* sp. (25.80%). The lowest protein values were found in the brown species *C. abies-marina* (6.81%) and *F. spiralis* (10.77%).

The crude fiber content was high in all species (Table 2). It was higher in *F. spiralis* (63.88%) followed by *G.*

Table 1 Wet and dry weight of samples given in gram (g) and yield given in percentage (%)

Species	Wet weight (g)	Dry weight (g)	Yield (%)
Rhodophyta			
Sphaerococcus coronopifolius	143.67	20.24	14.09
Gelidium microdon	301.74	86.26	28.59
Pterocladiella capillacea	106.70	27.26	25.55
Porphyra sp.	156.00	31.30	20.06
Osmundea pinnatifida	101.72	9.92	9.75
Phaeophyta			
Cystoseira abies-marina	121.94	19.75	16.20
Fucus spiralis	106.50	19.22	18.05
Chlorophyta			
Ulva compressa	111.50	18.90	16.95

microdon (57.37%), *C. abies-marina* (56.34%), *P. capillacea* (52.08%) and lower in *O. pinnatifida* (33.82%).

Discussion

In general, the crude protein content recorded for the studied red and brown seaweeds was similar to the one reported in other studies (e.g., Fleurence 1999; Rupérez and Saura-Calixto 2001; Burtin 2003; McDermid and Stuercke 2003; Barbarino and Lourenço 2005; Marinho-Soriano et al. 2006; Dawczynski et al. 2007; Hwang et al. 2007; Marsham et al. 2007; Chakraborty and Santra 2008; Polat and Ozogul 2008). On the other hand, the crude protein content obtained for *U. compressa* (26.62%, Table 2) in the present study is higher than the one published for the genus by other authors (3–14%, see Dere et al. 2003; McDermid and Stuercke 2003; Aguilera-Morales et al. 2005; Renaud and Luong-Van 2006; Chakraborty and Santra 2008). These results may reflect the influence of geographic origin, climate, and season and are also likely to be related to environmental differences or different sampling methodologies. In fact, protein content of seaweed varies greatly and could be influenced by season and environmental conditions (Fleurence 1999; Dawczynski et al. 2007). Galland-Irmouli et al. (1999) working with *Palmaria palmata* (Linnaeus) Kuntze registered higher protein levels in plants collected during the end of the winter period and spring and lower amounts in the ones sampled during the summer months.

In general, all the studied species presented high crude fiber content (Table 2), in agreement with other studies (Wong and Cheung 2000; Rupérez and Saura-Calixto 2001; McDermid et al. 2005). From all species, *F. spiralis* had the highest crude fiber content (63.88%), even higher than the value reported by Rupérez and Saura-Calixto (2001) for other species of the genus (*F. vesiculosus* Linnaeus, 50.09±1.77%). This fact may be related to the species, geographical location, season, and/or temperature (Dawes 1998; Jiménez-Escrig and Combrodón 1999). It is also known that the drying method could affect the nutritional value of seaweeds (Chan et al. 1997). If properly dried, seaweed samples can be stored for a number of years without appreciable loss of their gel content (FAO 1976).

Conclusion

This is the first study investigating the nutritional composition of seaweeds usually consumed in the Azores Islands. It revealed important results in what concerns protein and fiber content. The level of digestibility of proteins seems to be related to the amount of soluble fiber in the algae, preventing bioavailability of the proteins (MacArtain et al. 2007). Further work involving biotechnological treatment of the studied seaweeds by enzymatic degradation of algal fibers could improve protein digestibility and, therefore, will increase their nutritional value.

Table 2 Crude protein and crude fiber proximate composition given in mean relative%, (average of $n=2$)

Species	Crude protein	Mean value	Crude fiber	Mean value
Rhodophyta				
Gelidium microdon	14.61	15.18	56.71	57.37
	15.75		58.02	
Osmundea pinnatifida	20.32	20.64	33.94	33.82
	20.97		33.69	
Porphyra sp.	25.64	25.80	43.09	40.98
	25.97		38.86	
Pterocladiella capillacea	20.56	20.52	52.96	52.08
	20.48		51.19	
Sphaerococcus coronopifolius	19.60	19.56	40.60	41.25
	19.51		41.91	
Phaeophyta				
Cystoseira abies-marina	6.94	6.81	56.26	56.34
	6.69		56.40	
Fucus spiralis	10.56	10.77	61.79	63.88
	10.97		65.97	
Chlorophyta				
Ulva compressa	27.52	26.62	40.24	41.16
	25.72		42.08	

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