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Proximate Composition of Some Selected Seaweeds from Coastal Areas of Cox's Bazar and the St. Martin's Island, Bangladesh

Kamrun Nahar Chowdhury[1], Md. Kawser Ahmed[1,2*], Kazi Turjaun Akhter[3], Md. Jobaer Alam[1], Seema Rani[2] and Makidul Islam Khan[2]

[1]Department of Oceanography, University of Dhaka, Dhaka 1000, Bangladesh
[2]International Centre for Ocean Governance (ICOG), University of Dhaka, Dhaka 1000, Bangladesh
[3]Institute of Nutrition and Food Science, University of Dhaka, Dhaka 1000, Bangladesh

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ABSTRACT

The present study assesses the proximate composition of eight wild seaweed species viz. *Hypnea* sp., *Enteromorpha* sp., *Sargassum* sp., *Hydroclathrus clathratus*, *Padina pavonica*, *Colpomenia sinuosa*, *Petalonia fascia* and *Dictyota ciliolata* and one cultured species viz. *Hypnea* sp. collected from western coast of the St. Martin's Island and Nunairchhara, Cox's Bazar, respectively. Standard analytical methods were used to estimate moisture, ash, lipid, crude fiber and protein contents, while carbohydrates were measured by subtracting ash, fat, fiber and protein contents from 100 on a dry weight basis. Results showed average moisture content in different seaweed species ranged between 12.09% to 29.65% and varied from species to species. Maximum ash content was found in brown seaweed *H. clathratus* (61.98%), while the lowest was recorded in wild red algae *Hypnea* sp. (7.05%). This study showed mean lipid contents in all seaweed species were much lower than other contents of proximate composition. The highest crude fiber content was observed in *P. fascia* (10.08±0.07%), while the lowest was observed in *Enteromorpha* sp. (0.23±0.01%). The highest protein (23.64±1.44%) and carbohydrate content (46.71±0.54%) was found in *Hypnea* sp. This study showed that mean carbohydrate content was higher in Rhodophyta, Chlorophyta and Phaeophyta, whereas, lipid content was lower in the three groups. Proximate composition of ash, lipid, crude fiber and protein content within species varied due to habitat differences, changes of body structures or physiological alterations, changes in growth rates and photosynthetic function of seaweed species and geographical differences. The mean moisture and ash content were the highest in cultured *Hypnea* sp., whereas, lipid, crude fiber, protein and carbohydrate were formed to the highest in wild *Hypnea* sp. Results suggest wild *Hypnea* sp. was much nutritive because of having higher amount of protein, fiber, carbohydrate and lipid than cultured ones. The study indicates that seaweeds might be used as a potential source of protein, fiber and carbohydrate.

Introduction

Marine macro-algae or seaweeds are the ecologically and biologically important sources of bioactive compounds e.g., carotenoids, fats, proteins, dietary fibers, fatty acids, vitamins and minerals, etc. (Foster and Hodgson, 1998; Fleurence, 1999; Gullón et al., 2020; Rengasamy et al., 2020). Seaweeds are considered a high-quality food all over the world because of having a significant amount of minerals, fiber, omega-3 fatty acids, and adequate amount of fats and proteins for human nourishment. The bioactive compounds and nutritional values of seaweeds may vary species to species basically depending on season, environmental factors and geographical locations (Kaehler and Kennish, 1996; Rupérez, 2002; Dawczynski et al., 2007).

Three main groups or phyla of seaweed i.e., Rhodophyta (red algae), Chlorophyta (green algae) and Phaeophyta (brown algae) that include thousands of seaweed species (Rindi et al., 2012) are found around the world. All of these seaweeds comprise a great quantity of carbohydrate as structural, storage, and functional polysaccharides that may range from 20-76% of dry weight and might be varied from species to species (Holdt and Kraan, 2011). In general, the seaweed protein comprises most of the

* Corresponding Author
E-mail: kawser@du.ac.bd (Md. Kawser Ahmed)

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essential amino acids and particularly contains high amount of glycine, arginine, alanine, and glutamic acid (Dawczynski et al., 2007). Though seaweed is considered a better source of protein compared to other protein-rich foods, it contains very insignificant amount of lysine and cysteine (Ramos et al., 2000). Red seaweed holds the greatest amount of protein and it ranges between 30–40% of dry matter that could be comparable to the protein contents in legumes. On the other hand, brown and green seaweeds comprise around 15% and 30% of protein, respectively (Murata and Nakazoe, 2001). Seaweed contains a very little amount of lipid that generally fluctuated in between 1-5% of dry matter (McDermid and Stuercke, 2003; Kumari et al., 2010). Two most important groups of lipids in seaweeds are neutral lipids and glycolipids, and the percentage of essential fatty acids found in seaweed is greater than that found in most terrestrial plants (Shannon and Abu-Ghannam, 2019). However, the quantity and the composition of fat in seaweeds can be significantly varied from species to species. Therefore, seaweeds are considered a noble source of health stimulating polyunsaturated fatty acid (PUFA) compared to other plants and animals originated diets.

Bangladesh is the largest deltaic nation in the world. Though most of the lands of this country is plain and low land, it has a long coastline in the northeast and the southeast areas and some other parts in the north and northwestern part along with the Bay of Bengal. The coastline of Bangladesh is about 710 km long and the coastal zone is about 23% of the area. There are 38.66 million people in the 19 coastal districts including 147 coastal upazilas which is about 23% of total population (BBS, 2021). The coastal zone has copious natural resources such as fish, corals, seaweeds and minerals and tourism potential and much more to explore. Most of the coastal people are dependent on aquatic resources such as fish and shellfish, corals, etc. and tourisms for their livelihoods (e.g., Ahamed et al., 2012; Gazi et al., 2020; Rani et al., 2020; etc.). However, most of the people in coastal Bangladesh are not aware about the contribution of seaweeds as a food source and a livelihood option. Merely trivial amount of seaweed biomass is consumed by tribal people of Mog or Rakhyine and seaweed harvesters of the St. Martin's Island (Sarkar et al., 2016).

In the coastal region of Bangladesh, around 193 seaweed species under 94 genera (Sarkar et al., 2016) or 215 seaweed species under 102 genera (DoF, 2019) are available. About 140 and 155 seaweed species are found in coastal waters of the St. Martin's Island and Cox's Bazar, respectively. However, seaweeds are plentiful in western coast of the St. Martin's Island (Sarkar et al., 2016). Till now scientists of Bangladesh Fisheries Research Institute (BFRI) have confirmed that 132 seaweed species are present in coastal waters of Bangladesh (BFRI, 2019). Among them, the number of commercially important seaweed species is 10 (Khan, 1990; Majumder, 2010) or 19 (Sarkar et al., 2016) or 20 (DoF, 2014). Most recent studies reported that 17 commercially significant seaweeds are available in the St. Martin's Island (Rani et al., 2020).

Though some studies are carried out to assess the distribution, abundance of bioactive compounds and nutritional values of seaweed species in Bangladesh (e.g., Siddique et al., 2013; Khan et al., 2016; Sarkar et al., 2016; Hossain et al., 2021a; Hossain et al., 2021b; etc.), they are scattered and fragmented. In addition, the nutritional properties of most of the important seaweeds are poorly studied or limited in Bangladesh. So, this study aimed to estimate proximate composition (moisture, ash, protein, lipid, crude fiber and total carbohydrate) of eight important seaweed species collected from the St. Martin's Island and Cox's Bazar in order to provide more comprehensive nutritional information of those seaweeds.

Materials and Methods

Collection of Seaweeds

Marine seaweeds were collected from north Nuniarchhara area of Cox's Bazar which is located 21°28'27"N and 91°57'60"E, and western coast of the St. Martin's Island which is located at 20°37'05"N and 92°19'26"E of the most south-eastern border of Bangladesh, northern Bay of Bengal (Figure 1). The samples were collected during February, 2018.

A total of eight wild seaweeds viz. *Hypnea* sp., *Enteromorpha* sp., *Sargassum* sp., *Hydroclathrus clathratus*, *Padina pavonica*, *Colpomenia sinuosa*, *Petalonia fascia* and *Dictyota ciliolata* were collected from the western coast of the St. Martin's Island (Figure 2). However, only one cultured seaweed of *Hypnea* sp. was collected from Nunairchhara, Cox's Bazar. Seaweed samples were identified based on taxonomic references such as examination of morphological characteristics following the guidelines of BFRI (2019).

The samples were collected systematically during low tide by hand from the intertidal area of the above-mentioned locations. A few of the floating seaweeds were also collected from the shallow coastal water. All samples were thoroughly washed in running seawater and rinsed with fresh water to remove all undesirable substances such as salt and external substances e.g., epiphytes, shells, sand, debris, etc. Then samples were preserved into plastic jars using 4-5% of alcohol.

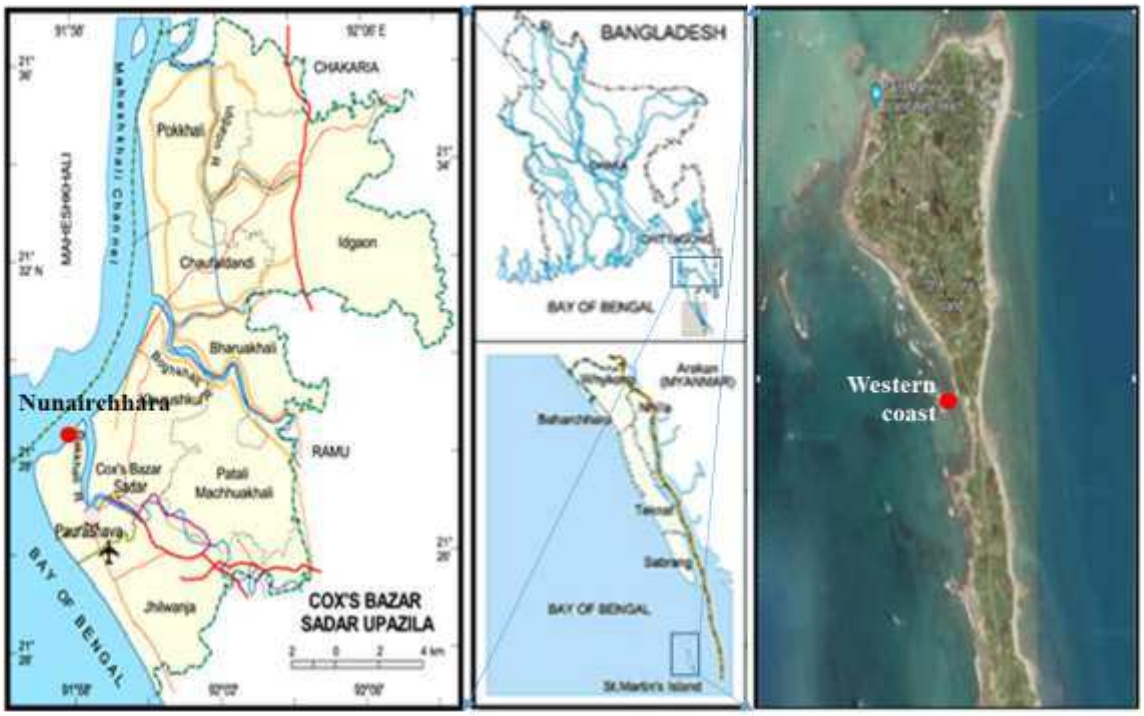

Figure 1: Location of sampling sites in Nunairchhara of Cox's Bazar and western coast of the St. Martin's Island, Bay of Bengal

Figure 2: Photographs of seaweed samples A. *Hypnea* sp., B. *Enteromorpha* sp., C. *Sargassum* sp., D. *Hydroclathrus clathratus*, E. *Padina pavonica*, F. *Colpomenia sinuosa*, G. *Petalonia fascia*, and H. *Dictyota ciliolata* collected from Nunairchhara of Cox's Bazar and western coast of the St. Martin's Island, Bay of Bengal

Sample Preparation

All seaweed samples were brought back to the laboratory of the Institute of Nutrition and Food Science (INFS) in the Dhaka University. In the laboratory, samples were gently washed with distilled water and air-dried the samples around 3 days. After then samples were oven-dried at 105°C for overnight and then the dried seaweed samples were grinded into powder using a mortar and pestle. All powdered seaweed samples were kept in desiccators at room temperature until chemical analyses were done. All chemical analyses were conducted at the INFS, University of Dhaka.

Estimation of Proximate Composition

Biochemical analyses to estimate the proximate composition of marine seaweeds such as moisture, ash, protein, crude fiber, lipid and carbohydrate were conducted following the official methods of the Association of Official Analytical Chemist (AOAC, 2000).

Moisture Content

Moisture content was estimated by heating the samples at 100-105°C for 3-5 hrs. in the oven and cooling it in desiccators to absorb the moisture. The percentage of the moisture content was estimated following the equation:

$$\% \text{ Moisture} = \frac{W_1 \text{ (g)} - W_2 \text{ (g)}}{\text{Weight of the fresh sample (g)}} \times 100$$

Where,

W_1 = Sample weight + Crucible weight (before heating)

W_2 = Sample weight + Crucible weight (after heating)

Ash Content

The ash content of the samples was measured by drying the samples at 550-650°C temperature. A muffle furnace was used and operated at 600°C temperature for 4 to 5 hrs. to get the result. The percentage of ash content was estimated following the formula:

$$\% \text{ Ash} = \frac{\text{Weight of ash (g)}}{\text{Weight of the sample (g)}} \times 100$$

Where,

Weight of ash = Total weight of sample and crucible after heating – Weight of crucible

Weight of the sample = Total weight of sample and crucible before heating – Weight of crucible

Lipid Content

Lipid content in seaweed samples was quantified as crude ether extract of the dry material. At the end, the ether was removed by evaporation at 80-100°C temperature and the flask containing fat was weighted. The percentage of fat content was determined following the formula:

$$\% \text{ Lipid} = \frac{\text{Weight of extracted fat (g)}}{\text{Weight of the sample (g)}} \times 100$$

Where,

Weight of extracted fat = Weight of extracted fat and conical flask – Weight of empty conical flask

Crude Fiber Content

The crude fiber was quantified based on gravimetric technique. Moisture and fat free sample is needed for the analysis. Crude fiber was estimated by chronological extraction of the sample with 1.25% (0.255 N) of H_2SO_4 and 1.25% (0.313 N) of NaOH. The insoluble filtrate was gathered by filtration and the filtrate was dried and weighed. Crude fiber content in seaweeds was estimated following the formula:

$$\% \text{ Crude fiber} = \frac{100 \times \text{Weight of fiber (a} - \text{b)}}{\text{Sample weight (moisture and fat free)}}$$

Where,

a = Crucible weight with fiber and ashes after drying in an oven at 105°C for three hrs.

b = Crucible weight with ashes after drying in muffle furnace at 600°C for three to four hrs.

Protein Content

The protein content of seaweeds was measured by calculating nitrogen value of the material and multiplying it by 6.25. Nitrogen value was estimated using Kjeldhal method which relies on organic nitrogen that turned into $(NH_4)_2SO_4$ when digested with concentrated H_2SO_4. Ammonia (NH_3) released to make the solution alkaline, and it was distilled into a known volume of standard acid (H_2SO_4) which was then back titrated with sodium hydroxide (NaOH). Protein content of the sample was estimated following the formula:

$$\% \text{ Protein} = \frac{(b - c) \times 14 \times d \times 6.25 \times 100}{a \times 1000}$$

Where,

a = Sample weight (g)

b = Volume of NaOH require for the back titration and to neutralize 20 ml of 0.1 N H_2SO_4 (for sample)

c = Volume of NaOH require for the back titration and to neutralize 20 ml of 0.1 N H_2SO_4 (for blank)

d = Normality of NaOH used for titration

14 = Atomic weight of nitrogen

6.25 = Conversion factor of nitrogen to protein

Carbohydrate Content

Carbohydrates percentage in seaweeds was quantified by subtracting total amount of ash, fat, fiber and protein from one hundred on dry weight basis. Carbohydrate content was calculated following the method of James (1995):

Carbohydrate (%) = 100 - (crude fiber + protein + ash + lipid)

Data Analysis

Microsoft Excel (version-13) was used for statistical analysis of the data. Descriptive statistics such as mean ± SD were used and data were presented in tabular and graphical forms.

Results and Discussion

This study showed that collected 8 different types of seaweed species were belongs to three major phyla or groups such as Rhodophyta or red algae (*Hypnea* sp.), Chlorophyta or green algae (*Enteromorpha* sp.) and Phaeophyta or brown algae (*Sargassum* sp., *H. clathratus*, *P. pavonica*, *C. sinuosa*, *P. fascia* and *D. ciliolata*).

Proximate Composition of Seaweeds

The proximate composition of moisture, ash, fat, crude fiber, protein and carbohydrates of the collected seaweeds were described below:

This study showed that average moisture content among the seaweed species ranged between 12.09% to 29.65%. The greatest moisture content was observed in *D. ciliolata* and the lowest in *P. pavonica* (Table 1), both of them were brown seaweed. However, the mean moisture content in different brown seaweeds varied from species to species. The moisture content in both red and green seaweed species were almost similar (15.43% and 15.79%, respectively). Amount of moisture content in seaweeds is a key benchmark in estimating shelf-life and quality of processed seaweed products because moisture level beyond optimal condition might accelerate microbial growth (Rohani-Ghadikolaei et al., 2012).

The maximum ash content was found in the brown seaweed *H. clathratus* (61.98%), while the lowest was observed in wild red algae *Hypnea* sp. (7.05%) (Table 1). Most of the brown seaweeds (*H. clathratus*, *P. pavonica*, *C. sinuosa* and *D. ciliolata*) showed higher amount of ash content than red algae (*Hypnea* sp.) and brown algae (*Enteromorpha* sp.).

Usually, seaweeds have great amount of ash content due to their cell wall polysaccharides and protein containing anionic carboxyl, sulfate and phosphate groups that are outstanding binding sites to hold metals (Davis et al., 2003) that consistently directs the existence of substantial quantities of various mineral constituents (Matanjun et al., 2009). Ash was the most abundant component of dried material in all species, even though none are calcareous (McDermid and Stuercke, 2003). The ash content of the current study is comparably greater than those reported by Tabarsa et al. (2012) for *C. sinuosa* (39.28±0.7%); Mwalugha et al. (2015) for *H. clathratus* (33.58±8.01%) and *Dictyota* sp. (22.70±0.11%), and Khan et al. (2016) for *Hypnea* sp. (3.96±0.9%) and *E. intestinalis* (15.2±1.5%). However, Tabarsa et al. (2012) and Mwalugha et al. (2015) reported higher amount of ash content in *P. pavonica* (33.08±0.82%) and *Sargassum* sp. (25.64±0.39%) respectively which was higher than the present study.

The mean lipid content among various seaweed species varied from 0.15% to 2.75%. Results revealed that the highest and the lowest lipid content were found in brown seaweeds *P. fascia* (2.75%) and *H. clathratu*s (0.15), respectively (Table 1). It was found in this study that mean lipid content in all seaweed species was much lower than other contents of proximate composition that might be because of their body structures or physiological variations. Burtin (2003) and Polat and Ozogul (2008) also showed that seaweeds usually contain comparatively lower amount of lipid (around 1–5% of dry weight). The reported values of fat content of the studied seaweeds in the current study were comparatively lesser than the results of Mwalugha et al. (2015) for *D. ciliolata* (4.04±0.00%), *H. Clathratus* (1.62±0.07), *Sargassum* sp. (2.19±0.19%); Tabarsa et al. (2012) for *C. sinuosa* (1.46±0.38%), *P. pavonica* (1.79±0.56%) and Khan et al. (2016) for *Hypnea* sp. (0.78±0.3%) which might be varied because of geographical differences.

Table 1: Proximate composition analysis (Mean ± SD) of wild seaweed species collected from western coast of the St. Martin's Island

Name of phyla	Name of species	Proximate composition					
		Moisture (%)	Ash (%)	% of dry weight			
				Lipid	Crude Fiber	Protein	Carbohydrate
Rhodophyta	*Hypnea sp.*	15.43±0.85	7.05±0.27	1.46±0.30	5.72±1.17	23.64±1.44	46.71±0.54
Chlorophyta	*Enteromorpha sp.*	15.79±0.66	32.40±1.75	0.59±0.06	0.23±0.01	18.35±1.51	32.65±3.88
Phaeophyta	*Sargassum sp.*	20.29±1.25	19.44±0.74	0.39±0.07	7.78±0.42	13.36±0.15	38.75±1.01
	H. clathratus	17.79±1.29	61.98±0.54	0.15±0.06	2.19±0.23	7.20±0.31	10.70±0.16
	P. pavonica	12.09±2.92	54.51±8.07	0.23±0.08	0.83±0.02	7.64±1.29	24.72±6.54
	C. sinuosa	12.74±1.36	57.21±1.91	0.20±0.03	5.68±0.29	7.15±0.52	17.04±2.44
	P. fascia	17.80±0.07	18.51±2.42	2.75±0.14	10.08±0.07	7.24±0.45	43.63±2.72
	D. ciliolata	29.65±1.92	44.49±2.40	1.68±0.06	1.76±0.06	7.69±1.02	14.74±3.31

Results also revealed that the highest crude fiber content was found in the brown seaweed *P. fascia* (10.08±0.07%), while the lowest was observed in green seaweed *Enteromorpha* sp. (0.23±0.01%). Kasimala et al. (2017) reported that one seaweed species (*Enteromorpha clathrate*) contained 17.17% of crude fiber that was greater than the estimated value of it in the present study. Khan et al. (2016) showed that wild *Hypnea* sp. contained lower amount of crude fiber (4.1±0.5%) that supports the finding of this study. The variations in crude fiber content of seaweeds might be occurred because of dissimilarities in growth phases and photosynthetic function between seaweed species (Wong and Cheung, 2000; Siddique et al., 2013). It might also be varied because of seasonal environmental factors that could control photosynthesis and nutrients uptake of the seaweeds.

From this study, it was found that the maximum amount of protein and carbohydrate content was in the red seaweed *Hypnea* sp. and it was 23.64% and

46.71%, respectively (Table 1). The lowest protein and carbohydrate contents were observed in brown seaweed *C. sinuosa* (7.15%) and *H. clathratus* (10.70%), respectively (Table 1). The mean protein contents in red and green seaweeds were greater than all brown seaweed species. However, they also showed higher amount of carbohydrate content than some of the brown seaweeds such as *P. pavonica*, *C. sinuosa* and *D. ciliolata*. Khan et al. (2016) and Mwalugha et al. (2015) reported almost similar values of 22.31±1.0% and 21.39±0.06%, respectively for protein content in *Hypnea* sp. than the present study. However, Tabarsa et al. (2012) reported higher amount of protein content (10.11±0.38%) in *C. sinuosa* than the current study. The protein content in different species might be varied because of geographical differences. Haroon et al. (2000) showed that protein content of seaweed species differed geographically that supports the findings of the present study. Another study stated that protein content of different seaweed species might be varied from species to species (Dhargalkar et al., 1980). Results showed that carbohydrate was the main constituent in the proximate composition of all seaweeds. Khan et al. (2016) reported a higher amount of carbohydrate (51.4±0.5%) in *Hypnea* sp. which was greater than the present study. Mwalugha et al. (2015) showed other species (*Sargassum* sp. and *D. ciliolata*) contained lower amount of carbohydrate than *Hypnea* sp. that was in line with the current study.

Variation of Proximate Composition in Algal Groups

A total of three seaweed species, one from each group, such as *Hypnea* sp. in Rhodophyta, *Enteromorpha* sp. in Chlorophyta and *Sargassum* sp. in Phaeophyta were selected to compare the proximate composition. This study showed that among the three groups, the percentage of mean carbohydrate content was the highest and lipid content was the lowest (Figure 3).

From the above discussion, it was clearly understood that among three algal groups Rhodophyta had the highest carbohydrate; protein and fiber content than the other two groups. The broad difference of proximate composition in the three-seaweed species from three algal groups of the current study might have occurred due to different factors like differences in geographical position, season, photoperiods, temperature and salinity (Marinho-Soriano et al., 2006).

Variation of Proximate Composition of Hypnea sp. in Two Sites

In this study, wild and cultured *Hypnea* sp. were collected from western coast of the St. Martin's Island and Nunairchhara, Cox's Bazar respectively to compare their proximate composition. The mean moisture and ash content were higher in cultured *Hypnea* sp., whereas, lipid, crude fiber, protein and carbohydrate contents were higher in wild *Hypnea* sp. (Figure 4).

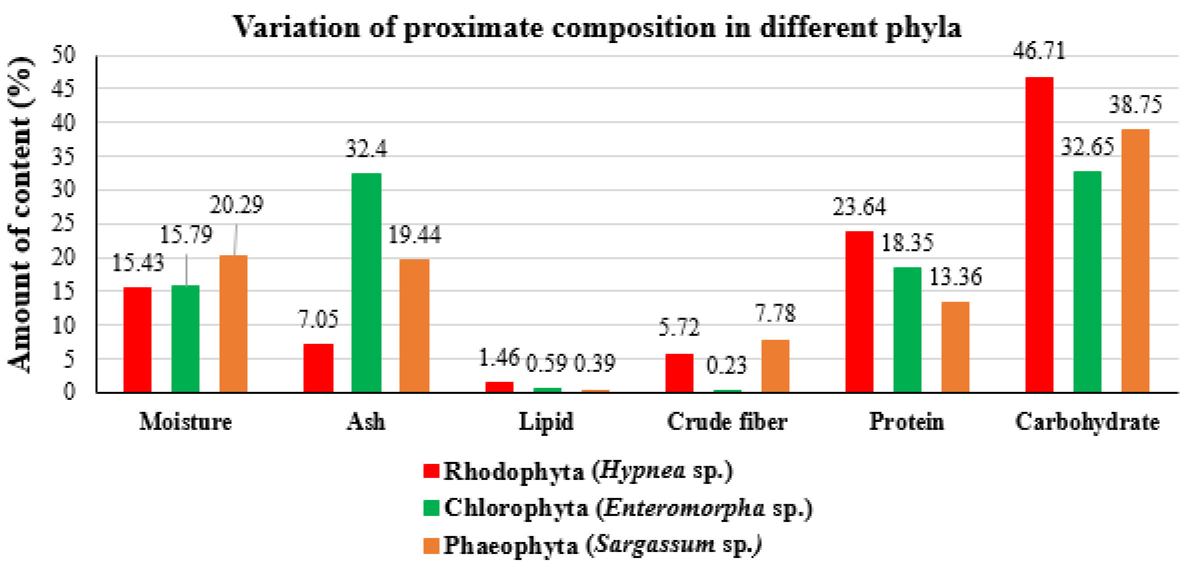

Figure 3: Differences of proximate compositions (% dry weight) in three algal groups

In this study, proximate composition of wild and cultured *Hypnea* sp. from two different sites showed which type of *Hypnea* sp. was more nutrient rich. Generally, nutritional compositions of seaweeds are varied depending on numerous environmental factors like changes of water temperature, salinity fluctuation, light and nutrients availability, etc. (Dawes, 1998). These environmental factors might also vary due to seasonal fluctuations in ecological circumstances that can stimulate or obstruct the biosynthesis of many nutrients (Lobban et al., 1985). The results of this study suggested that wild *Hypnea* sp. from the St. Martin's Island was much more nutritious because of having higher amount of protein, fiber, carbohydrate and lipid than the cultured ones. In addition, the St. Martin's Island has rocky substratum that are suitable for natural growth of seaweeds where it's temperature 24.62°C, salinity 31.72 ppt, pH 7.22, DO 5.88 mg/L (Islam et al., 2017). Moreover, in the wild, seaweeds grow separately in wide places, however, in the cultivation method, seaweeds are cultivated in one place crowdedly (e.g., rope method) which may be one of the reasons why cultured seaweeds have lower nutritious value (e.g., lipid, fiber, protein and carbohydrates) than wild counterparts.

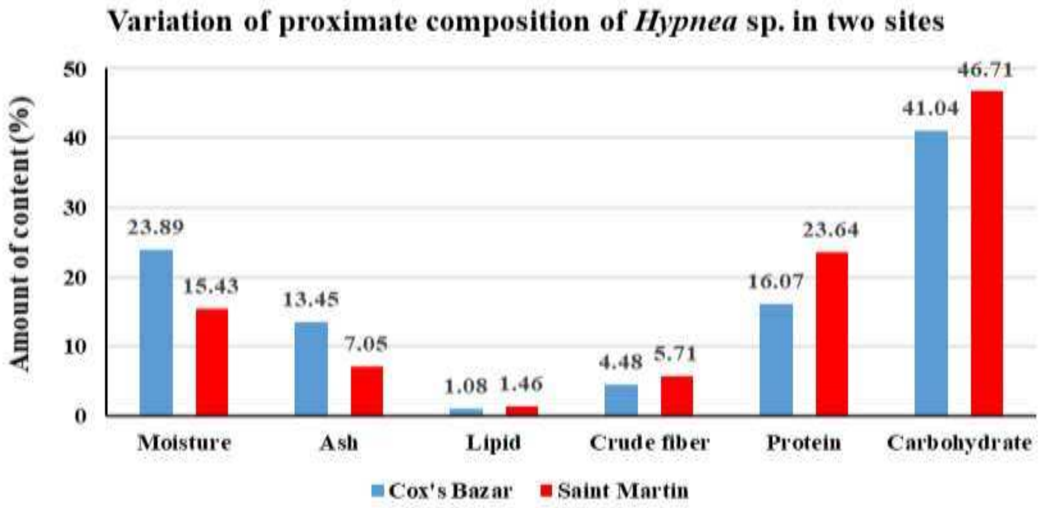

Figure 4: Variation of proximate composition (% dry weight) of *Hypnea* sp. (Rhodophyta or red algae) in two sites

Among the eight-seaweed species, five (5) seaweed species viz. *Hypnea* sp., *Enteromorpha* sp., *Sargassum* sp., *H. clathratus* and *P. pavonica* are commercially important (Sarkar et al., 2016) (Table 2). All the seaweed species are edible except *D. ciliolata* according to national and international scientific evidence. Thus, seaweeds can significantly support the poor people of coastal Bangladesh providing highly nutritious protein rich food.

Table 2: Studied seaweed species edibleness, types and their availability in ASEAN countries

			Bangladesh			ASEAN countries									
Name of phyla	**Scientific name**	**Local name**	**Edible**	**Wild**	**Cultured**	**Indonesia**	**Malaysia**	**Philippines**	**Singapore**	**Thailand**	**Vietnam**	**Brunei**	**Laos**	**Myanmar**	**Cambodia**
Rhodophyta	*Hypnea sp.**	Shemai Hazala	Y[a,b]	Y	Y	A	A	A	A	A	A	-	-	A	-
Chlorophyta	*Enteromorpha sp.**	Shobuj Shamudrik Shoibal	Y[c,d]	Y	Y	A	A	A	-	-	-	-	-	-	-
Phaeophyta	*Sargassum sp.**	Badami Shoibal	Y[e,f]	Y	-	A	A	A	A	A	A	-	-	A	-
	*H. clathratus**	Badami Shoibal	Y[g]	Y	-	A	A	A	A	A	A	-	-	-	-
	*P. pavonica**	Badami Shoibal	Y[h]	Y	-	-	-	A	A	A	-	-	-	A	-
	C. sinuosa	Badami Shoibal	Y[i]	Y	-	-	A	A	A	A	A	-	-	A	-
	P. fascia	Sea Petals, Broad Leaf Weed	Y[j,k]	Y	-	-	-	-	-	-	A	-	-	-	-
	D. ciliolata	Badami Kanta Hazala	-	Y	-	-	A	A	A	A	A	-	-	A	-

*Commercially important species (Sarkar et al., 2016), 'Y' = Yes, 'A' = Available, '-'= data not found

a. Rafiquzzaman et al. (2016), b. Alves et al. (2012), c. Okai and Higashi-Okai (1997), d. MacArtain et al. (2007), e. Yokoi and Konomi (2012), f. Yangthong et al. (2009), g. Wang et al. (2010), h. Güner (2021), i. Monla et al. (2020), j. MACOI (2021) and k. Uribe et al. (2018).

In Bangladesh, only two seaweed species (*Hypnea* sp. and *Enteromorpha* sp.) are cultured experimentally in coastal waters of Cox's Bazar and the St. Martin's Island. If the studied edible seaweed species of this study are brought under cultivation, the nutritional needs of the coastal poor will be met since 13.8% of the population lives under the poverty line in Bangladesh (World Bank, 2018). This will also create employment opportunities for the coastal people especially for women. After fulfilling the demand of the country, surplus production of the seaweeds can be exported to other countries where it has huge market demand. The studied seaweed species (except *P. fascia*) of this study are mostly available in ASEAN countries except Brunei, Cambodia and Laos (Table 2). However, there are scant studies on the culture methods of the studied seaweeds in the ASEAN countries. This might be because of farming some other commercially important edible seaweeds in ASEAN countries like *Gracilaria tenuistipitata* and *Caulerpa racemosa* in Thailand

(Yangthong et al., 2009), *Kappaphycus* sp. in Cambodia, Myanmar, Vietnam, Malaysia, Indonesia and Philippines (Hayashi et al., 2017), etc.

In Bangladesh, both wild and cultured seaweeds are mostly dispersed in the subtidal, tidal, and intertidal waters of the south-east especially in the east coast of Bangladesh, northern Bay of Bengal. But the estuaries and coastal waters of the east coast of Bangladesh have become severely polluted because of indiscriminate discharging of untreated wastewater from diverse sources (e.g., Rani et al., 2021) which exacerbated the potential accumulation of toxic metals in marine seaweeds (Chowdhury et al., 2021) and raised escalating health concerns around the world (e.g., Chen et al., 2018; Rajaram et al., 2020; Filippini et al., 2021; Jha et al., 2021; etc.). For example, a few metals such as Cd, Hg and Pb might be noxious even at a very low concentration and biologically indispensable elements might also originate toxic effects at higher concentrations. Heavy metal accumulation in fatty tissues and internal organs of the human body might also affect the central nervous system (Balali-Mood et al., 2021). Thus, future research should be directed on analyzing minerals and heavy metals composition in seaweeds to assess their potential health impacts on humans.

In addition, some tribal communities who live in coastal areas are not able to buy expensive nutritional foods for their families because of their hardships. As a result, pregnant women, elderly persons and children of poor coastal households remained malnourished. For them, seaweed will provide improved nutritious food at a low price. It is apparent that seaweed is a good source of valuable nutrients. Therefore, it is very obligatory to pay more attention to culture and process seaweeds because it will play a significant role in tackling the nutritional deficiencies of the poor people to deal with the food problem to some extent and to boost the economy of the country.

Conclusions and Policy Implications

Geographically, coastal areas of Bangladesh, especially the St. Martin's Island, are suitable for natural seaweed growth. Seaweeds can be an important nutritious food for the poor coastal people of Bangladesh who cannot afford to buy expensive nutritive foods. Besides these, seaweed farming and processing can generate employment opportunities for the unemployed poor coastal people as well as marginalized tribal communities who reside near the coastal areas. In addition, it could be considered an alternative employment source for fishery dependent coastal people particularly during the period of 65 days marine fishing ban. Many women can also be involved in seaweed farming and processing as it is easy to manage and less laborious.

There is a great potential for integrated farming of seaweeds with shrimps, mussels, crabs and marine fish. It is possible to minimize or remove waste from shrimp farming naturally through integrated farming of seaweed and shrimp in coastal areas. Seaweed farming and processing industry could open enormous opportunities for the country. If seaweed cultivation is strengthened, it will be possible to earn huge foreign currency after meeting the nutritional needs of the country. The amount of agar and carrageenan that Bangladesh government imports every year for use in laboratory, food, pharmaceutical and cosmetic industries can be produced from native seaweeds and can be exported abroad. In conjunction with the government, if industrial entrepreneurs of relevant sectors come forward, they can unlock a promising gateway of a new horizon in the blue economy which will advance the national economy. This study suggests further all-inclusive studies should be directed to assess the current status of naturally available seaweeds, their nutritive values and contemporary utilization and to formulate a strategy for application of these resources.

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