Plant Archives Volume 20 No. 1, 2020 pp. 2045-2054 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

SEAWEED: THE BLUE CROP FOR FOOD SECURITY AS MITIGATION MEASURE TO CLIMATE CHANGE

Kakoli Banerjee*, Archana Snehasini Turuk and Rakesh Paul

Department of Biodiversity & Conservation of Natural Resources, Central University of Orissa, Landiguda, Koraput, Pin-764020 (Odisha) India.

Abstract

With the ever-increasing demand for global food production, it has become a challenge for human food security in the changing *era* of climate change. The present study was undertaken to understand the biochemical composition of three selected seaweeds *viz*., *Caulerpa racemosa* (Chlorophyta), *Gracilaria corticata* (Rhodophyta) and *Padina tetrastromatica* (Phaeophyta) along with the physico-chemical parameters of seawater from September, 2015 to August, 2016 in Visakhapatnam coast of Andhra Pradesh. Highest protein, lipid and carbohydrate was recorded in *P. tetrastromatica* (25.81 ± 0.87%), *G. corticata* (10.50 ± 0.45%) and *G. corticata* (65.32 ± 2.78%) respectively. A significant difference between seasons and stations were observed as revealed through ANOVA analysis. Interrelationship between the physico-chemical and biochemical parameters reveals that seawater chemistry has played a significant role in the growth and sustenance of the species. The present research programme points to the importance of consuming seaweeds as an important food supplement of the coastal population.

Key words: *Caulerpa racemose*, *Gracilaria corticata*, *Padina tetrastromatica*, Physico-chemical parameters, Proximate composition.

Introduction

Seaweed aquaculture has been sustainably made viable on a commercial basis to improve the livelihood of the coastal populations in several countries like Philippines, Indonesia, Tanzania including India (Valderrama, 2012) India has a long coastline of 7500 km (Rao and Sharma, 1995) and hence has immense potentiality for seaweed culture. In India about 58,715 tones wet weight of seaweed resources are available and about 7500 tones wet weight is found in Andhra Pradesh (Reddy *et al*., 2014). Seafood has been thought to be the future prospects in the changing climate scenario. In order to meet the food deficiency of coastal population, resilient strategies are being developed to improve the livelihood of the coastal population and hence seaweed farming has taken a lead role in this perspective.

According to IPCC, (2007) larger scale effect on food security will be a need and hence adaption strategies are to be developed in order to meet the challenges of impact of climate on agriculture and other sectors. This blue crop has immense potentiality for its culture and can produce 50 to 70% food by 2050. Seaweed is known to be harvested for the preparation of agar, carrageenan and alginate and also a source of bio-ethanol production. Algae also provide the bulk of the earth's oxygen supply through photosynthesis. Seaweeds make a substantial contribution to marine primary production and provide habitat for near-shore benthic communities (Mann, 1973). Apart from acting as a good sink of CO_2 for biomass enhancement, they can also be utilized as a food supplement in the changing *era* of climate change. Even where food production is a crisis in coastal areas, seaweed farming can substantially benefit in meeting the protein deficiencies of pregnant mothers and as well as for the malnutrition population. According to IPCC, (2014) human system adaptation to a natural system can facilitate the effect of changing the climate.

***Author for correspondence :** E-mail: banerjee.kakoli@yahoo.com

Seaweeds are one of the most important marine renewable and valuable living resources and could be termed "futuristically promising plants of the oceans", with an immense economical and commercial value (Chapman and Chapman, 1980). The exploitation of marine algae for nutritional purposes is primarily based on the biochemical constituents (Parekh and Chauhan, 1982).

The seaweeds show great variation in the nutrient contents from species to species, level of maturity, their geographical distribution and environmental conditions like seawater temperature, salinity, light and nutrients (Dawes, 1998). Generally, green and red seaweeds contain higher protein contents (10-30% of dry weight) than brown seaweeds (5-15% of dry weight). The lipid content of seaweeds accounts for 1-6% of dry weight and provides a low amount of energy (Ruperez, 2002). However, very few studies have been done on biochemical components such as protein, carbohydrate, lipid, etc from seaweeds occurring along the coastal waters of Visakhapatnam (Sarojini and Subbarangaiah, 1999) and there is no published data on biochemical composition of seaweeds after 2004 Tsunami along the coastal waters of Visakhapatnam.

On this background, the present paper aims to monitor the proximate composition of seaweeds (green, red and brown) from Visakhapatnam coast of Andhra Pradesh, India as a potential measure to meet the food deficiency of the coastal population of India in the changing climatic scenario, which is approximately 1.28 billion (www.indiaonlineages.com).

Material and Methods

Study site

The study of three marine seaweeds (otherwise termed as macro-algae) namely *Caulerpa recemosa* (Chlorophyta), *Gracilaria corticata* (Rhodophyta) and *Padina tetrastromatica* (Phaeophyta) were carried out in two selected stations *viz.*, station-1 Vuda Park (17º43'26.759"N, 83º20'22"E) and station-2 Tenneti Park (17º44'50.207"N, 83º20'59.2434"E) in the Visakhapatnam coast of Andhra Pradesh on the east coast of India (Fig. 1). This coast is rich for marine intertidal biota (Lakshmi

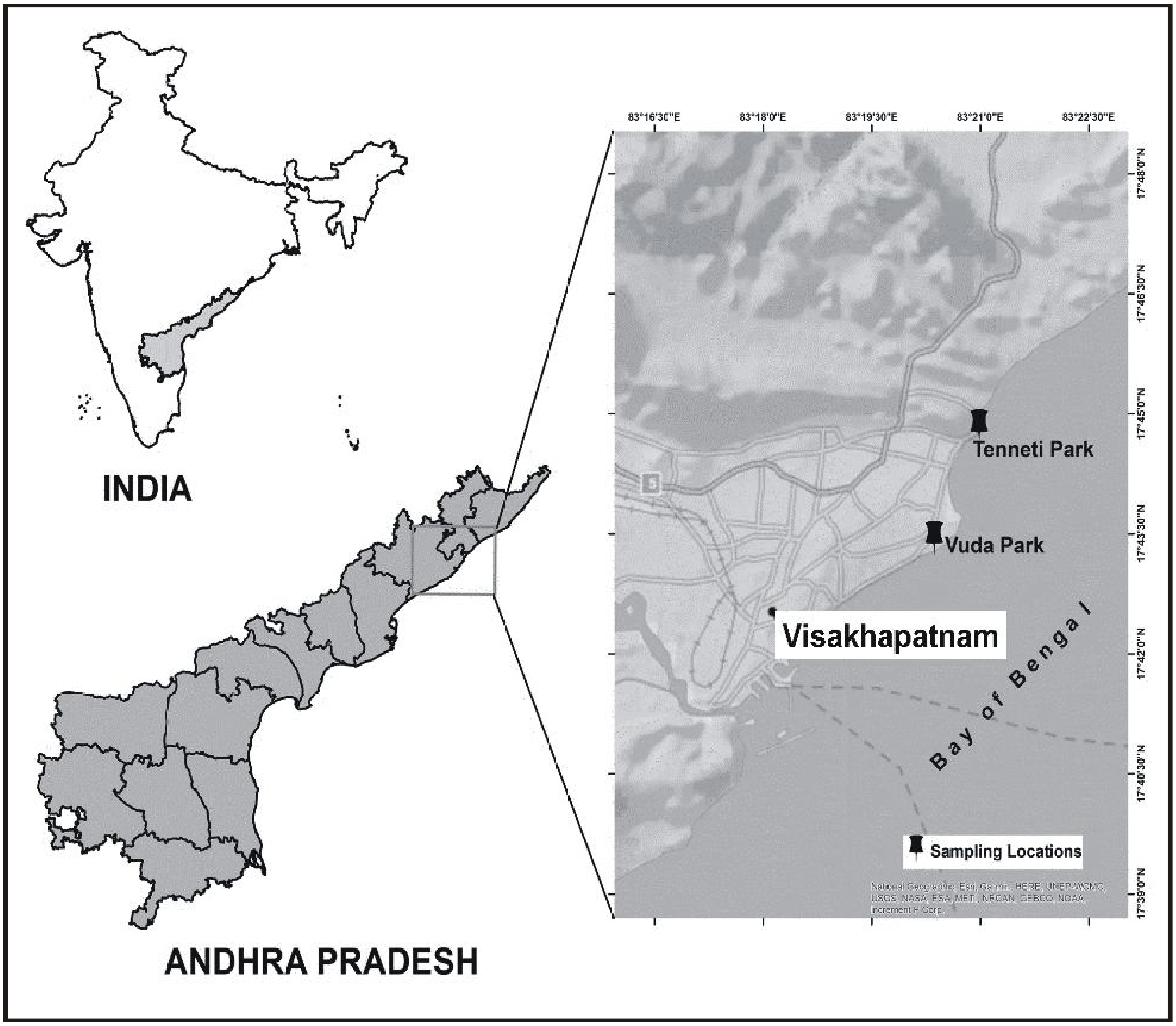

Fig. 1: Sampling station at Visakhapatnam coast of Andhra Pradesh, India.

Table 1: Seasonal variation in physico-chemical parameter of seawater at the selected stations.

Parameters	Stations	Pre-monsoon	Monsoon	Post-monsoon	Mean	Prescribed standards for coastal waters
Temperature (°C)	Vuda Park (Station 1)	28.60 ± 0.16	28.32 ± 0.12	27.71 ± 0.22	28.21 ± 0.17	26-30°C*
	Tenneti Park (Station 2)	27.85 ± 0.14	27.10 ± 0.12	26.83 ± 0.12	27.26 ± 0.13	
pH value	Vuda Park (Station 1)	7.91 ± 0.12	7.71 ± 0.13	7.80 ± 0.11	7.81 ± 0.12	6.5-8.5*
	Tenneti Park (Station 2)	8.12 ± 0.12	7.93 ± 0.12	8.10 ± 0.11	8.05 ± 0.12	
Salinity (psu)	Vuda Park (Station 1)	28.08 ± 0.12	26.12 ± 0.13	27.56 ± 0.12	27.25 ± 0.12	ND
	Tenneti Park (Station 2)	26.22 ± 0.11	25.13 ± 0.12	25.62 ± 0.12	25.66 ± 0.12	
Nitrate (mg l^{-1})	Vuda Park (Station 1)	0.054 ± 0.01	0.078 ± 0.01	0.069 ± 0.01	0.067 ± 0.02	0.01-0.06 mg l^{-1}**
	Tenneti Park (Station 2)	0.038 ± 0.01	0.047 ± 0.01	0.033 ± 0.002	0.039 ± 0.01	
Phosphate (mg l^{-1})	Vuda Park (Station 1)	0.018 ± 0.001	0.019 ± 0.001	0.016 ± 0.002	0.018 ± 0.001	0.001-0.01 mg l^{-1}**
	Tenneti Park (Station 2)	0.010 ± 0.001	0.014 ± 0.001	0.008 ± 0.001	0.011 ± 0.001	
Silicate (mg l^{-1})	Vuda Park (Station 1)	0.084 ± 0.01	0.117 ± 0.01	0.110 ± 0.02	0.104 ± 0.01	2.8 mg l^{-1} (avg)**
	Tenneti Park (Station 2)	0.078 ± 0.01	0.114 ± 0.01	0.098 ± 0.03	0.097 ± 0.01	

*Water quality standards for coastal waters marine outfalls (1986); **South African water quality guidelines for coastal marine waters (1996); ND: not detected

and Rao, 2009). The stations provide a very good habitat for seaweed growth, because of the presence of large rocks in the sandy shore.

Sample collection and analysis

Seaweed samples were collected from September, 2015 to August, 2016 from the study sites by placing 5 random quadrants of 0.25 m^2. The seaweeds were scrapped off the rock including as much of the holdfast as possible (Gillespi and Critchley, 1997). The species were identified as per the standard taxonomic keys (Rao and Sreeramulu, 1964). The collected samples were analysed for biochemical parameters (protein, carbohydrate and lipid) as per standard literature (Lowry, 1951; Sadasivan and Manickam, 2007; AOAC, 2005). Simultaneous analysis of seawater was also done during low tide for surface water temperature, pH, salinity, nitrate, phosphate and silicate respectively as per standard methodologies outlines by Strickland and Parsons, (1972) and APHA, (2005). All analyses were done seasonally (pre-monsoon, monsoon and post-monsoon) to understand the variation in selected physico-chemical and biochemical parameters.

Statistical analysis

All values for physico-chemical and biochemical parameters were expressed in terms of mean±standard deviation. Pearson's correlation coefficient and ANOVA were carried out using SPSS 13.1 to find the interrelationship between the parameters and their differences with respect to the selected stations.

Results and Discussion

Variation in physico-chemical parameters of seawater

The seawater sampled from the study area showed a temperature variation from 26.83 ± 0.12°C in station 2 during post-monsoon to 28.60 ± 0.16°C in station 1 during pre-monsoon, pH ranged from 7.71 ± 0.13 in station 1 during monsoon to 8.12 ± 0.12 in station 2 during pre-monsoon, salinity ranged between 25.13 ± 0.12 psu at station 2 during monsoon to 28.08 ± 0.12 psu at station 1 during pre-monsoon, nitrate values ranged from 0.033 ± 0.002 mg l^{-1} in station 2 during post-monsoon to 0.078 ± 0.01 mg l^{-1} in station 1 during monsoon, phosphate values ranged from 0.008 ± 0.001 mg l^{-1} in station 2 during post-monsoon to 0.019 ± 0.001 mg l^{-1} in station 1 during monsoon and silicate values ranged from 0.078 ± 0.01 mg l^{-1} in station 2 during pre-monsoon to 0.12 ± 0.01 mg l^{-1} in station 1 during monsoon respectively. The results of the selected parameters showed that nitrate and phosphate concentration at station 1 is at the borderline as per South Africa Water Quality Guidelines for Coastal Marine Water, (1996) permissible level is concerned (Table 1). This is because of the excess amount of tourist pressure and effluent discharge of the city at station 1. Low pH at station 1 may be due to the fact that higher bacteria load caused due to anthropogenic pollution, although an excessive amount of nutrients in the water has led to the increased biomass of the seaweed. Such observations are also being supported by earlier workers (Archana and Babu, 2013). This shows that the present physico-chemical parameters of ambient media are well suited for the growth of seaweeds. The spatio-temporal analysis of the selected parameters also showed significant variation between stations which proves the stations are distinctly different from each other although located in the same geographical locale and hence the seasonal difference is not pronounced. The significant variation of silicate with respect to seasons may be due to the fact of the precipitation and huge efflux from the adjacent city as well as the churning action of the water which has led to the changing silicate concentrations with respect to seasons. However vice-versa in the case of silicate with respect to stations (Table 2). Owing to the similar water quality of the area, the profuse growth of seaweed is possible.

Variation in biochemical parameters of seaweeds

Seaweeds collected from 0.25 m^2 quadrates were monitored for biomass estimation which showed the range from 1.76 ± 0.12 g m^{-2} in *P. tetrastromatica* at station 2 during pre-monsoon to 8.12 ± 0.51 in *C. racemosa* at station 1 during monsoon (Fig. 2). The sea surface temperature and salinity showed insignificant relationship ($r_{temp\ x\ biomass}$ = 0.286, 0.336, 0.022, p = IS; $r_{sal\ x\ biomass}$ = 0.155, 0.179, -0.375, p = IS) with respect to biomass owing to the adaptability of selected species to the tropical climate of India (Glenn *et al.*, 1999) (Fig. 3). pH showed significantly negative relationship ($r_{pH\ x\ biomass}$ = -0.973, -0.962, - 0.750, $p < 0.01$) whereas nitrate, phosphate and silicate have shown a significant positive relationship at 1% level of significance ($r_{NO3\ x\ biomass}$ = 0.927, 0.945, 0.650, $p < 0.01$; ($r_{PO4\ x\ biomass}$ = 0.795, 0.766, 0.560, $p < 0.01$; $r_{SiO3\ x\ biomass}$ = 0.841, 0.794, 0.900, $p < 0.01$) with respect to all the selected species *viz*., *C. racemosa*, *G. corticata* and *P. tetrastromatica* (Fig. 3).

Table 2: Spatio-temporal variations.

	Parameters	Variables	F_{cal}	F_{crit}
Physico-chemical parameters of seawater at the selected stations	Temperature (°C)	Between seasons	15.51	19
		Between stations	45.96	18.51
	pH value	Between seasons	16.20	19
		Between stations	73	18.51
	Salinity (psu)	Between seasons	8.57	19
		Between stations	27.54	18.51
	Nitrate (mg l^{-1})	Between seasons	2.64	19
		Between stations	21.19	18.51
	Phosphate (mg l^{-1})	Between seasons	6.77	19
		Between stations	49	18.51
	Silicate (mg l^{-1})	Between seasons	58.77	19
		Between stations	7	18.51

	Species	Variables	F_{cal} Biomass (g m^{-2})	F_{cal} Protein (%)	F_{cal} Carbohydrate (%)	F_{cal} Lipid (%)	F_{crit}
Biochemical parameters of selected seaweeds	*G corticata*	Between Stations	42.81	48.94	45.99	31.79	18.51
		Between Seasons	15.82	23.55	30.63	28.03	19
	C. racemosa	Between Stations	30.55	5.67	68.17	19.89	18.51
		Between Seasons	14.44	11.90	139.38	14.31	19
	P. tetrastromatica	Between Stations	194.63	39.62	22.22	4.66	18.51
		Between Seasons	1202.13	30.63	6.35	1.35	19

Protein percentage calculated seasonally for the 3 species showed variation from 18.91 ± 0.50% in *G. corticata* at station 2 during pre-monsoon to 25.81 ± 0.87% in *P. tetrastromatica* at station 1 during monsoon (Fig. 2). Insignificant negative correlation of protein was found with respect to surface water temperature and salinity ($r_{temp\ x\ protein}$ = -0.035, 0.374, 0.235, p = IS; $r_{sal\ x\ protein}$ = -0.145, 0.103, 0.037, p = IS) in all the selected species, which proved that temperature and salinity has insignificant role in protein synthesis of all the selected species throughout the year. Similar observations were also noted by Kim *et al*., (2007) while working in Cobscook Bay, Maine, USA (Fig. 2). pH showed a significantly negative relationship with protein showing the decrease in protein synthesis by seaweeds with increasing acidity (Bui *et al*., 2018) (Fig. 3). With respect to nitrate, phosphate and silicate protein has shown significant positive relationship at 1% level significance ($r_{NO3\ x\ protein}$ = 0.754, 0.939, 0.868, $p < 0.01$; ($r_{PO4\ x\ protein}$ = 0.585, 0.806, 0.787, $p < 0.01$; $r_{SiO3\ x\ protein}$ = 0.967, 0.799, 0.876, $p < 0.01$) for all the species (Fig. 3). This can be explained as to more anthropogenic waste in station 1 hence, an excess amount of nitrate is recorded in station 1. Since nitrate is an important constituent of protein, hence it is heavily absorbed by the seaweeds. Therefore, station 2 is devoid of anthropogenic pressure hence available nitrate is less owing to the maximum level of absorption by seaweeds, where *G. corticata* species has been found to be a more efficient absorber of NO_3 (Fig. 3). Similar result on high protein percentage in seaweed during monsoon has also been documented by earlier workers (Dhargalkar *et al*., 1980; Banerjee *et al*., 2009).

Carbohydrate which is stored glucose of plants varied from 49.34 ± 0.33% in *C. racemosa* at station 2 during monsoon to 65.32 ± 2.78% in *G. corticata* at station 1 during pre-monsoon respectively (Fig. 2). Carbohydrate synthesis was totally based on temperature, pH and salinity parameters along with nutrient nitrate and silicate for both seasons and stations, respectively. Hence, carbohydrate concentration was found to higher in pre-monsoon season in all three seaweeds. The high carbohydrate content in *G. corticata* may be due to higher phycolloids in their cell wall (Dhargalkar *et al*., 1980). As per Haroon *et al*., (2000), a relatively higher proportion of carbohydrate was recorded in red seaweed as has also been documented in the present study (Fig. 2). Significant positive correlation has been found between the surface temperature and salinity with carbohydrate concentrations in the selected seaweeds ($r_{temp\ x\ carbohydrate}$ = 0.694, 0.693, 0.721, $p < 0.01$; $r_{sal\ x\ carbohydrate}$ = 0.871, 0.931, 0.991, $p < 0.01$) including phosphate in case of *P. tetrastromatica* (Banerjee *et al*., 2009). pH, nitrate and phosphate have shown insignificant relationship in case of *C. racemosa* and *G. corticata* excepting nitrate and phosphate ($r_{NO3\ x\ carbohydrate}$ = 0.011, 0.335, 0.441, p = IS; $r_{PO4\ x\ carbohydrate}$ = 0.224, 0.354, 0.528, p = IS, $p < 0.05$) in *P. tetrastromatica* at 5% level of significance. (Pramanick *et al*., 2016) (Fig. 3).

A similar trend of lipid was also found in the studied species where the values ranged from 4.54 ± 0.24% in *P. tetrastromatica* at station 2 during pre-monsoon to 10.50 ± 0.45% in *G. corticata* at station 1 during post monsoon (Fig. 2). Lipid content showed a trend of post-monsoon > monsoon > pre-monsoon, due to the fact that the increase in heat during pre-monsoon liquefies the stored lipid content. *P. tetrastromatica* showed low lipid content in comparison to the other 2 species as has also been recorded from Visakhapatnam coast by Sarojini and

Table 3: Proximate chemical composition of different *Caulerpa* sp., *Gracilaria* sp. and *Padina* sp. reported by various authors (Values are given as percent of dry matter).

Species name	Biomass (g m⁻²)	Protein (%)	Carbohydrate (%)	Lipid (%)	Season	Country
C. racemosa	**8.12 ± 0.13**	**23.79 ± 0.12**	**53.73 ± 0.13**	**9.68 ± 0.13**	**AC**	**India**
C. cupressoides	ND	3.9	4.9	7.9	AC	France
C. racemosa	ND	1.9	2.0	2.8		
C. sertularioides	ND	3.2	4.4	10.1		
C. lentillifera	ND	12.49 ± 0.3	59.27 ± 1.54	0.86 ± 0.10	Summer	Thailand
C. racemosa	ND	19.72 ± 0.77	48.97 ± 1.22	7.65 ± 1.19	AC	Bangladesh
C. racemosa	ND	38.48 ± 1.21	64.41 ± 1.54	16.50 ± 0.57	AC	India (A.P)
C. racemosa	ND	5.17 ± 0.06	ND	ND	Rainy	Kenya
C. scapelliformis	ND	18.05 ± 0.08	ND	ND		
C. racemosa	ND	10.53	20.92	3.72	AC	Pakistan
C. taxifolia	ND	0.1	0.3	0.32	Winter	India (A.P)
C. sertulariodes	ND	12.3	23.5	2.8	AC	Persian Gulf
C. lentillifera	ND	ND	53.08 ± 0.10	ND	AC	Malaysia
C. serrulata	ND	14.5 ± 0.006	45.6 ± 0.003	4.24 ± 0.003	Winter	Egypt
C. lentillifera	ND	6.6	12.8	2.7	Winter	Australia
C. racemosa	ND	6.9	14.4	4.4		
C. racemosa	ND	3.98 ± 0.22	3.60 ± 0.28	ND	Spring	Mexico
C. taxifolia	ND	9.75	14.00	9.00	AC	Pakistan
G. corticata	**7.81 ± 0.15**	**24.47 ± 0.41**	**65.32 ± 0.32**	**10.50 ± 0.21**	**AC**	**India**
G. bursa pastoris	ND	15.9 ± 0.61	ND	1.87 ± 0.66	Winter	Turkey
G. gracilis	ND	15.9 ± 0.14	ND	1.95 ± 0.54		
G. edulis	ND	16.6 ± 0.5	45.8 ± 2.2	2.6 ± 0.4	Summer	India (T.N)
G. arcuata	ND	13.79 ± 0.31	ND	ND	Rainy	Kenya
G. salicornia	ND	9.55 ± 0.71	ND	ND		
G. corticata	ND	19.99 ± 1.54	67.75 ± 1.72	5.94 ± 0.64	AC	India (A.P)
G. gracilis	ND	20	88	ND	Winter	Argentina
G. compressa	ND	ND	11.62	ND	AC	Egypt
G. verucossa	ND	ND	11.15	ND		
G. corticata	ND	10.9	41.72	16.0	AC	Persian Gulf
G. fisheri	ND	11.6 ± 1.1	ND	2.7 ± 0.6	Summer	Thailand
G. corticata	ND	ND	43.0 ± 5.58	1.8 ± 0.48	AC	Iran
G. verrucosa	ND	ND	74.11 ± 0.77	ND	AC	Malaysia
G. verrucosa	ND	19.34 ± 21.22	ND	1.72 ± 3.60	Winter	Turkey

Table 3 Continue ...

Continue table 3 ...

G. cervicornis	16.92 ± 6.05	19.70 ± 2.70	63.13 ± 3.50	0.43 ± 0.56	AC	Brazil
G. changgi	ND	6.9	ND	3.3	AC	Malaysia
G. cornea	ND	5 47 ± 0.14	36.29 ± 0.44	ND	Spring	Mexico
P. tetrastromatica	**3.92 ± 0.13**	**25.81 ± 0.43**	**57.97 ± 0.12**	**7.43 ± 0.12**	**AC**	**India (A.P)**
P. gymnospora	ND	17.32	29.85	1.5	AC	India (T.N.)
P. tetrastromatica	ND	15.77	27.34	2.55		
P. cfsanctae-crucis	ND	8.2	3.1	3.6	AC	France
P. tetrastromatica	ND	7.62 ± 0.38	ND	ND	Rainy	Kenya
P. pavonia	ND	8.35 ± 0.02	90.50 ± 0.25	0.006 ± 0.0003	AC	Egypt
P. pavonia	ND	8.86	ND	3.87	AC	Turkey
P. pavonia	340	ND	32.36	ND	Winter	Pakistan
P. tetrastromatica	345	ND	33.01	ND		
P. gymnospora	ND	ND	26.86 ± 0.17	ND	AC	Malaysia
P. tetrastromatica	ND	3.873 ± 0.009	15.54 ± 0.003	3.92 ± 0.009	Winter	Egypt
P. gymnospora	ND	9.86 ± 0.31	1.86 ± 0.05	ND	Spring	Mexico
P. pavonia	ND	7.00	33.20	4.40	AC	Pakistan
P. vickersiae	ND	18.62	ND	1.43	AC	Saudi Arabia
2002 Joint WHO/FAO Expert Consultation Recommendations	ND	10-15	55-75	2.5-3.5		

AC: Annual Cycle, A.P: Andhra Pradesh, T.N: Tamil Nadu, ND: not determined

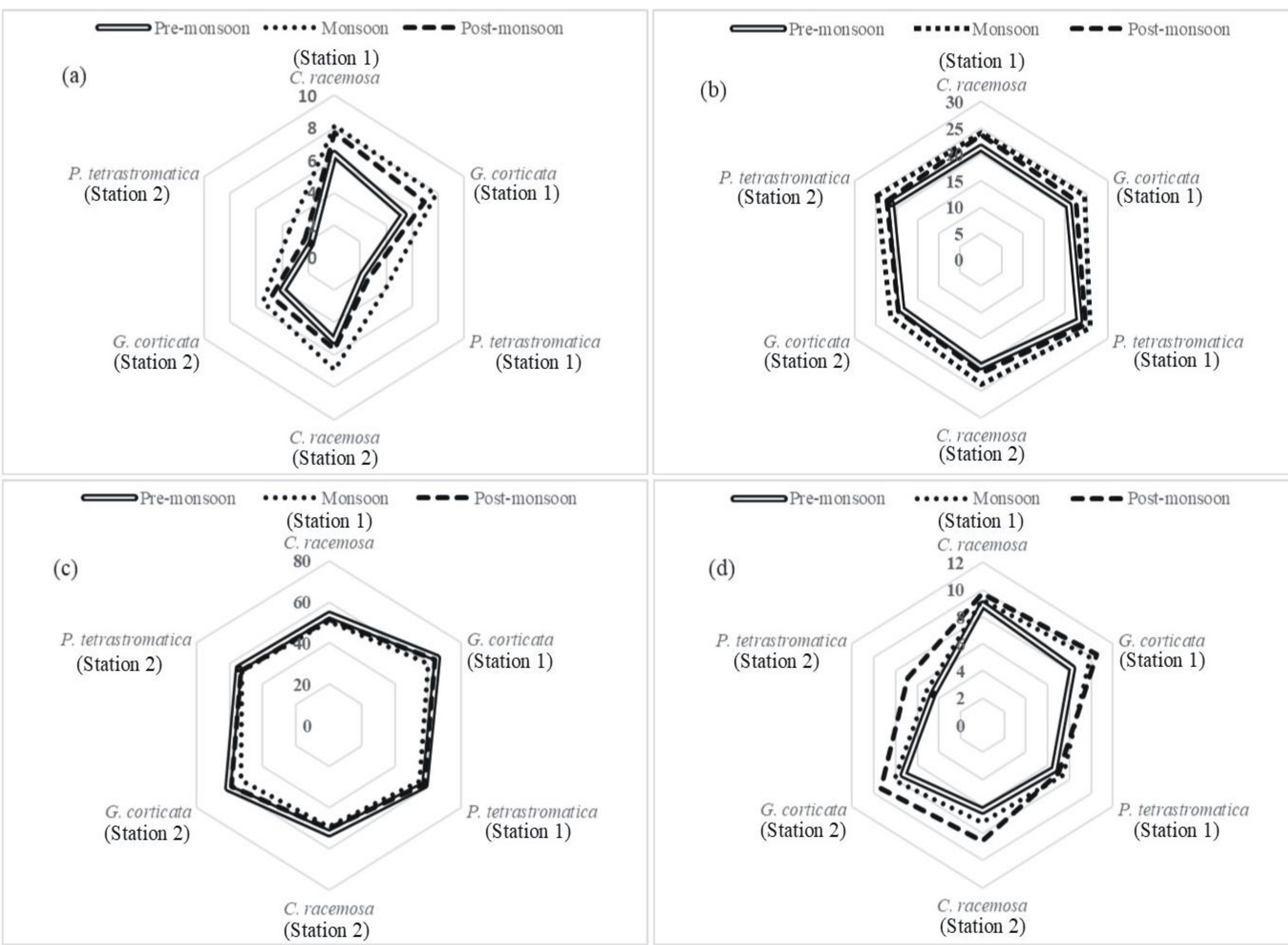

Fig. 2: Variation in biochemical composition **(a)** Biomass (g m^{-2}), **(b)** Protein (%), **(c)** Carbohydrate (%), **(d)** Lipid (%) of selected species at the selected stations.

Subbarangaiah, (1999). India being a tropical country, the impact of temperature and salinity has not shown a significant effect on the lipid synthesis of the selected seaweeds (Pramanick *et al*., 2016). pH showed a significantly negative correlation ($r_{pH\ x\ lipid}$ = -0.708, -0.661, -0.619, p < 0.01 with all the selected seaweeds respectively because with increasing pH concentrations in the seawater, the lipid synthesis will decrease and vice-versa (Qiu *et al*., 2017). Significant positive relationship of nitrate, phosphate, silicate ($r_{NO3\ x\ lipid}$ = 0.689, 0.656, 0.604, p < 0.01; $r_{PO4\ x\ lipid}$ = 0.583, 0.360, 0.459, p < 0.01, p = IS, p < 0.05; $r_{SiO3\ x\ lipid}$ = 0.458, 0.673, 0.451, p < 0.05, p = 0.01). Such effects have also been documented by Marinho-Soriano *et al*., 2006.

ANOVA result reflects pronounced variation between stations and seasons excepting protein in *C. racemosa* and lipid in *P. tetrastromatica* and for seasons, biomass of *P. tetrastromatica*, protein of *C. racemosa*, carbohydrate of *P. tetrastromatica* and lipid of *C. racemosa* and *P. tetrastromatica* (Table 2).

Looking at the values of protein, lipid and carbohydrate of the three selected species and comparing

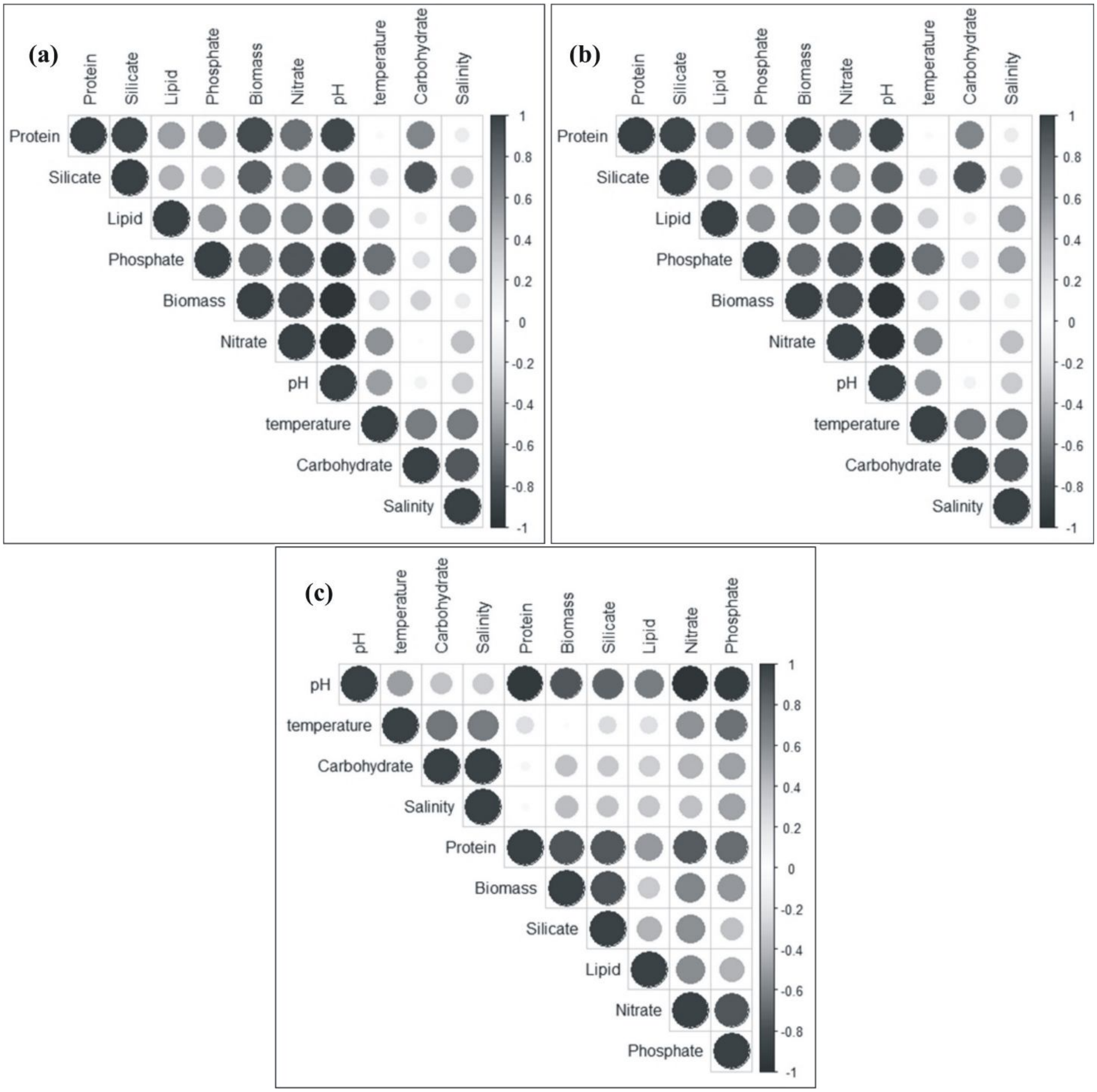

Fig. 3: Interrelationship between physico-chemical parameters and biochemical parameters of selected seaweeds **(a)** *Caulerpa racemose*, **(b)** *Gracilaria corticata*, **(c)** *Padina tetrastromatica*.

them with the values of the other parts of the world the values are almost in range as per the works cited in table 3. Comparing the other works of literature of the world, the protein content of *P. tetrastromatica* in our study was higher (Table 3). As per WHO/FAO, (2002) protein and lipid content in our study were found to be quite higher which speaks of the potentiality of using these seaweeds as a protein supplement in food.

As per FAO, (2016) the annual production of seaweed is 27.3 million tons in 2014 with a growth rate of 8% per year. This comprises of 27% of total marine aquaculture production. The study suggests that culturing these species in the coastal zone of India can help in further expansion of the seaweed industry and development of skilled labour force which will increase the suitable areas of farming. The emergence of this "Blue Crop" will help in the expansion of the blue industry (Mazarrasa *et al*., 2014). Hence compensating the farmers and encouraging them in seaweed production will help in climate change mitigation and adaptation for increased food security.

Conclusion

The results of the present research speak of taking a stepwise approach to establish the high value of seaweed and flourishing it as a blue crop in the coastal zone of India. In addition, the placement of seaweed farms needs consideration of the habitat requirement (Kerrision *et al*., 2015) as well as optimizing the quality of crops for targeted use (Bruhn *et al*., 2016). Because of the low investment and ample amount of coastal waters in India seaweed aquaculture can give a sound strategy to meet the food security problems in the near future and help in mitigating the problems of climate change.

Acknowledgements

The second author is grateful to Central University of Orissa, Koraput for providing financial assistance as Non-NET fellowship letter no. (CUO/ACA/ADM-RP/CBCNR/63(5) and Orissa University of Agriculture and Technology, Bhubaneswar for facilitating in laboratory analysis. There was no necessary permission for sampling and observation field studies have been obtained by the authors from the competent authorities.

Funding

This study was not funded by any institute/agency.

References

Ahmad, F., M.R. Sulaiman, W. Saimon, C.F. Yee and P. Matanjun (2012). Proximate compositions and total phenolic contents of selected edible seaweed from Semporna, Sabah, Malaysia. *Borneo science.*, **31:** 85-96.

Ahmed, K., S. Munawar, T. Mahmood and I. Mahmood (2015). Biochemical analysis of some species of seaweeds from Karachi coastal area. *FUUAST Journal of Biology.*, **5(1):** 43-45.

Amaya-Farfan, J. (2002). Protein and amino acid requirements in human nutrition report of a joint. FAO/WHO/UNU expert consultation. World Health Organization, 265.

Archana, A. and K.R. Babu (2013). Seasonal variations of physico-chemical parameters in coastal waters of Visakhapatnam, east coast of India. *Middle-East Journal of Scientific Research.*, **14(2):** 161-167.

Banerjee, K., R. Ghosh, S. Homechaudhuri and A. Mitra (2009). Biochemical composition of marine macro-algae from Gangetic Delta at the apex of Bay of Bengal. *African Journal Basic and Applied Science.*, **1(5-6):** 96-104.

Behairy, A.K.A. and M.M. EL-Sayed (1983). Biochemical composition of some marine brown algae from Jeddah coast, Saudi Arabia. *Indian Journal of Marine Sciences.*, **12:** 200-201.

Benjama, O. and P. Masniyom (2012). Biochemical composition and physico-chemical properties of two red seaweeds (*Gracilaria fisheri* and *G. tenuistipitata*) from the Pattani Bay in Southern Thailand. *Songklanakarin Journal of Science and Technology.*, **34(2):** 223-230.

Bhuiyan, Md. K.A., S. Qureshi, A.H.M. Kamal, S. Aftab Uddin and M.A. Momin Siddique (2016). Proximate chemical composition of sea grapes *Caulerpa racemosa* (J. Agardh, 1873) collected from a sub-tropical coast. *Virology & Mycology.*, **5:** 2.

Bramarambica, K., J.V.V.S.N. Murthy and S. Harasreeramulu (2014). A study on the geographical variation of nutritive aspects of *Caulerpa*-a marine alga of Visakhapatnam coast, India. *Journal of Algal Biomass Utilization.*, **5(4):** 44-49.

Bruhn, A., D.B. Torring and M. Thomsen (2016). Impact of environmental conditions on biomass yield, quality and bio-mitigation capacity of *Saccharina latissima*. *Aquaculture environment interactions.*, **8:** 619-636.

Bui, H.T.T., T.Q. Luu and R. Fotedar (2018). Effects of temperature and pH on the growth of *Sargassum linearifolium* and *S. podacanthum* in potassium-fortified inland saline water. *American Journal of Applied Sciences.*, **15(3):** 186-197.

Chapman, V.J. and D.J. Chapman (1980). *Seaweeds and their uses*, ed. 3rd. Chapman and Hall London, New York.

Cirik, S., Z. Cetin, A.K. Ilknur, S. Cirik and T. Goksan (2010). Greenhouse cultivation of *Gracilaria verrucosa* (Hudson) Papenfuss and determination of chemical composition. *Turkish Journal of Fisheries and Aquatic Sciences.*, **10:** 559-564.

Dawes, C.J. (1998). Marine Botany. John Wiley & Sons, New York. 480. CJ Dawes-1998- books.google.com.

Dhargalkar, V.K., T.G. Jagtap and A.G. Untawale (1980).

Biochemical constituents of seaweeds along the Maharashtra coast. *Indian Journal of Marine Science.*, **9(4):** 297-299.

Dromard, C.R., Y. Bouchon-Navaro, M. Harmelin-Vivien and C. Bouchon (2017). The nutritional quality of non-calcified macro-algae in Guadeloupe (Lesser Antilles) evaluated by their biochemical composition. *Gulf and Caribbean Research.*, **28:** 1-6.

El-Said, G.F. and A. El-Sikaily (2013). Chemical composition of some seaweed from Mediterranean Sea coast, Egypt. *Environmental Monitoring and Assessment.*, **185(7):** 6089-6099.

EL-Shafay, S.M. (2014). Biochemical composition of some seaweed from Hurghada Coastal along Red Sea Coastal, Egypt. *International Journal of Basic & Applied Sciences.*, **14:** 01.

Gaithersburg, M.D. (2005). *AOAC (Association of Official Analytical Chemists) Official methods of analysis.* ed. 16th. AOAC International.

Gillespie, R.D. and A.T. Critchley (1997). Morphometric studies of *Sargassum* spp. from Reunion Rocks, KwaZulu-Natal, South Africa. I. Receptacle studies. *South African Journal of Botany.*, **63:** 356-362.

Glenn, E.P., D. Moore, M. Akutagawa, A. Himler, T. Walsh and S.G. Nelson (1999). Correlation between *Gracilaria parvispora* (Rhodophyta) biomass production and water quality factors on a tropical reef in Hawaii. *Aquaculture.*, **178:** 323-331.

Haroon, A.M., A. Szaniawska, M. Normant and U. Janas (2000). The biochemical composition of *Enteromorpha* spp. from the Gulf of Gdañsk coast on the southern Baltic Sea. *Oceanologia.*, **42(1):** 19.

IPCC (2014). *Climate Change 2014-Impacts, Adaptation and Vulnerability*. Cambridge University Press, Cambridge and New York.

Irkin, L.C. and H. Erdugan (2017). Investigation of seasonal variations in biochemical composition of some red algae distributed in the Strait of Canakkale (Dardanelles), Turkey. *Archives of Applied Science Research.*, **9(2):** 1-8.

Kerrison, P.D., M.S. Stanley, M.D. Edwards, K.D. Black and A. Hughes (2015). The cultivation of European kelp for bioenergy: Site and species selection. *Biomass Bioenergy.*, **80:** 229-242.

Khan, F., Q. Abbas and R. Qari (2013). Alginic acid yield, biochemical composition and biomass in brown seaweed species of Cape Monze shore Karachi. eds: *Scientific Publisher India.*, 220.

Kim, J.K., G.P. Kraemer, C.D. Neefus, I.K. Chung and C. Yarish (2007). Effects of temperature and ammonium on growth, pigment production and nitrogen uptake by four species of *Porphyra* (Bangiales, Rhodophyta) native to the New England coast. *Jour. of Applied Phycology.*, **19:** 431-440.

Lakshmi, K.P. and G.M.N. Rao (2009). Some numerical studies on marine algae of Visakhapatnam Coast. *Journal of Algal Biomass Utilization.*, **1(1):** 60-85.

Mann, K. (1973). Seaweeds: Their productivity and strategy for growth. *Science.*, **182:** 975-981.

Marinho-Soriano, E., P.C. Fonseca, M.A.A. Carneiro and W.S.C. Moreira (2006). Seasonal variation in the chemical composition of two tropical seaweeds. *Bioresource Technology.*, **97:** 2402-2406.

Martin, L.A., M.C. Rodriguez, M.C. Matulewicz, E.N. Fissore, L.N. Gerschenson and P.L. Leonardi (2013). Seasonal variation in agar composition and properties from *Gracilaria gracilis* (Gracilariales, Rhodophyta) of the Patagonian coast of Argentina. *Phycological Research.*, **61:** 163-171.

Mazarrasa, I., Y.S. Olsen, E. Mayol, N. Marba and C.M. Duarte (2014). Global unbalance in seaweeds production, research effort and biotechnology markets. *Biotechnology Advance.*, **32:** 1028-1036.

Mohammadi, M., H. Tajik and P. Hajeb (2013). Nutritional composition of seaweeds from the Northern Persian Gulf. *Iranian Journal of Fisheries Sciences.*, **12(1):** 232-240.

Mwalugha, H.M., J.G. Wakibia, G.M. Kenji and M.A. Mwasaru (2015). Chemical composition of common seaweeds from the Kenya coast. *Journal of Food Research.*, **4:** 6.

Norziah, M.H. and C.Y. Ching (2000). Nutritional composition of edible seaweed *Gracilaria changgi*. *Food Chemistry.*, **68:** 69-76.

Osman, N.A., I.M. El-Manawy and A. Amin Sh. (2011). Nutritional composition and mineral content of five macro-algae from red sea. *Egyptian Journal of Phycology.*, **12**.

Parekh, R.G. and V.D. Chauhan (1982). Seasonal variations in the chemical constituents of the marine alga *Ulva* and seawater. *Seaweed Research and Utilization.*, **5(1):**1-4.

Polat, S. and Y. Ozogul (2013). Seasonal proximate and fatty acid variations of some seaweed from the northeastern Mediterranean coast. *Oceanologia.*, **55(2):** 375-391.

Pramanick, P., D. Bera, K. Banerjee, S. Zaman and A. Mitra (2016). Seasonal Variation of Proximate Composition of Common Seaweeds in Indian Sundarbans. *International Jour. of Life-Sciences Scientific Research.*, **2(5):** 570-578.

Qari, R. and R. Qasim (1993). Biochemical constitutions of seaweeds from Karachi coast. *Indian Journal of Marine Science.*, **22:** 229-231.

Rani, D.S., P.Y. Rao and I.R. Sirisha (2015). Biochemical constituents of red alga *Gracilaria corticata* Agardh, 1852 from coastal waters of Visakhapatnam, east coast of India. *International Journal of Green and Herbal Chemistry.*, **4(3):** 417-422.

Rao, M.U. and T. Sreeramulu (1964). An ecological study of some intertidal algae of the Visakhapatnam coast. *Journal of Ecology.*, **52(3):** 595-603.

Rao, P.J.V.R. and R. Sharma (1995). Dakshini Asiai Mahasagar Ke Tatiya Chetron Men Niyjan Evaam Prabandhan Hetu Chamta Nirman. Report (Hindi). Mahasagar Vikas Vibhag, New Delhi. Pub. PID, New Delhi. 120.

Rao, P.Y., D.S. Rani, D.N.K. Veni and I.R. Sirisha (2015). Seasonal changes of biochemical composition of green algae *Ulva fasciata* Delile, 1813 and *Caulerpa racemosa* Agardh, 1873 from coastal waters of Visakhapatnam, east coast of India. *Asian Jour. of Plant Science and Research.*, **5(6):** 57-62.

Ratana-arporn, P. and A. Chirapart (2006). Nutritional evaluation of tropical green seaweeds *Caulerpa lentillifera* and *Ulva reticulate*. *Kasetsart Jour. (Natural Science).*, **40:** 75-83.

Ravi, P. and G. Subramanian (2017). Biochemical studies on marine algal species of *Padina* (Phaeophyceae) from Mandapam coastline, Tamil Nadu, India. *World Journal of Pharmaceutical Research.*, **6(14):** 44-52.

Reddy, C.R.K., P.V. Subba Rao, G. Meenakshisundaram, K. Eswaran, S.H. Zaidi and V.A. Mantri (2014). The seaweed resources of India. In: A.T. Critchely, M. Oho and D.B. Largo (eds.): World Seaweed Resources (in DVD format), ETI Information Services Ltd., Wokingham, Berkshire, U.K.

Renaud, S.M. and J.T. Luong-Van (2006). Seasonal variation in the chemical composition of tropical Australian marine macro-algae. *Journal of Applied Phycology.*, **18:** 381-387.

Rice, E.W., R.B. Baird, A.D. Eaton and L.S. Clesceri (2005). *APHA: Standard Methods for the Examination of Water and Wastewater*, ed. 22nd. American Public Health Association/American Water Work Association/Water Environment Federation, Washington D.C., New York.

Robledo, D. and Y.F. Pelegrin (1997). Chemical and mineral composition of six potentially edible seaweed species of Yucatan. *Botanica Marina.*, **44:** 301-306.

Rohani-Ghadikolaei, K., E. Abdulalian and Ng. Wing-Keong (2012). Evaluation of the proximate, fatty acid and mineral composition of representative green, brown and red seaweeds from the Persian Gulf of Iran as potential food and feed resources. *Journal of Food Science and Technology.*, **49(6):** 774-780.

Ruperez, P. (2002). Mineral content of edible marine seaweeds. *Food Chemistry.*, **79:** 23-26.

Sadasivam, S. and A. Manickam (1997). *Biochemical methods*, ed 2nd: New age international (p) Ltd. Publisher, New Delhi. 5-207.

Saroj, P.M. (2016). Nutritional evaluation of three marine macro-algae on the coast of Kanyakumari district. *International Journal of Pure & Applied Science.*, **4(1):** 193-198.

Sarojini, Y. and G. Subbarangaiah (1999). Seasonal variation in biochemical composition of some macro-algae along Visakhapatnam, east coast of India. *Journal of Phycological Society (India).*, **38(1&2):** 71-79.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (2007). IPCC: Climate Change, Summary for Policymakers In: ed: The Physical Science Basis, Cambridge University Press, Cambridge. United Kingdom and New York, NY, USA. 996.

South african water quality guidelines for coastal marine waters (1996). *International Target Values for the Natural Marine Environment.*, **Vol.1:** B-1-B-3 and Chapter 4.2., 31.

Strickland, J.D.H. and T.R. Parsons (1972). *A practical handbook of seawater analysis*, ed. 2nd. Fisheries research board of Canada Ottawa.

The state of world fisheries and aquaculture (2016). Contributing to food security and nutrition for all. Rome. 200.

Valderrama, D. (2012). Social and Economic Dimensions of Seaweed Farming: A Global Review. Food and Resource Economics Department. University of Florida, USA. 1-11.

Water quality standards for coastal waters marine outfalls (1986). SW-II Standard. Central Pollution Control Board, New Delhi.