Red Sea Water and Biochemical Composition of Seaweeds at Southern Coast of Jeddah, Saudi Arabia

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Abstract: This study was conducted to investigate the physico-chemical properties of Red Sea water and the chemical composition of commonly occurring seaweeds along the Southern Coast of Jeddah, Saudi Arabia. The different parameters of the surface water like temperature, salinity, pH, dissolved oxygen and dissolved nutrients were measured. Seaweeds viz. *Halimedaopuntia*, *Gracillariacorticata* and *Turbinariatriquetra* were analyzed for mineral content, moisture, ash, carbohydrate, protein and lipid. The bioaccumulation of heavy metals inside the investigated seaweeds was within the corresponding range. Total carbohydrate was the most abundant contents in these seaweeds. The vitamins, phytohormones, alginic acid, agar, carrageenan, amino acid profiles and fatty acids of seaweeds were also studied. The seaweed samples were enriched in essential amino acids, ω3and ω6. The results exposed that these seaweed species contain high nutritive value and are promising in the field of pharmaceuticals and industry.

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1. Introduction

Jeddah is a major metropolitan city along the eastern coast of the Red Sea. The Red Sea of Jeddah is characterized by the presence of great varieties of seaweeds. Seaweeds have been used as human food since ancient times by several civilizations (Bezerra and Marinho-Soriano, 2010). Seaweeds constitute an important source of natural resources for fertilizers and play an important role in agriculture and horticulture (Fan *et al.,* 2011, Bierman and Rosen, 2013; Cordell and White, 2013, FAO, 2013). Seaweeds have gained importance as foodstuffs and most recently as components of functional foods because of their high dietary fiber, mineral, vitamins, low energy levels and high concentrations of certain polyunsaturated fatty acids, carotenoids, protein and carbohydrate (Garcia-Rodriguez *et al*., 2010). Seaweeds are a known source of plant growth regulators, organic osmolites (eg. betaines), amino acids, mineral nutrients, vitamin and vitamin precursors (Spinelli *et al.*, 2010). The nutritional quality of protein in seaweeds can be evaluated from amino acid composition and essential amino acid score (Wong and Cheung, 2001). Their protein contents differ according to the species and seasonal conditions (Jadeja and Tewari, 2008). 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). Agar, carrageenan and alginate are polysaccharides derived from seaweeds (Yang *et al*., 2011). Seaweeds could represent a source of polyunsaturated fatty acids, including ω-3 fatty acids. 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; 2011). Ferrier *et al*. (1995) reported that food enriched with ω-3 fatty acids produced significant increase in docosahexaenoic acid (DHA) concentration and other polyunsaturated ω-3 fatty acids in phospholipid fraction of human blood.The nutrients compositions of seaweeds vary and they are affected by species, geographic area, maturity and environmental growth conditions (Benjamaand Masniyom, 2012). The fundamental one is metabolic activity but this is controlled by temperature and the concentration of essential nutrients of the surrounding water. Accordingly, our study concerned with the physicochemical characteristics of the Red Sea water at south of Jeddah and the biochemical constituents of three species of seaweeds (green, red and brown) were characterized, so that they can be used for industrial applications.

2. Materials and Methods

2.1 Study area

The area of study is called Al-Kumrah and it lies about 36 km south of Red Sea of Jeddah. It is located at 39°07^{I}15.66^{II}E and Lat. 21°12^{I}24.13^{II}N. The study area is characterized by a tropical to subtropical climate. The wind is mostly north to north–northwest throughout the year round. The surface water samples

and the dominant seaweeds were collected from the study area during spring 2011. Three replicates were collected from the site.

2.2 Physicochemical analysis of water

The water sample was collected at a depth of 50 cm below the surface. The water samples were filtered using membrane filter of 47 mm diameter and 0.45 µm pore size, and the filtered water samples were kept frozen at -20°C for later analysis. Physico-chemical parameters were measured according to the standard methods for examination of water (APHA, 1992) which including temperature, pH, salinity, DO, NO_2, NO_3, NH_4, PO_4, Ca and Mg. The total contents of different elements were determined according to Allen *et al.* (1997).

2.3 Biochemical composition of seaweeds

Seaweed species were belonged to green (*Halimedaopuntia*), red (*Gracilariacorticata*) and brown algae (*Turbinariatriquetra*). The biochemical composition was carried out using dried powder of algae. Moisture and ash of seaweeds were measured as described by AQAC (1995). Total carbohydrate was estimate according to Duboies *et al.* (1956). Total protein and lipid was determined by using AQAC (1995) method. Phytohormones (Cytokinin, Gebberellic Acid, Indol Acetic Acid and Abscisic Acid) were estimated by using Gas Liquid Chromatography Trace GC Ultra. Aginic acid, agar and Carrageenan were determined by the method of Lobban *et al.* (1988). Vitamins A, B1, B2, B6 and C were estimated according to Thimmaiah (1999). Total free amino acid was analyzed by using Automatic Amino Acid Analyzer, AAA 400 Ingos Ltd. Fatty acids were analyzed with a Pye Unicam Series 304 Gas Liquid Chromatography.

2.4Statistical analysis

The mean and standard error for all analyses were calculated and reported. The data is the mean of three replicates. Data are subjected to ANOVA test using by the software program SPSS 20.

3. Results and Discussion

3.1 Physical and chemical properties of water and mineral composition of seaweeds

The surface water temperature was represented by 29°C at the study area (Table 1). The results in Table 1 showed that the average of water salinity was 39.82 ‰ at the study area. The high salinity in the Red Sea is attributed to the enhancement of water evaporation in the closed areas. The pH value of the Red Sea water was 8.1 and the dissolved oxygen was tended to be 3.64 mg/l at the study area (Table 1). The presence of nutrients for phytoplankton growth has been considered as one of the main factors controlling production in aquatic systems. The results in Table 1 clarified that the values of nitrite, nitrate, ammonia and phosphate were 15.32, 34.76, 12.56 and 4.12 µg/l, respectively. Concerning the major elements, Ca and Mg, in the surface water, the results recorded 68.65 and 251.21 mg/l, respectively (Table 1). The high metal contents in the Red Sea waters at Jeddah may be attributed to the interaction with coral reef fragments, the metals released from the sediments to the overlying waters occurs and the sewage dumping in the sea (Saad and Fahmy, 1994).

The mineral composition of the green, red and brown seaweeds was demonstrated in Table 2. It can be noted that the greatest values of phosphorous (0.13 ppm) and nitrogen (2.41 ppm) were recorded with *G. corticata*. The major constituent of the investigated seaweeds was calcium (ranged from 2.87 to 4.12 ppm) which formed the bulk of total minerals. The next important contents of seaweeds were magnesium (1.08-2.85 ppm), sodium (0.97-2.18 ppm) and potassium (2.37-3.10 ppm). The present result clarified that calcium (4.12 ppm) and magnesium values (2.85ppm) of *H. opuntia* were actually high, whereas the richest K (3.10 ppm) was reported with *T. triquetra*. It is known that themembers of *Halimeda*sp. gathered large amounts of lime and very effective in producing carbonate sand in these seas (Turna*et al.*, 2000). It can be showed that Na/K ratio was below 2.0 which are interesting from the point of view of nutrition, since the intake of sodium and diet with a high Na/k ratio have been related to the occurrence of hypertension.

Trace elements are natural constituents in marine environment and are divided into two subclasses. The first one include Co, Cu, Fe, Mn and Zn which are necessary for the biochemical processes but it may be toxic at high concentrations, while Hg, Cd, Cr and Pb belong to the second subclass of metals without biological function and includes the more important contaminates in the aquatic environment. Trace element contents of Red sea surface water at the study area were presented in Table 3. The results showed that the concentrations of trace elements in the surface water were decreased in the following order: B (0.143 ppm) > Zn (0.044 ppm) > Co (0.032 ppm) > Fe (0.012 ppm)> Cu (0.010 ppm)>Mn (0.009 ppm)>Pb (0.008 ppm) > Cr (0.005 ppm) > Ni and Cd (0.001 ppm). El Sayed (2002) found that the distribution of the elements is correlated tothe dilution of the effluent water and the free exchange of water between the coast and the main sea, which cause reducing in concentration of pollutants that find their way into the bottom.

In comparison of microelements of tested species (Table 3), *H. opuntia* showed the highest B (1.167ppm), Fe (0.428 ppm), Mn (0.328 ppm), Cu (0.081 ppm), Cr (0.061 ppm) and Pb (0.014 ppm). The maximum values for Zn (0.031 ppm), Co (0.008ppm),

Ni (0.007ppm) and Cd (0.003 ppm) were observed in *G. corticata*, while the lowest value of microelements was recoded with *T. triquetra.* Several studies were made by various workers in different seaweeds to know the elemental composition and nutrition value.In marine algae, the metals showed variable distribution and this may be due to the variation in metal concentrations of the seawater (Qariand Siddiqui, 2005).

To compare heavy metal contents in the algal biomass and in the sea water, the bioaccumulation coefficients have been calculated (Table 3).The greatest bioaccumulation for Mn (36.44), Fe (35.66), Cr (12.20), B (8.16), Cu (8.10) and Pb (1.75) were observed in *H. opuntia*, whereas Ni (7.0), Cd (3.0), Zn (0.70) and Co (0.25) were more concentrated in *G. corticata*. The minimum bioaccumulation of these metals was reported in the brown alga, *T. triquetra*. The general recommended limits for some elements are 2, 100, 100, 20 and 50 ppm for Pb, Ni, Cr, Cu and Zn, respectively (Mageswaranand Sivasubramantam, 1984). This means that the bioaccumulations of these metals inside the algae were within the corresponding range. The physical and chemical forms of metals in sea water are controlled by environmental parameters, such as pH, salinity, alkalinity, organic matter, ionic properties of the metals and biological activity. Seaweeds have the ability to regulate the uptake of these metals and hence do not accumulate them to such a great extent.

3.2 Biochemical composition of seaweeds

The data in Table 4 showed apparently a clear variation in the biochemical composition among tested green, red and brown seaweeds. There was a wide range of ash contents (20.54–53.79% dry weight), with the highest percentages (53.79% dry weight) in the heavily calcified *H. opuntia,* followed by *T. triquetra* (40.34 % dry weight) and then *G. corticata* (20.54% dry weight). The results in the present study for the highlycalcified *Halimeda*, concur with the findings of Kaehler and Kennish (1996) that all calcified seaweed species were high in ash and low in nutrients, and they were dissimilar to non-calcified species, regardless of taxonomic group.

The carbohydrate concentrations of the investigated seaweeds varied from 39.48 to 52.93% dry weight (Table 4). The maximum concentration was recorded from *G. corticata* (52.93 g/100 g) followed by *T. triquetra*(45.68 g/100 g) and *H. opuntia* (39.48 g/100 g). In agreement with the present result, Narasimman and Murugaiyan (2012) showed that the highest percent of carbohydrate content was in *Gracilariacorticata*when compared to the other Sargassaceae members *Sargassumlongifolium*and *Turbinariaconoides.* The protein content exhibited notable variation with the highest value of 15.06% in *G. corticta*, followed by 10.12 % in *T. triquetra*and 8.0 %in *H. opuntia* (Table 4). In accordance with our results Renaud et *al*. (2006) reported that the lowest percentages of total protein were found in *Halimedaopuntia.* The highest amounts of protein were in members of the rhodophytes, while lowest percentages were showed in the chlorophytes, which are of the same order as results for 11 chlorophyte, phaeophyte and rhodophyte species (ranged from 6.4 to 8.0%) (Kaehlerand Kennish, 1996). The total lipid contents in the investigated seaweeds were within the range of 2.33 to 5.98% (Table 4). The highest lipid content was observed in *G. corticta* (5.98%), followed by *T. triquetra* (4.83%) and then *H. opuntia* (2.33%). Manivannan *et al*. (2009) showed that the crude fat content was low in green algae and higher in red followed by brown algae.

The contents of alginic acid, agar and carrageenan in tested seaweeds were recorded in Table 4. The percentage of alginic acid in the brown alga *T. triquetra* was represented by 30.11 % dry weight, meanwhile agar and carrageenan recorded 18.44 and 18.0 % dry weight in the red alga *G. corticata*. In *Sargassumwightii*the alginic acid content varied from 21.3% to 31.7% and in *Turbinariaconoides* 23.2% to 35.6% (Chennubhotia *et al*., 1982). Peak quantities were found in these two brown seaweeds. Agar content was reported in the red algae, *Gracilarialichenoides, Hypneamusciformis Gelidiellaaceros,* by Thomas (1977) who found that seasonal variation in yield and physical properties of agar-agar from *Gracilariaverrucosa*were ranged from 26% to 43%.

The data on vitamins were given in Table 4. Among the investigated seaweeds, *H. opuntia* was the richest in the content of Vitamin A (104.6 µg/g dry weight), Vitamin B2 (67.78 µg/g dry weight) and Vitamin B6 (184.56 µg/g dry weight). *G. corticata* had the highest Vitamin C content (284.81 µg/g dry weight), followed by *T. triquetra* (219.17 µg/g dry weight) and *H. opuntia* (194.48 µg/g dry weight). The minimum values of Vitamin B1 (240.72 µg/g dry weight) and Vitamin B2 (32.69 µg/g dry weight) were represented in *G. corticata*, whereas *T. triquetra* presented the lowest content of Vitamin A (45.65µg/g dry weight) and Vitamin B6 (85.45µg/g dry weight). Seaweeds have high content of vitamins and represent an excellent source of vitamins A, B, C, D, E, B-complex and B12 (Drum, 2003).

The results in Table 4 showed the different ranges of cytokinin (2264.13-2675 mg/100 g), gibberellins (45.56-77.05 mg/100g), IAA (3.978-14.815 mg/100g) and ABA (7.303-19.869 mg/100g) in the investigated seaweeds. The brown alga, *T. triquetra*, contained the highest content of cytokinin (2675.43 mg/100g) and gibberellins (77.05 mg/100g) and the lowest values of IAA (3.978 mg/100g) and

ABA (7.303 mg/100g). The greatest values of IAA (14.815 mg/100g) and ABA (19.869 mg/100g) and the lowest gibberellins (45.56 mg/100g) were reported in the red alga, *G. corticata*. However, the minimum content of cytokinin (2264.13 mg/100g) was found in the green alga, *H. opuntia.* It is now recognized that many of the common higher plant hormones (abscisic acid, auxins, cytokinins and gibberellins) occur in seaweeds (Craigie, 2011). Abscisic acid induces gene transcription for proteinase inhibitors (Davies, 2004) and this may explain the presence of high content of protein in *G. corticata*.

3.3 Amino acids

Data of the total amino acids of investigated seaweeds were illustrated in Table 5. The non-essential amino acids (Non-EAA), namely aspartic acid, serine, glutamic acid, proline, glycine, alanine and histidine were ranged from 1.10 to 14.11% dry weight. The species contained large amount of aspartic (10.92-13.21% dry weight) and glutamic acids (12.71-14.11% dry weight), which are responsible for the special flavor and taste. The greatest values of glutamic acid (14.11 and 13.53% dry weight) and aspartic acid (12.01 and 13.21% dry weight) were recorded in *G. corticata* and *T. triquetra,* respectively. However, *H. opuntia* tended to show the minimum percentage of both aspartic acid (10.92% dry weight) and glutamic acid (12.71% dry weight). All groups were rich in glycine (6.13-6.58% dry weight) and alanine (7.15-8.53% dry weight). The red alga *G. corticata* showed a general trend of higher proline content (5.15 % dry weight) as reported by (Chakrabortyand Bhattacharya, 2012).

The seaweed sampleswere enriched in the essential amino acids (EAA), leucine, valine, lysine, phenylalanine, threonine, arginine, and isoleucine (Table 5). The analytical method used could not determine tryptophan. Yeoh and Truong (1996) reported that in acid hydrolysis some amino acids are partially or totally destroyed (e.g. tryptophan, cystine, methionine and serine). The percentage of different essential amino acids was ranged from 1.21 to 8.85% dry weight. The red alga, *G. corticata* showed the highest percentage of leucine (8.85% dry weight), lysine (6.76% dry weight) and arginine (5.92% dry weight). The largest percentage of some amino acids, threonine (5.91% dry weight) and isoleucine (4.80% dry weight) were found in the green alga *H. opuntia*. However, the most abundant amino acids valine (6.95% dry weight) and phenylalanine (5.82% dry weight) were reported in the brown alga *T. triquetra*. Tabarsa *et al.* (2012) reported that there were some pronounced differences between the amino acid profiles of different seaweeds. The percentages of methionine and cysteine were found to be low in all investigated groups and their values in red (01.96 and 01.58% dry weight, respectively) and brown algae (02.24 and 1.69% dry weight, respectively) tended to show the highest percentages as compared with the green alga (1.44 and 1.21% dry weight, respectively). Previous result revealed that the sulfur-containing amino acids of the brown and red seaweeds were higher than those of green seaweeds (Lourençoet *al.,* 2002). The ratios of EAA to total amino acids of tested species were almost 0.5 and the ratios of EAA to non-EAA were nearly 1.0. The present result is in agreement with that of Benjamaand Masniyom (2012).

3.4 Fatty acids in seaweeds

In the present study saturated fatty acids of tested *H. opuntia* (66.11%), *G. corticata* (74.42%) and *T. triquetra* (56.02%) were dominating the other groups of fatty acids among the total fatty acids (Table 6). The individual contribution of palmitic (55.21, 51.31 and 24.63%) and myristic acid (6.14, 17.12 and 16.50%) were reported as the most dominant saturated fatty acids in *H. opuntia*, *G. corticata* and *T. triquetra,* respectively. Palmitic and myristic acids were recorded as major fatty acids in seaweeds as found by Shanmugamand Palpandi (2008).

The total monounsaturated fatty acids (∑MUFAs) of *H. opuntia* (6.30%), *G. corticata* (5.72%) and *T. triquetra* (16.71%) were represented in Table 6 with the highest levels of mostly oleic acid C18:1n (ω9) which recorded relative percentage of 3.84, 4.71 and 15.24%, respectively. The total polyunsaturated fatty acids (∑PUFAs) contributed 27.58, 19.85 and 27.26% in *H. opuntia, G. corticata* and *T. triquetra,* respectively. The polyunsaturated fatty acids were mainly represented by linoleic acid C18:2n (ω6) in *H. opuntia* (15.03%)*, G. corticata* (10.11%) and ecosapentaenoic C20:5n (ω3) (EPA) in *T. triquetra* (15.31%). The unsaturated fatty acid docosahexaenoic (DHA) C22:6n (ω3) was only recorded in *H. opuntia* and accounted for 7.95% of all fatty acid. Results indicated that the investigated seaweeds contained low lipid contents and high level of polyunsaturated fatty acids of the omega-3 and omega-6 families. As clear from Table 10, the n-6/n-3 ratios of *H. opuntia*, *G. corticata* and *T. triquetra* were represented by 1.4:1, 1.6:1 and 0.5:1, respectively. The results of Dawczynski *et al*. (2007) study showed that the percentage of n-6 fatty acid is comparably low in seaweed varieties and n-6/n-3 ratio (1.1:1 in red algae and 0.8:1 in brown algae) is beneficial. This n-6/n-3 ratio is comparable with those of cold water fishes. Thus, consumption of seaweed products can contribute to the improvement of the dietary supply of n-3 fatty acid.

Table 1. Physicochemical parameters and inorganic constituents of Red Sea water (Mean ± SE, N=3)

Temp. (°C)	Salinity (‰)	pH	DO (mg/l)	NO_2 (µg/l)	NO_3 (µg/l)	NH_4 (µg/l)	PO_4 (µg/l)	Ca (mg/l)	Mg (mg/l)
29±1.0	39.82±1.12	8.10±0.2	3.64±0.12	15.32±0.72	34.76±2.12	12.56±1.12	6.12±0.72	68.65±3.12	251.21±4.12

Table 2. Inorganic constituents of seaweeds

Sample	P	N	Ca	Mg	Na	K	Na/K
			(ppm)				
H. opuntia	0.07 a ±0.01	1.28 a ±0.09	4.12 a ±0.37	2.80 a ±0.13	2.18 a ±0.06	2.37 a ±0.12	0.91a
G. corticata	0.13 b ±0.03	2.41 b ±0.15	3.07 a ±0.42	1.42 b ±0.08	0.97 b ± 0.02	2.85 a ±0.21	0.34b
T. triquetra	0.11 b ±0.02	1.62 a ±0.05	2.87 b ±0.25	1.08 c ±0.03	1.66 c ±0.32	3.10 b ±0.10	0.53c

The data are expressed in mean ± SE. n=3 in each group.
Means marked with different letters in the same column significantly differ at 5% level of probability

Table 3. Micronutrients in red sea water and seaweeds and bioaccumulation coefficients of heavy metals in seaweeds/water environments

Element (ppm)	Sea water	*H. opuntia*	B.C	*G. corticata*	B.C	*T. triquetra*	B.C
Zn	0.044±0.001	0.028±0.012	0.63a	0.031±0.001	0.70a	0.025±0.002	0.56a
Pb	0.008±0.001	0.014±0.010	1.75b	0.013±0.002	1.62b	0.011±0.001	1.37b
Ni	0.001±0.000	0.006±0.001	6.00c	0.007±0.002	7.00c	0.005±0.001	5.00c
Mn	0.009±0.002	0.328±0.014	36.5d	0.309±0.008	34.3d	0.144±0.002	16.0d
Fe	0. 012±0.001	0.428±0.018	35.7d	0.323±0.011	26.9d	0.277±0.003	23.0e
Cu	0.010±0.001	0.081±0.003	8.10c	0.062±0.001	6.20c	0.049±0.002	4.90c
Cr	0.005±0.002	0.061±0.001	12.2e	0.043±0.002	8.60c	0.041±0.001	8.20c
Cd	0.001±0.000	0.001±0.000	0.00a	0.003±0.001	3.00b	0.001±0.000	0.00f
Co	0.032±0.001	0.002±0.000	0.06a	0.008±0.002	0.25a	0.002±0.000	0.06f
B	0.143±0.002	1.167±0.013	8.16c	0.686±0.003	4.79b	0.694±0.002	4.85c

B.C, Bioaccumulation Coefficient. The data are expressed in mean ± SE. n=3 in each group. Means marked with different letters in the same column significantly differ at 1% level of probability

Table 4. Biochemical composition of seaweeds

Biochemical	*H. opuntia*	*G. corticata*	*T. triquetra*
Moisture(%)	12.96±0.32a	10.53±0.47a	15.83±0.31a
Ash(%)	53.79±3.34a	20.54±1.52b	40.34±2.60c
T. Carbohydrate(g/100g)	39.48±1.86a	52.93±2.65b	45.68±1.94c
T. Protein (%)	08.00±0.38a	15.06±0.31b	10.12±0.17c
T. lipid (%)	02.33±0.12a	05.98±0.25b	04.83±0.34c
Alginic acid (%)	ND	ND	30.11±2.07c
Agar (%)	ND	18.44±1.01	ND
Carrageenan (%)	ND	18.00±1.71	ND
Vitamins (µg/g DW)			
Vitamin A	104.6±4.01a	74.48±2.23b	45.65±1.76c
Vitamin B1	470.4±6.38a	240.7±4.73b	553.3±7.34c
Vitamin B2	67.78±3.46a	32.69±2.61b	54.92±2.23c
Vitamin B6	184.5±5.01a	142.8±3.78b	85.45±0.89c
Vitamin C	194.4±10.0a	284.8±13.3b	219.1±11.3c
Phytohormone(mg/100g)			
Cytokinin	2264.1±15.3a	2400.4±21.1b	2675.4±34.65c
GA3	65.61±3.23a	45.56±2.66b	77.05±3.0c
IAA	06.57±0.67a	14.81±2.25b	3.97±0.51c
ABA	11.33±0.62a	19.86±1.78b	7.30±0.33c

ND, not determined. The data are expressed in mean ± SE. n=3 in each group.
Means marked with different letters in the same row significantly differ at 5% level of probability

Table 5. Amino acid contents of seaweeds

Amino acids (%)	*H. opuntia*	*G. corticata*	*T. triquetra*
Aspartic acid	10.92±0. 24	12.01±1.22	13.21±0.71
Serine	04.75±0.16	03.27±0.87	04.12±0.32
Glutamic acid	12.71±0.36	14 .11±0.95	13.53±0.62
Proline	04.62±0.15	05.15±0.02	04.06±0.14
Glycine	06.58±0.28	06.25±1.14	06.13±0.87
Alanine	08.53±0.27	07.15±1.85	08.01±0.51
Histidine	01.53±0.11	01.37±0.03	01.10±0.06
∑Non-EAA	49.64	49.31	50.16
*Leucine	07.99±0.47	08.85±0.89	08.46±0.86
*Valine	05.87±0.19	06.54±0.67	06.95±0.96
*Lysine	05.93±0.07	06.76±0.06	05.63±0.67
*Phenylalanine	05.60±0.03	05.40±0.21	05.82±0.04
*Threonine	05.91±0.18	05.67±0.12	05.66±0.26
*Arginine	05.42±0.15	05.92±0.62	05.57±0.81
*Isoleucine	04.80±0.31	04.11±0.09	04.45±0.16
*Tyrosine	03.86±0.23a	03.04±0.04a	02.14±0.06b
*Methionine	01.44±0.13a	01.96±0.15a	02.24±0.03b
*Cysteine	01.21±0.11	01.58±0.07	01.69±0.02
*Tryptophane	ND	ND	ND
Ammonia	02.33±0.04a	0.86±0.07b	1.23±0.02c
∑EAA	48.03	49.83	48.61
∑AA	100	100	100
∑EAA/ AA	0.48	0.50	0.49
∑EAA/Non-EAA	0.97	1.01	0.97

* EAA, Essential amino acids; Non-EAA, Non-essential amino acid; ND, not determined Concentrations of ammonia correspond to nitrogen recovered from some amino acids destroyed during acid hydrolysis. The data are expressed in mean ± SE. n=3 in each group.
Means marked with different letters in the same row significantly differ at 5% level of probability

Table 6. Fatty acid profiles of seaweeds (% of total fatty acids)

Fatty acids (%)	*H. opuntia*	*G. corticata*	*T. triquetra*
Decanoic C10:0	2.06±0.05	1.52±0.13	2.14±0.01
Lauric C12:0	1.27±0.13	1.51±0.41	1.20±0.01
Myristic C14:0	6.14±1.04	17.12±1.67	16.50±0.97
Palmitic C16:0	55.21±2.36	51.31 ±2.23	24.63±1.56
Hecanoicepta C17:0	ND	1.33±0.11	2.13±0.02
Stearic C18:0	1.41±0.26a	1.60±0.36a	2.65±0.15b
Archidic C20:0	ND	ND	3.77±0.25
∑TSFAs	66.11a	74.42a	56.02b
Palmitolieic C 16:1n	2.46±0.21a	1.01±0.01b	1.47±0.03b
Oleic C18:1n (ω9)	3.84±0.75a	4.71±0.86a	15.24±0.78b
∑MUFAs	6.30a	5.72a	16.71b
Linoleic C18:2n (ω6)	15.03±1.21a	10.11±0.26b	6.67±0.56c
Linoeladic C18:2n (ω6)	1.41±0.05a	2.31±0.08b	2.89±0.14b
Alpha-linolenic C18:3n (ω3)	3.18±0.76a	5.23±0.06b	2.38±0.01a
Ecosapentaenoic (EPA) C20:5n (ω3)	ND	2.20±0.04a	15.31±0.72b
Docosahexaenoic (DHA) C22:6n (ω3)	7.95±1.06	ND	ND
∑ω6	16.44a	12.42b	9.56c
∑ω3	11.14a	7.435b	17.69c
ω6/ ω3	1.47	1.671	0.54
∑PUFAs	27.58a	19.85b	27.26a
∑TUFAs	33.89a	25.58b	43.97c
TUFAs/ TSFAs	0.51	0.34	0.78

ND, not determined. The data are expressed in mean ± SE. n=3 in each group.
Means marked with different letters in the same row significantly differ at 5% level of probability

4. Conclusions

It can be concluded that, Red Sea water characterized by high salinity and abundance of nitrate, Ca, Mg and B. There were variations in the chemical composition among species. The green *H. opuntia* was the richest in Ca, Mg, Na, Mn, Fe, ash, Vitamin A, B2 and B6, and the red *G. corticata* was the highest in P, N, carbohydrate, protein, lipid, Vitamin C, IAA, ABA, carrageenan, agar and essential amino acids. The macro-element potassium, Vitamin B1, cytokinin, GA3, alginic acid and total unsaturated fatty acid were the most contents in the brown *T. triquetra*. The investigated seaweeds contained low lipid contents and high level of polyunsaturated fatty acids.

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