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Original Article

Biochemical composition and physicochemical properties of two red seaweeds (*Gracilaria fisheri* and *G. tenuistipitata*) from the Pattani Bay in Southern Thailand

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Abstract

The proximate composition, dietary fiber, element and amino acid contents, as well as some physicochemical properties of the two red seaweeds (*Gracilaria fisheri* and *G. tenuistipitata*) collected from the Pattani Bay in Southern Thailand in the rainy and summer seasons of 2006 were determined in order to evaluate their potential nutritional value. The protein content of *G. tenuistipitata* (21.6% DW) was significantly higher than that of *G. fisheri* (11.6% DW) (P<0.05). The two seaweed species contained lipid (1.7–3.6% DW), ash (7.9–22.9% DW), total dietary fiber (TDF) (57.5–64.0% DW), soluble dietary fiber (SDF) (15.6–18.8%DW) and insoluble dietary fiber (IDF) (38.9–45.2% DW). *G. tenuistipitata* collected in the rainy season had higher level of lipid (P<0.05) whereas the level of ash was higher in the summer. In contrast, *G. fisheri* had higher levels of lipid, ash and TDF (P<0.05) when collected in rainy season. There was no significant differences in SDF, ISF and TDF between the two seaweeds. The result indicated that the two species contained high levels of K and Cl. The essential amino acids with the highest content in the two species were arginine, leucine and threonine. The swelling capacity (SWC), water holding capacity (WHC) and oil holding capacity (OHC) ranged from 5.2 to 12.5 ml/g DW, 5.5 to 10.1 g/g DW and 1.8 to 2.3 g oil/g DW, respectively, with the SWC, WHC and OHC of *G. tenuistipitata* being higher than those of *G. fisheri*. This study suggested that both *Gracilaria* species could potentially be used as raw material or ingredients to improve nutritive value and functional properties in human diet and animal feed.

Keywords: seaweed, marine algae, chemical composition, nutrient, physicochemical properties, seasonal variation

1. Introduction

Currently, marine macroalgae or seaweeds are used worldwide for many different purposes. The human consumption of seaweed is common in Asian countries, mainly Japan, China, Korea, Vietnam, Indonesia and Taiwan (Dawes, 1988). In Western countries, seaweeds have been used as sources of phycocolloids, and thickening and gelling agents for various applications, including food and pharmaceutical industries. Furthermore, they are also used for improving nutrients in animal feed, cosmetics, herbal medicine, fertilizers, etc (Fleurence, 1999; Marinho-Soriano *et al.*, 2006). Seaweeds are known as valuable sources of protein, elements, dietary fibers, vitamins, essential amino acids and essential fatty acids. Moreover, seaweeds also contain potential bioactive compounds which exhibit antibacterial, antiviral and antifungal properties (Marinho-Soriano *et al.*, 2006).

The nutritional quality of protein in seaweeds can be evaluated from amino acid composition and essential amino

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acid score (FAO/WHO/UNU, 1985; Wong and Cheung, 2000). Fat contents of seaweeds were found within the range of 1–6 g/100 g DW with high concentrations of long-chain polyunsaturated fatty acids (Darcy-Vrillon, 1993; Ortiz *et al.*, 2006). Fatty acids are important for human and animal health because they are precursors in the biosynthesis of eicosanoids, which are important bioregulators in many cellular processes (Gressler *et al.*, 2010). The high element contents in seaweed are shown by their ash contents, which are in the range of 8–40% DW (Mabeau and Fleurence, 1993). Edible seaweeds may be important sources of the elements, which are useful for metabolic reactions in human and animal such as enzymatic regulation of lipid, carbohydrate and protein metabolism (Nisizawa *et al.*, 1987). The total dietary fiber content of seaweeds described from previous reports ranges from 33 to 50%DW (Lahaye, 1991; Rupérez and Saura-Calixto, 2001). Dietary fibers are classified as soluble and insoluble fractions. The dietary fibers and their physicochemical properties are associated with technological functionality and physiological effects (Elleuch *et al*., 2011).

However, the nutrient composition of seaweeds vary depend on the species, maturity, environmental growth conditions and seasonal period (Ito and Hori, 1989; Ortiz *et al*., 2006). The changes in ecological conditions have an influence on the synthesis of nutrients (Lobban *et al.*, 1985). Studies of seasonal variation in the chemical composition of some red and brown seaweeds have been investigated in previous studies of *Gracilaria cervicornis*, *Sargassum vulgare* (Marinho-Soriano *et al.*, 2006) and *Grateloupia turuturu* (Denis *et al.*, 2010).

In the South of Thailand, some red seaweeds, namely *Gracilaria fisheri* and *G. tenuistipitata*, are abundant in Pattani Bay. Their utilization is limited to people living in the coastal areas. These seaweeds are mainly used as fresh vegetable and dried products (Benjama and Masniyom, 2011). However, the biochemical composition and physicochemical properties of two *Gracilaria* species are poorly known. The purpose of this study was to determine the chemical composition including amino acids and element contents of *G. fisheri* and *G. tenuistipitata*. To provide more intensive nutrient information, the samples were collected in rainy and summer seasons for analysis. Their physicochemical properties (swelling, water and oil holding capacities) were also investigated so as to assess their potential applications.

2. Materials and Methods

2.1 Samples

The *Gracilaria fisheri* and *G. tenuistipitata* seaweeds were collected manually from the coastal area of the Pattani Bay, Pattani Province, the lower region of Southern Thailand, during the summer (April) and rainy seasons (December) of 2006. The samples were thoroughly rinsed with fresh water to remove salt and foreign materials such as epiphytes, shells, sand, etc. All cleaned seaweeds were dried at 60°C in an air oven until they had constant weight. After being ground into fine powder that could pass through a 0.5 mm mesh sieve, the samples were stored in hermetic bags at room temperature for further analysis.

2.2 Methods

2.2.1 Proximate analysis

Protein, ash, lipid and moisture contents of seaweeds were determined according to the standard method (AOAC, 2000). The moisture content was determined by oven method at 105°C until constant weight was obtained. Crude protein content was analyzed by the Kjeldahl method with a conversion factor of 6.25 to convert total nitrogen into crude protein. Ash content was done by incinerating the seaweeds in a muffle furnace at 550°C for 16 hours and the content was determined gravimetrically. Crude lipid was extracted from seaweed powder with chloroform:methanol (2:1, v/v) in a Soxhlet extractor by the method of Bligh and Dryer (1959). The crude lipid content was measured gravimetrically after oven-drying (80°C) the extract overnight. The total, soluble and insoluble dietary fiber contents were determined according to an enzymatic–gravimetric procedure (AOAC, 2000).

2.2.2 Macro, trace and ultra trace elements analyses

The element contents of the samples were analyzed by atomic absorption spectrophotometry (AAS) for Ca, Mg, K and Na (method 985.35, AOAC, 2000), by inductively coupled plasma optical emission spectrometry (ICP-OES) for Fe, Cu and Zn (method 984.27, AOAC, 2000), gravimetric method for P (Kolthoff *et al*., 1969) and chloride analyzer for Cl. Analyses of two toxic elements, namely Pb and Cd, were conducted by flame atomic absorption spectrophotometry according to the methods of Evan (1978) and Suddendorf *et al.* (1981).

2.2.3 Amino acid analysis

The samples were hydrolyzed with 6 N HCl containing 1% phenol in a heating block at 110°C for 22 hours in sealed glass tubes under a N_2 atmosphere. The HCl and phenol were then driven off by evaporation. An internal standard was then added into the cooled hydrolysate, which was diluted with deionized water and then 10 μL of this filtrate was mixed with 70 μL of AccQ fluor derivatization buffer and 20 μL of AccQ fluor reagent. Samples were then heated at 55°C for 10 min in a heating block, before being cooled and analyzed by high-performance liquid chromatography (HPLC) with a WATERS Alliance 2659 and a WATERS 2475 Multi λ Fluorescence detector set at an excitation wavelength of 250 nm and an emission wavelength of 395 nm. Separation was achieved in an AccQ Wag column (150x3.9 mm, particle size 4 μm) (Liu *et al*., 1995). A set of amino acid standards (Sigma Chemicals) was analyzed with each set of experimental samples. Identification of the amino acids in the samples was carried out by comparison with retention times of the standards.

The obtained essential amino acids were compared with the FAO/WHO reference amino acid pattern for the pre-school children and the score was calculated by the method of FAO/WHO/UNU (1985) as shown below:

$$\text{Amino acid score (\%)} = \frac{\text{mg of amino acid per g of test protein}}{\text{mg of amino acid per g of reference protein}} \times 100$$

2.2.4 Physicochemical properties

The physicochemical properties of seaweeds were studied at room temperature (30±2°C). Swelling capacities (SWC) of seaweed samples were measured by the bed volume technique after equilibrating in excess solvent (Kuniak and Marchessault, 1972). Water holding capacities (WHC) were performed by the modified centrifugation method described by Suzuki *et al.* (1996). Oil holding capacities (OHC) of samples were determined by the slightly modified method of Caprez *et al.* (1986). The results of SWC, WHC and OHC were expressed as ml/g DW, g/g DW and g oil/g DW, respectively.

2.3 Statistical analysis

All determinations were performed at least in triplicate. Statistical analysis was carried out by using the SPSS 10.0 version software for Windows. The analyzed data were expressed as mean with standard deviation (SD). Paired sample t-test was used to identify significant differences at $P<0.05$ between the mean values of the two species and between the mean value of each species in two different seasons (rainy and summer seasons).

3. Results and discussion

3.1 Chemical composition

The chemical composition of *G. fisheri* and *G. tenuistipitata* under present study is given in Table 1. The moisture contents of the two species collected in summer and rainy seasons were found similar in all samples, within the range of 3.6–5.5% of the dry weight (DW). The protein contents found in both seaweeds were relatively high. *G. tenuistipitata* (21.6% DW) had protein contents higher than *G. fisheri* (11.6% DW) ($P<0.05$). This result agreed with the previous report described by Fleurence (1999) that red and green seaweeds had protein content within the wide range 10–47% (DW). In this study, the protein contents of both species were higher than that of *Sargassum polycystum* (5.4% DW) (Matanjun *et al.*, 2009), *G. domingensis* (6.2% DW) and *G. birdiae* (7.1% DW (Gressler *et al.*, 2010). *G. fisheri* had protein content similar to *Gelidium pristoides* (11.8% DW) (Foster and Hodgson, 1998). *G. tenuistipitata* appeared to be an interesting potential source of food proteins as it had protein contents similar to *Halymenia formosa* (21.2%) (McDermid and Stuercke, 2003), *G. cervicornis* (23.0% DW) (Marinho-Soriano *et al.*, 2006) and *Grateloupia turuturu* (22.9% DW) (Denis *et al.*, 2010). However, the protein contents of the two species were lower than those of other seaweed species such as *Porphyra tenera* (47% DW) and *Palmaria palmata* (35% DW) (Fleurence, 1999). These levels varied depending on algal species, season and environment (Ito and Hori, 1989).

The lipid contents varied from 2.2% DW in *G. fisheri* to 2.8% DW in *G. tenuistipitata*. These amounts were consistent with the previous reports (1-3% DW) (Fleurence, 1999) and also similar to *G. coronopifolia* (2.1%), *G. salicornia* (2.4%), and *G. parvispora* (2.8% DW) (McDermid and Stuercke, 2003). However, two seaweed species contained lipid higher than other red seaweeds such as *G. cervicornis* (0.43% DW) and *Sargassum vulgare* (0.45%) (Marinho-

Table 1. Chemical composition of dried seaweeds (% DW)

Seaweeds	Sampling period	Protein	Lipid	Ash	Moisture	Total dietary fiber
G. fisheri	Summer	11.6 ± 1.1	2.7 ± 0.6	22.9 ± 2.2	5.2 ±0.6	64.0 ± 0.2
	Rainy	11.6 ± 0.8	1.7 ± 0.4	21.4 ± 0.3	5.7 ± 0.1	57.5 ± 9.0
	Mean ± SD	11.6 ± 0.8	2.2 ± 0.7	21.2 ± 1.6	5.5 ± 0.5*	60.7 ± 6.6
G. tenuistipitata	Summer	20.3 ± 2.4	1.9 ± 0.0	26.0 ± 0.1^{S}	3.3 ± 0.2	60.2 ± 3.4
	Rainy	22.9 ± 2.5	3.6 ± 0.3^{R}	7.9 ± 0.9	3.9 ± 0.6	56.6 ± 14.4
	Mean ± SD	21.6 ± 2.6*	2.8 ± 0.9	17.0 ± 10.0	3.6 ± 0.4	58.4 ± 8.8

Values are expressed as mean ± standard deviation, n=3
^{R} Signifies significantly higher in rainy season ($P<0.05$).
^{S} Signifies significantly higher in summer ($P<0.05$)
*Signifies significantly higher between two species ($P<0.05$).

Soriano *et al*., 2006). However, the variations in fat contents of the same genus can be due to geographical origin and seasonal periods (Marinho-Soriano *et al*., 2006).

The ash contents of the two analyzed samples were 21.2% to *G. fisheri* and 17.0% to *G. tenuistipitata*. The amounts of ash obtained in the present study were in agreement with the previous studies (Rupérez and Saura-Calixto, 2001; Sánchez-Machado *et al*., 2004). Their ash values were similar to those of *G. domingensis* (23.8%DW) and *G. birdiae* (22.5%DW) (Gressler *et al*., 2010), *Hypnea japonica* (22.1% DW) and *H. charoides* (22.8%DW) (Wong and Cheung, 2000). The ash contents in most marine seaweeds are usually much higher than those in terrestrial plants (5–10% DW) (USDA, 2001). The differences in ash contents depend on seaweed species, physiological factors, environmental changes, methods of mineralization and type of processing (Nisizawa *et al*., 1987; Rupérez, 2002).

3.2 Dietary fiber

Seaweeds contained large amounts of polysaccharides, which comprise of high levels of soluble and insoluble dietary fibers (Lahaye, 1991). In this study, the amounts of soluble, insoluble, and total dietary fibers of the two *Gracilaria* species ranged from 15.6–18.8%, 38.9–45.2% and 57.5–64.0% DW, respectively (Table 2). However, no significant differences in soluble dietary fiber (SDF), insoluble dietary fiber (ISF) and total dietary fiber (TDF) were found between the two seaweeds. The contents of total dietary fiber in seaweeds were higher than those in terrestrial plants such as whole wheat (44.5% DW), beans (36.5% DW) and onions (16.9% DW) (Prosky *et al*., 1992; Wong and Cheung, 2000).

Furthermore, the ratios of SDF/IDF in both species were well balanced (close to 1:2) as the suggested by Figuerola *et al.* (2005). *Gracilaria* species has SDF as sulphated galactans, which is regarded influential in slowing digestion and absorption of nutrients, as well as reducing levels of blood cholesterol and glucose (Scheneeman, 1987; Wong and Cheung, 2000). In contrast, IDF increases fecal bulk and decreases intestinal transit time (Potty, 1996; Elleuch *et al.*, 2011). They have several beneficial physiological effects on humans in preventing constipation, colon cancer, cardiovascular disease and obesity (Dreher, 1987; Ortiz *et al.*, 2006). Therefore, both *Gracilaria* species can be alternatively used as raw materials for high fiber food production or as ingredients in food industry**.**

3.3 Seasonal variations in chemical composition

The variation in the nutrient contents of seaweeds is associated with several environmental factors such as water temperature, salinity, light and nutrients (Dawes, 1998). The environmental parameters differ with seasonal periods and the changes in ecological conditions can influence the synthesis of nutrients in seaweeds (Lobban *et al.*, 1985). The present study showed that there was a higher percentage of lipid in *G. tenuistipitata* collected in rainy season but a higher level of ash in summer (P<0.05). Seasonal variations in chemical composition of *G. tenuistipitata* were agreement with previous reports for *Gracilaria cervicormis*, *Sargassum vulgare* (Marinho-Soriano *et al*., 2006), *Grateloupia turuturu* (Denis *et al.*, 2010), *Ulva pertusa* and *U. intestinalis* (Benjama and Masniyom, 2011).

3.4 Element contents

The elements in the two seaweeds are listed in Table 3. The means of macro elements (Ca, P, K, Mg, Na and Cl) and trace elements (Cu and Zn) contents ranged from 218.5–8082.5 mg/100 g DW and 0.2–6.4 mg/100g DW, respectively. Thus the two seaweed species were rich in K and Cl but low in Na. Furthermore, their Na/K ratios were low (0.03–0.05) and therefore the two seaweeds can help balance Na/K ratio diets and reduce hypertension risk as described in the studies of the red and brown seaweeds by Rupérez (2002). As for the trace elements, copper plus zinc contents were found within the range of 1.1–5.1 mg/100 g and also below the maximum level allowed in seaweeds for human consumption in Japan and France (10 mg/100 g) (Indegaard and Minsaas, 1991).

Most of the trace elements present in the seaweeds are heavy metals (As, Cd, Cu, Hg, Pb, Zn). The harmful toxic elements in the two seaweed species were Pb (0.8–5.7 mg/kg) and Cd (0.05–0.1 mg/kg). The levels of detected elements fit

Table 2. Composition of dietary fiber in *G. fisheri* and *G. tenuistipitata* (% DW)

Seaweeds	Sampling period	SDF	IDF	TDF	SDF/IDF
G. fisheri	Summer	18.8 ± 2.1	45.2 ± 2.3	64.0 ± 0.2	0.42 ± 0.07
	Rainy	16.3 ± 4.9	41.2 ± 4.0	57.5 ± 9.0	0.39 ± 0.08
	Mean ± SD	17.5 ± 3.4	43.2 ± 3.6	60.7 ± 6.4	0.41 ± 0.06
G. tenuistipitata	Summer	15.6 ± 1.5	44.6 ± 1.9	60.2 ± 3.4	0.35 ± 0.02
	Rainy	17.7 ± 7.1	38.9 ± 7.3	56.6 ± 14.4	0.45 ± 0.10
	Mean ± SD	16.7 ± 4.4	41.7 ± 5.5	58.4 ± 8.8	0.40 ± 0.08

Values are expressed as mean ± standard deviation, n=3

Table 3. The elements contents of *G. fisheri* and *G. tenuistipitata*

Elements	*G. fisheri* Sampling period Summer	*G. fisheri* Sampling period Rainy	Overall Mean	*G. tenuistipitata* Sampling period Summer	*G. tenuistipitata* Sampling period Rainy	Overall Mean
Macro elements (mg/100g DW)						
K	7532	8633	8082.5	7411	4172.5	5791.8
Cl	1740.5	1170	1455.3	2703	1257.5	1980.3
Mg	377	549.5	463.3	271	890	580.5
Na	358.5	158.5	253.5	391.5	192	291.8
P	315.5	278.5	297.0	351	272	311.5
Ca	145.5	295.5	220.5	156	281	218.5
Trace elements (mg/100g DW)						
Cu	0.20	0.18	0.20	0.20	1.00	0.60
Zn	1.00	0.70	0.90	2.55	6.45	4.50
Toxic elements (mg/kg DW)						
Pb	1.11	0.59	0.85	6.10	5.28	5.70
Cd	0.14	0.09	0.10	0.06	0.04	0.05

Values are expressed as mean (n = 3)

within the allowed ranges in previous reports (Mabeau and Fleurence, 1993; Rupérez, 2002). The present study indicates the possibility of both seaweed species being used as food supplements to improve the nutritive value for the human diet and animal feed.

3.5 Amino acid composition

The amino acid contents of the two *Gracilaria* spp. are illustrated in Table 4. Their essential amino acids (EAA) included methionine, leucine, isoleucine, lysine, phenylalanine, tyrosine, arginine, threonine and valine. However, the analytical method used could not determine tryptophane and cysteine. The levels of different essential amino acids ranged from 3.43 to 8.96 mg/100 mg DW. Both species were rich in arginine, leucine and threonine. Their Non-EAA, namely histidine, aspartic acid, glutamic acid, serine, proline, glycine, and alanine, ranged from 3.40 to 8.96 mg/100 mg DW. The two species contained large amount of aspartic and glutamic acids, which are responsible for the special flavor and taste. Similar results have been obtained in previous studies (Wong and Cheung, 2000; Gressler *et al.*, 2010)

The means of total amino acid contents were 8.02 mg/ 100 mg DW to *G. fisheri* and 17.57 mg/100 mg DW to *G. tenuistipitata* while the protein contents of *G. fisheri* and *G. tenuistipitata* were 11.6 and 21.6% DW, respectively. The ratios of EAA to total amino acids of both seaweeds species were almost 0.5. The results also indicated a good ratio of EAA to non-EAA (1.0) in the two species.

From this study, the levels of essential amino acids were also compared with the reference amino acid pattern of pre-school children by FAO/WHO/UNU (1985). The essential amino acid scores of two species were found within the range of 41.6–165.4% (Table 5), while the greatest scores of *G. fisheri* and *G. tenuistipitata* were threonine and isoleucine, respectively. The result also showed that the most common limiting amino acid of both species was lysine. The amino acid scores of lysine were 41.6% for *G. fisheri* and 82.2% for *G. tenuistipitata*. These findings suggested that the two *Gracilaria* species can be used as alternative nutrient sources of protein and amino acid for human and animal consumption.

3.6 Physicochemical properties

Most seaweeds are rich in dietary fiber (>50% DW) (Darcy-Vrillon, 1993; Mabeau and Fleurence, 1993) and the principal physiological effects of dietary fiber correlate to their physicochemical properties (Rupérez and Saura-Calixto, 2001). The physicochemical properties of the two seaweeds are influenced by the chemical structure of the constituent polysaccharides and their proteins (Fleurence *et al.*, 1995; Wong and Cheung, 2000). In this study, the protein content and TDF in the seaweed samples ranged between 11.6–22.9 and 57.5–64.0% DW, respectively.

The SWC, WHC and OHC of two seaweed species are shown in Table 6. The WHC, SWC and OHC of *G. tenuistipitata* were higher than those of *G. fisheri* ($P<0.05$). While the SWC and WHC of both species ranged from 5.22–12.53 ml/g DW and 5.48–10.06 g/g DW, respectively. Their SWC and WHC values were similar to those of *Fucus vesiculosus*, *Chondrus crispus* and *Porphyra tenera* (Rupérez

Table 4. Amino acid composition (mg/100 mg DW) of *G. fisheri* and *G. tenuistipitata*

Amino acid	*G. fisheri*			*G. tenuistipitata*		
	Summer	Rainy	Overall Mean	Summer	Rainy	Overall Mean
Aspartic acid[b]	0.67	0.98	0.82	2.02	1.87	1.94
Serine[b]	0.46	0.63	0.55	1.13	1.22	1.17
Glutamic acid[b]	0.81	1.05	0.93	2.09	2.18	2.13
Glycine[b]	0.53	0.66	0.6	1.06	1.20	1.13
Histidine[b]	ND	ND	ND	ND	ND	ND
Arginine[a]	0.52	0.92	0.72	1.27	1.38	1.32
Threonine[a]	0.49	0.64	0.56	1.09	1.23	1.16
Alanine[b]	0.55	0.73	0.64	1.33	1.40	1.36
Proline[b]	0.38	0.47	0.43	0.95	1.09	1.02
Tyrosine[a]	0.33	0.31	0.32	0.64	0.47	0.55
Valine[a]	0.45	0.59	0.52	1.03	1.12	1.08
Lysine[a]	0.17	0.40	0.28	1.02	1.04	1.03
Isoleucine[a]	0.39	0.52	0.45	1.00	1.00	1.00
Leucine[a]	0.56	0.73	0.65	1.42	1.61	1.51
Phenylalanine[a]	0.52	0.58	0.55	0.94	1.11	1.17
Tryptophane[a]	ND	ND	ND	ND	ND	ND
Total AA	6.83	9.22	8.02	16.99	17.92	17.57
EAA	3.43	4.70	4.05	8.41	8.96	8.82
Non-EAA	3.40	4.53	3.97	8.58	8.96	8.75
EAA/Non-EAA	1.01	1.04	1.02	0.98	1.00	1.01
EAA/ Total AA	0.50	0.51	0.50	0.49	0.50	0.50

Values are expressed as mean, n=3.
[a] EAA, Essential amino acid.
[b] Non-EAA, Non essential amino acid.
ND, not determined.

Table 5. Essential amino acid scores of *G. fisheri* and *G. tenuistipitata*.

Amino acids	*G. fisheri* (mg/g protein)	*G. tenuistipitata* (mg/g protein)	Reference (mg/g protein)[a]	Score of *G. fisheri*	Score of *G. tenuistipitata*
Leucine	56.0	69.9	66	84.9	105.9
Isoleucine	38.79	46.3	28	138.5	165.4
Lysine	24.1	47.7	58	41.6	82.2
Methionine+Cysteine	ND	ND	25	ND	ND
Threonine	48.3	53.7	34	142.0	157.9
Tyrosine+Phenylalanine	75	79.6	63	119.0	126.3
Tryptophane	ND	ND	11	ND	ND

[a] Reference amino acid pattern of pre-school children (2-5 years) (FAO/WHO/UNU, 1985).

and Saura-Calixto, 2001), *Ulva pertusa* and *U. intestinalis* (Benjama and Masniyom, 2011) and some agricultural by-products (Elleuch *et al.*, 2011).

OHC is another functional property of food ingredients used in formulated food. Ingredients with a high OHC values allow the stabilization of food emulsions and high fat food products. In this study, the OHC of seaweed samples was of moderate level within the range of 1.83–2.35 g oil/g DW. *G. tenuistipitata* had higher OHC values than *G. fisheri* ($P<0.05$). This OHC levels of the two seaweeds were similar to the OHC of barley fiber (2.0 g oil/g DW) (Mongeau and Brassard, 1982) and autoclaved wheat bran (2.3 g oil/g DW) (Caprez *et al.*, 1986)

However, the chemical composition of the two

Table 6. Physicochemical properties of *G. fisheri* and *G. tenuistipitata*

Seaweeds	Sampling period	SWC (ml/g DW)	WHC (g/g DW)	OHC(g oil/g DW)
G. fisheri	Summer	5.87 ± 0.39	5.55 ± 0.31	1.83 ± 0.08
	Rainy	5.22 ± 1.14	5.48 ± 0.17	1.76 ± 0.06
	Mean ± SD	5.54 ± 0.84	5.53 ± 0.22	1.79 ± 0.07
G. tenuistipitata	Summer	7.99 ± 2.29	7.87 ± 1.75	2.12 ± 0.03
	Rainy	12.53 ± 1.76	10.06 ± 0.90	2.35 ± 0.10^R
	Mean ± SD	10.26 ± 3.08*	8.97 ± 1.73*	2.23 ± 0.15*

Values are expressed as mean ± standard deviation, n=3
^{R} Signifies significantly higher in rainy season (P<0.05).
^{S} Signifies significantly higher in summer (P<0.05).
*Signifies significantly higher between two species (P<0.05).

seaweeds, the anatomy and the physiological characteristics of their fiber can influence the physicochemical properties (Elleuch *et al.*, 2011). From this study, the adequate SWC, WHC and OHC values of *G. fisheri* and *G. tenuistipitata* suggested that both seaweeds can potentially be used as functional ingredient in human diets or modifier of texture and viscosity of formulated food.

4. Conclusion

The edible seaweeds *G. fisheri* and *G. tenuistipitata* analyzed in this study had appreciable protein contents, high ash and dietary fiber contents, as well as relatively high levels of elements and essential amino acids. Their physicochemical properties (swelling, water and oil holding capacities) were of high values and comparable to those of some fiber-rich products. Therefore, these two *Gracilaria* species appear to be potential sources or ingredients in functional food products and animal feed. More studies are necessary (e.g. fatty acids, vitamins, toxic elements and other bioactive compounds) to further our knowledge and promote the exploitation of these marine algae.

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