Seasonal variation in the biochemical composition of red seaweed (*Catenella repens*) from Gangetic delta, northeast coast of India

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The biochemical composition of red seaweeds, *Catenella repens* was investigated in this present study along with subsequent analysis of relevant physico-chemical variables. In this study, the relationship between the nutritive components of this species and the ambient environmental parameters was established. Protein content varied from $2.78 \pm 0.30\%$ of dry weight (stn.3) to $16.03 \pm 0.96\%$ of dry weight (stn.1) with highest values during monsoon. The protein levels were positively correlated with dissolved nitrate content and negatively correlated with water temperature (except stn.3) and salinity. Carbohydrate content of this species varied significantly ($p < 0.05$) during pre-monsoon between stations and the values showed positive relationship with salinity and surface water temperature. In contrast to carbohydrate, lipid concentration was lowest in values and varied very slightly between seasons and stations. Astaxanthin content of the seaweed species was greater in pre-monsoon than monsoon and post-monsoon in all the selected stations. Compared with the three seasons, samples of red seaweed collected in pre-monsoon has high carbohydrate–astaxanthin in contrast to protein–lipid which showed high values during monsoon. Statistical analysis computed among the environmental and biochemical parameters suggests the potential role played by the abiotic parameters on biosynthetic pathways of seaweed. This paper also highlights the influence of the nutritional quality of water that can be used for mass cultivation of *Catenella repens*.

1. Introduction

About eight million tonnes wet seaweeds are harvested annually worldwide and stranded seaweed on the beach constitute a considerable part of it (McHugh 2003). Currently, human consumption of green algae (5%), brown algae (66.5%) and red algae (33%) is high in Asia, mainly Japan, China and Korea (Dawes 1998). However, demand for seaweed as food has now also extended to North America, South America and Europe (McHugh 2003). The different species consumed present a great nutritional value as source of proteins, carbohydrates, minerals and vitamins. These seaweeds are harvested and utilized for a variety of purposes such as feed, fertilizer and as a source of raw material for industrial production of photochemical of commercial importance (Kirkman and Kendrick 1997; Robledo and Freile-Pelegrin 1997). The seaweeds are also known to contain bioactive products that display antibacterial, antiviral and antifungal properties (Trono 1999). Generally seaweeds at the surf zone also provide a niche environment for juvenile fishes and wrack-inhabiting organisms (Lenanton *et al* 1982). Accumulations of beach cast wreck are of immense ecological

significance and contribute enormous quantities of organic matter in the ecosystem (Mitchell and Hunter 1970; Dooley 1972; Lenanton *et al* 1982; Robertson and Lenanton 1984; Safran and Omori 1990; Blanche 1992; Kirkman and Kendrick 1997), which provide nourishment to the macroalgae. Ecological significance and knowledge of chemical composition of marine seaweed is important for both assessment of nutritional value to marine invertebrate or vertebrate herbivores (Hawkins and Hartnoll 1983) and for the evaluation of potential sources of protein, carbohydrate and lipid for commercial use (Chapman and Chapman 1980) or for possible human consumption (Abbott 1988).

Seaweeds are exposed to seasonal variations of abiotic factors that influence their metabolic responses (photosynthesis and growth rates) and levels of proximate constituents (Orduña-Rojas *et al* 2002). For subtropical species seawater temperature, light and nutrients have been shown to be the primary factors that modify the seasonal photosynthesis in *Hypnea musciformis* (Wulfen) Lamouroux (Durako and Dawes 1980a) and *Gracilaria tikvahiae* McLachlan (Lapointe and Ryther 1978; Penniman and Mathieson 1985; Lapointe 1987). Seasonal variations in the chemical composition and nutritive value have been reported in common marine seaweeds from different parts of the world; Kaehler and Kennish (1996) reported the same from Hong Kong, Kumar (1993) from coastal India and Mercer *et al* (1993) from Ireland. The nutritional properties of seaweeds and their seasonal oscillation are poorly known and normally are evaluated from the chemical composition (Mabeau and Fleurence 1993).

In this context study on the temporal variations in chemical composition of tropical seaweeds from the Gangetic delta of Sundarbans, West Bengal, India is in a very dormant stage. This mangrove dominated deltaic lobe at the apex of Bay of Bengal exhibits significant spatial and temporal variations of salinity owing to varied geographic features. Recent studies suggest that, mariculture of this species would require subtropical to tropical condition and hence, this species can be considered as an important candidate for aquaculture due to the characteristics of its high carotenoid content (Mitra *et al* 2006). The common dominant seaweed under class rhodophyceae found in this region is *Catenella repens*.

The present paper aims to analyze the seasonal variations of the levels of proximate constituents (protein, carbohydrate, lipid and astaxanthin) with respect to relevant hydrological parameters (like surface water temperature, pH, salinity, dissolved oxygen (DO), extinction coefficient 'K', nutrients [nitrate (NO_3), phosphate (PO_4), silicate (SiO_3)], phytopigment (Chl a, b and c), etc.

2. Materials and methods

2.1 *Study site*

The Indian Sundarbans (within the latitude $21°13'$N to $22°40'$N and longitude $88°03'$E to $89°07'$E) at the apex of the Gangetic delta is one of the most biologically productive and taxonomically diversified, low line, mangrove detritus based, open, dynamic, heterogeneous coastal ecotone. This mangrove forest has been declared as the World Heritage Site by IUCN in 1987, Biosphere Reserve under Man and Biosphere Programme by UNESCO in 1989 and is a proposed RAMSAR site. It is the only mangrove forest in the world that is inhabited by Royal Bengal Tiger (*Panthera tigris tigris*).

The climate of the area is humid (upto 96%), tropical with temperature ranging from $11.8°$C to $34.5°$C. The climate is monsoonal with an average rainfall of 1900 mm during monsoon months (July–October). The estuarine system becomes dominated by fresh water during monsoon resulting in strong predominance of ebb tides. From November–February, the system becomes salinity gradient dominated and during pre-monsoon period (March–June) effects of tide are considerably accentuated resulting in the system more or less marine dominated.

The low-lying tidal flats of Indian Sundarbans during the quaternary period have been developed from alluvial deposits of river Hugli, Saptamukhi and Matla together with tidal incursions. The soil consists of clayey loam or different black clay and there is no rock. The areas are about 1 m above the mean sea level and are submerged under saline estuarine waters for several hours in the spring tide twice a day.

Three stations selected in the eastern part of Indian Sundarbans region (figure 1) are distributed in three distinct salinity regimes: Gosaba – stn.1 ($22°08'53.66''$N; $88°56'34.20''$E), Chhotomollakhali – stn.2 ($22°10'21.74''$N; $88°53'55.18''$E) and Bali – stn.3 ($22°04'35.17''$N; $88°44'55.70''$E). The stations were selected on the basis of the availability of the red seaweed *Catenella repens* through seasons.

2.2 *Sampling and analysis of* Catenella repens

Seasonwise sampling was done from the uppermost littoral zone from November 2007 to October 2008 within 500 m coastal stretch at three different selected stations. During sampling, the shore washed seaweeds were collected by placing 5 random quadrates of $0.25 \, m^2$. The seaweeds thus harvested were brought to laboratory, washed and weighed. For determining biomass, the collected sample from each quadrate was weighed
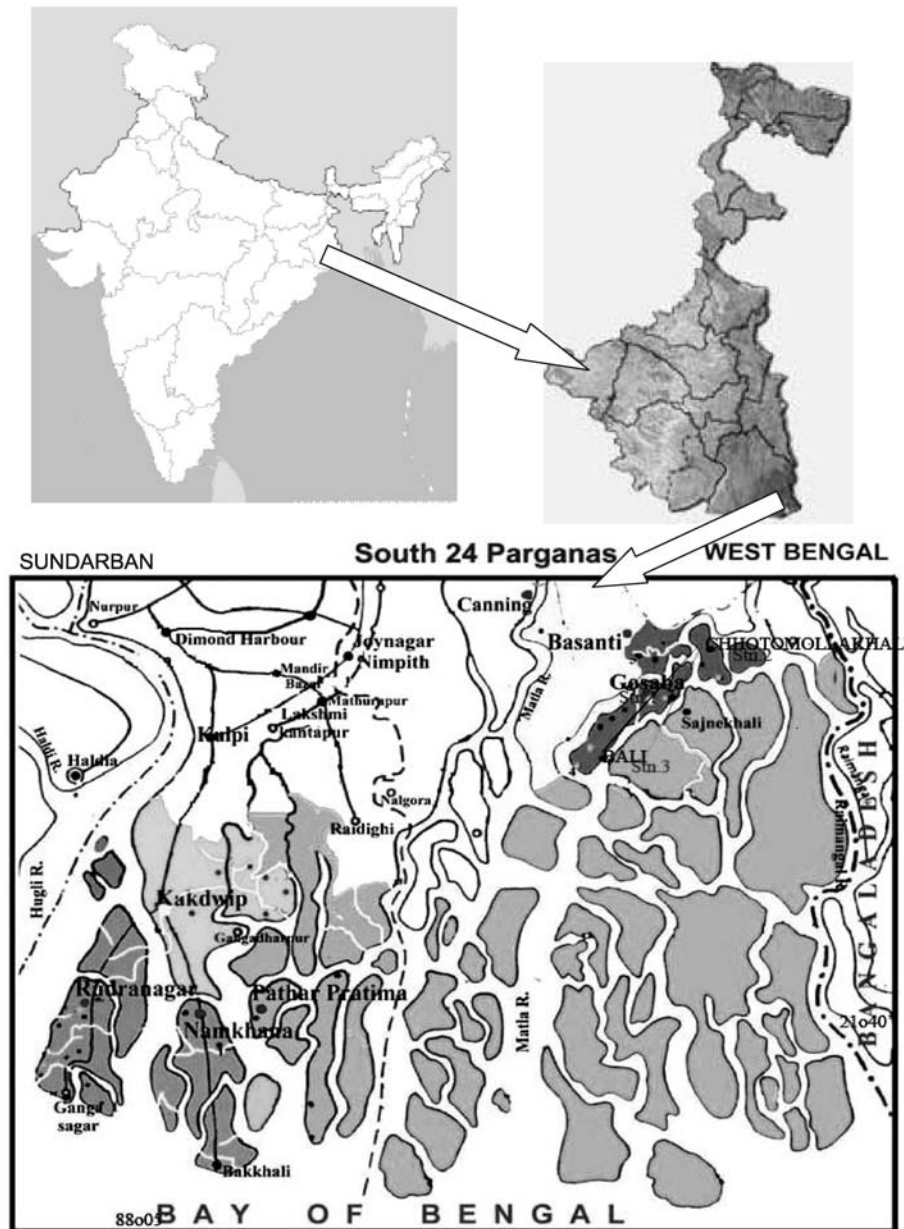
Figure 1.   Map of India and West Bengal showing the study site of Indian Sundarbans.

and expressed as g fresh weight m^{-2}. The data of biomass of red seaweed for the entire study period are shown in figure 2.

Duplicate analyses were averaged for each of the triplicate samples for soluble carbohydrate, total protein, total lipid and astaxanthin. The total carbohydrate content was assayed by the phenol-sulphuric acid method (Dubois *et al* 1956) after extraction with 2.5 N HCl. The results were calculated from a glucose standard curve. Total lipid was determined by Soxhlet method as described by Folch *et al* (1957). The total protein content was determined with Folin reagent with bovine albumin serving as standard (Lowry *et al* 1951). Astaxanthin was monitored by standard

spectrophotometric method (Schuep and Schierle 1995). Its value in percentage was converted to ppm level for easy interpretation of data. Lipid, protein and carbohydrate contents were expressed as the percentage of dry weight. The results are given as a mean with standard deviation ($\pm$SD) as quality assurance to the data.

2.3 *Analysis of hydrological parameters*

Surface water samples from all the selected stations were collected during high tide condition in clean TARSON bottles for analysis of hydrological parameters like surface water temperature, salinity, pH, dissolved oxygen (DO), extinction coefficient
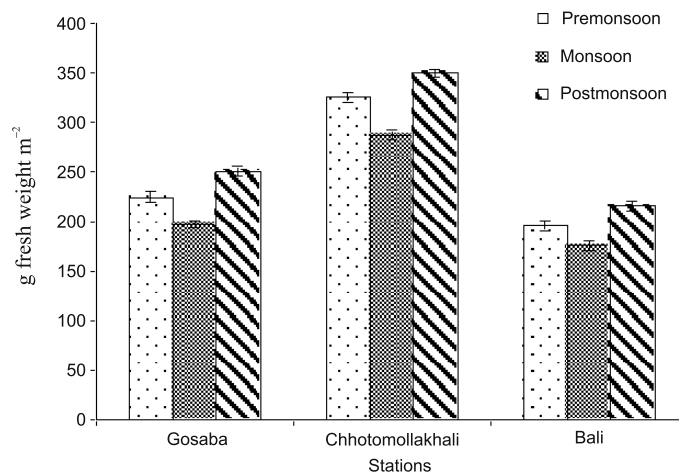
Figure 2. Variation in biomass content (g fresh weight m^{-2}) at three collection sites from Indian Sundarbans.

(K), nitrate (NO$_3$), phosphate (PO$_4$) and silicate (SiO$_3$) on monthly basis. Analyses were done as per the standard methodology outlined in Strickland and Parsons (1972) and APHA (1998). The extinction co-efficient (K), which is the inverse of transparency was determined as per the expression $K = 1.44/D$, where D is the maximum depth of secchi disk visibility in meter (Raymont 1980). For pigment analysis, one litre of surface water was collected from each of the sampling stations for determination of the chlorophyll pigment (Chl a, b and c) by spectrophotometric method after extraction with 90% acetone (Jeffrey and Humphrey 1975).

2.4 *Statistical analysis*

All data were expressed in terms of mean ±SD (standard deviation) and range. In addition, data concerning the environmental parameters, biomass and content of proteins, carbohydrates, lipids and astaxanthin for the species were analyzed by Duncan's multiple range test at $p < 0.05$ (SPSS 9.0 1999) for the identification of significant statistical seasonal differences during the study period. The Pearson correlation coefficient (r) was also computed between the biochemical composition of the species and environmental parameters.

3. Results and discussions

3.1 *Spatial and temporal variation in observed variables*

Data on environmental parameters and biomass of *C. repens* are reported in table 1 and figure 2. During the study period water temperature varied from $28.20 \pm 0.05°$C during post-monsoon

(stn.1) to $32.65 \pm 0.05°$C during pre-monsoon (stn.3). Salinity oscillated between $11.48 \pm 0.03‰$ at stn.1 (monsoon) to $24.33 \pm 0.15‰$ at stn.3 (pre-monsoon). Similar trend of pH was also noted throughout the study period with low values during monsoon (8.08 ± 0.01) at stn.1 and high values during pre-monsoon (8.31 ± 0.02) at stn.3. Extinction coefficient which is a measure of turbidity in water showed highest values during monsoon ($9.31 \pm 0.04 \, \text{m}^{-1}$) at stn.1 and low values during pre-monsoon ($7.56 \pm 0.02 \, \text{m}^{-1}$) at stn.3. Nutrient load (NO$_3$, PO$_4$ and SiO$_3$) showed higher values during monsoon and lower values during pre-monsoon excepting at stn.2, where SiO$_3$ values were low during post-monsoon. This might be attributed to the heavy runoff and precipitation during monsoon which brings lot of nutrients from the adjacent landmasses, agricultural field and shrimp farms. The lower values of nutrients is due to the fact that NO$_3$, PO$_4$ and SiO$_3$ (being the major building blocks of phytoplankton) are being absorbed from the ambient aquatic phase. Dissolved oxygen values were usually higher during monsoon ($6.21 \pm 0.03 \, \text{mg/l}$ at stn.1; $6.03 \pm 0.09 \, \text{mg/l}$ at stn.2 and $5.52 \pm 0.19 \, \text{mg/l}$ at stn.3) in all the stations due to the heavy flushing from the rivers and churning actions of the seabed due to runoff processes. Phytopigment (Chl a, b and c) showed highest values during pre-monsoon at stn.3 ($4.10 \pm 0.02 \, \text{mg/m}^3$; $1.84 \pm 0.03 \, \text{mg/m}^3$ and $2.06 \pm 0.03 \, \text{mg/m}^3$ respectively) and lowest values during monsoon at stn.1 ($2.39 \pm 0.05 \, \text{mg/m}^3$; $0.91 \pm 0.04 \, \text{mg/m}^3$ and $1.77 \pm 0.02 \, \text{mg/m}^3$ respectively). The physico-chemical variables except surface water temperature and pH showed a sharp seasonal variation in all three selected stations (table 1). The surface water salinity, pH, transparency (expressed as extinction coefficient) and

Table 1. *The mean (±SD) results of physico-chemical parameters in surface waters from Indian Sundarbans*.*

Stations	Salinity	pH	Dissolved oxygen	Temperature	Extinction coefficient	Nitrate	Phosphate	Silicate	Chl a	Chl b	Chl c
Pre-monsoon											
Gosaba	15.44 ± 0.04^c	8.11 ± 0.01^c	6.04 ± 0.02^a	32.23 ± 0.15^b	8.97 ± 0.01^a	26.5 ± 0.10^a	2.25 ± 0.01^a	89.91 ± 0.01^b	2.92 ± 0.01^c	1.24 ± 0.02^c	1.97 ± 0.01^c
Chhotomo-llakhali	19.74 ± 0.03^b	8.17 ± 0.01^b	5.96 ± 0.02^b	32.50 ± 0.05^a	7.77 ± 0.03^b	25.69 ± 0.05^b	1.66 ± 0.02^b	90.27 ± 0.02^b	3.66 ± 0.02^b	1.66 ± 0.01^b	2.01 ± 0.01^b
Bali	24.33 ± 0.15^a	8.31 ± 0.02^a	5.55 ± 0.01^c	32.65 ± 0.05^a	7.56 ± 0.02^c	20.56 ± 0.40^c	0.92 ± 0.01^c	110.47 ± 0.56^a	4.10 ± 0.02^a	1.84 ± 0.03^a	2.06 ± 0.03^a
Monsoon											
Gosaba	11.48 ± 0.03^c	8.08 ± 0.01^c	6.21 ± 0.03^a	29.96 ± 0.28^b	9.31 ± 0.04^a	30.16 ± 0.77^a	2.74 ± 0.04^a	100.21 ± 1.34^b	2.39 ± 0.05^b	0.91 ± 0.04^c	1.77 ± 0.02^b
Chhotomo-llakhali	16.69 ± 0.29^b	8.14 ± 0.02^b	6.03 ± 0.09^b	30.18 ± 0.06^{ab}	9.25 ± 0.04^b	29.10 ± 0.23^b	2.32 ± 0.03^b	96.81 ± 2.09^b	2.91 ± 0.09^a	1.10 ± 0.03^b	1.55 ± 0.04^c
Bali	20.11 ± 0.24^a	8.29 ± 0.01^a	5.52 ± 0.19^c	30.39 ± 0.16^a	8.09 ± 0.05^c	24.83 ± 0.31^c	1.09 ± 0.05^c	116.83 ± 2.53^a	2.86 ± 0.21^a	1.52 ± 0.06^a	1.97 ± 0.03^a
Post-monsoon											
Gosaba	13.15 ± 0.03^c	8.10 ± 0.06^c	6.02 ± 0.01^a	28.20 ± 0.05^b	9.11 ± 0.01^a	28.60 ± 0.02^a	2.39 ± 0.02^a	91.67 ± 0.02^b	2.78 ± 0.01^c	1.16 ± 0.01^c	1.88 ± 0.02^c
Chhotomo-llakhali	17.14 ± 0.1^b	8.17 ± 0.01^b	5.91 ± 0.01^b	28.40 ± 0.26^{ab}	8.56 ± 0.02^b	27.67 ± 0.03^b	2.05 ± 0.01^b	89.76 ± 0.02^c	3.02 ± 0.01^b	1.45 ± 0.01^b	1.97 ± 0.01^b
Bali	22.60 ± 0.20^a	8.30 ± 0.01^a	5.50 ± 0.02^c	28.60 ± 0.01^a	7.89 ± 0.02^c	21.53 ± 0.15^c	1.02 ± 0.01^c	113.12 ± 1.31^a	3.66 ± 0.04^a	1.73 ± 0.03^a	2.01 ± 0.02^a

*Means in a whole column with different superscripts (a–c) are significantly different ($p < 0.05$, Duncan multiple range test).

phytopigment (excepting Chl c at stn.2) in the area of investigation varied as per the order station 3 > station 2 > station 1. However, for nutrients (except silicate) and dissolved oxygen the order of variation was station 1 > station 2 > station 3. This spatial trend was observed in all the seasons of the year, irrespective of stations.

Significant seasonal variations in biomass of *Catenella repens* have been observed in all the three sampling stations. The biomass showed a declining trend from post-monsoon to monsoon (figure 2). The biomass of seaweeds largely depends upon season, population structure and several other ecological factors (Krishnamurthy 1967). Further, the physico-chemical variable especially nutrients and salinity also contribute to the multiplication of the thallus (growth of seaweed) (Thakur *et al* 2008). The biomass of seaweed can be correlated with the abiotic factors that prevailed before or during the collection period (McQuaid 1985). In the present work, maximum growth of the red seaweed was observed during post-monsoon season; the period characterized by optimum nutrient load, temperature, salinity, pH and extinction coefficient. This is confirmed from the significant positive correlation between biomass and pH and significant negative correlation with nutrients (NO_3 and PO_4) and extinction coefficient excepting phytopigment, surface water temperature and salinity (table 3). Seaweeds as compared to other marine plants are short-lived with successive growth periods and more than two growth peaks during their lifespan when the season is conducive (Thakur *et al* 2008). The lowest biomass values obtained during monsoon could be attributed to an intermittent period in which some population rejuvenate and recover from wholesome detachment. Ambient parameter is also not favourable during monsoon because of high turbidity that prevents light penetration for photosynthetic activities of seaweeds. The seaweed growth season in Indian Sundarbans begins from November to March. In general, biomass maximum coincides with carbohydrate maximum suggesting a link between seaweed growth and carbohydrate content (Marinho-Soriano *et al* 2006). However, our result did not support the above fact because of extremely high surface water temperature and salinity during pre-monsoon; which is a characteristic feature of the present geographical locale. This condition results in desiccation and subsequent reduction of seaweed biomass.

Protein values showed more or less similar trend in all the three stations and the values were in order station 1 > station 2 > station 3. The fluctuation in the protein values in all the three stations can be explained by variation in environmental conditions such as temperature, salinity and nutrients.

Table 2. *The mean ($\pm$SD) values of protein, lipid, carbohydrate and astaxanthin in* Catenella repens *from Indian Sundarbans*[*].

Stations	Protein (% of dry weight)	Lipid (% of dry weight)	Carbohydrate (% of dry weight)	Astaxanthin (ppm of dry weight)
Pre-monsoon				
Gosaba	9.51 ± 0.73^a	0.19 ± 0.02^a	25.42 ± 1.18^c	104.08 ± 2.72^c
Chhotomollakhali	8.66 ± 0.78^a	0.18 ± 0.02^a	28.48 ± 1.45^b	134.41 ± 3.12^b
Bali	2.78 ± 0.30^b	0.17 ± 0.02^a	35.74 ± 1.55^a	188.34 ± 2.89^a
Monsoon				
Gosaba	16.03 ± 0.96^a	0.23 ± 0.02^a	23.09 ± 1.41^c	87.49 ± 2.34^c
Chhotomollakhali	13.79 ± 0.86^b	0.24 ± 0.01^a	26.36 ± 1.27^b	108.72 ± 2.45^b
Bali	8.53 ± 1.14^c	0.22 ± 0.02^a	28.93 ± 0.18^a	174.45 ± 3.62^a
Post-monsoon				
Gosaba	12.42 ± 1.12^a	0.22 ± 0.01^a	21.52 ± 1.87^b	97.50 ± 1.84^c
Chhotomollakhali	11.43 ± 1.86^a	0.20 ± 0.01^a	23.32 ± 1.67^b	128.07 ± 2.72^b
Bali	4.01 ± 1.28^b	0.20 ± 0.01^a	26.53 ± 1.89^a	182.04 ± 3.07^a

[*]Means in a whole column with different superscripts (a–c) are significantly different ($p < 0.05$, Duncan multiple range test).

This observation is confirmed by the positive correlation of protein content with dissolved nitrate and negative correlation with temperature and salinity (table 3). Carbohydrate values showed a reverse trend with respect to protein values in all the three selected stations. The values were in the order pre-monsoon > monsoon > post-monsoon, which emphasizes the role of temperature and salinity on carbohydrate synthesis. No significant temporal and spatial variations were observed for lipid content in the seaweed species thriving in the present study area (table 2). Astaxanthin values varied both spatially and temporally as per the order station 3 > station 2 > station 1 and pre-monsoon > post-monsoon > monsoon respectively. This might be probably due to the proximity of these stations to Bay of Bengal and higher temperature prevailing during pre-monsoon in the study site. This has been supported by several workers that environmental variables such as high irradiance, nutrient deficiency, high salinity and high temperature play a leading role in astaxanthin accumulation (Kobayashi *et al* 1992; Tjahjono *et al* 1994; Harker *et al* 1996; Boussiba 2000; Sarada *et al* 2002).

3.2 *Seasonal variation in biochemical composition*

The protein content showed highly significant seasonal variation ($p < 0.05$) with higher values during monsoon ($16.03 \pm 0.96\%$ of dry weight at stn.1) owing to the presence of high nitrate load in the ambient waters (table 2). Similar results were observed by Bird (1984) while working with *Gracilaria verrucosa*. The dependence of protein level in algae on available nitrogen was also pointed out by Lapointe (1981) and Dawes (1998).

Significant seasonal variations in carbohydrate content of the seaweed was also observed in the present study ($p < 0.05$), irrespective of stations (table 2). The values were highest in pre-monsoon and lowest in post-monsoon indicating the role of surface water temperature to be vital for photosynthesis. The positive influence of water temperature, salinity and pH on carbohydrate synthesis was confirmed by several workers (Munda and Kremer 1977; Perfeto 1998). Significant positive correlation between salinity and surface water temperature and carbohydrate values in our study also supports the above results (table 3). The inverse relationship between carbohydrate and protein with temperature and salinity correspond to a pattern observed for several species of seaweeds (Mourandi-Givernaud *et al* 1993). The trend may be attributed to the positive role of light intensity, temperature and decrease of nitrogen for carbohydrate synthesis, while for the proteins these parameters act inversely (Rosemberg and Ramus 1982; Rotem *et al* 1986). Thus, the active period of carbohydrate synthesis coincides with the decrease in protein concentration in seaweed and *vice-versa*.

In general, seaweeds exhibit low lipid contents (Dawes 1998). The lipid content ranged from $0.17 \pm 0.02\%$ of dry weight at stn.3 (pre-monsoon) to $0.24 \pm 0.01\%$ of dry weight at stn.2 (monsoon). These values were smaller than those obtained for most seaweed, which range from 1% to 3% of dry matter as reported by Mabeau and Fleurence (1993). Although this value is relatively low, it is comparable to the results obtained previously by Indergaard and Minsaas (1991).

Astaxanthin is widely used as a natural red colourant in marine fish aquaculture (Johnson 1991; Benemann 1992). The coincidence of high

Table 3. *Correlation coefficients between environmental variables and biochemical composition of* Catenella repens *at three collection sites from Indian Sundarbans.*

	Biomass	Protein	Carbohydrate	Lipid	Astaxanthin
Gosaba					
Salinity	0.147	−0.950*	0.490**	−0.775*	0.944*
pH	0.728*	−0.754*	0.161	−0.393	0.777*
Dissolved Oxygen	−0.881*	0.794*	0.058	0.540**	−0.860*
Temperature	−0.465**	−0.464**	0.798*	−0.498**	0.428
Extinction coefficient	−0.603*	0.940*	−0.340	0.760*	−0.940*
Nitrate	−0.484**	0.908*	−0.437	0.796*	−0.891*
Phosphate	−0.695*	0.933*	−0.270	0.740*	−0.947*
Silicate	0.760*	0.915*	−0.217	0.656*	−0.938*
Chl *a*	0.696*	−0.930*	0.257	−0.683*	0.961*
Chl *b*	0.698*	−0.934*	0.283	−0.721*	0.950*
Chl *c*	0.518**	−0.882*	0.432	−0.822*	0.836*
Biomass		−0.504**	−0.394	−0.309	0.557*
Protein			−0.440	0.805*	−0.883*
Carbohydrate				−0.484**	0.262
Lipid					−0.735*
Chhotomollakhali					
Salinity	0.226	−0.860*	0.597*	−0.777*	0.770*
pH	0.739*	−0.596*	0.149	−0.603*	0.719*
Dissolved Oxygen	−0.966*	0.319	0.392	0.445**	−0.566*
Temperature	−0.309	−0.497**	0.830*	−0.343	0.297
Extinction coefficient	−0.586*	0.889*	−0.347	0.886*	−0.938*
Nitrate	−0.549**	0.885*	−0.371	0.871*	−0.918*
Phosphate	−0.519**	0.900*	−0.366	0.892*	−0.912*
Silicate	−0.871*	0.736*	0.230	0.843*	−0.876*
Chl *a*	0.214	−0.867*	0.594*	−0.779*	0.763*
Chl *b*	0.700*	−0.924*	0.207	−0.924*	0.960*
Chl *c*	0.883*	−0.892*	0.044	−0.892*	0.971*
Biomass		−0.631*	−0.374	−0.631*	0.803*
Protein			−0.243	0.887*	−0.741*
Carbohydrate				0.022	0.098
Lipid					−0.897*
Bali					
Salinity	0.654*	−0.920*	0.861*	−0.812*	0.884*
pH	0.188	−0.680*	0.418	−0.913*	0.602*
Dissolved Oxygen	−0.102	0.073	−0.122	0.022	−0.147
Temperature	−0.362	−0.230	0.657*	−0.587*	0.450**
Extinction coefficient	−0.449	0.851*	−0.933*	0.877*	−0.901*
Nitrate	−0.744*	0.944*	−0.778*	0.781*	−0.867*
Phosphate	−0.476**	0.787*	−0.937*	0.831*	−0.925*
Silicate	−0.523**	0.865*	−0.653*	0.746*	−0.720*
Chl *a*	0.665*	−0.928*	0.785*	−0.793*	0.836*
Chl *b*	0.664*	−0.888*	0.822*	−0.750*	0.851*
Chl *c*	0.465**	−0.766*	0.850*	−0.855*	0.909*
Biomass		−0.670*	0.417	−0.250	0.580*
Protein			−0.686*	0.811*	−0.746*
Carbohydrate				−0.681*	0.891*
Lipid					−0.743*

*Significance ($p < 0.01$)   **Significance ($p < 0.05$).

astaxanthin value of *Catenella repens* with its carbohydrate level in the pre-monsoon season (table 2) was observed in the present study. The correlation values, however, indicate significant positive correlation of seaweed astaxanthin with salinity (table 3), in all the stations, but with surface water temperature, such positive correlations were not observed for all the stations. This might be due to tropical type of climate in the present geographical locale, where temperature oscillates little with season. Similar results on increase in carotenoids content with increasing temperature and salinity with high astaxanthin production were also found by Tripathy *et al* (2002). In case of nutrient, Ausich (1997) stated that when the *Haematococcus* culture is subjected to stress in which nutrients are eliminated from growth medium then the alga produces and accumulate astaxanthin. In our case also significant negative correlation ($p < 0.01$) at all the selected stations depict that astaxanthin accumulation increases with decrease in nutrient level (table 3).

The results obtained in our study establish the fact that physico-chemical parameters have profound influence on the biochemical composition of red seaweed, *Catenella repens*. Significant correlation values computed among the environmental parameters and protein, lipid, carbohydrate, astaxanthin suggest that the abiotic parameters have potential role on biosynthetic pathways of seaweed. A number of studies are still needed to evaluate the nutritional potentiality of this seaweed for its mass cultivation as food source for the coastal communities.

Acknowledgements

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