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Nutritional profiling of the edible seaweeds *Gracilaria edulis*, *Ulva lactuca* and *Sargassum* sp.

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ABSTRACT

In the present study, nutritional composition of the edible seaweeds, *Gracilaria edulis* (red seaweed), *Ulva lactuca* (green seaweed) and *Sargassum* sp. (brown seaweed) were evaluated. Results showed that the seaweeds had protein content of 13.84±3.55 to 18.21±0.00%; fat 0.73±0.001 to 0.93±0.00%, carbohydrate 30.32±0.21 to 43.19±1.75% and total dietary fibre (TDF) content of 53.625±0.18 to 63.175±0.46% on dry weight basis. Among the three seaweeds, *Sargassum* sp. contained highest protein content (18.21±0.00%) and *G. edulis* possessed highest TDF (63.175±0.46%). Macronutrients *viz*., Na, P and Ca and the micronutrients Fe, Se, Mn, Cu and Zn were present in all three seaweeds. *G. edulis* had highest Na (423.33±1.15 mg 100 g^{-1}), P (282.5±0.5 mg 100 g^{-1}), Ca (223.33±0.58 mg 100 g^{-1}) and Fe (65.28±0.33 mg 100 g^{-1}), whereas highest Se content was recorded in *Sargassum* sp (49.82±0.09 mg 100 g^{-1}). Palmitic acid (C16:0), oleic acid (C18:1) and linoleic acid (C18:2, ω-6) were the most abundant saturated fatty acid (SFA), monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA), respectively. Fatty acid profile also revealed that small quantity of docosahexaenoic acid (DHA) (C22:6, ω-3) ranging from 0.064 to 0.494% was present in all the three seaweed species but eicosapentaenoic acid (EPA) (C20:5, ω-3) was present only in *Sargassum* sp. at a concentration of 0.583%. *G. edulis* had higher vitamin D2 (2.590 mg 100 g^{-1}), vitamin E (1.017 mg 100 g^{-1}) and vitamin K1 (0.714 mg 100 g^{-1}) than *Sargassum* sp. and *U. lactuca*. The results clearly indicates that these three seaweeds can be considered as a good source of dietary fibre, protein, minerals and vitamins and can be used for fortifying foods or as components of functional foods.

Keywords: *Gracilaria edulis*, Minerals, Nutritional profiling, *Sargassum* sp., Total dietary fibre, *Ulva lactuca*, Vitamins

Introduction

Seaweeds have been commonly utilised as a component of oriental diets, especially in Japan, China and Korea since ancient times owing to the presence of beneficial nutrients (Murata and Nakazoe, 2001; Prabhasankar *et al*., 2009). World wide, 65% of the commercially exploited seaweeds are being used for human nutrition (Zemke-White and Ohno, 1999). During 2005, total global seaweed production was 16.1 million t, of which 8 and 92% were from capture and culture, respectively (FAO, 2007). In Japan, seaweeds have been used for preparation of different types of products such as jam, cheese, wine, tea, soups and noodles (Nisizawa *et al*., 1987) and the *per capita* consumption is more than 1.6 kg $year^{-1}$ (dry weight) (Fleurence, 1999). Additionally, seaweeds are major source of phycocolloids extraction (agar, algin and carrageenan) for several industrial applications like pharmaceutical, cosmetics and the food industry as gelling, stabilising and thickening agents (Jimenez-Escrig and Sanchez-Muniz, 2000). Moreover, direct consumption of seaweeds as human food has been increasing in recent decades in western countries and other parts of the world.

Seaweeds are considered healthy food owing to their richness in protein, vitamins, minerals and bioactive compounds, at the same time having relatively lower calorie content (Lee *et al*., 2008; Gomez *et al*., 2010). The nutrient profile of seaweeds is influenced by diverse factors such as seaweed species, habitat, maturity stage, season, temperature and the sampling conditions (Khotimchenko *et al*., 2005; Renaud and Luong-Van, 2006). Gupta and Abu-Ghannam (2011) observed relatively higher carbohydrate content in red and green seaweeds and higher content of soluble fiber and iodine in brown seaweeds. Seaweeds are also a good source of dietary fibre, which includes soluble as well as insoluble dietary fibres (based on solubility in water). Soluble dietary fibre helps to increase viscosity and reduce glycemic response and plasma cholesterol in humans (Venugopal, 2008; Elleuch

et al., 2011). Insoluble dietary fibres are responsible for bulking effect caused by high water absorption capacity which is attributed in weight management, improvement in cardiovascular and gastrointestinal health and cancer prevention (Braithwaite *et al*., 2014). Most recently seaweeds are recognised as ingredients for functional food family, due to their extraordinary nutritional as well as nutraceutical properties (Shahidi, 2009).

Porphyra sp., *Laminaria* sp., *Undaria* sp., *Sargassum* sp., *Ulva* sp., *Euchema* sp. and *Gracilaria* sp. are the commonly used seaweeds for human consumption. *Gracilaria edulis* (red seaweed), *Ulva lactuca* (green seaweed) and *Sargassum* sp. (brown seaweed), are grown abundantly and harvested in large quantities in both east and west coasts of India. Their utilisation is mostly restricted to phycocolloids extraction, as fertiliser for agriculture and animal feeds in India (Kaliaperumal, 1993). Even though, several studies have been conducted on nutritional aspects of seaweed, very little work has been done on this aspect in India. Moreover, most of the studies on nutrients of seaweeds have been concentrated on fresh weeds and very little attention has been paid to dried seaweeds. Hence this study was conducted to determine the proximate composition, dietary fibre, minerals, fatty acid profile and fat soluble vitamins profile of shade dried *G. edulis*, *U. lactuca* and *Sargassum* sp. Studies on chemical composition will provide more knowledge on nutritional aspects of these seaweeds. This information might increase the possibilities of their consumption as a vegetable diet and as nutrient supplement in India, where seaweeds are not consumed traditionally.

Materials and methods

Sample collection

The seaweeds *G. edulis* (red seaweed), *U. lactuca* (green seaweed) and *Sargassum* sp. (brown seaweed) were collected from Mandapam, Tamil Nadu, India. Seaweed samples were handpicked and cleaned with seawater to remove foreign particles, grit particles and epiphytes. The seaweeds were cleaned thoroughly using potable water in the laboratory and dried under shade (2 - 3 days), powdered, vacuum packed and stored at room temperature.

Chemical analysis

Moisture, protein, fat, carbohydrate, ash, calcium (Ca), potassium (K) and sodium (Na) were estimated as per standard methods (AOAC, 1990). Iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), cobalt (Co), and selenium (Se) were analysed following AOAC (2000) with Atomic Absorption Spectrophotometer (Varian Spectra AA 220, Australia).

Dietary fibre

Total dietary fibre (TDF) was estimated by digesting the seaweed samples using α-amylase, amyloglucosidase, and protease (AOAC, 1997).

Fatty acid analysis

Total lipid extraction and fatty acid profiling were carried out by gas chromatography (Varian CP 3800, USA) (Folch *et al*., 1957; AOAC, 2000).

Fat soluble vitamin analysis

Seaweed samples were subjected to lipid extraction (Folch *et al.*, 1957) and saponification (AOAC, 2000). About 150 mg of seaweed lipids was refluxed with methanolic KOH under N_2 in a water bath for half an hour and then the fat soluble vitamins were extracted with petroleum ether, identified and quantified by high performance liquid chromatography (HPLC; Shimadzu LC 10AS) equipped with C18 Reversed Phase column and ultraviolet (UV) detector as per Chatzimichalakis *et al*. (2004) using acetonitrile and methanol in the simple linear gradient system.

Statistical analysis

All results are presented on dry weight basis (DWB). Variation in the nutrient component of seaweeds were tested at 5% probability level using one way analysis of variance (ANOVA) followed by Duncan's multiple range test. All the analyses were carried out using SPSS software version 16.0.

Results and discussion

Proximate composition and total dietary fibre (TDF)

Proximate composition of seaweeds namely *G. edulis*, *U. lactuca* and *Sargassum* sp. is presented in Table 1. Protein content of seaweeds ranged from 13.84±3.55 to 18.21±0.00% on DWB. The highest protein content was found in brown

Table 1. Nutritional composition of *Gracilaria edulis, Sargassum* sp. and *Ulva lactuca*

Nutritional composition (% dry weight basis)	*Gracilaria edulis*	*Sargassum* sp.	*Ulva lactuca*
Moisture	87.14±1.10^{b}	81.84±1.41^{a}	84.81±0.22^{ab}
Protein	14.26±0.88^{a}	18.21±0.00^{a}	13.84±3.55^{a}
Fat	0.93±0.00^{c}	0.73±0.001^{a}	0.86±0.00^{b}
Ash	7.63±0.11^{a}	12.95±0.35^{b}	12.41±0.32^{b}
Carbohydrate	32.39±1.90^{a}	30.32±0.21^{a}	43.19±1.75^{b}
Total dietary fibre (TDF)	63.175±0.46^{c}	58.25±0.35^{b}	53.625±0.18^{a}

Values within a row with different superscripts are significantly different ($p<0.05$)

seaweed *Sargassum* sp. at a concentration of 18.21±0.00% followed by *G. edulis* (14.26±0.88%) and *U. lactuca* (13.84±3.55 %). There was no significant difference ($p>0.05$) of protein content among the three seaweed species. However, higher protein content of seaweeds was observed in present study as compared to previous reports (Wong and Cheung, 2000; Syad *et al*., 2013; Sakthivel and Devi, 2015) of 0.668±0.10% in *G. edulis*, 0.061±0.01% in *Gracilaria acerosa*; 0.15±0.02% in *S. wightii* and 7.06±0.06% in *U. lactuca*.

In the present study, lipid content (Table 1) ranged from 0.73±0.001 to 0.93±0.00%; with highest level in *G. edulis* (0.93±0.00%) and lowest in *Sargassum* sp. (0.73±0.001%). In general, seaweeds are low in lipid content ranging from 1 to 3% (Mabeau and Fleurence, 1993). The lipid content previously reported for *G. edulis* was 0.83±0.1% (Sakthivel and Devi, 2015) and in *G. acerosa*, a related species, was 2.8±0.01% (Syad *et al*., 2013), which were higher than recorded in the present study for *G. edulis*. Lipid content of *Sargassum* sp. and *U. lactuca* were 0.73±0.001% and 0.86±0.00%, respectively. Contrary to this study, Wong and Cheung (2000) and Syad *et al*. (2013) reported lipid content of 2.72±0.36% in *S. wightii* and 1.64±0.10% in *U. lactuca*. However, significant difference ($p<0.05$) was observed in lipid content among the three seaweeds studied.

Ash content ranged from 7.63±0.11 to 12.95±0.35%, which was higher than previous reports (Pak and Araya, 1996a; b). Seaweeds have higher ash content than most of the vegetables (Rupe´rez *et al*., 2002). Ash content in *G. edulis* differed significantly ($p<0.05$) from that of *U. lactuca* and *Sargassum* sp., with no significant difference ($p>0.05$) in ash content between the latter two species.

U. lactuca showed highest carbohydrate content (43.19±1.75%), which differed significantly ($p<0.05$) from carbohydrate content of *Sargassum* sp. Sakthivel and Devi (2015) reported total carbohydrate content of *G. edulis* to be 10.16±1.8%, which is considerably lower than the total carbohydrate content of *G. edulis* recorded in this study. Wong and Cheung (2000) reported carbohydrate content of the red algae *Hypnea japonica, H. charoides* and *U. lactuca* as 4.28±1.52%, 7.02±4.06% and 14.6±4.94%, respectively, which were all lower than the carbohydrate content of seaweeds recorded in the present study.

Highest TDF was found in *G. edulis* (63.175±0.46%) followed by *Sargassum* sp. (58.25±0.35%) and *U. lactuca* (53.625±0.18%). Significant difference ($p<0.05$) in dietary fibre content were observed among the three different seaweeds. The TDF content of seaweeds reported in the present study is in agreement with that of previous studies (Ortiz *et al*., 2006; Dawczynski *et al*., 2007). Sakthivel and Devi (2015) reported 8.9±0.62% dietary fibre in *G. edulis*, which is much lower than our observation of the same species. Dietary fibre has been consumed for its health beneficial properties such as prevention of cardiovascular disease, diabetes, prevention of constipation issues as well as colon cancer (Elleuch *et al*., 2011; Braithwaite *et al*., 2014). Hence, seaweed dietary fibre can be utilised as a potential alternative source to cereal based fibres.

The wide dissimilarity in the nutritional composition observed in the three seaweed species in our study could be attributed to diverse factors such as variations in geographical location, season, sunlight intensity, temperature and salinity (Marinho-Soriano *et al*., 2006).

Macro and micro mineral composition

Seaweeds are a major source of macro and micro minerals. Mineral content of *G. edulis*, *Sargassum* sp. and *U. lactuca* are presented in Table 2.

Macro minerals, namely Na, K and Ca are inorganic elements and required in relatively large quanities for various key physiological functions such as body fluid regulation, electrolyte balance, muscle contraction, blood clotting, Fe utilisation and regulation of hypertension in the human body. Results of macronutrient analysis shows that seaweeds are rich in Na, K and Ca content. Among all the three seaweeds,

Table 2. Mineral composition of *Gracilaria edulis, Sargassum* sp. and *Ulva lactuca*

Minerals (mg %)	*Gracilaria edulis*	*Sargassum* sp.	*Ulva lactuca*
Macronutrients			
Na	423.33±1.15^{c}	389.33±0.58^{b}	351.67±1.53^{a}
K	282.5±0.5^{c}	244.33±1.15^{b}	209.00±1.73^{a}
Ca	223.33±0.58^{c}	176±1.73^{a}	180.67±1.15^{b}
Micronutrients			
Fe	65.28±0.33^{b}	32.21±1.57^{a}	34.47±1.10^{a}
Zn	1.7±0.06^{a}	5.81±0.06^{b}	1.78±0.02^{a}
Cu	1.78±0.01^{b}	1.62±0.02^{a}	1.83±0.005^{c}
Se	3.70±0.14^{b}	49.82±0.09^{c}	1.60±0.04^{a}
Mn	3.96±0.01^{a}	3.27±0.25^{a}	4.8±0.02^{a}

Results are mean ± standard deviation. Values within a row with different superscripts are significantly different ($p<0.05$)

G. edulis possessed highest Na (423.33±1.15 mg%), K (282.5±0.5 mg%), Ca (223.33±0.58 mg%) content and least were found in *U. lactuca*. However, content of Na, K, Ca differed significantly ($p<0.05$) among all seaweeds studied. Sakthivel and Devi (2015) reported much lower values of Na, K and Ca in *G. edulis* than the values obtained in the present study. Na (351.67±1.53 mg%), K (209.00±1.73 mg%) and Ca (180.67±1.15 mg%) content in *U. lactuca* observed in our study were lower than that determined by Yaich *et al.* (2011). In the present study Na, K and Ca content in *Sargassum* sp. was 389.33±0.58 mg%, 244.33±1.15 mg% and 176±1.73 mg%, respectively. The differences in macronutrients content in seaweeds could be a result of variations in climate and location (Marinho - Soriano *et al*., 2006).

Micro minerals namely Fe, Cu, Zn, Mn and Se though needed only in trace amounts, are significant in regular functioning of the human body. Among the seaweeds studied, Fe content was significantly higher ($p<0.05$) in *G. edulis* (65.28±0.33 mg%) followed by *U. lactuca* (34.47±1.10 mg%) and *Sargassum* sp. (32.21±1.57 mg%). Fe content in our study was relatively higher than that reported by other authors (MacArtain *et al*., 2007; Matanjun *et al*., 2009). According to the WHO, around 2 billion people of the world are affected by Fe deficiency leading to increased fatal pregnancy and morbidity in children (WHO, 2015). Results of the present study demonstrated that seaweeds could be used as a source of Fe to combat iron deficiency disorders.

In present study, Zn content of seaweeds varied from 1.7±0.06 to 5.81±0.06 mg%. Significantly higher ($p<0.05$) Zn content was found in *Sargassum* sp. Cu is necessary for Fe utilisation in body and as a cofactor for enzymes which metabolise glucose and for synthesis of hemoglobin, connective tissue and phospholipids (Celik and Oehlenschlaager, 2004). Significantly higher ($p<0.05$) Cu content was observed in *U. lactuca* (1.83±0.005 mg%).

Selenium is an essential trace mineral of immense significance to human health and is well known as an antioxidant and catalyst for thyroid hormone production (Rayman, 2000). Se content of the three seaweeds showed wide range from 1.60±0.04 to 49.82±0.09 mg% with higher ($p<0.05$) content in *Sargassum* sp. (49.82±0.09 mg%). Lowest content was found in *U. lactuca*.

Manganese is vital for the formation of bones, connective tissues, sex hormones and clotting of blood. It is also involved in metabolism of fat and carbohydrate, absorption of calcium and regulation of blood sugar as well as for brain and nerve function. All three seaweeds were found rich in Mn and the contents ranged from 3.27±0.25 to 4.8±0.02 mg% and there was no significant ($p>0.05$) difference in manganese content among the three seaweeds.

This study revealed that seaweeds are a good source of macro and micro nutrients. Essential mineral content in seaweeds are at much higher levels than many terrestrial mineral sources such as spinach (Savindra *et al*., 2015). Dietary reference intake recommends that approximately 25 g of seaweed in a day can fulfill the mineral requirements in adult human (Gebhardt and Thomas, 2002).

Fatty acid composition

Palmitic acid (C16:0) was the most dominant saturated fatty acid (SFA) in the seaweed samples analysed (Table 3). The amount of palmitic acid (C16:0) was highest in *G. edulis* (65.01%) followed by *U. lactuca* (61.10 %) and *Sargassum* sp. (43.10 %). Dominance of palmitic acid has been reported by other authors for *U. lactuca* and *Porphyra* sp. (Ortiz *et al*., 2006; Dawczynski *et al*., 2007; Yaich *et al*., 2011). Seaweeds studied in our study also had negligible levels of myristic acid (C14:0) (1.09 to 1.66%) and stearic acid (C18:0) (1.46 to 1.73%).

Oleic acid (C18:1) was the most dominant monounsaturated fatty acid (MUFA) in the seaweeds and it ranged from 16.61 to 19.66%. Higher content of C18:1 was found in *Sargassum* sp. than in *G. edulis* and *U. lactuca* (Table 3). Oleic acid was also present in similar quantities in *Porphyra* sp. and *Laminaria* sp., whereas lower concentrations were reported in *Undaria pinnatifida* and *Hizikia fusiforme* than the values observed in this study (Dawczynski *et al*., 2007). Small quantity of palmitoleic acid (C16:1) was present in *Sargassum* sp. (2.74%). Fatty acid analysis revealed that seaweeds also have essential fatty acids *viz*., linoleic acid (C18:2, ω-6) and α-linolenic acid (C18:3, ω-3) in the range of 8.24 to 10.25% and 0.48 to 2.56%, respectively. Linoleic acid level in *U. lactuca* (1.72 ± 0.91%) reported by Ortiz *et al*. (2006) was lower than our observation for the same species. Syad *et al*. (2013) reported presence of SFA and unsaturated fatty acids (USFA) in the red alga *G. acerosa*, but their values were lower than the observed values for *G. edulis*, *Sargassum* sp. and *U. lactuca* in the present study.

Present study revealed, the presence of small quantities of ω-3 polyunsaturated fatty acid (PUFA) docosahexaenoic acid (DHA; C22:6; 0.06 to 0.50%) in all the three seaweeds, whereas eicosapentaenoic acid (EPA; C20:5) was present only in *Sargassum* sp. (0.58 %). Kumari *et al*. (2010) also demonstrated the presence of ω-3 PUFA such as stearidonic acid (18:4), EPA and DHA in seaweeds. Health benefits of ω-3 PUFA in particular EPA and DHA are well documented (Lauritzen, *et al*., 2001). Our study revealed that all three seaweeds are rich in both saturated and unsaturated fatty acids.

Table 3. Fatty acid profile of *Gracilaria edulis, Sargassum* sp. and *Ulva lactuca*

Fatty acids	% of total fatty acids		
	Gracilaria edulis	*Sargassum* sp.	*Ulva lactuca*
SFA			
C12:0	0.13	nd	nd
C14:0	1.66	1.61	1.09
C15:0	0.66	0.26	0.35
C16:0	65.01	43.10	61.10
C17:0	nd	0.16	0.17
C18:0	1.73	1.64	1.46
C20:0	nd	1.12	0.28
C21:0	nd	0.06	nd
C22:0	nd	0.84	2.25
C23:0	nd	0.07	nd
C24:0	nd	nd	0.07
Total	69.20	48.84	66.76
MUFA			
C14:1 ω-5	nd	nd	0.15
C16:1 ω-7	0.04	2.74	0.06
C17:1 ω-7	0.04	0.19	0.27
C18:1 ω-9	17.26	19.66	16.61
C20:1 ω-9	nd	0.36	0.02
Total	17.33	22.95	17.12
PUFA			
C18:2 ω-6	10.25	9.62	8.24
C18:3 ω-3	0.48	2.56	1.36
C20:2 ω-6	nd	0.66	nd
C20:3 ω-9	nd	0.68	nd
C20:4 ω-6	nd	8.90	nd
C20:5 ω-3	nd	0.58	nd
C22:2 ω-6	0.73	0.34	0.83
C22:6 ω-3	0.06	0.50	0.16
Total	11.52	23.82	10.59

nd- not detected

Results of the present study showed that seaweeds contain high total level of SFA than MUFA and PUFA. Total level of MUFA was found to be lowest in *U. lactuca* and the highest concentration of PUFA was found in *Sargassum* sp.

Fat soluble vitamins

The content of fat soluble vitamins namely vitamin A, D, E and K of *G. edulis*, *Sargassum* sp. and *U. lactuca* are shown in Table 4. Vitamin analyses revealed that *G. edulis* had highest content of vitamin D2 (2.59 mg%) followed by vitamin E (1.02 mg%) and vitamin K1 (0.71 mg%). In *Sargassum* sp, vitamin E (0.49 mg%) was recorded, while vitamins A, D2 and K1 were below detectable levels. VitaminA was not detected in *U. lactuca*. However, *U. lactuca* possessed vitamin D2, K1 and E at concentrations of 0.12 mg %, 0.22 mg % and 0.06 mg %, respectively. Sakthivel and Devi (2015) reported that *G. edulis* contains vitamin A and E, at 0.021 mg% and 0.013 mg% respectively. Ortiz *et al*. (2006) suggested that the daily vitamin requirements of the human body could be met by consuming 100 g of seaweeds.

Table 4. Fat soluble vitamins in *Gracilaria edulis, Sargassum* sp. and *Ulva lactuca*

Vitamins (mg%)	*Gracileria edulis*	*Sargassum* sp.	*Ulva lactuca*
Vit A	0.001	BDL	nd
Vit D2	2.59	BDL	0.12
Vit K1	0.72	BDL	0.22
Vit E	1.02	0.49	0.06

nd- not detected, BDL - Below detectable level.

The present study indicated that the red seaweed *G. edulis*, the green seaweed *U. lactuca* and the brown seaweed *Sargassum* sp. were rich in dietary fibre, carbohydrate, protein and minerals such as Na, P, Ca, Fe, Se, Mn, Cu and Zn and also have essential fatty acids such as linoleic acid, DHA and EPA as well as fat soluble vitamins in minor quantities. *G. edulis* was found to have higher nutritional value compared to *Sargassum* sp. and *U. lactuca*. The results clearly indicate that the red, brown and green seaweeds are promising alternatives to land crops and can be considered as cheap sources of vegetables from sea to satiate the dietary needs of the growing population. Seaweeds can be used as fortifying ingredients to enrich the nutritional status of foods, especially in terms of dietary fibre and Fe content.

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