ACTA SCIENTIFIC AGRICULTURE (ISSN: 2581-365X)

Volume 3 Issue 5 May 2019

Research Article

# Role of Physico-Chemical Variables on Growth of Seaweeds

**Kakoli Banerjee*, Archana Snehasini Turuk and Gopal Raj Khemundu**

*Department of Biodiversity and Conservation of Natural Resources, Central University of Orissa, Landiguda, India*

***Corresponding Author:** Kakoli Banerjee, Department of Biodiversity and Conservation of Natural Resources, Central University of Orissa, Landiguda, India.

**Received:** March 25, 2019; **Published:** April 15, 2019

## Abstract

Poverty alleviation in rural and coastal areas cannot be addressed only with increased agricultural development in land resources. Seaweeds can act as seafood vegetables in order to mitigate global food production and play a substantial role in meeting the dietary deficiencies of the country. Given this potential an attempt was made to study the biochemical composition of five dominant seaweeds namely, *Catenella repens*, *Ulva lactuca, Caulerpa racemosa*, *Enteromorpha intestinalis* and *Chaetomorpha melagonium* in two selected stations *viz.,* station-1 (Vuda Park) and station-2 (Govt. Fishing Harbour) from Visakhapatnam coast of Andhra Pradesh, India. Seawater samples were also collected simultaneously and monitored for temperature, salinity, pH, $NO_3$, $PO_4$, $SiO_3$ and Chl *a*, *b*, *c*. Seaweed samples were collected and analyzed for biomass, protein, carbohydrate, astaxanthin, lipid, moisture content and Chl *a* and *b*. The study revealed luxuriant growth of *E. intestinalis* (8.23 kg/$m^2$) whereas poor growth was observed in *C. melagonium* (5.04 kg/$m^2$) at stn.1. The highest protein content was obtained from *C. melagonium* (18.22%) at stn.2 and lowest was obtained from *E. intestinalis* (11.85%). The maximum carbohydrate and astaxanthin concentration was recorded in the same species of seaweed i.e. *C. repens* and the least concentration was recorded from *U. lactuca* and the similar case was found in both Chl *a*, Chl *b* that they showed highest in *U. lactuca* and lowest in case of *C. melagonium*. The lipid content was highest in *C. melagonium* (0.48%) at stn.1 and least content in *C. repens* (0.75%) at stn.2. However moisture content was maximum in *C. melagonium* (85.55%) at stn.2 and minimum in *C. repens* (52.59%) at stn.1. Owing to the food characteristics of the selected seaweeds, these seaweeds are recommended for dietary supplement for coastal population as a wholesale, healthy and tasty food product to meet the food security challenges adequately. The environmental parameters reveal the appropriate culture condition that can be taken up in order to propagate these seaweeds into culture in order to make it a future food crop in the *era* of climate change.

**Keywords:** Seaweeds; Biochemical Composition; Climate Change; Food Crop; Environmental Variables

## Introduction

The seas and oceans are the valuable resources of the earth which has all solutions to mitigate the effects of climate change. Our oceans are already in locked death spiral. According to International Programme on the State of Oceans (IPSO), a consortium of 27 top mean experts in the world, the effects of climate change, ocean acidification and oxygen depletions have already triggered the phase of extinctions of marine species. The oceans are the last wild spaces on earth which are ungoverned and untouched by human hands. However in the changing *era* of climate crisis, we have little choice to exploit the ocean resources sustainably.

Unlike land-based plants, seaweeds do not require any fertilizers, pest clearing, water, etc, rather they act as bioremediation agent in cleaning the water as they absorbs huge quantity of nutrients like $NO_3$ and $PO_4$ which actually is used for building their own biomass. Hence to form this blue crop, the basic concept of its biochemical constituents is a must which will pave the way for its culture and consumption by human. It is estimated that by 2050, there will be 2.5 billion people on earth and food crop scarcity will be a major challenge. Seawater greenhouses can be an answer to this problem as mentioned by Charlie Paton, as these seaweeds are eaten by microscopic animals to blue whale. Present day seaweeds are being used by food-processing industry and sold as 'sea vegetables'

preserved in frozen, dry and canned or salted form [36,54]. It has been reported that about 10,000 species of macroalgae are reported to exist [21,22], however only 200 species are consumed worldwide as sea vegetables [45]. Although seaweeds are consumed to a large extent in Asia however Indians have accepted seaweeds as vegetables owing to the large scale productions of rice, wheat and vegetables in the country. However in the changing climatic conditions, sea resources utilization should be practiced so that in case of salinization of land, sea resources can be utilized as sustainable crop as they are rich sources of nutrients.

Seaweed farming could contribute to the coastal aquaculture sector in creating new occupations and improved poverty circumstances to develop coastal livelihoods. The environmental parameters which govern the growth of seaweeds are also an important parameter for its propagation and its culture technology. It also addresses the climate change mitigation measure by providing valuable biomass with potential for delivering food, feed, bimolecular and energy (http: www.fao.org/docrep/field/003/AC287E/AC287E01.htm). On this background, the present programme aims to study the biochemical constitution in selected seaweeds in Visakhapatnam coast of Andhra Pradesh along with the relevant environmental parameters to designate them as potential sea vegetable in future food stock.

## Materials and Methods

### Study site

India encompasses 3214 km from North to South and 2933 km from East to West. It has a land frontier of 15,200 km and a coastline of 7517 km. The present study site i.e. Visakhapatnam coast of Andhra Pradesh located in this huge coastline is second in position after Gujarat with a length of 1037 km (http://www.quora.com). Out of 1931.21 km [59] of east coastline, 53.69% is occupied by Andhra Pradesh, hence it is an important site for initializing seafood industry here. But unfortunately this huge coastline with numerous seaweed resources is untapped.

To examine the potentiality of the resource, two stations were selected all along the coast in Visakhapatnam coast of Andhra Pradesh, India *viz.,* Station-1 Vuda Park (17° 43' 26.7594" N, 83° 20' 22.2" E) and Station-2 Govt. Fishing Harbour (17° 41' 45.7" N, 83°18'6.4" E) (Figure 1). Five dominant seaweeds comprising one red and four green seaweeds were identified and collected following standard taxonomic keys (Rao and Sreeramulu 1964) [48] from these sites. Sampling was done during postmonsoon 2016.

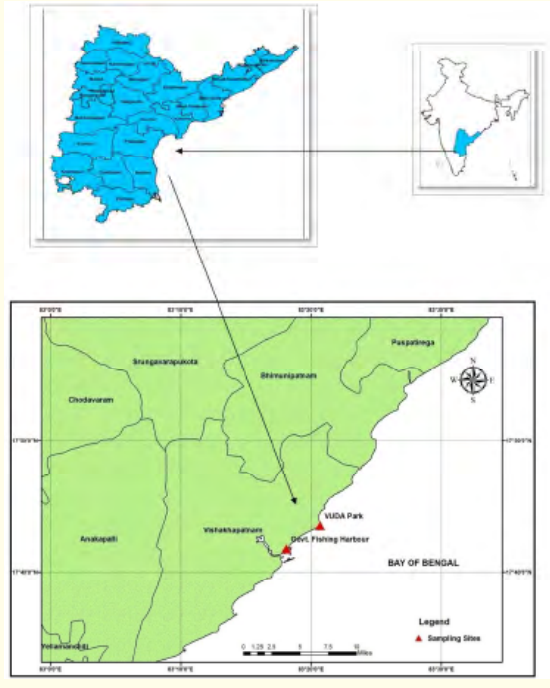


**Figure 1:** Map location of selected stations.

### Sampling and analysis of seawater

Seawater samples were collected from the seaweed growing area for in-situ analysis of temperature, pH and salinity using standard instruments (MEXTECH Multi stem handheld portable LCD digital thermometer with sensor probe -50°C to 2300°C or -58°F to 572°F, Oakton eco-testr pH 2 Waterproof pH tester 0.0 to 14.0 pH range and Hand Refractometer, ERMA). Seawater samples were collected for laboratory analysis of nutrients ($NO_3$, $PO_4$ and $SiO_3$) and Chl *a*, *b*, *c* following standard spectrophotometric measurements [58].

### Sampling and analysis of seaweeds

Collection of seaweeds was done during the low tide at the intertidal zones and was picked with hand and immediately washed with seawater to remove the extraneous foreign particles, sand particles and epiphytes. Then it was kept in an ice box containing slush ice and immediately transported to the laboratory and washed thoroughly using tap water to remove the salt on the surface of the sample. Then the seaweeds were spread on blotting paper to remove excess water before they were sundried to constant weight, and ground into powder. The powdered samples were subsequently kept in dark and stored in room temperature for further analysis.

For collection of seaweeds a 0.25 $m^2$ quadrate was fixed randomly. Biomass was estimated from this quadrate by weight difference method. Proximate analysis of protein, carbohydrate, astaxanthin, lipid and moisture were done as per methodologies outlined by Lowry 1951 [31]; Sadasivan and Manickam 2007 [52]; spectrophotometric method [4]; Soxhlet Apparatus Method 1879 [55] and AOAC 2005 [26] respectively Chl *a* and Chl *b* were analysed by spectrophotometric method [43].

### Statistical analysis

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

## Results and Discussion

Data on environment parameters and biomass of *Catenella repens*, *Ulva lactuca*, *Caulerpa racemosa*, *Enteromorpha intestinalis* and *Chaetomorpha melagonium* are reported in Table 1 and Figure 2. During the study period temperature did not show any variation owing to the location of the stations in the same geographical locale. pH in both the stations were same (8.3) owing to the buffer property of seawater. Salinity was higher in stn.1. Nitrate concentration (15.26 ppm) was higher in stn.1 owing to the presence of the sewage outfall directly from the city of Visakhapatnam. Phosphate concentration (0.36 ppm) was higher in case of stn.2, owing to the fact that huge amount of waste is generated from the fishing activity. Silicate concentration (50.42 ppm) was found to be lower in case of stn.1 rather than stn.2. This is because of the huge dredging activity in the port area as well as major churning activity taking place between the water body and the sediment compartment. Phytopigment (Chl *a*, Chl *b*, Chl *c*) showed a higher concentration in stn.2 owing to the huge nutrient influx due to anthropogenic activities. High pigment concentration is observed in both the stations owing to a very congenial environment of phytoplankton as the sampling was carried out during the post-monsoon season. This season is characterized with a secondary peak blooming period of phytoplankton.

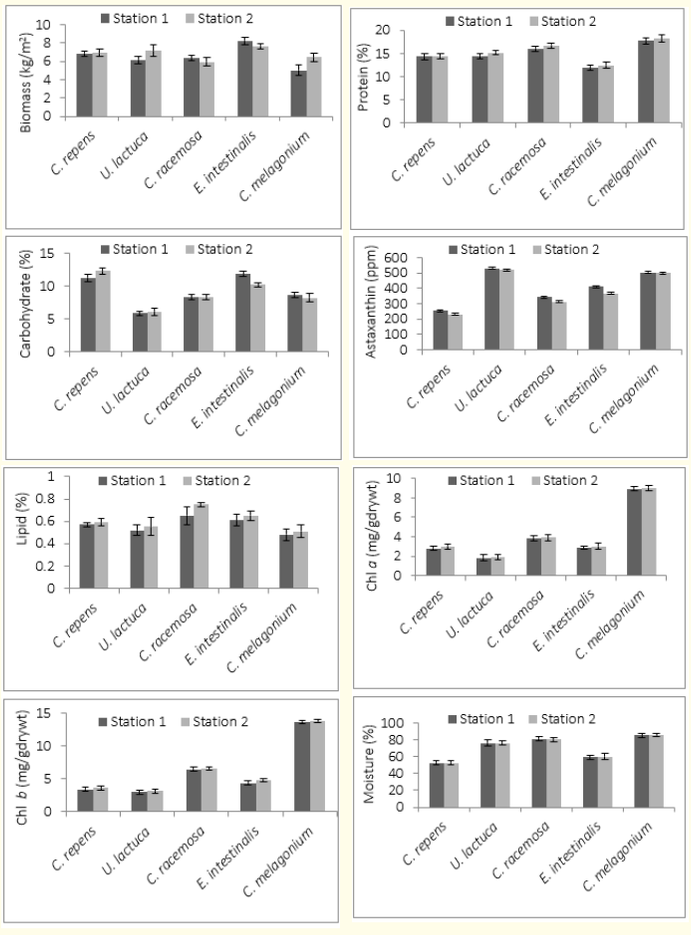


**Figure 2:** Variation in biochemical composition of seaweeds in selected stations

| Sl/No. | Water | Station-1 | Station-2 | Prescribed standards for Coastal Waters |
|---|---|---|---|---|
| 1. | Temperature (°C) | 26.6 ± 1.21 | 27.2 ± 1.19 | 28-30 °C* |
| 2. | pH value | 8.3 ± 0.4 | 8.3 ± 0.39 | 6.5-8.5* |
| 3. | Salinity (PSU) | 30 ± 3.27 | 28 ± 3.32 | 33-34 PSU* |
| 4. | Chl *a* (µg/L) | 2.11 ± 0.39 | 5.21 ± 0.41 | 0.5 to 3.7 µg/L |
| 5. | Chl *b* (µg/L) | 4.92 ± 0.45 | 7.25 ± 0.55 | NA |
| 6. | Chl *c* (µg/L) | 6.32 ± 0.49 | 9.59 ± 0.43 | NA |
| 7. | Nitrate (ppm) | 15.26 ± 0.96 | 14.08 ± 0.42 | 0.01-0.06 mg/L** |
| 8. | Phosphate (ppm) | 0.3 ± 0.67 | 0.36 ± 0.55 | 0.001-0.01 mg/L** |
| 9. | Silicate (ppm) | 50.42 ± 0.83 | 93.05 ± 0.62 | 2.8 mg/L (avg)** |

**Table 1:** Variation in physico-chemical parameters of two selected stations

* Decree of the State Minister of the Environment Number 51of 2004 Regarding Standard Quality of Seawater State Minister of the Environment, Republic of Indonesia (2004).

** Republic of South Africa, Department of Environmental Affairs. South African Water Quality Guidelines for Coastal Marine Waters - Natural Environment and Mariculture Use. Cape Town (2018): 1-164.

NA: Not Available

The biomass of seaweeds largely depends upon season, population structure and several other ecological factors [29]. The physico-chemical variables especially nutrients and salinity contribute to the multiplication of the thallus (growth of seaweed) [60]. The biomass of seaweeds can be correlated with the abiotic factors that prevailed before or during the collection period [35]. Significant seasonal variations in biomass of *C. repens*, *U. lactuca C. racemosa*, *E. intestinalis* and *C. melagonium* have been observed in both sampling stations. The biomass of seaweeds were in the order *E. intestinalis* > *C. repens* > *C. racemose* > *U. lactuca* > *C. melagonium* in stn.1 and *E. intestinalis* > *U. lactuca* > *C. repens* > *C. melagonium* > *C. racemosa* in stn.2 (Figure 2). In the present work, maximum growth of the green seaweed *E. intestinalis* in stns.1 and 2 respectively was observed during post-monsoon season (the optimum level of biomass as per FAO standard for red and green seaweed is mentioned in Table 4); the period characterized by optimum nutrient load, temperature, salinity and pH. This is confirmed from the significant positive correlation (at 1% level of significance except for salinity and nitrate in *U. lactuca* at stn.1) between biomass, pH, salinity and nutrients ($NO_3$ and $PO_4$) (Tables 2 and 3). Seaweeds as compared to other marine plants are short-lived with successive growth periods and has more than two growth peaks during their lifespan when the season is conducive [60]. The lower biomass values obtained in stn.1 for all the species except *C. racemosa* and *E. intestinalis* than stn.2 could be attributed to an intermittent period in which some population rejuvenate and recover from wholesome detachment (Figure 2). Seaweed utilizes nitrogen in water to synthesize protein and phosphorus which is needed for the production of nucleic acids and ATP for energetic functions. Barsanti and Gualtieri [6] reported the importance of phosphorus as it is connected mainly to the growth of seaweeds. If all phosphorus is consumed, autotrophic growth will cease, no matter how much nitrogen is available. The concept of Liebig is the "Law of the Minimum", meaning that seaweed growth is not limited by the total amount of nutrients available but by the nutrient available in the smallest quantity relative to its requirement. Concentration will be an indicator of limitation of a specific nutrient, however, and the rate of supply of that nutrient or its turnover time is more important in determining the degree of limitation [6].

| Combination | r-value | | | | | p-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *C. repens* | *U. lactuca* | *C. racemosa* | *E. intestinalis* | *C. melagonium* | *C. repens* | *U. lactuca* | *C. racemosa* | *E. intestinalis* | *C. melagonium* |
| Biomass X temperature | -0.976* | 0.999 | -0.957* | -0.976* | -0.976* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.786 | -0.911* | 0.737 | 0.786 | 0.786 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X salinity | 0.077 | 0.165 | 0.151 | 0.077 | 0.077 | IS | IS | IS | IS | IS |
| X Chl *a* | 0.931 | -0.991* | 0.901 | 0.931 | 0.931 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | -0.387 | 0.154 | -0.455** | -0.387 | -0.387 | IS | IS | <0.05 | IS | IS |
| X Chl *c* | -0.992* | 0.934 | -0.999* | -0.992* | -0.992* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.636 | -0.432 | 0.692 | 0.636 | 0.636 | <0.01 | IS | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.764 | -0.897* | 0.714 | 0.764 | 0.764 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | -0.700* | 0.851 | -0.645* | -0.700* | -0.700* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Protein X temperature | -0.997* | -0.722* | -0.985* | -0.998* | -0.933* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.863 | 0.351 | 0.812 | 0.875 | 0.685 | <0.01 | IS | <0.01 | <0.01 | <0.01 |
| X salinity | -0.061 | 0.583** | 0.034 | -0.085 | 0.225 | IS | <0.05 | IS | IS | IS |
| X Chl *a* | 0.972 | 0.607 | 0.946 | 0.977 | 0.866 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | -0.257 | -0.809* | -0.347 | -0.233 | -0.520** | IS | <0.01 | IS | IS | <0.05 |
| X Chl *c* | -0.966* | -0.912* | -0.986* | -0.959* | -0.999* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.523 | 0.944 | 0.602 | 0.503 | 0.744 | <0.05 | <0.01 | <0.01 | <0.05 | <0.01 |
| X $PO_4$ | 0.846 | 0.319 | 0.791 | 0.858 | 0.659 | <0.01 | IS | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | -0.792* | -0.228 | -0.731* | -0.806* | -0.586** | <0.01 | IS | <0.01 | <0.01 | <0.05 |
| Carbohydrate X temperature | -0.723* | 0.997 | -0.999* | -0.934* | -0.851* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.352 | -0.866* | 0.911 | 0.688 | 0.539 | IS | <0.01 | <0.01 | <0.01 | <0.05 |
| X salinity | 0.582 | 0.066 | -0.615* | 0.221 | 0.389 | <0.05 | IS | <0.01 | IS | IS |
| X Chl *a* | 0.608 | -0.974* | 0.991 | 0.868 | 0.760 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | -0.808* | 0.251 | -0.154 | -0.517** | -0.668* | <0.01 | IS | IS | <0.05 | <0.01 |
| X Chl *c* | -0.913* | 0.965 | -0.934* | -0.999* | -0.978* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.943 | -0.519** | 0.432 | 0.741 | 0.853 | <0.01 | <0.05 | IS | <0.01 | <0.01 |
| X $PO_4$ | 0.320 | -0.849* | 0.897 | 0.663 | 0.511 | IS | <0.01 | <0.01 | <0.01 | <0.05 |
| X $SiO_3$ | -0.229 | 0.795 | -0.851* | -0.589** | -0.428 | IS | <0.01 | <0.01 | <0.01 | IS |
| Astaxanthin X temperature | -0.849* | -0.999* | -0.995* | -0.805* | -0.976* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.537 | 0.916 | 0.854 | 0.468 | 0.786 | <0.05 | <0.01 | <0.01 | <0.05 | <0.01 |
| X salinity | 0.403 | -0.176 | -0.043 | 0.474 | 0.076 | IS | IS | IS | <0.05 | IS |
| X Chl *a* | 0.758 | 0.993 | 0.968 | 0.704 | 0.931 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | -0.671* | -0.143 | -0.274 | -0.727* | -0.387 | <0.01 | IS | IS | <0.01 | IS |
| X Chl *c* | -0.977* | -0.929* | -0.971* | -0.957* | -0.992* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.855 | 0.421 | 0.538 | 0.894 | 0.636 | <0.01 | IS | <0.05 | <0.01 | <0.01 |
| X $PO_4$ | 0.508 | 0.902 | 0.836 | 0.437 | 0.764 | <0.05 | <0.01 | <0.01 | <0.05 | <0.01 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| X $SiO_3$ | -0.424 | -0.857* | -0.781* | -0.351 | -0.700* | IS | <0.01 | <0.01 | IS | <0.01 |
| Lipid X temperature | -0.997* | -0.751* | -0.917* | -0.999* | -0.866* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.866 | 0.963 | 0.655 | 0.882 | 0.564 | <0.01 | <0.01 | <0.01 | <0.01 | <0.05 |
| X salinity | -0.066 | -0.759* | 0.264 | -0.100 | 0.373 | IS | <0.01 | IS | IS | IS |
| X Chl *a* | 0.974 | 0.844 | 0.845 | 0.981 | 0.779 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | -0.251 | 0.515 | -0.554** | -0.218 | -0.646* | IS | <0.05 | <0.05 | IS | <0.01 |
| X Chl *c* | -0.965* | -0.487 | -0.998* | -0.955* | -0.983* | <0.01 | IS | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.519 | -0.248 | 0.770 | 0.489 | 0.838 | <0.05 | IS | <0.01 | IS | <0.01 |
| X $PO_4$ | 0.849 | 0.972 | 0.629 | 0.866 | 0.535 | <0.01 | <0.01 | <0.01 | <0.01 | <0.05 |
| X $SiO_3$ | -0.795* | -0.989* | -0.553** | -0.815* | -0.453** | <0.01 | <0.05 | <0.01 | <0.01 | <0.05 |
| Chl *a* X temperature | -0.851* | -0.976* | -0.952* | -0.705* | -0.918* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.539 | 0.786 | 0.724 | 0.327 | 0.655 | <0.05 | <0.01 | <0.01 | IS | <0.01 |
| X salinity | 0.399 | 0.077 | 0.170 | 0.603 | 0.264 | IS | IS | IS | <0.01 | IS |
| X Chl *a* | 0.760 | 0.931 | 0.892 | 0.587** | 0.845 | <0.01 | <0.01 | <0.01 | <0.05 | <0.01 |
| X Chl *b* | -0.668* | -0.387 | -0.472** | -0.824* | -0.554** | <0.01 | IS | <0.05 | <0.01 | <0.05 |
| X Chl *c* | -0.978* | -0.992* | -0.999* | -0.901* | -0.998* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.853 | 0.636 | 0.705 | 0.952 | 0.770 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.511 | 0.764 | 0.700 | 0.295 | 0.628 | <0.05 | <0.01 | <0.01 | IS | <0.01 |
| X $SiO_3$ | -0.428 | -0.700 | -0.630 | -0.204 | -0.553** | IS | <0.01 | <0.01 | IS | <0.05 |
| Chl *b* X temperature | -0.826* | -0.713* | -0.918* | -0.957* | -0.890* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.500 | 0.339 | 0.655 | 0.737 | 0.605 | <0.05 | IS | <0.01 | <0.01 | <0.01 |
| X salinity | 0.441 | 0.592 | 0.264 | 0.151 | 0.325 | IS | <0.05 | IS | IS | IS |
| X Chl *a* | 0.729 | 0.597 | 0.845 | 0.901 | 0.809 | <0.01 | <0.05 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | -0.702* | -0.816* | -0.554** | -0.455** | -0.607* | <0.01 | <0.01 | <0.05 | <0.05 | <0.01 |
| X Chl *c* | -0.967* | -0.907* | -0.998* | -0.999* | -0.991* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.877 | 0.948 | 0.770 | 0.382 | 0.809 | <0.01 | <0.01 | <0.01 | IS | <0.01 |
| X $PO_4$ | 0.470 | 0.307 | 0.629 | 0.714 | 0.578 | <0.05 | <0.05 | <0.01 | <0.01 | <0.05 |
| X $SiO_3$ | -0.385 | -0.217 | -0.553** | -0.645* | -0.498** | IS | IS | <0.05 | <0.01 | <0.05 |
| Moisture X temperature | -0.682* | 0.659 | -0.941* | 0.962 | -0.918* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.297 | -0.920* | 0.702 | -0.749* | 0.655 | IS | <0.01 | <0.01 | <0.01 | <0.01 |
| X salinity | 0.628 | 0.837 | 0.203 | -0.134 | 0.264 | <0.01 | <0.01 | IS | IS | IS |
| X Chl *a* | 0.561 | -0.768* | 0.878 | -0.909* | 0.845 | <0.05 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | -0.841* | -0.622* | -0500** | 0.439 | -0.554** | <0.01 | <0.01 | <0.05 | IS | <0.05 |
| X Chl *c* | -0.887* | 0.370 | -0.999* | 0.998 | -0.998* | <0.01 | IS | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.961 | 0.371 | 0.728 | -0.679* | 0.770 | <0.01 | IS | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.264 | -0.933* | 0.677 | -0.726* | 0.629 | IS | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | -0.172 | 0.963 | -0.605 | 0.658 | -0.553** | IS | <0.01 | <0.01 | <0.01 | <0.05 |

**Table 2:** Correlation between physico-chemical parameters and biochemical parameters at the station 1 (Vuda Park).

| Combination | r-value | | | | | p-value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *C. repens* | *U. lactuca* | *C. racemosa* | *E. intestinalis* | *C. melagonium* | *C. repens* | *U. lactuca* | *C. racemosa* | *E. intestinalis* | *C. melagonium* |
| Biomass X temperature | 0.999 | 0.830 | 0.919 | 0.988 | 0.993 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.999 | 0.866 | 0.943 | 0.996 | 0.962 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X salinity | 0.978 | 0.945 | 0.989 | 0.995 | 0.991 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *a* | 0.972 | 0.954 | 0.993 | 0.991 | 0.986 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | 0.991 | 0.918 | 0.975 | 0.999 | 0.998 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *c* | 0.987 | 0.928 | 0.981 | 0.999 | 0.996 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.966 | 0.961 | 0.995 | 0.988 | 0.982 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.947 | 0.986 | 0.999 | 0.976 | 0.968 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | 0.984 | 0.935 | 0.984 | 0.997 | 0.994 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Protein X temperature | 0.877 | 0.999 | 0.893 | 0.984 | 0.960 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.908 | 0.996 | 0.922 | 0.994 | 0.905 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X salinity | 0.971 | 0.961 | 0.978 | 0.997 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *a* | 0.977 | 0.953 | 0.984 | 0.994 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | 0.949 | 0.979 | 0.960 | 0.999 | 0.995 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *c* | 0.958 | 0.973 | 0.967 | 0.999 | 0.997 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.982 | 0.945 | 0.988 | 0.991 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.992 | 0.901 | 0.996 | 0.981 | 0.996 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | 0.963 | 0.969 | 0.972 | 0.999 | 0.998 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Carbohydrate X temperature | 0.997 | 0.931 | 0.999 | 0.921 | 0.987 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.999 | 0.953 | 0.999 | 0.945 | 0.950 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X salinity | 0.984 | 0.993 | 0.979 | 0.989 | 0.995 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *a* | 0.978 | 0.996 | 0.973 | 0.993 | 0.992 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | 0.994 | 0.982 | 0.992 | 0.976 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *c* | 0.991 | 0.986 | 0.988 | 0.982 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.973 | 0.998 | 0.967 | 0.996 | 0.989 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.956 | 0.999 | 0.949 | 0.999 | 0.977 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | 0.989 | 0.989 | 0.985 | 0.985 | 0.998 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Astaxanthin X temperature | 0.972 | 0.916 | -0.557** | 0.989 | 0.968 | <0.01 | <0.01 | <0.05 | <0.01 | <0.01 |
| X pH | 0.985 | 0.941 | -0.612* | 0.997 | 0.917 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X salinity | 0.999 | 0.988 | -0.751* | 0.994 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *a* | 0.999 | 0.992 | -0.768* | 0.990 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | 0.999 | 0.974 | -0.699* | 0.999 | 0.998 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *c* | 0.999 | 0.979 | -0.717* | 0.998 | 0.000 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.997 | 0.995 | -0.784* | 0.987 | 0.998 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.990 | 0.999 | -0.822* | 0.974 | 0.993 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | 0.999 | 0.983 | -0.731* | 0.997 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lipid X temperature | 0.893 | 0.921 | 0.984 | 0.993 | -0.899* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.922 | 0.946 | 0.994 | 0.999 | -0.819* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Salinity | 0.978 | 0.990 | 0.997 | 0.991 | -0.981* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *a* | 0.984 | 0.994 | 0.994 | 0.986 | -0.986* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | 0.960 | 0.977 | 0.999 | 0.998 | -0.964* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *c* | 0.967 | 0.982 | 0.999 | 0.996 | -0.970* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.988 | 0.996 | 0.991 | 0.982 | -0.989* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.996 | 0.999 | 0.981 | 0.968 | -0.997* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | 0.972 | 0.985 | 0.999 | 0.994 | -0.975* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Chl *a* X temperature | 0.911 | 0.969 | 0.988 | 0.986 | 0.997 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.937 | 0.981 | 0.996 | 0.995 | 0.971 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Salinity | 0.986 | 0.999 | 0.995 | 0.996 | 0.985 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *a* | 0.990 | 0.999 | 0.991 | 0.993 | 0.979 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | 0.971 | 0.998 | 0.999 | 0.999 | 0.995 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *c* | 0.977 | 0.999 | 0.999 | 0.999 | 0.992 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.993 | 0.998 | 0.988 | 0.989 | 0.974 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.999 | 0.984 | 0.976 | 0.979 | 0.958 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | 0.981 | 0.999 | 0.997 | 0.998 | 0.989 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Chl *b* X temperature | 0.999 | 0.889 | 0.919 | 0.988 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.999 | 0.919 | 0.943 | 0.996 | 0.985 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Salinity | 0.979 | 0.977 | 0.989 | 0.995 | 0.971 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *a* | 0.973 | 0.982 | 0.993 | 0.991 | 0.964 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | 0.992 | 0.958 | 0.975 | 0.999 | 0.986 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *c* | 0.988 | 0.965 | 0.981 | 0.998 | 0.982 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.967 | 0.987 | 0.995 | 0.988 | 0.957 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.949 | 0.999 | 0.999 | 0.976 | 0.937 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | 0.985 | 0.969 | 0.984 | 0.997 | 0.978 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Moisture X temperature | 0.968 | 0.962 | 0.981 | 0.924 | 0.994 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X pH | 0.983 | 0.978 | 0.992 | 0.948 | 0.999 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Salinity | 0.999 | 0.999 | 0.998 | 0.991 | 0.934 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *a* | 0.999 | 0.999 | 0.996 | 0.994 | 0.924 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *b* | 0.998 | 0.999 | 0.999 | 0.978 | 0.958 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X Chl *c* | 0.999 | 0.999 | 0.999 | 0.983 | 0.951 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $NO_3$ | 0.998 | 0.989 | 0.993 | 0.997 | 0.914 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $PO_4$ | 0.993 | 0.999 | 0.984 | 0.999 | 0.886 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| X $SiO_3$ | 0.999 | 0.999 | 0.999 | 0.986 | 0.944 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

**Table 3**: Correlation between physico-chemical parameters and biochemical parameters at the station 2 (Govt. Fishing Harbour).

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

| Species | Parameters | Our study (average value) | FAO level of red seaweed |
|---|---|---|---|
| *C. repens* | Biomass (kg/m$^2$) | 6.89 | ***500,00 |
| | Protein (%) | 14.34 | *3-29 |
| | Carbohydrate (%) | 11.83 | **31.02 |
| | Astaxanthin (ppm) | 241.74 | NA |
| | Lipid (%) | 0.58 | **1.49-2.65 |
| | Chl *a* (mg/gdrywt) | 2.88 | NA |
| | Chl *b* (mg/gdrywt) | 3.53 | NA |
| | Moisture (%) | 52.61 | ***80-90 |
| | | | **FAO level of green seaweed** |
| *U. lactuca* | Biomass (kg/m$^2$) | 6.68 | ***500,00 |
| | Protein (%) | 14.8 | *6-26 |
| | Carbohydrate (%) | 5.99 | **33.17-50.83 |
| | Astaxanthin (ppm) | 525.8 | NA |
| | Lipid (%) | 0.54 | **2.09-10.76 |
| | Chl *a* (mg/gdrywt) | 1.87 | NA |
| | Chl *b* (mg/gdrywt) | 3.07 | NA |
| | Moisture (%) | 75.96 | ***80-90 |
| *C. racemosa* | Biomass (kg/m$^2$) | 6.16 | |
| | Protein (%) | 16.33 | |
| | Carbohydrate (%) | 8.33 | |
| | Astaxanthin (ppm) | 327.45 | |
| | Lipid (%) | 0.7 | |
| | Chl *a* (mg/gdrywt) | 3.89 | |
| | Chl *b* (mg/gdrywt) | 6.52 | |
| | Moisture (%) | 80.68 | |
| *E. intestinalis* | Biomass (kg/m$^2$) | 7.95 | |
| | Protein (%) | 12.15 | |
| | Carbohydrate (%) | 11.16 | |
| | Astaxanthin (ppm) | 388.96 | |
| | Lipid (%) | 0.62 | |
| | Chl *a* (mg/gdrywt) | 2.93 | |
| | Chl *b* (mg/gdrywt) | 4.34 | |
| | Moisture (%) | 59.44 | |
| *C. melagonium* | Biomass (kg/m$^2$) | 5.74 | |
| | Protein (%) | 17.96 | |
| | Carbohydrate (%) | 8.47 | |
| | Astaxanthin (ppm) | 500.67 | |
| | Lipid (%) | 0.51 | |
| | Chl *a* (mg/gdrywt) | 8.98 | |
| | Chl *b* (mg/gdrywt) | 13.69 | |
| | Moisture (%) | 85.35 | |

**Table 4:** Recommended level of biochemical constituent in seaweeds as food for human beings.

*Use of algae and aquatic macrophytes as feed in small-scale aquaculture – A review

**Comparison of nutrient compositions and calorific values of eight tropical seaweeds.

***Seaweed aquaculture for food security, income generation and environmental health in tropical developing countries

NA: Not Available

The moisture content of seaweeds were in the order *C. melagonium* > *C. racemose* > *U. lactuca* > *E. intestinalis* > *C. repens* in stns. 1 and 2 respectively. The quantitative analysis of moisture content ranged from 85.28% to 90.57%. Higher moisture content was found in red seaweeds *G. corticata* (90.57%) followed by green seaweeds *E. clathrata* (87.22%) and lower in brown seaweed *S. linearifolium* (85.57%). The difference in moisture content may be due to the fleshy foliose structure of the species (Figure 2).

The protein content of seaweeds were in order *C. melagonium* > *C. racemosa* > *U. lactuca* > *C. repens* > *E. intestinalis* in both stns. 1 and 2. Protein values showed more or less similar trend in all the stations and the values were in order stn.2 > stn.1 (Figure 2). The protein content of marine algae differs according to species. Generally, it is low for brown seaweeds (3-15% of dry weight), moderate for green seaweeds (9-26% of dry weight) and high for red seaweeds (maximum of 47% of dry weight) [18]. The fluctuation in the protein values in two stations can be explained by variation in environmental conditions such as temperature, salinity and nutrients. A protein content of less than 10% has been reported from the species of *Sargassum* and *Gracilaria* [8]. Significant variation in protein in the same species of algae growing at different localities and different periods was also stated by (Parekh., *et al*. 1977) [42]. Usually high protein content (10-47%) has been reported in red seaweeds [64], while in green seaweeds it is fairly low [13].

The carbohydrate values in seaweeds were in the order *C. repens* > *E. intestinalis* > *C. melagonium* > *C. racemosa* > *U. lactuca* in stns. 1 and 2. The maximum carbohydrate values was obtained in stn.1 for *E. intestinalis* and *C. melagonium* which may be due to the absorption of $NO_3$ and $PO_4$ from the ambient media for building the biomass, represented in terms of carbohydrate concentration (Figure 2). Carbohydrate comprises 50-60% of the dry weight of seaweeds [55]. Soluble carbohydrate reported in *Enteromorpha*, *Ulva* and *Porphyra* varied from 8.1-337% [28]. As per Manivannan., *et al.* 2009 [32] the carbohydrate concentration of seaweeds varied from 20-24%. Our results are far below the above stated values. The decrease in carbohydrate may be observed due to extensive growth of thallus of algae [12].

The lipid content of seaweeds varied from 3.15% to 5.30% [44]. The percentage of lipid was 2.82±0.24%, 2.94±0.45% and16±0.45% in green, brown and red seaweeds, respectively [37]. The lipid of seaweeds were in the order *C. racemosa* > *E. Intestinalis* > *C. repens* > *U. lactuca* > *C. melagonium* in stn.1 and stn.2 respectively. Total lipid content of *Ulva*, *Sargassum* and *Gracilaria* reported from west coast of Maharashtra ranged from 4.2 to 6.3%, highest being in brown alga *Sargassum*. Lipid content in sea vegetables is very low, ranging from 1-5% of dry matter [24]. In general, seaweeds exhibit low lipid contents (Dawes 1998) [10] as has been observed in the present study too (Figure 2).

The astaxanthin of seaweeds were in the order *U. lactuca* > *C. melagonium* > *E. intestinalis* > *C. racemosa* > *C. repens* in stns. 1 and 2, respectively (Figure 2). Astaxanthin is widely used as a natural red colourant in marine fish aquaculture [5,27]. The coincidence of high astaxanthin value of *C. repens* with its carbohydrate level in the study area 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.* [61]. In case of nutrient, Ausich [3] 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.

The Chl *a* of seaweeds were in the order *C. melagonium* > *C. racemosa* > *E. intestinalis* > *C. repens* > *U. lactuca* in stn.1 that was similar in stn.2. The lowest Chl *a* values was obtained in *Ulva lactuca* in stn.1 and stn.2 respectively. The maximum Chl *b* values obtained in *C. melagonium* in stn.1 and stn.2 respectively (Figure 2). The seaweed growth season in Visakhapatnam coast of Andhra Pradesh, India, begins from November to March. In general, biomass maximum coincides with carbohydrate maximum suggesting a link between seaweeds growth and carbohydrate content [33]. However, our results supported the above fact because of extremely high surface water temperature and salinity during study period, which is a characteristics feature of the present geographical locale. This condition results in desiccation and subsequent reduction of seaweed biomass.

## Effect of temperature on biochemical properties of seaweeds

Biomass value showed a ($p<0.01$) negative relationship with temperature except in *U. lactuca* at stn.1 and all the species of stn.2 showed positive relationship. The temperature range is different for different species and different processes of growth and development [23]. Liu and Dong [30] found that light and temperature have an important influence on the growth and biochemical component of *Gracilaria tenuistipitata*. Protein has showed a significant ($p<0.01$) negative relationship with temperature at stn.1 in all the selected species in contrast to all the species at stn.2 which showed a positive relationship. This may be due to prolonged

negative pressure on seaweeds by the trawling activities at the Fishing Harbour which has made the seaweeds for susceptible to higher temperature. With respected to carbohydrate temperature has shown significant ($p<0.01$) positive relationship at stn.2 and *U. lactuca* in stn.1. In case of all the selected except in *C. repens*, *C. racemosa*, *E. intestinalis* and *C. melagonium* at stn.1 which has shown a significantly ($p<0.01$) negative relationship. Temperature plays a vital role with respect to physiology of the plants although; the species at stn.2 have shown their vigour growth with respect to temperature. Temperature plays a major role in astaxanthin production in plants. Since the study site is located close to the equator in the southern half of Indian subcontinent hence it has comparatively high temperature which possesses a positive impact in the synthesis of astaxanthin. The significant ($p<0.01$) negative relationship of astaxanthin with temperature is revealed at stn.1 in all the species and in *C. racemosa* at stn.2. Lipid showed a ($p<0.01$) negative relationship with respect to temperature in all the species at stn.1 and *C. melagonium* in stn.2. This shows that with increase in the temperature the lipid content in seaweeds usually decrease. With respect to Chl *a* and Chl *b* temperature has shown a significant ($p<0.01$) negative relationship in stn.1 in contrast to stn.2. This shows that phytopigments (Chl *a,* Chl *b*) in seaweeds are basically depend on other factors rather than temperature. In *U. lactuca* and *E. intestinalis* significant positive correlation ($p<0.01$) was observed in both stn.1 and all the species of stn.2 except in *C. repens, C. racemosa* and *C. melagonium* at stn.1 with respect to moisture content and temperature. This proves that with increase in temperature moisture content in the plant is increased which may be an adaptation of the seaweeds to overcome the extreme saline condition.

## Effect of pH on biochemical properties of seaweeds

With respect to biomass and pH has a significant ($p<0.01$) positive relationship except in *U. lactuca* at stn.1. This shows that pH of seawater noted at the selected site is perfectly congenial for the growth of the plants. Ambient pH resulted in higher biomass and higher specific growth rate [7]. The significant positive correlation ($p<0.01$) between protein and pH in all the species in both the stations. Protein values are proportional to the pH values to its consumption by the seaweeds in growth and reproduction. With respect to carbohydrate and pH, pH has a significant positive relationship ($p<0.01$) in all the species in both the stations except in *U. lactuca* at stn.1. The conformation of the polysaccharide chains is markedly dependent on the pH, the ionic strength of the medium, but also on the temperature [25]. The significant positive relationship ($p<0.01$) of pH with astaxanthin except in *C. racemosa* at stn.2 reveals the pH possess a positive role in synthesis of astaxanthin in seaweeds. With respect to lipid and pH relationship the results are showing positive significant relationship ($p<0.01$) in all the selected species in both the stations except in *C. melagonium* in stn.2. This may be due to the positive effect of the marine environment on the seaweeds adaptation. In case of phytopigment (Chl *a*, Chl *b*) of the seaweeds there is an overall ($p<0.01$) positive significant relationship of pH which shows that each has a major role in the growth of seaweeds. pH of seawater has shown a significant ($p<0.01$) positive relationship with moisture content at stn.2 and stn.1 except in *U. lactuca* and *E. intestinalis* at stn.1. It is clear that due to low ocean acidification the pH level is increasing which simultaneously supporting the moisture of seaweeds.

## Effect of salinity on biochemical properties of seaweeds

A positive relationship of biomass has been observed with respect to salinity in both the stations which indicates that salinity conditions are suitable for the growth of the seaweeds where as in case of stn.1 nutrient rather than salinity has lead to the increased growth of the seaweeds. In general it can be stated that the selected seaweeds poses an extreme salt tolerance covering a wide range/spectrum 17‰-34‰ [63]. Salinity also contributes to the multiplication of the thallus (growth of seaweed) [60]. Salinity has shown a significant ($p<0.01$) positive relationship in both the stations among all the species except in *C. repens* and *E. intestinalis* at stn.1 with respect to protein. Rupérez and Saura-Calixto 2001 [51], explained by lower seawater salinity in winter than in summer season results higher value of protein. However, contradictory results were found in our study which may be due to high salinity tolerance of our selected seaweeds species. With respect to salinity and carbohydrate showed a positive relationship except in *C. racemosa* in stn.1. According to Munda and Kremer 1977 [39], seaweeds synthesise higher carbohydrate influenced by increased values of seawater temperature, salinity and sunlight intensity, which confirms the influence of these parameters. In case of astaxanthin salinity has posed a positive impact on the astaxanthin except in *U. lactuca* and *C. racemosa* in stn.1 and *C. racemosa* in stn.2. This clearly shows that with the increase of salinity the astaxanthin synthesis in the seaweeds increases. In case of lipid salinity has posed a negative impact in *C. repens*, *U. lactuca* and *E. intestinalis* at stn.1 and *C. melagonium* at stn.2. The majority of marine algae have very low lipid content ranging from 0.3 to 7% of DW [66]. Although salinity represents one of the possible factors that can influence lipid content in seaweeds [53]. The phytopigment (Chl *a*, Chl *b*) value of seaweeds has shown insignificant ($p<0.01$) relationship of case of stn.1 which may be due to the excess amount of city

discharges from the outlet canals of the Visakhapatnam city. In case of stn.2 there is positive significant relationship ($p<0.01$) which clearly states that the selected species in the study area very much acclimatized to the saline environment. Salinity and moisture has a significant positive relationship ($p<0.01$) in both the stations in all the species except *E. intestinalis* in at stn.1. Ginneken 2018 [20] described that compensatory responses to salinity stress pressed seaweed moisture.

### Effects of nutrients ($NO_3$, $PO_4$, $SiO_3$) on biochemical properties of seaweeds

With respect to nitrate and phosphate, biomass of the seaweeds have shown positive relationship with nitrate and phosphate (except silicate, where in some cases it has shown a negative relationship). This may probably be due to the requirement of aquatic nutrients for proper photosynthesis of the seaweeds at the cellular level. This shows that biomass directly proportional to the phytopigment concentration in the seaweeds. This shows that nutrients in the ambient media play a vital role in growth of the seaweeds. In case of nitrate and phosphate with protein shown a positive relationship ($p<0.01$) with all the species at both the stations. Silicate values has also shown positive relationship ($p<0.01$) in case of stn.2, contrast to all the species of stn.2 although it has no major impact on protein synthesis of the seaweeds. As per carbohydrate nutrients has shown positive significant relationship ($p<0.01$) at stn.2 and stn.1 excepting for *U. lactuca* at stn.1 for nitrate and phosphate but in case of nitrate contradiction was found i.e. *U. lactuca* was accepted rest of other species at stn.1. With respect to astaxanthin with nutrients shows a ($p<0.01$) positive relationship at stn.1 and stn.2 except *C. racemosa* at stn.2, whereas silicate shows an insignificant and ($p<0.01$) negative relationship with astaxanthin. Astaxanthin does not have any specific relationship with nutrient concentration in water and hence no specific relationship trend has been observed with respect to nutrient and astaxanthin. Nutrient have shown a ($p<0.01$) positive relationship with lipid concentration for all the species at stn.2 except in *C. melagonium* and in case of silicate except in all the species of stn.1. This may be due to extreme unfavourable condition which shows the area to be more eutrophic in nature. At stn.1 similar trend was observed for nitrate and phosphate in all the species except in *U. lactuca* which has shown an insignificant relation with nitrate. As per biomass, similar is the trend for phytopigment with respect to nutrients in both the stations for all the species. This may probably be due to the requirement of aquatic nutrients for proper photosynthesis of the seaweeds at the cellular level. Nutrient concentration has not shown any significant ($p<0.01$) trend with respect to moisture content of the seaweeds. Nitrate has shown a significant positive relationship ($p<0.01$) in both the stations for all the selected species at 1% level of significance except *E. intestinalis* in stn.1. This may be attributed to the protein synthesis requirement in the plant tissues.

Due to impact of climate change the global concern has been rising (Straub., *et al.* 2016) [57] with challenges like the growing population according to (FAO 2009) [17]. It is predicted that in 2050, due to continued urbanization, 6.4 billion of these people (70%) would live in cities (Forster and Radulovich 2015) [19] and keeping that in view by 2050 excessive food demand by 70% or about 5.4 thousand million tons (Gt; FAO 2009) is required. By two orders of magnitude the ratio of terrestrial agriculture exceeds seaweed aquaculture [40]. The production of land-based various agriculture products, most of which are plants were over 10 billion tonnes $year^{-1}$, whereas merely 100 million tonnes $year^{-1}$ of marine aquaculture products were produced (according to various FAO reports and Duarte., *et al.* 2007) [14]. This is extremely surprising to know that in a world whose surface is 70% water receives most of the world's sunshine and many seaweeds species were acknowledged as nutritious, healthful and tasty foods but still in case of global food production seaweeds have shown a very modest scale production [35,38,47,46]. However, seaweeds and their farming technologies can be business model for the coastal population which encourages both the production and importance of the cultivated algal biomass [9,41]. Out of the world's population data nearly 40% of the population lives in the coastal areas (UNEP, 2006). Thus, for coastal communities seaweeds can be termed as an opportunity for wealth and sustainable livelihood [49].

## Conclusion

Seaweeds offer untapped plethora of health benefits. The long recognized traditional health benefits of certain seaweeds are being now confirmed by modern scientific research. Seaweeds are being used for its rich nutrient content and antioxidant property in treating major degenerative and deficiency diseases. Though seaweeds are consumed extensively by Indonesians, Japanese and Koreans who have understood the nutritional properties and valuable health benefits of seaweeds Indians are yet to explore its benefits. It is reported that seaweeds like *C. repens*, *U. lactuca*, *C. racemosa*, *E. intestinalis* and *C. melagonium* are highly concentrated in the coastal belt of Andhra Pradesh. The biochemical composition was studied simultaneously in relation to environmental factors such as water temperature, salinity, suspended particulate matter and nutrients (nitrate, phosphate and silicate). The study reveals

that ambient environment conditions strongly regulate the protein, lipid, carbohydrate and astaxanthin contents of the seaweeds. They are also capable of withstanding wide range of salinity. This speaks in favour of incorporating the seaweeds in fish or poultry feed preparation, which can provide employment to island dwellers of coastal area in several tiers like collection, culture, animal feed preparation etc. The opening of a seaweeds based small scale industry can be an optimistic conclusion, which needs to be translated into reality for upgrading the economic profile of the area.

## Acknowledgements

This research laboratory analysis facilitated by OUAT (Orissa University of Agriculture and Technology), Bhubaneswar.

## Conflict of Interest

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).

## Bibliography

1. Abhilash PK and Nair SM. "Comparison of nutrient compositions and calorific values of eight tropical seaweeds". *Phycological Society, India* 45.1 (2015): 62-74.

2. Almela C. "Heavy metal, total arsenic, and inorganic arsenic contents of algae food products". *Journal of Agricultural and Food Chemistry* 50 (2002): 918-923.

3. Ausich RL. "Commercial opportunities for carotenoid production by biotechnology". *Pure and Applied Chemistry* 69 (1997): 2169-2173.

4. Banerjee K., *et al*. "Screening mangroves in search of Astaxanthin" *Seshaiyana* 14.1 (2006): 1-2.

5. Benemann JR. "Microalgae aquaculture feeds". *Journal of Applied Phycology* 4 (1992): 233-245.

6. Barsanti L and Gualtiari P. Algae: Anatomy, Biochemistry, and Biotechnology. *Phycological Society of America* 43 (2007): 412-414.

7. Bui HTT., *et al*. "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 (2018): 186-197.

8. Chidambaram K and Unny MM. "Note on the value of seaweeds as manure". *International Seaweed Symposium* (1953): 67-68.

9. Chopin T. "Open-water integrated multi-trophic aquaculture: environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture". *Reviews in Aquaculture* 4 (2012): 209-220.

10. Dawes CJ. Marine Botany. 2nd edition. John Wiley and Sons, Inc. New York, (1998): 480.

11. Decree of the State Minister of the Environment Number 51 of 2004 Regarding Standard Quality of Seawater State Minister of the Environment, Republic of Indonesia (2004).

12. Dhargalkar VK. "Biochemical studies on Ulva reticulata Forsskal. Proc. Int. Symp". Marine algae of Indian Ocean region, CSMCRI, Bhavnagar, 40 (1979).

13. Dhargalkar VK. "Biochemical studies on Ulva reticulata Forsskal". *Mahasagar Bulletin of the National Institute of Oceanography* 19.1 (1986): 4557.

14. Duarte CM., *et al*. "Rapid domestication of marine species". *Science* 316 (2007): 382-383.

15. Eaton AD. "APHA. Standard Methods for the Examination of Water and Wastewater, 21st edition". American Public Health Association/American Water Work Association/Water Environment Federation, Washington, D. C. (2005).

16. FAO. "The State of World Fisheries and Aquaculture". Contributing to Food Security and Nutrition for All: Rome: FAO. (2016).

17. FAO. "How to Feed the World in 2050. FAO, Rome". (2009).

18. Fleurence J. "Seaweed proteins: biochemical, nutritional aspects and potential uses". *Trends in Food Science and Technology* 10.1 (1999): 25-28.

19. Forster J and Radulovich R. "Seaweed and food security". *Elsevier Inca* (2015): 289-313.

20. Ginneken V. "Some Mechanism Seaweeds Employ to Cope with Salinity Stress in the Harsh Euhaline Oceanic Environment". *American Journal of Plant Science* 9 (2008): 1191-1211.

21. Guiry MD and Guiry GM. "AlgaeBase. World-wide electronic publication, National University of Ireland, Galway" (2017).

22. Guiry MD and Morrison L. "The sustainable harvesting of Ascophyllum nodosum (Fucaceae, Phaeophyceae) in Ireland, with notes on the collection and use of some other brown algae". *Journal of Applied Phycology* 25 (2013): 1823-1830.

23. Guist GG., *et al*. "Mariculture of the red seaweed, Hypnea musciformis". *Aquaculture* 28.3-4 (1982): 375-384.

24. Haroon A. M., Oceanologia 42.1 (2000): 19.

25. Holdt LS and Kraan S. "Bioactive compounds in seaweed: functional food applications and legislation". *Journal of Applied Phycology* 23 (2011): 543-597.

26. Horwitz W and Latimer GW. "AOAC. (Association of Official Analytical Chemists) Official Methods of Analysis of the Association of Analytical Chemists International, 18th edition". Gathersburg, MD U.S.A Official methods (2005).

27. Johnson EA. "Astaxanthin from microbial sources". *Critical Reviews in Biotechnology* 11 (1991): 297-326.

28. Kennish R and Williams GA. "Feeding preference of the herbivorous crab Grapsus albolineatus: the differential influence of algae nutrient content and morphology". *Marine Ecology Progress Series* 147 (1997): 87-95.

29. Krishnamurthy V. "Seaweed drift on the Indian coast. Proceedings of the Symposium "Indian Ocean". *Journal of the Indian Institute of science* 38 (1967): 657-666.

30. Liu JW and Dong SL. "Interactions between light and temperature on the growth and levels of chemical constituents of Gracilaria tenuistipitata var. Liui". *Journal of Ocean University of Qingdao* 31.3 (2001): 332-338.

31. Lowry OH. "Protein measurement with the Folin phenol reagent". *The Journal of Biological Chemistry* 193 (1951): 265-275.

32. Manivannan K. "Proximate composition of different group of seaweeds from Vedalai coastal waters (Gulf of Mannar): Southeast Coast of India". *Middle-East Journal of Scientific Research* 4.2 (2009): 72-77.

33. Marinho-Soriano E., *et al*. "Seasonal variation in the chemical composition of two tropical seaweeds". *Bioresource Technology* 97 (2006): 2402-2406.

34. McHugh DJ. "A Guide to the Seaweed Industry". Technical Paper 441. FAO, Rome. (2003).

35. McQuaid CD. "Seasonal variation in biomass and zonation of nine intertidal algae in relation to changes in radiation, sea temperature and tidal regime". *Botany Marina* 28 (1985): 539-544.

36. Mesnildrey L., *et al*. "Seaweed industry in France". Report. Interreg program NETALGAE. Les publications du Pôle halieutique AGROCAMPUS OUEST n°9 (2012): 1-34.

37. Mohammad RH and Chakrabarti R. "FAO fisheries and aquaculture technical paper". 531 (2009): ISSN 2070-7010.

38. Mouritsen OG. Seaweeds, "Edible Available and Sustainable". University of Chicago Press, Chicago, IL. (2013).

39. Munda IM and Kremer BP. "Chemical composition and physiological properties of fucoids under conditions of reduced salinity". *Marine Biology* 42 (1977): 9-15.

40. Neori A. "Can sustainable mariculture match agriculture's output?". The Global Aquaculture Advocate Website design by Visible Logic Inc (2016): 1-6.

41. Neori A. "The need for a balanced ecosystem approach to blue revolution aquaculture". *Environment: Science and Policy for Sustainable Development* 49 (2007): 36-43.

42. Parekh RG., *et al*. "Protein content of green seaweeds from Saurashtra coast". *Botanica Marina* 20.6 (1977): 359-362.

43. Parsons TR and Strickland JDH. "Discussion of spectrophotometric determination of marine plant pigments, with revised equations for ascertaining chlorophylls and carotenoids". *Journal of Marine Research* 21 (1963): 155-163.

44. Parthiban C., *et al*. "Biochemical composition of some selected seaweeds from Tuticorin coast". *Advances in Applied Science Research* 4.3 (2013): 362-366.

45. Pereira L and Neto JM. "Marine Algae: Biodiversity, Taxonomy, Environmental Assessment, and Biotechnology". CRC Press, Boca Raton, FL (2015).

46. Radulovich R., *et al*. "Tropical seaweeds for human food, their cultivation and its effect on biodiversity enrichment". *Aquaculture* 436 (2015): 40-46.

47. Rajapakse N and Kim SK. "Nutritional and Digestive Health Benefits of Seaweed". *Advances in Food and Nutrition Research*, Elsevier, Amsterdam (Chapter 2) 64. (2011).

48. Rao MU and Sreeramulu T. "An ecological study of some intertidal algae of the Visakhapatnam coast". *Journal of Ecology* 52.3 (1964): 595-603.

49. Rebours C., *et al*. "Seaweeds: An opportunity for wealth and sustainable livelihood for coastal communities". *Journal of Applied Phycology* 26.5 (2014).

50. Republic of South Africa, Department of Environmental Affairs. South African Water Quality Guidelines for Coastal Marine Waters - Natural Environment and Mariculture Use. Cape Town (2018): 1-164.

51. Rupérez P and Saura-Calixto F. "Dietary fibre and physicochemical properties of edible Spanish seaweeds". *European Food Research Technology* 212 (2001): 349-354.

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

53. Schmid M., *et al*. "Fatty acid contents and profiles of 16 macroalgae collected from the Irish Coast at two seasons". *Journal of Applied Phycology* 26 (2014): 451-463.

54. Schreiber L. "Edible Vegetables from the Sea". Maine News Index- MaineBiz European Journal of Phycology 1 (2014): 14-16.

55. Sekine T., *et al*. "Laboratory manual for physiological studies of Rice". International Rice Research institute, Manila, India (1965).

56. Soxhlet F. Die gewichtsanalytische Bestimmung des Milchfettes, Polytechnisches J. (Dingler's) 232 (1879): 461-465.

57. Straub S. "The dynamic biogeography of the Anthropocene: the speed of recent range shifts in seaweeds". In Seaweed Phylogeography (Hu, Z.-M. and Fraser, C., editors), Springer, Amsterdam (2016): 63-93.

58. Strickland JDH and Parsons TR. "A practical handbook of seawater analysis". 2nd edition: Fisheries research board of canada ottawa. (1972).

59. Summer WC. "The East Coast of India". *Bulletin of the American Geographical Society* 45.2 (1913): 81-92.

60. Thakur MC., *et al*. "Seasonal variation in biomass and species composition of seaweeds stranded along Port Okha, northwest coast of India". *Journal of Earth System Science* 117 (2008): 211-218.

61. Tripathy U., *et al*. "Effect of culture conditions on growth of green alga - Haematococcus pluvialis and astaxanthin production". *Acta Physiologiae Plantarum* 24.3 (2002): 323-329.

62. Van Netten C., *et al*. "Elemental and radioactive analysis of commercially available seaweed". *The Science of the Total Environment 255*.1-3 (2000): 69-175.

63. Waite T and Mitchell R. "The Effect of Nutrient Fertilization on the Benthic Alga Ulva lactuca". *Botanica Marina* 15 (1972): 151-156.

64. Wong KH and Cheung CK. "Nutritional evaluation of some subtropical red and green seaweeds Part I-proximate composition, amino acid profiles and some physico-chemical properties". *Food Chemistry* 71 (2000): 475-482.

65. Yarish C., *et al*. "Seaweed aquaculture for food security, income generation and environmental health in tropical developing countries". *Environment and Natural Resources* 1-16.

66. Yuan YV. "Marine algal constituents. In marine nutraceuticals and functional foods". CRC Press and Taylor and Francis Group: Boca Raton, FL, USA (2008): 259-296.

**Volume 3 Issue 5 May 2019**