NUTRITIONAL CONTENT OF SELECTED MACROALGAE OF THE SOUTH-WEST COAST OF INDIA

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Abstract:

During the present work, thirty-one species of macroalgae collected from different locations on the south-west coast of India were subjected to nutritional analysis to determine total crude protein, total crude lipids, total soluble sugars, starch, total free amino acids, iodine content, and vitamin C content. It could be derived that the protein content varied from a minimum of 10.8±0.7 mg g-1 in the red alga *Amphiroa fragilissima* to a maximum of 180.0±0.7 mg g^{-1} in *Chaetomorpha linum* (Chlorophyceae), followed by118.0±0.3 mg g^{-1} in *Sargassum marginatum* (Phaeophyceae). The lipid content was recorded to be a maximum of 150.0±0.2 mg g^{-1} in the brown alga *Padina tetrastroematica* and a minimum of 8.0±0.4 mg g^{-1} in the calcareous red alga *Cheilosporum spectabilis*. The maximum free amino acid concentration was found to be 17.06±0.6 mg g^{-1} in the green alga *Caulerpa sertularioides*, the maximum value for Vitamin C content was 11.0±0.4 mg $100g^{-1}$ in the green alga *Caulerpa chemnitzea*, and the maximum iodine content of 86.90±1.0 mg $100g^{-1}$ in green alga *Caulerpa peltata.* The Vitamin C content was found to be reasonably high in almost all algal species studied, as also the iodine content. The overall observation shows that marine macroalgae are rich sources of Proteins, Carbohydrates, Amino acids, Vitamin C, and Iodine, hence can have great implications as source materials in the preparation of food, food supplements, and nutraceuticals.

Keywords: Marine macroalgae, South-west Indian coast, Nutritional composition

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Introduction

Seaweeds form a very important renewable resource in the marine environment and have been a part of human civilization from time immemorial. The reports on the uses of seaweeds have been cited as early as 2,500 years ago in Chinese literature (**Tseng, 2004**). The history of seaweed utilization for a variety of purposes is indicative that some of their constituents are superior and valuable in comparison to their terrestrial counterparts. Seaweeds synthesize an array of chemicals, some of which are the only natural resources to produce useful substances such as agar-agar, carrageenan, and alginates. Seaweeds form a valuable source of food containing proteins, carbohydrates, lipids, iodine, vitamins, and bioactive molecules with potential as nutritional supplements, pharmaceuticals, cosmeceuticals, fine chemicals, and enzymes (**Pereira, 2018a, b; Peñalver *et. al*. 2020**). Marine macroalgae are also rich sources of several bioactive substances like polysaccharides, polyphenols, phytochemicals, and polyunsaturated fatty acids with potential therapeutic uses against inflammation, cancer, oxidative stress, allergies, diabetes, thrombosis, obesity, hypertension, lipidemia, and many degenerative diseases (**Tanna and Mishra, 2019**); hence these marine plants help to improve the quality of life (**Holdt & Kraan, 2011; Shannon** & **Abu-Ghannam, 2019).** Due to their various health benefits, there is an increasing interest in utilizing them as culinary ingredients. Parallelly the ever-increasing population is compelling humans to opt for non-conventional and alternative food resources such as seaweeds. The world's annual production of edible seaweeds through aquaculture is 6 million tons of fresh weight (**Fleurence, 1999**). In all 152 seaweed species have been utilized for food purposes globally, of which 83 are from Rhodophyta, 40 from Phaeophyta, and 29 from Chlorophyta. The main edible seaweeds are Japanese kelp (*Laminaria japonica*), Kombu (*Sacharinna* spp.), *Gracilaria* spp., Nori Nei (*Porphyra* spp.), Eucheuma seaweeds (*Eucheuma* spp.), Laver or Nori (*Porphyra tenera*), Wakame (*Undaria pinnatifida*), Elkhorn Sea moss (*Kappaphycus alvarezii*), Hiziki (*Sargassum fusiforme*), Umudggasari *(Gelidium amansii*), and Gamtae (*Ecklonia cava*), among others (**Sarker *et al.*, 2021; Zhang *et. al.*, 2022**).

India (08.04 – 37.06 N and 68.07 – 97.25 E), a tropical South Asian country has a stretch of about 7500 km coastline, excluding its island territories with 2 million km^2 Exclusive Economic Zone (EEZ) and nine maritime states. The seaweed flora of India is highly diversified and comprises mostly tropical species, but boreal, temperate, and subtropical elements have also been reported. A total of 830 species of marine algae have been recorded from different parts of the Indian coast including the Andaman-Nicobar and Lakshadweep Islands (**Reddy *et al*., 2014**). Many of the rocky beaches, mudflats, estuaries, coral reefs, and lagoons along the Indian coast provide ideal habitats for the growth of seaweeds. In India, though seaweeds have not gained much popularity as human food there are stray reports of their use in food formulations. In some coastal places of Tamil Nadu, (Tiruchandur- Kanyakumari sector), southern India, people are reported to take “Seaweed Ganji” (water in which seaweed *Hypnea sp.* is boiled) for getting rid of stomach disorders, as well as seaweed extracts from species of *Ulva* in the preparation of sweets. In Madurai city of Tamil Nādu, Agar is added to a milkshake-like summer drink called ‘Jigarthanda’ (in place of gelatine) to give it its thick consistency, along with sabja seeds (sweet basil), sarsaparilla (Smilax sp.) or rose syrup, milk, and ice cream (**Cordelia, 2021**). By keeping in mind that seaweeds form a potential alternative vegetarian diet in a developing country like India, it is worthwhile to review in detail the nutritional value of seaweeds as human food in the new millennium. Since the author has been working extensively on the marine algal resources of Kerala, the present work was undertaken to analyse the nutritional composition of selected marine macroalgae of the southwest coast of India, predominantly the Kerala coast.

Materials and Methods

Sample collection

Kerala state is situated on the southwest coast of India between Lat. 8020’ to 12^{0}51’N and Long. 74^{0}53’to 77^{0}33’E; the length of the coastline is 560 km stretching from Thiruvananthapuram in the south to Kasaragod in the north. The substratum is mostly rocky in nature which facilitates rich and varied algal growth. The bit of coastline extending from Cape Comorin in the peninsular tip to Thiruvananthapuram also supports rich and diverse algal growth. Using a 0.5m^2 wooden quadrate, samples of the algae from the selected/productive areas on the southwest coast of India (Cape Comorin in the peninsular tip to Kasaragod in the northern tip of Kerala) were collected (Fig.1) and different species were noted down separately and their biomass studied (August 2018- July 2019). The identification of the algal samples was carried out with the help of standard flora (**Iyengar, 1927**; **Boergesen, 1935; Boergesen, 1938; Krishnamurthy, 1971; Desikachary, 1967; Untawale *et al.*, 1983; Nair *et al*., 1986; Kaliaperumal, 2006)**. Based on the above survey, 31 species were later selected for biochemical analyses. The voucher specimens were given accession numbers and deposited at the ‘Marine Algae Herbarium,’ Dr. KSM Centre for Algal Biotechnology, Thiruvananthapuram.

Hydrographic studies

At the time of algal sampling, atmospheric, and surface water temperatures were recorded using standard thermometers. Hydrographic parameters such as salinity, pH, and dissolved oxygen (**Martin, 1969**), and nutrients such as phosphates, nitrates, nitrites, and silicates (**Strickland and Parson, 1972**) were also estimated. Light penetration was measured using a Secchi disc. For the convenience of the study, the year is divided into three seasons viz. pre-monsoon (February to May) the monsoon (June to September), and the post-monsoon (October to January) seasons.

Chemical analysis

Thirty-one species of edible marine algae (Green, Brown, and Red) collected from the study area were subjected to biochemical analyses. The collected thalli were washed thoroughly with fresh water 3 to 4 times to remove associated fauna, epiphytes, and debris and dried under shade. These were then powdered and stored in airtight plastic containers (food grade) until the time of analysis. Total crude protein was estimated using Folin – Phenol reagent with bovine serum albumin serving as standard (**Lowry, 1951**); total lipid content was determined by extraction with the chloroform-methanol mixture using a separating funnel (**Bligh and Dyer, 1959**); total soluble sugars (pentoses, hexoses, disaccharides including sucrose, maltose, lactose, and hexuronic acid) by using Anthrone and Phenol-sulphuric acid reagents (**Yemm & Willis, 1954**); and total free amino acids was estimated by modified Ninhydrin method byYemm and Cocking, 1955 (**Hyman, 1957**), and starch converted to sugar by extraction with Perchloric acid and calculated in terms of glucose equivalent; a conversion factor is used to convert glucose to starch (**Mahadevan and Sridhar, 1996**). The iodine content in the seaweeds was estimated by iodometric titration using Sodium thiosulphate (**UNICEF *et al.*, 1995**). Vitamin C was determined by use of an oxidation-reduction reaction by redox titration using potassium iodate in the presence of Potassium iodide. (**Tee *et al.*, 1988).**

Fig. 1: Algae collection sites of SW Coast of India

Statistical Analysis

For biochemical estimation, triplicate samples of each species were analysed, the results of which were calculated as mean ± Standard Error (SE).

Results and Discussion

Studies on the seasonal variation in various physicochemical parameters such as salinity, pH, Dissolved Oxygen, and Nutrients like Phosphate, Nitrate, Nitrite, and silicate at the collection sites were carried out coinciding with the algal collection during the period from August 2018 to July 2019

Temperature: - Distinct seasonal fluctuations were noted in the distribution of both atmospheric and surface water temperatures. Atmospheric temperature varied from 26^0C to 31.5^0C and surface water temperature from 27.5^0C to 29^0C along the algae collection locations during the period of study.

Light penetration: - The Sechi Disc transparency was found to range from 190 to 380 cm during the period of study.

Salinity: - The salinity values varied from $27.25\%^0$ to $34.25\%^0$ along the area studied. High values were generally recorded during the pre-monsoon season. Low values were recorded during the monsoon periods

pH: - the pH varied from 6.53 to 8.04 along the coast. Water was found to be alkaline at the Varkala and Thirumullavaram coasts.

Phosphate values were moderate, found to vary from 0.97 to 4.99 μg.at. L^{-1}. The higher phosphate values were recorded during periods of heavy rainfall. This may be due to the added nutrients through drainage and upwelling.

Nitrate level showed a wide variation from 3 to 36 μg.at. L^{-1} The highest nitrate concentrations were recorded corresponding to heavy rainfall. The monsoon rains and the resultant drainage could be a contributing factor in increasing the nitrate concentration during this period.

Nitrite varied from 0.32 to 17.0 μg.at. $L^{-1.}$ The nitrite values were always found to be much lesser than the nitrate values and higher values were recorded during the monsoon seasons.

Silicate content generally read very high, especially during the monsoon periods; it was found to vary from 47.47 to 321 μg.at. L^{-1}. It is now well known that the freshwater is rich in Silica than seawater and freshwater discharge during monsoon season has been accepted as a source of silicate during monsoon season.

During the present work, it could be observed that, though the heavy monsoon rains coupled with a turbulent sea proved to be unfavourable for the growth of many of the edible algal species, brown algae like *Chnoospora bicanaliculata* and *Sargassum* spp.; green algae like *Ulva* spp., *Enteromorpha prolifera*, *Chaetomorpha antennina* & *Valoniopsis pachynema,* and red algae like *Gracilaria corticata* were found to predominate the coast to the exclusion of other algae during the monsoon period.

Studies correlating the physicochemical properties and macroalgal abundance of the Kerala coast have been meager (**Nair *et al*., 1986, Chennubhotla, 1991; Maya, 1990; Maya 2010; Shynu *et al*., 2012; Sushanth & Madaiah, 2014; Aravindh & Ruban, 2019**). Since the present paper primarily deals with the nutritional composition of seaweeds, in-depth environmental details have not been discussed.

Nutritional composition

Among the 31 species of marine algal species chosen for nutritional analyses *Caulerpa peltata*, *C. sertularioides*, *Chaetomorpha linum, C. antennina, Enteromorpha prolifera, Padina tetrastromatica, sargassum* spp., *Gracilaria spp., Acanthophora spp*., *Champia parvula*, and *Rhodymenia* sp. are the most edible species found worldwide. The seaweed species were chosen for analyses based on edibility, standing crop, and seasonal availability. Table 1. furnishes the list of 31 algae analysed and the results of the nutritional analysis of seaweed species collected from the southwest coast of India. The protein content of the algae varied from 17.1±1.0 to 180.0±0.7 mg g-1 in Chlorophyceae; 49.3±0.2 to 118.0±0.4 mg g^{-1} in Phaeophyceae and from 10.8±0.7 to 90.3±0.4 mg g^{-1}in Rhodophyceae. The protein content of seaweeds is found to differ according to the species. Generally, the protein fraction of brown seaweeds is low (3 to 15% dry wt.) as compared with that of green seaweeds (10 to 47% dry wt.) (**Arasaki and Arasaki, 1983**). In some green seaweeds like *Ulva*, the protein content varies between 10 to 26% of the plant (dry wt.) (**Fujiwara-Arasaki *et al*., 1984**). During the present work, *Ulva fasciata* which is one of the commonest green seaweeds of the Indian coast is found to have a protein content of about 9% (dry wt.) and hence its suitability was evaluated in the preparation of protein-rich biscuits and other food products during this work.

Table 1: **Nutritional content of selected marine algae of the south-west coast of India**

SL. No.	Name of algae	Protein mg. g^{-1}	Lipid mg. g^{-1}	Carbohydrate (Total soluble) mg. g^{-1}	Starch mg. g^{-1}	Amino acid mg. g^{-1}	Vitamin C mg. 100g^{-1}	Iodine mg. 100g^{-1}
	CHLOROPHYTA	**Mean±SE (n=3)**						
1	*Caulerpa peltata*	77.0± 3.0	14.0±0.8	3.8±0.4	4.0±0.4	5.9±0.2	8.5±0.2	86.9±1.0
2	*Caulerpa sertularioides*	64.3±3.0	73.4±0.6	31.1±0.8	28.0±0.4	17.1±0.6	3.4±0.1	52.9±1.0
3	*Caulerpa chemnitzea*	124.0±1.0	32.0±1.0	19.6±0.8	18.0±0.5	9.3±0.3	11±0.4	61.3±1.0
4	*Chaetomorpha antennina*	58.6±2.0	11.0±1.0	13.8±1.0	12.9±1	3.5±0.3	4.0±0.1	47.2±1.0
5	*Chaetomorpha linum*	180±0.7	113.0±0.8	10.6±0.9	9.0±0.8	1.6±0.1	3.0±0.1	50.8±2.0
6	*Cladophora sp.*	46±0.1	4.0±0.4	5.8±1.0	5.0±0.8	10.6±0.5	8.0±0.0	86.7±1.0
7	*Ulva fasciata*	91.0±0.1	28.0±1	34.1±1.0	36.1±0.9	2.5±0.1	4.2±0.1	27.5±1.0
8	*Enteromorpha prolifera*	17.1±1.0	20.0±1.0	6.9±0.4	5.4±0.4	4.8±0.3	7.5±0.1	50.8±0.1
9	*Valoniopsis pachynema*	43.7±0.7	20.0±04	38.4±1.0	34.0±0.9	2.2±0.2	7.3±0.5	36.0±1.0
	PHEOPHYTA							
10	*Padina tetrastromatica*	51.7±1.0	150.0±2.0	12.0±1.0	10.3±1.0	2.6±0.3	7.3±0.1	25.5±2.0
11	*Chnoospora bicanaliculata*	49.3±2.0	12.6±.08	16.6±1.0	14.9±1.0	6.0±0.3	6.1±0.1	33.8±1.0
12	*Sargassum marginatum*	118.0±0.3	12.0±0.6	40.8±1.0	36.3±0.7	3.8±0.3	8.6±0.1	23.3±4.0
13	*Sargassum tenerrimum*	87.0±2.0	9.0±0.8	24.0±0.8	21.0±0.5	3.7±.4	9.6±0.1	19.1±3.0
14	*Sargassum cinereum*	117.0±0.4	12.0±1.0	20.6±0.2	19.3±0.8	5.4±0.3	5.3±0.1	23.2±1.0
15	*Sargassum wightii*	65.7±0.5	14.0±0.4	12.5±0.2	10.7±0.2	7.06±0.2	6.4±0.2	36.0±1.0
	RHODOPHYTA							
16	*Spyridia insignis*	29.3±1.0	45.0±1.0	9.0±0.4	8.0±0.9	7.6±0.2	5.2±0.1	36.0±.01
17	*Spyridia hypnoides*	24.0±0.4	34.0±0.8	39.6±0.8	35.7±0.8	13.2±0.4	10.8±0.1	33.8±1.0
18	*Centroceras clavulatum*	31.7±0.3	70.0±2.0	21.5±0.9	19.2±0.9	15.6±0.6	5.4±0.1	35.9±1.0
19	*Amphiroa fragilissima*	10.8±0.7	10.0±2.0	4.3±0.8	3.1±0.7	3.2±0.1	1.4±0.1	25.5±3.0
20	*Gelidiopsis variabilis*	34±0.2	93.4±1.0	27.1±1.0	27.0±0.5	35.6±0.3	3.0±0.1	33.8±1.0
21	*Grateloupia lithophila*	40.7±0.2	40.0±0.8	37.8±0.2	35.3±0.5	4.4±0.3	3.7±0.1	49.0±1.0
22	*Laurencia brongniartii*	56.3±1.0	80.0±2.0	17.9±0.5	15.8±0.1	4.9±0.2	5.0±0.1	34.0±3.0
23	*Accanthophora specifera*	29.3±3	80.0±2.0	24.9±1.0	21.9±1	8.1±0.5	3.7±0.1	52.9±1.0
24	*Acanthophora najadiformis*	26.0±0.2	NA	24.4±1.0	NA	NA	NA	NA
25	*Rhodymenia sp.*	52.0±0.2	20.0±1.0	15.2±0.3	14.3±0.8	9.8±0.4	4.6±0.1	33.8±1.0
26	*Champia parvula*	68.33±3	60.0±1.0	27.4±1.0	23.3±1	8.1±0.3	2.4±0.1	52.9±1.0
27	*Gracilaria corticata*	22.1±1.0	142.0±2.0	8.5±0.9	6.3±0.8	1.7±0.2	4.4±0.1	38.1±0.0
28	*Gracilaria fergusonii*	55.66±1.0	100.0±2.0	39.7±0.5	36.3±0.5	4.8±0.1	4.0±0.1	27.6±1.0
29	*Gracilaria foliifera*	56.3±0.9	40.0±1.0	11.4±0.9	9.6±0.8	10.2±0.3	3.3±0.1	40.2±1.0
30	*Chelosprum spectabilis*	31.33±1.0	8.0±0.4	2.20±1.0	2.0±0.1	2.2±0.1	2.1±0.1	23.26±1.0
31	*Enantiocladia sp.*	90.33±0.4	20.0±0.8	22.4±1.0	20.8±0.8	2.2±0.1	6.8±0.1	NA

NA- Not analysed

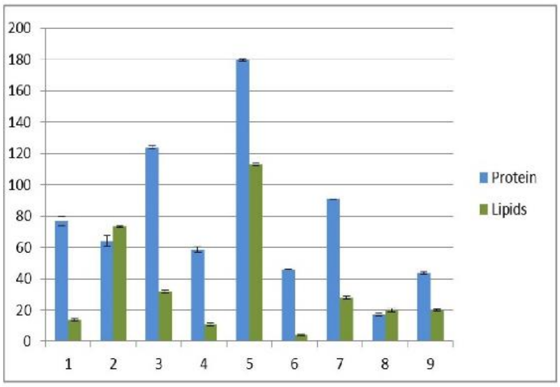
According to **Paul *et al.* (2007)**, the protein levels in seaweeds vary according to the season and the species. For most species, aspartic and glutamic acids constitute a large part of the amino acid makeup of these proteins. These levels are highest in brown seaweeds, with red seaweeds having the lowest amounts. During the present inquiry, red seaweeds were found to have a comparatively low protein content as opposed to the study by **Dere *et al.* (2003)** where brown algae were found to have low protein content. High protein content in Rhodophyta, moderate in Chlorophyta, and lowest in Phaeophyta was recorded in seaweeds of the Tamil Nadu coast by **Rameshkumar (2013)**. During the present analysis, the protein content in the seaweeds was found to be comparatively lower than that recorded for the Kerala coast by **Nair *et al.* (1991)**. The protein content in *Ulva fasciata* was lower compared to earlier studies along Indian coasts (**Sitaker Rao and Tipnis, 1964; Dhargalkar *et al.*, 1980; Nair *et al.*, 1991**). Similarly, the protein value for *Acanthophora specifera* is much lower than that reported by **Rameshkumar (2013)**. During the present analysis, the highest protein content of 18% was recorded in *Chaetomorpha linum*, followed by *Sargassum marginatum* (11.8%) and *S. cinereum* (11.7%). The least protein content (1% & 3%) was found to be in the calcareous red algae *Amphiroa fragilissima* and *Cheilosporum spectabilis* respectively. Green and red seaweeds have higher protein contents than brown seaweeds, as high as 47% of their dry weight (**Černá 2011; O'Connor *et al.*, 2020**). *Porphyra* spp., *Pyropia* spp., *Palmaria palmata,* and *Ulva* spp. are the seaweeds richest in protein (**Pereira 2011; Taboada *et al*. 2013; Angell *et al*., 2016).** According to **Ganesan *et al.* (2019)** brown seaweeds contain the least protein while moderate concentrations of protein are reported from green seaweeds, and the highest content is estimated in red seaweeds.

Overall, lipids make up about 1–5% of seaweed dry weight, and Polyunsaturated fatty acids (PUFA) constitute a significant part of the seaweed lipid profile **(Penalver *et al*., 2020).** During the present analysis, the lipid concentration was found to be low in most of the algal species studied varying from 1.0 to 15%, which is in tune with the findings of ***Nehal et al***. (**2011).** The values were found to vary from a minimum of 4.0±0.4 mg g^{-1} to a maximum of 113.0±0.8 mg g^{-1} in Chlorophyceae; from 9.0±0.8 to 150.0±2.0 mg g^{-1} in Phaeophyceae and from 8.0±0.4 to 142.0±2.0 mg g^{-1} in Rhodophyceae. Present lipid values are much higher than that given by **Nair *et al*. (1991)** for most of the algal species of the Kerala coast, though the lipid value for *Caulerpa peltata* (1.4%) is in agreement with the above work. The lipid values for *Chaetomorpha antenna* (1.1%) and *Valoniopsis pachynema* (2%) reported at present are much higher than those given by **Nair *et al.* (1991)**. In the nutritional studies carried out on the algal species of the Bay of Bengal coast (**Rameshkumar, 2013**), *Caulerpa racemose* was found to have a lipid content of 19.1%, *Ulva fasciata* - 10.5%, *Chnoospora* minima - 0.9%, *Padina gymnospora*- 11.4% and *Acanthophora specifera* 2.1%. During the present analysis, *Caulerpa* spp. were found to have lipid contents ranging from 1.4 to 7.3%, and *U. fasciata* with a value of 2.8%, which is lower than that in the former report. Nevertheless, the values for *Chnoospora bicanaliculata* (1.2%), *Padina tetrastromatica* (15%), and *Acanthophora specifera* (8%) during the present work are higher than that reported by **Rameshkumar (2013).** The lipid content reported for *Gracilaria foliifera*, *Sargassum wightii*, *S. tenerrimum*, and *Ulva lactuca* by **Manivannan (2008 a, b)** is like the results of the present analysis. In general, seaweeds exhibit low lipid contents (Dawes, 1998), and the differences in the lipid content could be attributed to factors like climate, the geography of development to methods of extraction (**Oritz *et al*., 2006**). Figs. 2 to 4 furnish the protein and lipid contents in different algal classes. Overall, lipids make up about 1–5% of seaweed dry weight (**Penalver *et al*., 2020**). A recent study showed that the lipid content of red alga

Asparagopsis taxiformis was 2.9–6.2 g per 100 g dry wt., which contributed about 9.5% to the RDI (**Mellouk *et al.*, 2017; Nunes *et al.*, 2019**).

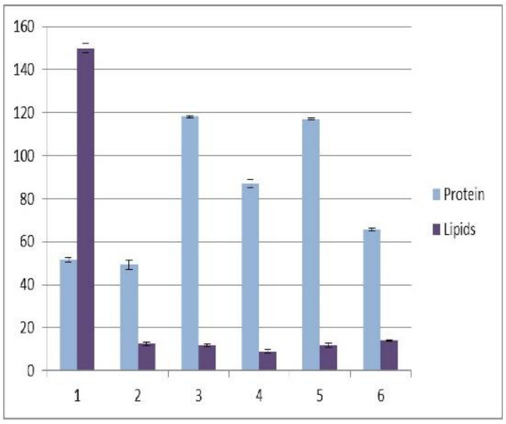
The carbohydrates in seaweeds consist of monosaccharides, disaccharides, and polysaccharides. The first two are simple sugars with low molecular weight, soluble in water such as glucose, galactose, fucose, ribose, and mannitol. Polysaccharides are complex sugars with high molecular weight insoluble in water and these include cellulose, starch, agar, alginate, and carrageenan. The total polysaccharide content in macroalgae ranges from 4% to 76% of dry weight (**Holdt and Kraan, 2011**). The highest carbohydrate contents are found in red algal genera like *Porphyra* and green seaweed genera such as *Ulva* (**Holdt and Kraan**, **2011**), these polysaccharides represent the main nutritive storage in algae with numerous applications. Thus, the polysaccharide profile in seaweeds is quite extensive and deserves special study by itself. Seaweed polysaccharides have numerous beneficial properties such as probiotic activity, inhibition of viruses, suppression of gastrointestinal inflammation, anticancer properties, reduction in cholesterol uptake, and anti-glycosidase activity (**Rajapakse & Kim, 2011; Wang *et al.*, 2012; Necas & Bartosikova, 2013; Cotas *et al.*, 2020; Daub *et al.*, 2020**). In addition, seaweed fibres contain negligible amounts of starchy carbohydrates, resulting in a lower glycaemic load, which is beneficial in regulating the glycaemic index of diabetic patients (**Wee & Henry, 2020**).

The total soluble carbohydrates during the present analysis were found to vary from a minimum of 3.80±0.4 mg g^{-1} in *Caulerpa peltata* to a maximum of 38.40 mg g^{-1} in *Valoniopsis pachynema* (Chlorophyceae); from 12.0±1.0 mg g-1 in *Padina tetrastromatica* to 40.8± mg g^{-1} in *Sargassum marginatum* (Phaeophyceae) and from 2.2±1.0 mg g^{-1} in *Cheilosporum spectabilis* to 39.6±0.8 mg $g^{-1\ in}$ *Spyridia hypnoides* (Rhodophyceae).



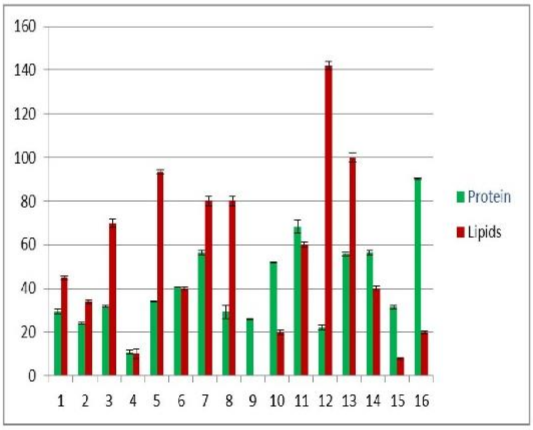
	CHLOROPHYTA
1	*Caulerpa peltata*
2	*Caulerpa sertularioides*
3	*Caulerpa chimnetzea*
4	*Chaetomorpha antennina*
5	*Chaetomorpha linum*
6	*Cladophora sp.*
7	*Ulva fasciata*
8	*Enteromorpha prolifera*
9	*Valaniopsis pachynema*

Fig. 2: Protein and Lipid content in green algae



	PHAEOPHYTA
1	*Padina tetrastromatica*
2	*Chnoospora bicanaliculata*
3	*Sargassum marginatum*
4	*Sargassum tenerrimum*
5	*Sargassum cinereum*
6	*Sargassum wightii*

Fig. 3: Protein and Lipids in brown algae



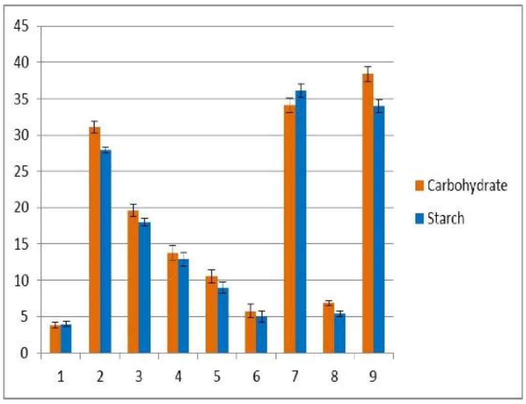
RHODOPHYTA

1	*Spyridia insignis*
2	*Spyridia hypnoides*
3	*Centroceras clavulatum*
4	*Amphiroa fragilissima*
5	*Gelidiopsis variabilis*
6	*Grateloupia lithophila*
7	*Laurencia brongniartii*
8	*Accanthophora specifera*
9	*Acanthophora najadiformis*
10	*Rhodymenia sp.*
11	*Champia parvula*
12	*Gracilaria corticata*
13	*Gracilaria fergusonii*
14	*Gracilaria foliifera*
15	*Chelosprum spectabilis*
16	*Enantiocladia sp.*

Fig. 3: Protein and Lipids in red algae

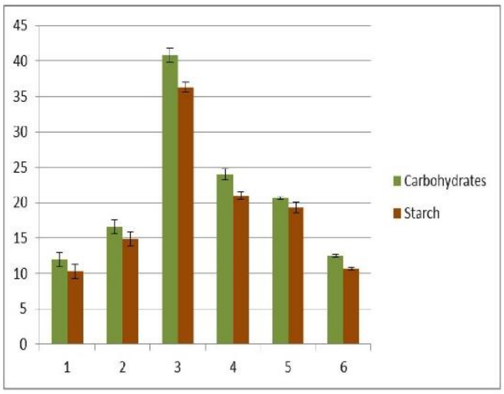
The values for soluble carbohydrates were found to be much lower than the total carbohydrate values reported by **Nehal *et al.* (2011)**; there appears to be not much variation in carbohydrate content among the different algal groups. According to the report given by **Nehal *et al*. (2011)**, the membranous Phaeophycean species are found to have lower carbohydrate content than the Chlorophycean members. Studies by **Marinho-Soriano *et al*. (2006)** showed that changes in carbohydrate content can be observed over a period. **Rosenberg and Ramus (1982),** related carbohydrate synthesis to periods of maximum growth, increased photosynthetic activity, and reduction in protein contents, suggesting a link between seaweed growth and carbohydrate content. During the present study, the variation in starch content was like that in soluble sugars. It was found to vary from 4.0±0.4 mg g-1 in *Caulerpa peltata* to 36.1±0.9 mg g-1 in *Ulva fasciata*; from 10.3±0.2 mg g-1 in *Padina tetrastromatica* to 36.3±0.7 mg g-1 Sargassum *marginatum* (Phaeophyceae), and from 2.0±0.1 mg g-1 in *Cheilosporum spectabilis* to 36.3±0.5 mg g-1 in *Gracilaria fergusonii* (Rhodophyceae). Figs. 5 to 7 furnish the soluble sugars and starch content in different classes of seaweeds. According to the work by **Meghanath *et al.* (2019),** on green macroalga *Ulva ohnoi*, the starch content was found to vary from 1.59% to 21.4% depending on the growth conditions and seasons. Besides, nutrient starvation was also found to significantly increase the starch content. Different seaweed groups contain a wide group of polysaccharides whose chemical composition and amount vary within various seaweed species (**Misurcova, 2011**). Hence deciphering carbohydrate content in seaweeds, by itself is an extensive topic to study, based on seasonal studies, geographic locations, growth stages of the plants, and methods of analyses.

Essential amino acids help to build up muscles, support their functioning, and regulate the blood sugar level (**Breitman *et al.*, 2011; Hayashi *et al.*, 2018**). Essential amino acids such as leucine, valine, and threonine are abundant in red seaweed species such as *Porphyra dioica*, *Porphyra umbilicalis*, and *Gracilaria vermiculophylla* (**Machado *et al.*, 2020**). The total free amino acid content was found to vary from a minimum of 1.6 ±0.1mg g^{-1} in *Chaetomorpha linum* to a maximum of 17.6±0.6 mg g^{-1}in *Caulerpa sertularioides* (Chlorophyceae); from 2.6±0.3 in *Padina tetrastromatica* to 7.06±0.2mg g^{-1} in *Sargassum wightii* (Phaeophyceae) and from1.7±0.2 mg g-1 in *Gracilaria corticata* to 35.6±0.3 mg g^{-1} in *Gelidiopsis variabilis* (Rhodophyceae). The amino acid values obtained are found to be far less than that obtained by **Dinesh *et al*. (2007**). Free amino acids have been found important contributors to the taste of seaweeds. They impart a sweet, sour, or bitter taste depending on the amino acid and its concentration (**Kawaai *et al*., 2012**).



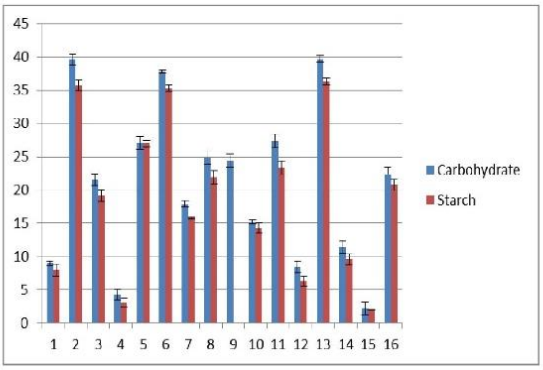
	CHLOROPHYTA
1	*Caulerpa peltata*
2	*Caulerpa sertularioides*
3	*Caulerpa chimnetzea*
4	*Chaetomorpha antennina*
5	*Chaetomorpha linum*
6	*Cladophora sp.*
7	*Ulva fasciata*
8	*Enteromorpha prolifera*
9	*Valaniopsis pachynema*

Fig. 5: Soluble carbohydrate and starch in green algae



	PHAEOPHYTA
1	*Padina tetrastromatica*
2	*Chnoospora bicanaliculata*
3	*Sargassum marginatum*
4	*Sargassum tenerrimum*
5	*Sargassum cinereum*
6	*Sargassum wightii*

Fig. 6: Soluble carbohydrate and starch in brown algae



RODHOPHYTA

1	*Spyridia insignis*
2	*Spyridia hypnoides*
3	*Centroceras clavulatum*
4	*Amphiroa fragilissima*
5	*Gelidiopsis variabilis*
6	*Grateloupia lithophila*
7	*Laurencia brongniartii*
8	*Accanthophora specifera*
9	*Acanthophora najadiformis*
10	*Rhodymenia sp.*
11	*Champia parvula*
12	*Gracilaria corticata*
13	*Gracilaria fergusonii*
14	*Gracilaria foliifera*
15	*Chielosprum spectabilis*
16	*Enantiocladia sp.*

Fig. 7: Soluble carbohydrate and starch in red algae

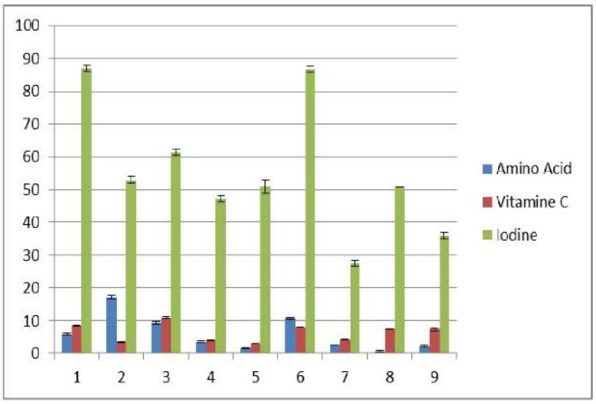
During the present work, the Vitamin C content was found to be reasonably high in almost all algal species analysed. It was found to vary (in mg100g $^{-1}$dry wt.) from the least value of 3.0±0.1 in *Chaetomorpha linum* to a maximum value of 8.5±0.2 in *Caulerpa peltata* (Chlorophyceae); from 6.1±0.1 in *Chnoospora bicanaliculata* to 9.6±0.1 in *Sargassum tenerrimum* (Phaeophyceae) and from 1.4±0.1 in *Amphiroa fragilissima* to 6.8±0.1 in *Enantiocladia* sp. (Rhodophyceae). However, the values are found to be much lower than that recorded for the marine algal species of the Gulf of Mannar by **Dinesh *et al.* (2007)** but comparable to that obtained for the benthic algae of Sundarbans (**Chakraborthy & Santra, 2008**). **Skrovankova (2011)** suggests that seaweeds growing closer to the surface level contain higher levels of Vitamin C than the seaweeds harvested from deeper waters. This may be due to the high antioxidant level needed for the seaweeds when exposed to the sun. According to a detailed review of the Vitamin C content of seaweeds by **Cecilie *et al*., (2021**) the Vitamin

C content in seaweeds (dry wt.) is found to have a mean value of 0.773 mg $g^{-1.}$ A study of taxonomical orders of species indicates that the green seaweeds of order Ulvales contain up to 3.0 mg g-1, whereas brown species of Fucales and Laminariales are found to have lower amounts of Vitamin C. During the present work, any prominent group-wise variation of Vitamin C content could not be observed. **Cecilie *et al*.** (**2021)** opine that Vitamin C content in seaweeds can vary due to biological, seasonal, locational, and treatment differences.

Iodine regulates the metabolism and proper growth of the human body and is an essential constituent of thyroid hormones that regulate major metabolic processes such as catabolism of carbohydrates, lipids and protein, cellular respiration, thermoregulation, intermediary metabolism, and nitrogen retention (**Abbaspour *et al.*, 2014; Nunes *et al.*, 2018**). Seaweeds are an excellent source of iodine; brown seaweeds contain the highest iodine content, with some species exceeding the RDI (150 µg per day) (**Rajapakse & Kim, 2011**). Red and green seaweed species such as *Eucheuma cottoni*, *E. spinosum*, *Palmaria palmata*, *Porphyra* sp., and *Ulva lactuca* also contain iodine but at lower concentrations (**Zava & Zava, 2011; Nitschke & Stengel, 2016; Rasyid, 2017; Cherry *et al.*, 2019**). Thus, the iodine requirement can be met by consuming seaweed or seaweed-based nutraceutical supplements (**Temjen, 2021**).

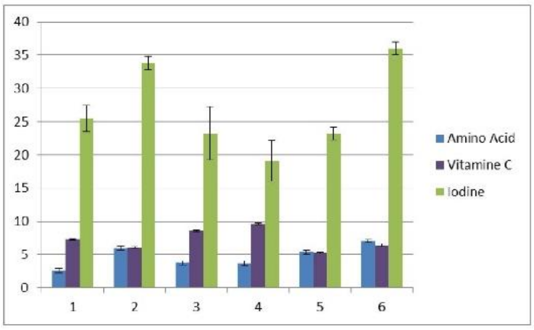
During the present study, the Iodine content was found to be high in almost all the algal species studied. It was found to vary from a minimum concentration (mg100g^{-1} dry wt.) of 27.6±1.0 in *Ulva fasciata* to a maximum values of 86.9±1.0 and 86.8±1.0 in *Caulerpa peltata* and *Cladophora* sp. respectively (Chlorophyceae); from a minimum of 19.1±1.0 in *Sargassum tenerrimum* to a maximum of 36.0±1.0 in (Phaeophyceae), and from a minimum of 23.3±1.0 in *Cheilosporum spectabilis* to a maximum of 52.9±1.0 in *Acanthophora specifera and Champia parvula* (Rhodophyceae). The present values for iodine content in seaweeds are much lower than that reported by **Nida**

***et al*. (2016)** for those studied along the Pakistan coast. However, the present iodine values are comparable to the low levels (0.2 to 0.5 mg $g^{-1)}$ recorded in *Sargassum* spp. from the Gujarat coast by **Ahmad *et al*. (1989)**. The present value of iodine content of 27.5±1.0 mg $100g^{-1}$ is higher than that obtained for *Ulva Lactuca* (**El-Tawil and Khalil, 1983**). Global studies on iodine content in seaweeds from different coastal regions of the world indicate wide fluctuations in the values. Various factors like salinity, season, depth of the plants, water temperature, and post-harvest conditions are some of the factors influencing iodine content in seaweeds (**Kravstova and Saenko, 1979**). Figs. 8 to 10 furnish the vitamin C and iodine content in seaweed species belonging to different classes.



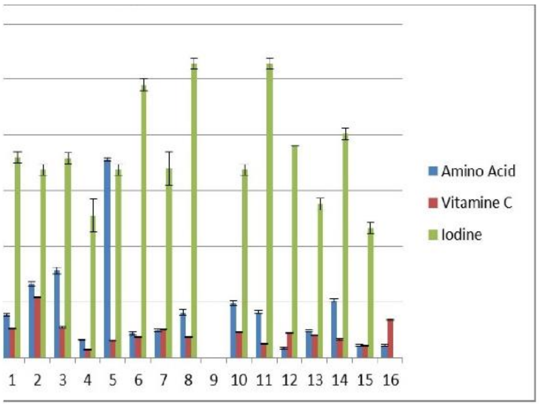
	CHLOROPHYTA
1	*Caulerpa peltata*
2	*Caulerpa sertularioides*
3	*Caulerpa chimnetzea*
4	*Chaetomorpha antennina*
5	*Chaetomorpha linum*
6	*Cladophora sp.*
7	*Ulva fasuata*
8	*Enteromorpha prolifera*
9	*Valaniopsis pachynema*

Fig. 8: Amino Acid, Vitamin C, and Iodine in green algae



	PHAEOPHYTA
1	*Padina tetrastromatica*
2	*Chnoospora bicanaliculata*
3	*Sargassum marginatum*
4	*Sargassum tenerrimum*
5	*Sargassum cinereum*
6	*Sargassum wightii*

Fig. 9: Amino Acid, Vitamin C, and Iodine in brown algae



RHODOPHYTA

1	*Spyridia insignis*
2	*Spyridia hypnoides*
3	*Centroceras clavulatum*
4	*Amphiroa fragilissima*
5	*Gelidiopsis variabilis*
6	*Grateloupia lithophila*
7	*Laurencia brongniartii*
8	*Acanthophora specifera*
9	*Acanthophora najadiformis*
10	*Rhodymenia sp.*
11	*Champia parvula*
12	*Gracilaria corticata*
13	*Gracilaria fergusonii*
14	*Gracilaria foliifera*
15	*Chelosprum spectabilis*
16	*Enantiocladia sp.*

Fig. 10: Amino Acid, Vitamin C, and Iodine in red algae

Conclusion

The overall observation of the present study shows that algae are rich sources of proteins, iodine, vitamins, and amino acids. These plants which are lavishly found in this ecosystem not only provide biomass by themselves but also have implications in the food and pharmaceutical industry as source materials in the preparation of food, food supplements, and fine chemicals. Nevertheless, only prolonged studies based on locations, depths, seasons, and various growth stages will help to derive any conclusive data on the nutritional composition of these edible marine plants. Besides not many studies have been undertaken on the toxic heavy metal contents of marine algae on Indian coasts, especially the southwest coast. Hence before incorporating these plants into the diet, it is essential to carry out an extensive study on their heavy metal profiling.

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