J Food Sci Technol (November–December 2012) 49(6):774–780
DOI 10.1007/s13197-010-0220-0

ORIGINAL ARTICLE

Evaluation of the proximate, fatty acid and mineral composition of representative green, brown and red seaweeds from the Persian Gulf of Iran as potential food and feed resources

Kiuomars Rohani-Ghadikolaei · Eessa Abdulalian · Wing-Keong Ng

Revised: 7 November 2010 / Accepted: 29 December 2010 / Published online: 29 January 2011

Abstract The proximate, fatty acid and mineral composition were determined for green (*Ulva lactuca* and *Enteromorpha intestinalis*), brown (*Sargassum ilicifolium* and *Colpomenia sinuosa*) and red (*Hypnea valentiae* and *Gracilaria corticata*) seaweeds collected from the Persian Gulf of Iran. Results showed that the seaweeds were high in carbohydrate (31.8–59.1%, dry weight) and ash (12.4–29.9%) but low in lipid content (1.5–3.6%). The protein content of red or green seaweeds was significantly higher ($p<0.05$) compared to brown seaweeds. The fatty acid composition of various seaweed lipids varied considerably with 51.9–67.4% of saturates, 22.0–32.9% of monoenes and 9.2–19.1% of polyunsaturated fatty acids (PUFA). *E. intestinalis* contained the highest total n-3 PUFA content with the lowest n-6/n-3 ratio. Persian Gulf seaweeds contained higher concentrations of all the minerals examined (K, Mg, Fe, Mn, Cu, Zn and Co) compared to terrestrial vegetables. Seaweeds could potentially be used as a food or feed additive in Iran.

Keywords Fatty acids · Minerals · Persian Gulf · Proximate composition · Seaweed

K. Rohani-Ghadikolaei (✉) · W.-K. Ng
Fish Nutrition Laboratory, School of Biological Sciences,
Universiti Sains Malaysia,
Penang 11800, Malaysia
e-mail: roohani2001ir@yahoo.cm

K. Rohani-Ghadikolaei · E. Abdulalian
Aquaculture Department,
Persian Gulf and Oman Sea Ecological Research Institute,
79167-93165, Bandar Abbass, Iran

Introduction

Seaweeds have been used as food, animal feeds, fertilizer and as sources of traditional medicine in many Asian civilizations since ancient times. Seaweeds are excellent dietary sources of vitamins, proteins, carbohydrates, trace minerals and other bioactive compounds (Kumar et al. 2008). In order to fully exploit the nutritional value of seaweeds, several studies on the biochemical and nutritional composition of various seaweeds collected from different parts of the world have been conducted (Rupérez 2002; McDermid and Stuercke 2003; Ortiz et al. 2006; Marsham et al. 2007; Chakraborty and Santra 2008; Matanjun et al. 2009). The biochemical composition of marine seaweeds is generally known to be highly influenced by geographical location and local environmental conditions.

In Iran, there is currently great interest to develop commercial seaweed farming to harness seaweeds with economical value as food, feed and fuel bio-resources. A number of surveys have recently been conducted to identify and map the distribution of Iranian coastal seaweeds. The dominant seaweeds found in Iran belong to the genus Phaeophyta (*Sargassum* spp., *Padina* spp., *Colpomenia sp.,* and *Cystoseira* spp.), Chlorophyta (*Caulerpa* spp., *Ulva* spp. and *Enteromorpha* spp.) and Rhodophyta (*Gracilaria* spp. and *Hypnea* spp.) (Rohani and Hossaini 2005; Rohani et al. 2007). Considering the great potential for the extensive culture of seaweeds along the coastal waters of the Persian Gulf, an initial essential step would be to determine the chemical composition of these indigenous seaweeds to ascertain their potential as a food and feed source, as well as potential industrial applications based on agar, alginate and carrageenans from seaweed processing.

As far as we know, there is currently no published data on the chemical composition of seaweeds from the Persian Gulf of Iran. In the present study, the proximate, fatty acid and mineral composition as well as the chlorophyll-*a* content of representative green, brown and red seaweeds collected from the Persian Gulf was determined.

Materials and methods

Sample collection and preparation

In total, six seaweeds, two green [*Ulva lactuca* (Linnaeus) and *Enteromorpha intestinalis* (Linnaeus) Nees], two brown [*Colpomenia sinuosa* (Endlicher) Derbès & Solier and *Sargassum ilicifolium* (Turner) C. Agardh], and two red [*Gracilaria corticata* (J. Agardh) J. Agardh and *Hypnea valentiae* (Turner) Montagne] were collected from the northern coast of the Persian Gulf of Iran for analyses in the present study. Immediately after collection, the seaweed samples were cleaned and washed with seawater to remove sand, debris, epiphytes and other extraneous matter attached to the thalli and transported to the laboratory. In the laboratory, the samples were sorted and then thoroughly cleaned by rinsing with distilled water. The cleaned seaweed samples were then freeze-dried (ZirBus VaCo 5, Germany). After reaching constant weight, the dried samples were ground (for 5 min) into a fine powder using a coffee grinder and passed through a 0.5 mm sieve before being stored in dark labeled glass jars in a refrigerator at 4° C until chemical analysis. All chemical analysis of seaweed samples was carried out in triplicates.

Proximate composition analysis

The moisture content (%) of seaweeds was determined by drying 2 g of samples in a thermo regulated incubator (Memert 40050ip20, Germany) at 105°C until constant weight (AOAC 1997). Moisture absorption (%) was determined by subtracting of freeze-dried from oven-dried seaweed sample. Ash content was determined by heating the samples for 4 h in a muffle furnace (Asan Godaz, Iran) at 500°C (AOAC 1997). Total carbohydrate was estimated by following the method used by Dubois et al. (1956) with glycogen used as standard. Total protein was determined with the method used by Lowry et al. (1951). Total crude lipid was determined gravimetrically by the Bligh and Dyer (1959) method.

Fatty acid analysis

Total lipid was extracted from 2 g of dried seaweed sample using the Bligh and Dyer (1959) procedure. The sample was extracted three times with chloroform: methanol (2:1, v/v; containing BHT 0.1 mg/100 g), purified using the method of Folch et al. (1957), and methylated and transesterified with boron trifluoride in methanol (AOAC 1997). A known amount of heneicosanoic acid (C21:0) was added as an internal standard (Sigma-Aldrich, USA). The resultant fatty acid methyl esters (FAME) samples were then resolved and analyzed by using a gas-liquid chromatograph (GC-SRI 8610C, USA) equipped with a fused silica capillary column Omega-wax 320 (60 m×0.25 mm, I.D., 0.25 μm film; Sigma-Aldrich, USA), and a flame ionization detector (FID) as previously described in Ng et al. (2003).

Chlorophyll-*a*

A common pigment, chlorophyll-*a*, was extracted using 90% acetone. Ten ml 90% acetone was added to a centrifuge tube containing 10 mg of well-powdered seaweed sample, wrapped with aluminum foil and kept overnight in the refrigerator. Samples were then centrifuged (Universal Tlettich, Germany) at 3000 rpm for 5 min and the supernatant transferred to a new tube. The amount of chlorophyll-*a* was determined calorimetrically by a spectrophotometer (Cecil Spectro, England) using the method described by Strickland and Parsons (1989).

Mineral analysis

For the determination of mineral elements (Fe, Mg, Mn, K, Cu, Zn and Co), samples were dissolved in 1 M HNO_3 and H_2O_2 before being digested by a microwave (Mileston, Ethos 1, Italy). The concentration of the elements in the dried seaweed samples were determined by means of an atomic absorption spectrometer (FS95, Thermo, England) equipped with a hollow cathode lamp according to the method described in MOOPAM (1989). The seaweed mineral concentrations were quantified from calibration curves of the respective standard elements. All chemicals used were of trace element analytical grade (Merck, Germany).

Statistical analysis

Data were analyzed with SPSS 16.0 software using parametric tests. One-way ANOVA was used to compare the means of chemical composition data determined for the three groups of seaweeds. When differences were found, Duncan multiple comparison test was used, and differences were considered significant at $p<0.05$.

Results and discussion

The protein, lipid, carbohydrate, ash, moisture and chlorophyll-*a* content of the six different species from three

different genera of seaweeds collected from the coastal waters of the Persian Gulf are shown in Table 1. The mean protein content of both the red and green seaweeds (with the exception of *E. intestinalis*) were significantly higher ($p<0.05$) compared to the brown seaweeds. *G. corticata* had the highest protein content (19.3%, dry weight basis) and *S. ilicifolium* the lowest (8.9%). Burtin (2003) reported that the protein content in brown seaweeds are generally lower (ranging from 5 to 15% of dry weight) compared to red and green seaweeds (ranging from 10 to 30%). Similar range of protein content in seaweeds was also reported by Chakraborty and Santra (2008) and Manivannan et al. (2009).

Seaweeds are relatively low in lipid (1–5% of dry weight) (Burtin 2003; Polat and Ozogul 2008). In the present study, the highest crude lipid content was observed in *U. lactuca* (3.6%) and *E. intestinalis* (2.9%), while the lowest content was found in *C. sinuosa* (1.5%) and *G. corticata* (1.8%). These results are comparably lower than those reported by Chakraborty and Santra (2008) for *E. intestinalis* (7.1%) and *U. lactuca* (4.4%), but higher than those estimated by Ortiz et al. (2006) for *U. lactuca* (0.3%). In the present study, the crude lipid content of green seaweeds was found to be generally significantly higher compared to both the red and brown seaweeds.

Carbohydrates were the major component in the proximate composition of all the seaweeds examined in the present study. The carbohydrate content ranged from 31.8% in *H. valentiae* to 59.1% in *U. lactuca*. The carbohydrate content in *U. lactuca* and *G. corticata* were both significantly higher compared to the other seaweeds. These results are comparatively higher than those reported by Chakraborty and Santra (2008) for *U. lactuca* (35.3%), and by Manivannan et al. (2008a) for *H. valentiae* (23.6%), but similar to those obtained by Ortiz et al. (2006) for *U. lactuca* (61.5%). Similar range of carbohydrate content was previously reported by Burtin (2003) and Matanjun et al. (2009) for various seaweeds.

In this study, the highest ash content was observed in the brown seaweed *S. ilicifolium* (29.9%), while the lowest was observed in *U. lactuca* (12.4%). Ash content in brown seaweeds was significantly higher compared to that determined in both the red and green seaweeds. The range of ash content determined in the present study was similar to that reported by Rupérez (2002) and Matanjun et al. (2009) but slightly lower than those reported by Renaud and Luong-Van (2006).

Despite undergoing the same drying and sample processing method, the observed differences in the moisture content of the freeze-dried seaweed samples may indicate that the powdered samples have different abilities to absorb atmospheric moisture during storage. The range of moisture content observed among the various seaweed samples varied from 6.8% (in *U. lactuca* powder) to 11.5% (in *C. sinuosa* powder). The higher and lower moisture absorption were observed for *E. intestinalis* (8.5%) and *U. lactuca* (0.2%), respectively. Moisture content is an important criterion in determining the shelf-life and quality of processed seaweed meals as high moisture may hasten the growth of microorganisms.

As previously mentioned, apart from species specific differences, geographical location and local environmental conditions can influence the proximate composition of seaweeds (McDermid and Stuercke 2003; Ortiz et al. 2006; Renaud and Luong-Van 2006; Marsham et al. 2007; Chakraborty and Santra 2008; Matanjun et al. 2009). The present study is the first published data on the proximate composition of representative green, brown and red seaweeds collected from the unique marine aquatic environment found in the Persian Gulf.

Table 1 Proximate composition (% dry weight of sample) and chlorophyll-*a* (mg/g dry weight) of representative green, brown and red seaweeds collected from the Persian Gulf of Iran [a]

Composition	Green seaweed		Brown seaweed		Red seaweed	
	U. lactuca	*E. intestinalis*	*S. ilicifolium*	*C. sinuosa*	*H. valentiae*	*G. corticata*
Protein	17.1±1.59^{a}	10.5±1.02^{b}	8.9±0.94^{b}	9.2±1.78^{b}	16.5±2.78^{a}	19.3±2.19^{a}
Crud lipid	3.6±0.42^{a}	2.9±0.25^{ab}	2.0±0.20^{c}	1.5±0.29^{c}	2.8±0.67^{b}	1.8±0.46^{c}
Carbohydrate	59.1±0.37^{a}	35.5±2.83^{c}	32.9±1.08^{c}	32.1±1.75^{c}	31.8±1.34^{c}	43.0±5.58^{b}
Ash	12.4±1.05^{c}	22.4±1.46^{b}	29.9±2.73^{a}	28.1±0.86^{a}	21.8±0.69^{b}	23.1±0.53^{b}
Moisture [b]	6.8±0.24^{c}	10.6±0.50^{ab}	10.4±0.33^{ab}	11.5±0.20^{a}	10.8±0.35^{ab}	9.2±0.15^{b}
Moisture absorption [c]	0.2±0.05^{c}	8.5±0.80^{a}	8.0±0.64^{a}	5.3±0.75^{ab}	6.5±0.60^{ab}	2.1±0.30^{b}
Chlorophyll-*a*	3.5±0.60^{c}	5.6±0.46^{bc}	13.3±0.83^{a}	12.1±0.30^{a}	6.1±0.26^{bc}	7.5±0.35^{b}

[a] Data are mean values of triplicate samples ± SD. Different superscript letters in the same row indicate significant differences ($p<0.05$)

[b] expressed as percentage of oven-dried sample

[c] expressed as percentage of freeze-dried minus oven-dried sample

The chlorophyll-*a* content (mg/g dry weight) of brown seaweeds; *S. ilicifolium* (13.3 mg/g) and *C. sinuosa* (12.1 mg/g), were found to contain the highest content of chlorophyll-*a*, while the lowest content was observed in *U. lactuca* (3.5 mg/g) with both the brown seaweed showing significantly higher content compared to all the other seaweeds examined. The chlorophyll-*a* content in the green algae (*U. lactuca* and *E. intestinalis*) from the Persian Gulf was considerably higher than that reported by Chakraborty and Santra (2008) for the same species (2.1 and 1.7 mg/g, respectively) collected from the Indian Sunderbans area.

The fatty acid composition of the different seaweeds in the present study varied considerably with 51.9–67.4% of saturated fatty acids (SFA), 22.0–32.9% of monounsaturated fatty acids (MUFA) and 9.2–19.1% of polyunsaturated fatty acids (PUFA) (Table 2). Among the SFA, myristic acid (C14:0; 4.5–12.4%) and palmitic acid (C16:0; 38.0–59.8%) were the predominant fatty acids. As for MUFA, palmitoleic acid (C16:1*n-7;* 3.7–10.6%) and oleic acid (C18:1*n-9;* 3.5–28.6%) were the predominant fatty acids. The most abundant PUFA was linolenic acid (C18:3*n-3*; 0.3–8.4%). Similarly, Matanjun et al. (2009) and Polat and Ozogul (2008) reported that palmitic acid and oleic acid were the major fatty acids found in the seaweeds that they examined.

Of the six seaweeds species investigated, *H. valentiae* (67.4%) and *U. lactuca* (66.3%) had the highest relative concentrations of SFA in their total lipid content of which more than half consisted of palmitic acid (Table 2). The brown seaweed species *C. sinuosa* (32.9%) and *S. ilicifolium* (27.5%) had the highest relative concentrations of MUFA, consisting mainly of oleic acid. The red seaweed, *G. corticata,* had the highest content of PUFA at

Table 2 Fatty acid composition (% total fatty acids) of representative green, brown and red seaweeds collected from the Persian Gulf of Iran[a]

Fatty acids	Green seaweed		Brown seaweed		Red seaweed	
	U. lactuca	*E. intestinalis*	*S. ilicifolium*	*C. sinuosa*	*H. valentiae*	*G. corticat*
C14:0	7.6±1.83^{b}	4.7±0.77^{c}	4.8±0.75^{c}	12.4±1.33^{a}	4.5±0.64^{c}	6.0±1.52^{b}
C16:0	50.7±4.28^{b}	38.9±2.62^{c}	46.1±2.80^{b}	38.0±1.42^{c}	59.8±1.09^{a}	43.6±3.14^{b}
C18:0	2.8±0.71^{bc}	15.0±2.85^{a}	1.9±0.46^{bc}	0.2±0.01^{c}	2.1±0.37^{bc}	2.2±0.72^{bc}
C20:0	0.8±0.63	0.5±0.07	0.6±0.05	1.0±0.05	0.4±0.01	0.4±0.06
C22:0	3.8±1.05^{a}	0.9±0.28^{c}	1.0±0.07^{c}	0.5±0.06^{c}	0.4±0.06^{c}	2.4±0.72^{b}
C24:0	0.6±0.16^{bc}	0.3±0.02^{cd}	0.9±0.08^{b}	0.1±0.02^{d}	0.2±0.01^{d}	1.0±0.24^{a}
Total SFA [b]	66.3±3.68^{a}	60.6±3.04^{ab}	55.2±3.33^{b}	51.9±2.08^{b}	67.4±0.31^{a}	58.7±3.75^{ab}
C14:1n-5	0.9±0.36^{a}	ND	ND	0.1±0.07^{b}	0.9±0.08^{a}	0.2±0.04^{b}
C16:1n-7	10.6±1.83^{a}	7.9±2.35^{b}	8.2±0.64^{ab}	3.7±0.69^{c}	8.5±0.14^{ab}	6.9±0.40^{b}
C18:1n-7	ND	6.2±1.85^{a}	ND	0.4±0.08^{c}	3.1±0.41^{b}	0.7±0.33^{c}
C18:1n-9	11.5±2.24^{cd}	9.5±1.19^{d}	18.8±2.16^{b}	28.6±2.30^{a}	3.5±0.28^{e}	13.8±3.30^{c}
C20:1n-9	0.4±0.02^{bc}	0.5±0.09^{b}	0.2±0.13^{c}	ND	6.8±0.42^{a}	0.2±0.07^{bc}
C22:1n-9	ND	0.4±0.23^{b}	ND	0.1±0.02^{c}	0.7±0.18^{a}	0.2±0.03^{bc}
C24:1n-9	0.5±0.28^{a}	0.4±0.04^{ab}	0.1±0.13^{c}	ND	0.2±0.08^{bc}	ND
Total MUFA [b]	23.8±3.13^{b}	24.8±2.02^{ab}	27.5±2.58^{ab}	32.9±1.60^{a}	23.6±0.68^{b}	22.0±3.65^{b}
C18:3n-3	2.5±0.80^{c}	8.4±0.37^{a}	5.9±0.72^{b}	1.8±0.28^{cd}	0.3±0.12^{d}	7.7±1.88^{a}
C20:3n-3	ND	1.3±0.82^{a}	0.2±0.03^{b}	0.2±0.06^{b}	0.5±0.02^{b}	ND
C20:5n-3 (EPA) [b]	1.3±0.53^{bc}	0.3±0.08^{e}	1.9±0.22^{b}	5.4±0.86^{a}	1.0±0.04^{cd}	ND
C22:6n-3 (DHA) [b]	1.1±0.30^{a}	ND	0.2±0.11^{c}	0.2±0.07^{c}	0.7±0.13^{b}	ND
C18:2n-6	3.5±1.26^{c}	0.9±0.30^{d}	7.9±0.42^{a}	3.1±0.24^{c}	0.4±0.07^{d}	6.0±0.20^{b}
C20:2n-6	0.5±0.14^{c}	1.2±0.46^{b}	0.3±0.11^{c}	3.9±0.53^{a}	0.7±0.17^{c}	0.2±0.03^{c}
C20:4n-6 (AA) [b]	1.1±0.46^{c}	2.7±0.53^{b}	1.0±0.12^{c}	0.4±0.04^{c}	5.4±0.42^{a}	5.2±0.88^{a}
Total PUFA [b]	9.8±1.20^{d}	14.8±0.74^{c}	17.4±0.68^{b}	15.3±0.75^{c}	9.2±0.80^{d}	19.1±2.86^{a}
Total n-3 PUFA	4.8±0.83^{c}	9.8±0.60^{a}	8.2±1.08^{b}	7.7±0.69^{b}	2.5±0.42^{d}	7.8±1.74^{b}
Total n-6 PUFA	5.1±1.14^{d}	4.8±0.75^{d}	9.2±0.44^{b}	7.6±0.68^{c}	6.7±0.53^{c}	11.2±0.70^{a}
n-6/n-3	1.1	0.5	1.1	1.0	2.7	1.4

[a] Data are mean values of triplicate samples ± SD. Different superscript letters in row indicate significant differences in mean ($p<0.05$)

[b] SFA, MUFA, EPA, DHA, AA and PUFA, represent saturated, monounsaturated, eicosapentaenoic, docosahexaenoic, arachidonic and polyunsaturated fatty acids, respectively

ND indicates not detectable fatty acid

19.1% of total fatty acids. In general, the SFA and MUFA content of the green algae *U. lactuca* and *E. intestinalis* determined in the present study were relatively higher than those reported for the same species by Chakraborty and Santra (2008), but determined PUFA content was lower in the present study. The SFA content observed in the present study was comparatively higher than previously reported for brown and red seaweed species (Polat and Ozogul 2008). The seaweed MUFA content determined in the present study was lower than those reported by Durmaz et al. (2008) for red algae. In contrast to the present study, Terasaki et al. (2009) reported that PUFA constituted the most abundant fatty acid class in brown seaweeds collected off the coast of Hakodate in Japan.

The health-beneficial eicosapentaenoic acid (EPA; C20:5*n-3*) was found in all seaweed species except *G. corticata*, with 5.4% of total fatty acids as the highest concentration found in *C. sinuosa*. The EPA content (0.3%) of *E. intestinalis* observed in the present study was lower than that reported by Chakraborty and Santra (2008) for the same species (2.90%). Docosahexaenoic acid (DHA; C22:6*n-3*), another physiologically important long-chain PUFA, was found in low concentrations in all seaweeds (ranging from trace to 1.1%). Arachidonic acid (AA; C20:4*n-6*) content ranged from 0.4–5.4% in the six seaweeds. The DHA and AA results in the present study were higher than those reported by Matanjun et al. (2009) where the DHA content was below the detection limit (<0.1% of total fatty acids), while AA content was 0.6%. Terasaki et al. (2009) reported relatively high concentrations of AA (11.6–14.8%) and EPA (9.7–12.0%) in *Sargassum* spp., despite not detecting any DHA in their lipid extracts. Variation in the PUFA concentration and profile of different seaweeds have been reported to be mainly dependent on the local water temperature from which the seaweeds were collected with temperature species containing higher levels of fatty acids with longer-chain and higher degree of unsaturation compared to tropical species (Bhaskar et al. 2004). Consumption of long-chain omega-3 PUFA are known to be beneficial to human health (Ruxton et al. 2005) and together with a low dietary *n-6/n-3* ratio, are fundamental for a diet with cardio-protective benefits. In the present study, the green seaweed, *E. intestinalis*, contained the highest total *n-3* PUFA content with the lowest *n-6/n-3* ratio among the seaweeds examined.

The mineral composition of the three groups of seaweed is shown in Table 3. Most of the seaweeds evaluated in the present study exhibited high amounts of potassium, magnesium and iron, but low concentrations of copper and cobalt, similar to values reported by Krishnaiah et al. (2008), but relatively higher than those reported by Rupérez (2002). Among the seven minerals determined, potassium content was the highest for all seaweeds (range 515.6–876.6 mg/100 g) but this was comparably lower than those reported in seaweeds examined by Matanjun et al. (2009) (8371.2–13155.2 mg/100 g). Higher potassium concentrations were found in the brown and red seaweeds as compared to the green seaweeds of the Persian Gulf.

Magnesium content in both brown and green seaweeds was significantly higher than in the red seaweeds ($p<0.05$). These results are higher than those determined by Manivannan et al. (2008b) in *U. lactuca* (17.5 mg/100 g) and *H. valentiae* (4.0 mg/100 g), and compatible to those estimated by Matanjun et al. (2009). The highest concentration of manganese was recorded from the red seaweed, *H. valentiae* (3.7 mg/100 g) followed by *G. corticata*

Table 3 Selected mineral composition (mg/100 g dry weight of sample) of representative green, brown and red seaweeds collected from the Persian Gulf of Iran, as compared to some vegetables[a]

Treatments	→ Minerals						
	Iron	Potassium	Magnesium	Manganese	Zinc	Cobalt	Copper
U. lactuca	46.4±1.53^{c}	515.6±35.68^{d}	79.1±2.66^{a}	1.5±0.26^{b}	1.6±0.28^{c}	0.07±0.02^{d}	0.34±0.08^{bc}
E. intestinalis	25.4±2.75^{d}	589.3±43.52^{c}	61.7±5.82^{b}	1.3±0.21^{b}	2.1±0.07^{b}	0.24±0.03^{c}	0.43±0.08^{ab}
S. ilicifolium	58.9±9.26^{b}	876.6±15.85^{a}	81.7±6.90^{a}	1.6±0.08^{b}	2.2±0.11^{b}	0.75±0.09^{a}	0.28±0.04^{c}
C. sinuosa	45.2±2.20^{c}	728.5±50.14^{b}	78.1±1.53^{a}	1.5±0.03^{b}	1.9±0.08^{bc}	0.43±0.03^{b}	0.51±0.06^{a}
H. valentiae	80.3±9.08^{a}	746.0±40.82^{b}	38.7±1.68^{c}	3.7±0.31^{a}	3.1±0.21^{a}	0.45±0.02^{b}	0.39±0.04^{bc}
G. corticata	85.0±5.13^{a}	713.0±46.50^{b}	18.3±1.37^{d}	3.3±0.25^{a}	3.2±0.36^{a}	0.81±0.18^{a}	0.33±0.07^{bc}
Lactuca sativa[b]	0.9	194	13	0.3	0.2	ND	0.03
Spinacia oleracea[b]	2.7	558	79	0.9	0.5	ND	0.13

[a] Data are mean values of triplicate samples ± SD. Different superscript letters in the same column indicate significant differences in mean ($p<0.05$)

[b] Common vegetables (USDA 2010)

ND = not detectable

(3.3 mg/100 g) while the lowest level was found in *E. intestinalis* (1.3 mg/100 g). The zinc content of the red seaweeds examined in the present study was significantly higher compared to the brown and green seaweeds; the values determined was also higher than the results reported by McDermid and Stuercke (2003).

The red seaweeds contain significantly higher levels of iron compared to that found in both the green and brown seaweeds (Table 3). The highest and lowest level of copper was found in the brown algae *C. sinuosa* (0.51 mg/100 g) and *S. ilicifolium* (0.28 mg/100 g), respectively, and this was significantly different. The iron and copper content determined for seaweeds in this study were higher than those reported by McDermid and Stuercke (2003) in other seaweed species of the same genus. The green seaweeds contained the lowest cobalt concentrations compared to both the brown and red seaweeds.

Seaweeds are able to selectively absorb minerals from the surrounding seawater and accumulate them in their thalli (Azmat et al. 2006). For this reason, their mineral composition and concentration are species and location specific. Edible brown and red seaweeds could be consumed as a food supplement to help fulfill the recommended daily intake of essential minerals and trace elements (Rupérez 2002). The present data showed that the seaweeds collected from the Persian Gulf generally contained higher concentrations of all the minerals examined compared to common vegetables such as lettuce (*Lactuca sativa*) and spinach (*Spinacia oleracea*) (Table 3). Potassium and magnesium content in the examined seaweeds were comparable or higher compared to that found in spinach (with the exception of Mg in red seaweeds) while content of the other minerals (Fe, Zn, Mn and Cu) in seaweeds were comparatively higher compared to that found in lettuce and spinach.

Chemical analysis of the seaweeds collected from the Persian Gulf of Iran showed that they were nutritionally rich in terms of protein (red and green seaweeds), carbohydrates (especially green seaweeds), lipids (in particular green seaweeds with higher content of *n-3* PUFA) and essential minerals. Therefore, these seaweeds could potentially be used, after processing, as a food or feed additive in Iran. The present study is the first report on the biochemical composition of seaweeds from the Persian Gulf and further studies are needed on the nutritional and toxicological aspects of seaweed utilization as food and feed resources for human and animal consumption, respectively.

Acknowledgments The authors would like to thank the Iranian Fisheries Research Organization (IFRO) for providing financial support and the Persian Gulf and Oman Sea Ecological Research Institute (PGOSERI) for their technical support. The authors are grateful to K.S. Lee for his editorial assistance.

References

AOAC (1997) Official methods of analysis, 16th edn. Association of Official Analytical Chemists, AOAC International, Arlington, VA, USA

Azmat R, Hayat A, Khanum T, Talat R, Uddin F (2006) The inhabitation of bean plant metabolism by Cd metal and Atrazine III: effects of seaweed *Codium Iyengaria* on metal, herbicide toxicity and rhizosphere of the soil. Biotechnol 5:85–89

Bhaskar N, Miyashita K, Hosokawa M (2004) Comparative evaluation of fatty acid composition of different *Sargassum* (Fucales, Phaeophyta) species harvested from temperate and tropical waters. J Aqua Food Pro Technol 13:53–70

Bligh EG, Dyer WJ (1959) A rapid method of total lipid extraction and purification. Can J Biochem Physiol 37:911–917

Burtin P (2003) Nutritional value of seaweeds. Electron J Environ Agric Food Chem 2:498–503

Chakraborty S, Santra SC (2008) Biochemical composition of eight benthic algae collected from Sunderban. Indian J Mar Sci 37:329–332

Dubois M, Gilles KA, Hamilton JK, Rebers PA, Smith F (1956) Colorimetric method for the determination of sugars and related substances. Analytical Chem 18:350–356

Durmaz Y, Duyar HA, Gökpinar S, Taskaya L, Öğretmen YO, Bandarra NM, Nunes ML (2008) Fatty Acids, α-tocopherol and total pigment contents of *Cystoseira* spp., *Ulva* spp. and *Zostera* spp. from Sinop Bay (Turkey). Int J Natural Enger Sci 2:111–114

Folch AJ, Less M, Sloan-Stanley GH (1957) A simple method for isolation and purification of total lipids from animal tissues. J Biolo Chem 226:497–509

Krishnaiah D, Sarbatly R, Prasad DMR, Bono A (2008) Mineral content of some seaweeds from Sabah's South China Sea. Asian J Sci Res 1:166–170

Kumar CS, Ganesan P, Suresh PV, Bhaskar N (2008) Seaweeds as a source of nutritionally beneficial compounds—A review. J Food Sci Technol 45:1–13

Lowry OH, Rosebrough NJ, Farr AL, Randall RJ (1951) Protein measurement with the Folin phenol reagent. J Biolo Chem 193:265–275

Manivannan K, Thirumaran G, Devi GK, Hemalatha A, Anantharaman P (2008a) Biochemical composition of seaweeds from Mandapam Coastal regions along Southeast Coast of India. Am-Euras J Bot 1:32–37

Manivannan K, Devi GK, Thirumaran G, Anantharaman P (2008b) Mineral composition of marine macroalgae from Mandapam Coastal regions; Southeast Coast of India. Am-Euras J Bot 1:58–67

Manivannan K, Thirumaran G, Devi GK, Anantharaman P, Balasubramanian T (2009) Proximate composition of different group of seaweeds from Vedalai Coastal waters (Gulf of Mannar): Southeast Coast of India. Middle-East J Sci Res 4:72–77

Marsham S, Scott GW, Tobin ML (2007) Comparison of nutritive chemistry of a range of temperate seaweeds. Food Chem 100:1331–1336

Matanjun P, Mohamed S, Mustapha NM, Muhammad K (2009) Nutrient content of tropical edible seaweeds, *Eucheuma cottonii*, *Caulerpa lentillifera* and *Sargassum polycystum*. J Appl Phycol 21:75–80

McDermid KJ, Stuercke B (2003) Nutritional composition of edible Hawaiian seaweeds. J Appl Phycol 15:513–524

MOOPAM (1989) Manual of oceanographic and pollutant analysis methods, 2nd edn. The Regional Organization for the Protection of the Marine Environment (ROPME), Kuwait, 458 p

Ng WK, Lim PK, Boey PL (2003) Dietary lipid and palm oil source affects growth, fatty acid composition and muscle α-tocopherol

concentration of African catfish, *Clarias gariepinus*. Aquaculture 215:229–243

Ortiz J, Romero N, Robert P, Araya J, Lopez-Hernández J, Bozzo C, Navarrete E, Osorio A, Rios A (2006) Dietary fiber, amino acid, fatty acid and tocopherol contents of the edible seaweeds *Ulva lactuca* and *Durvillaea antarctica*. Food Chem 99:98–104

Polat S, Ozogul Y (2008) Biochemical composition of some red and brown macro-algae from the Northeastern Mediterranean Sea. Int J Food Sci Nutr 59:566–572

Renaud SM, Luong-Van JT (2006) Seasonal variation in the chemical composition of tropical Australian marine macroalgae. J Appl Phycol 18:381–387

Rohani K, Hossaini MR (2005) A survey on distribution and biomass estimation of two species of Brown algae (*Colpomenia sinuosa* and *Iyengaria stellata*) in the Persian Gulf of Iran. Iranian Sci Fis J 13:55–64 (in *Persian with English abstract*)

Rohani K, Rajabi I, Rameshi H, Behzadi S, Dehghani R, Tamadoni S, Hossaini MR (2007) Study on distribution and biomass estimation of seaweeds in Hormozgan coastal waters and some of Persian Gulf Islands. Iranian Sci Fis J 15:59–68 (in *Persian with English abstract*)

Rupérez P (2002) Mineral content of edible marine seaweeds. Food Chem 79:23–26

Ruxton CHS, Calder PC, Reed SC, Simpson MJA (2005) The impact of long-chain *n*-3 polyunsaturated fatty acids on human health. Nutr Res Reviews 18:113–129

Strickland JDH, Parsons TR (1989) Discussion of spectrophotometric determination of marine plant pigments with revised equations for ascertaining chlorophylls and carotenoids. J Mar Res 21:155–163

Terasaki M, Hirose A, Narayan B, Baba Y, Kawagoe C, Yasui H, Saga N, Hosokawa M, Miyashita K (2009) Evaluation of recoverable functional lipid components of several brown seaweeds (Phaeophyta) from Japan with special reference to fucoxanthin and fucosterol contents. J Phycol 45:974–980

USDA National Nutrient Database for Standard Reference. Agricultural research service, nutrient data laboratory. United State Department of Agriculture. [Cited 2010 Jan 14]. Available from: http://www.ars.usda.gov/ba/bhnrc/ndl