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Seasonal Variation in the Biochemical Composition of Seaweeds from Chilika Lagoon, Odisha, India

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ABSTRACT

The two selected macro algae, namely, *Gracilaria verrucosa* (Red algae) and *Enteromorpha compressa* (Green algae) were seasonally collected from the central sector of Chilika lagoon and analyzed for their biochemical and mineral contents during 2022-23. The composition of biochemical components such as lipid, protein, carbohydrate, ash, nitrogen, total fiber and mineral contents like calcium, magnesium, phosphorus, potassium, sodium, iron, zinc, iodine, nickel, copper, molybdenum and selenium ware studied. The values of each triplicate sample were expressed on dry weight basis as the mean value with SD. The different proximate components of two species ranged from 27.4 to 56.2% (carbohydrate), 7.8 to 12.5 % (lipid), 28.8 to 57.1% (protein), 4.5 to 7.4% (ash), 11.65 to 14.95% (nitrogen) and 36 to 92 % (total fiber) dry weight, respectively. *E. compressa* had higher mineral content than *G. verrucosa* such as calcium, magnesium, phosphorus during monsoon and post monsoon season, respectively. Seasonal variation affected mineral contents with some fluctuations of biochemical composition across species *G. verrucosa* and *E. compressa* showing rich in protein, carbohydrate and low level of ash percentage during post-monsoon. The results showed that the carbohydrate and protein were in inverse relationship, while protein, nitrogen, ash and fiber levels were correlated positively. Among the minerals, calcium, potassium, sodium, iron, zinc, iodine having significantly higher value were observed in *E. compressa* during all seasons than that of *G. verrucosa*. Hence, marine macro algae have been gaining importance due to nutritive value and suggesting that the seaweed species have potential to be used as raw material of a healthy food for human being.

Key words: Biochemical, Lagoon, macroalgae, seasonal, seaweeds

INTRODUCTION

Macro algae or marine algae constitute one of the commercially important renewable marine living resources, which are main source of nutrients, food, fodder, pharmaceutical industries and various chemicals such as agar, alginate, etc. It has a variety of compounds with different properties of benefits to human health (Motshekga *et al*., 2023). The human consumption of seaweed is common in Asian countries, mainly Japan, China, Korea, Vietnam, Indonesia and Taiwan (Ali *et al*., 2025). In Western countries, seaweeds have been used as sources of phycocolloids, thickening and gelling agents for various applications, including herbal medicines, fertilizers, cosmetic, etc. (Qin, 2018). Seaweeds maintain different colour pigments including chlorophyll, carotenoids, xanthophylls, phycocyanin and phycoerythrin which give different colour to the macro algae. Proteins, carbohydrates and lipids are the most common and important biochemical components of algae. Lipids are widely distributed in several resistance stages of macroalgae (Lopes *et al*., 2021; Chen *et al*., 2023). Moreover, seaweeds also contain potential bioactive compounds which exhibit antibacterial, antiviral and antifungal

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properties. Edible seaweeds may be important sources of the elements, which are useful for metabolic reactions in human and animal such as enzymatic regulation of lipid, carbohydrate, protein metabolism, etc. Lipids represent only 1-8% DW of algal species which play an important role in the prevention of cardio-vascular diseases, osteoarthritis, diabetes, etc. Seaweeds are rich in carbohydrate, protein, lipid and minerals which do not cause any disorder of lungs, kidneys, stomach and intestine (Meinita *et al*., 2022). Seaweed polysaccharides are an extensive group of compounds playing a significant role as dietary fiber (DF) with various biological functions and chemical structures. Starch is the major storage polysaccharide of green seaweed. Seaweeds contain other essential micronutrients and minerals such as fiber, nitrogen, calcium, magnesium, potassium, sodium, iron, zinc, iodine phosphorus, manganese, nickel, etc. making them suitable for utilization as food and fodder.

However, the various nutrient composition of seaweeds depends on the genus, species, maturity, environmental growth conditions and seasonal period of different regions (Sultana *et al*., 2023). The changes in ecological conditions have an influence on the synthesis of nutrients (Chan and Matanjun, 2017). Now-a-days, marine macro algae or seaweeds are used worldwide for many different purposes. The present study worked on important biochemical constituents and mineral contents of two selected macro algae like *G. verrucosa* (Red algae) and *E. compressa* (Green algae) growing more abundantly in the Chilika lagoon.

MATERIALS AND METHODS

Seasonally field visit was made for collection of two different economical important algal samples of central sectors of Chilika lagoon during low tide because most of the littoral species remain under water during high tide period. Free floating forms were easy to collect; they were simply picked up and put in polythene bags while the attached forms were plucked or uprooted along with the hold fast. After collection of the samples were washed thoroughly for lab analysis.

The estimation of total carbohydrate content in the dry powder of two selected macro algae sample was estimated by the phenol-sulphuric acid method. D-glucose was taken as reference standard and was expressed in % dry weight. The protein content was extracted and determined by Folin reagent with bovine serum albumin serving as standard. It was expressed in % dry weight (DW) and calculated from the elemental N determination using the nitrogen-protein conversion factor of 6.25. Total lipids in algae samples were extracted using solvent with a chloroform-methanol mixture in a ratio (2:1 v/v) analyzed gravimetrically and expressed in % dry weight. The lipids in chloroform were dried over anhydrous sodium sulphate, after which the solvent was removed by heating at 80 ºC under vacuum. The ash content in algal sample was estimated by the ground dried samples overnight in a muffle furnace at 525°C and the content was expressed in % dry weight. The macronutrient like nitrogen content was measured using the Kjeldahl method. Total fiber concentration was analyzed enzymatically using the BIOQUANT kit.

The minerals and trace elements were analyzed in all macroalgae samples underwent pressure digestion by using 10% HNO*ƒ* with 1 μg/l rhodium in a closed microwave digestion system. Multi-element detection was performed using an inductively coupled plasma mass spectrometry system (ICP-MS/MS) (Agilent ICP-QQQ-MS, 8800). Oxygen and hydrogen were used as a reaction/collision gas mixture in mass-shift mode, while helium was utilized as a collision gas in on-mass mode to minimize interference. Selenium isotope dilution analysis was conducted using a 10 μg/l solution of enriched and mixed in equal proportions with a 10 μg/l solution of naturally occurring selenium. At last, the data were expressed as means ± standard deviation. Statistical significance was determined by ANOVA differences with a p-value < 0.05 were considered significant.

RESULTS AND DISCUSSION

During the study period seasonally biochemical composition such as carbohydrate, protein, lipid, ash, nitrogen and total fiber % DW of two macro algae from Central sector of Chilika lagoon were analyzed (Table 1). Seasonally the total mean carbohydrate content ranged from

Table 1. Seasonal distribution in biochemical composition of two macro algae from central sector of Chilika lagoon

Biochemical components	Pre-monsoon		Monsoon		Post monsoon	
	E. compressa	*G. verrucosa*	*E. compressa*	*G. verrucosa*	*E. compressa*	*G. verrucosa*
Carbohydrate (% DW)	55.4±1.11	31.3±1.02	49.1±0.28	33.7±0.17	56.2±1.48	27.4±0.95
Lipid (% DW)	10.5±0.07	12.5±0.09	10.2±0.16	11.8±0.13	7.8±0.88	8.1±0.22
Protein (% DW)	28.8±1.31	49.1±0.23	36.2±0.74	47.8±0.29	31.5±0.73	57.1±1.30
Ash	6.1±1.41	7.1±2.01	5.2±1.01	6.7±0.91	4.5±1.2 1	7.4±1.05
Nitrogen	11.65±0.89	14.87±0.87	13.80±0.92	14.75±0.89	13.50±0.85	14.95±0.85
Total fiber	38.0±0.65	89.0±0.76	40.0±0.72	92.0±0.78	36.0±0.61	87.0± 0.74

All data expressed as mean**±**SD (Standard deviation) and DW–Dry weight.

(49.1±0.28 to 56.2±1.48% DW) in case of *E. compressa* (Fig. 1) and from (27.4±0.95 to 33.7±0.17% DW) in *G. verrucosa* (Fig. 2). The major biochemical content such as carbohydrate, protein and lipid of green seaweed, the highest carbohydrate percentage was observed during post-monsoon, may be due to the extensive growth of thallus. The sea weeds of the Maharashtra and Kovalam coast of India recorded maximum carbohydrate content in Chlorophyceae members than that of Rhodophyceae members. The highest and lowest mean percentage value of carbohydrate was recorded in the green algae *E. compressa* (56.2±1.48% DW) and *G. verrucosa* (27.4±0.95% DW) during post-monsoon season. The minimum carbohydrate content was observed from red alga *G. folifera* and the green alga *Codium tomentosum* (Yucetepe *et al*., 2025). Furthermore, Zollmann *et al*. (2019) recorded

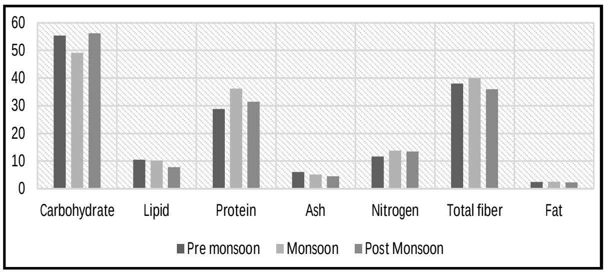

Fig. 1. Seasonal distribution in biochemical composition of *E. compressa.*

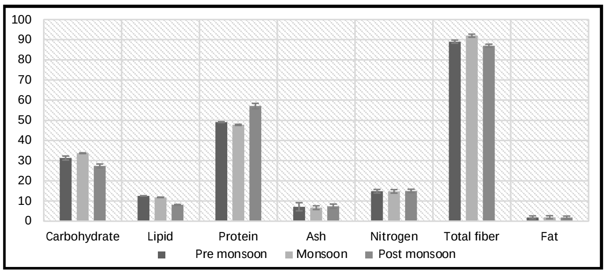

Fig. 2. Seasonal distribution in biochemical composition of *G. verrucosa.*

carbohydrate content of 20.4% in the green algae *E. intestinalis* showing that the fermentation of carbohydrates obtained from macroalgal biomass can be used for the production of bioethanol. The order of biochemical composition was post monsoon >pre-monsoon> monsoon season. These variations might be attributed to the changes in eco-hydrographical conditions and reproductive pattern of algae (Jiang *et al.,* 2025).

Large number of marine macro algae contained low percentage of lipids, which were the main sources of poly unsaturated fatty acids. The mean with SD of lipid content of *E. compressa* and *G. verrucosa* varied from (10.5±0.07 to 12.5±0.09% DW) during pre-monsoon, (10.2±0.16 to 11.8±0.13% DW) monsoon and (7.8±0.88 to 8.1±0.22% DW) post-monsoon season, respectively. The maximum and minimum mean and SD of lipid concentration was recorded (12.5±0.09 and 8.1±0.22% DW) during pre-monsoon and post-monsoon season in *G. verrucosa* species. The study showed that the lipid percentage of red macro algae was more than that of green algae. The maximum mean lipid content was recorded in the red seaweed *G. verrucosa* and than that of green seaweed *E. compressa.* This could have been attributed to hydrographical factors of development of sea weeds and ecological conditions of the brackish water (Sandgruber *et al*., 2021).

Seasonally mean and SD protein content was recorded in *E. compressa* (28.8±1.31% DW), (36.2±0.74% DW), (31.5±0.73% DW) and *G. verrucosa* (49.1±0.23% DW), (47.8±0.29% DW), (57.1±1.30% DW) during pre-monsoon, monsoon and post monsoon, respectively, due to algae were exposed to salinity changes, the movement of water occurs followed by ion fluxes, etc. Eventually the variations in total protein value in the marine algae depending on the depth of the sample collected and greatly depending on the sites. The maximum percentage of mean protein content in *G. verrucosa* (57.1±1.30 DW %) during post monsoon and the minimum protein content was recorded *E. compressa* (28.8±1.31% DW) during pre-monsoon season. The higher protein content was recorded in red and than green seaweeds (mean of 40 to 50% DW) as reported by Musa *et al*. (2024). Comparison of the amino acid compositions of seaweeds with the FAO reference pattern and those of other food proteins indicated the high nutritional value of seaweed proteins, which were able to make an active contribution to the total required amount of essential amino acids in food (Reynolds-Brandão *et al.,* 2025).

The mean and standard deviation of ash content was observed in *G. verrucosa* (7.4±1.05% DW), (7.1±2.01% DW) and (6.7±0.91% DW) during post-monsoon, pre monsoon and monsoon season, respectively (Table 1). In case of *E. compressa* the ash mean value varied between (4.5±1.21 to 6.1±1.41% DW) during post-monsoon and pre monsoon. The maximum ash content was recorded in species of *G. verrucosa* and minimum was in *E. compressa* during post-monsoon season. These are, therefore, considered unsuitable for biorefining. Seaweeds usually contained more than 20% ash content which was quiet high compared to most vegetables (Choudhary *et al*., 2021), in which ash value falls within the range of 5-10%.

Seasonally the higher value of total nitrogen was observed during post-monsoon, pre monsoon followed by monsoon in *G. verrucosa* but the value was slightly changed in case of *E. compressa.* The high value was recorded 14.95±0.85% DW and 13.80±0.92% DW in case of two respective species during post monsoon and monsoon season. The total fiber value was observed higher in case of *G. verrucosa* than that of the species *E. compressa* during monsoon but low value was recorded in post-monsoon season.

The correlation analysis of biochemical components in *G. verrucosa* and *E. compressa* revealed significant relationships between different parameters (Table 2). A strong negative correlation (r= -0.985, $P < 0.01$) was observed between carbohydrate and protein content, indicating that as carbohydrate levels increase, protein content significantly decreases. Similarly, carbohydrate and total fiber showed a strong negative correlation (r = -0.966, $P < 0.01$), suggesting an inverse relationship. Protein content demonstrated that a strong positive correlation with ash (r = 0.825, $P < 0.05$), nitrogen (r = 0.876, $P < 0.01$) and total fiber (r = 0.925, $P < 0.01$), indicated that protein levels increased with other components. Additionally, ash and total fiber showed a positive correlation (r = 0.867, $P < 0.05$), suggesting that higher fiber content leads to increased ash accumulation. However, lipid content had weak correlation with ash (r = 0.189) and indicated minimal dependence on other biochemical components. The findings suggested that carbohydrate and protein were an inverse relationship, while protein, nitrogen and fiber levels were positively correlated. The lipid content remained relatively independent, showing only weak associations with other nutrients. These results highlighted the seasonal variations in the biochemical composition of *G. verrucosa* and *E. compressa*, which could be useful in determining their nutritional value for various applications.

Seasonally the mineral composition of the two species *G. verrucosa* and *E. compressa* varied among the minerals (Table 3). Calcium (Ca) was significantly higher in *E. compressa* across all seasons ranging from (820 to 845 mg/100

Table 2. Correlation matrix of macronutrients

Variables	Carbohydrate	Protein	Lipid	Ash	Nitrogen	Total fiber
Carbohydrate	1	-0.985*	0.321	-0.878	-0.563	-0.966
Protein	-0.985*	1	-0.287	0.825	0.876	0.925
Lipid	0.321	-0.287	1	0.189	-0.153	-0.325
Ash	-0.878	0.825	0.189	1	0.473	0.867
Nitrogen	-0.563	0.876	-0.153	0.473	1	0.572
Total fiber	-0.966	0.925	-0.325	0.867	0.572	1

Significance levels: $P < 0.01$ (Highly significant*)*; $P < 0.05$ (Moderately significant). Values without stars not found statistically significant.

g) and red algae *G. verrucosa* revealed lower value from (9318 to 330 mg/100 g). These were also capable of accumulating more percentage of calcium from the calcareous bases during the growth (Jiang *et al.*, 2025) and calcium was one of the major constituents in the ash. During monsoon, the magnesium (Mg) content was observed higher in *E. compressa* peaking at 690 mg/100 g compared to *G. verrucosa*, which fluctuated between 428 and 440 mg/100 g during the study period. Similarly, potassium (K) content was notably higher in *E. compressa*, exceeding 1800 mg/100 g in all seasons, while *G. verrucosa* maintained a range between 665 to 690 mg/100 g. Sodium (Na) followed a similar trend, with *E. compressa* recording values above 1100 mg/100 g, while *G. verrucosa* remained slightly lower.

Iron (Fe) and zinc (Zn) contents of two species slightly differed: with *E. compressa* exhibiting higher concentrations (around 13 mg/100 g and 3.1-3.4 mg/100 g) compared to the content of *G. verrucosa* (9.2-10 mg/100 g and 1.6-1.9 mg/100 g). Iodine (I) content, expressed in both micrograms and milligrams per 100 g, was significantly greater in *E. compressa* across all seasons. Phosphorus (P) levels remained relatively stable, with slight seasonal fluctuations, but *E. compressa* tended to have a marginally higher concentration. Manganese (Mn) showed as an inverse trend in case of *G. verrucosa* and observed higher values (1.6-2.11 mg/100 g) compared to *E. compressa* (1.01-1.11 mg/100 g).

Nickel (Ni), copper (Cu), molybdenum (Mo) and selenium (Se) also varied across the seasons and species. Nickel content was observed higher in *G. verrucosa* during post-monsoon (10.67 mg/100 g), while *E. compressa* showed a steady rise, peaking at (11.87 mg/100 g). Copper content was higher in *G. verrucosa* during the monsoon (178 mg/100 g) but varied across seasonally, while the data fluctuated in case of *E. compressa* species. The marked changes in mineral constituents were found to occur with changes of season, environmental conditions as well as various phases of plant growth and reproductive cycles (Djoundi *et al.*, 2025). Molybdenum levels remained nearly similar between the two species, whereas selenium was higher in *E. compressa* across all seasons than that of *G. verrucosa*. Overall, *E. compressa* revealed that the higher concentrations of most minerals compared to *G. verrucosa*, suggesting its greater nutritional potential, particularly in terms of calcium, potassium, sodium, iron, zinc and iodine (Table 3). Some of the red seaweeds obtained high amount of iodine content, hence such seaweeds can be used as seasonal rather than direct consumption as vegetables to minimize the excess intake of other minerals (Banerjee *et al.*, 2025).

The correlation analysis of mineral content in *G. verrucosa* and *E. compressa* across different seasons revealed several significant relationships. Magnesium (r = 0.9999, P = 0.0107) and sodium (r = 0.9998, P = 0.0126) exhibited strong positive correlations and a consistent trend between the two macroalgae species, suggesting similar absorption or accumulation patterns. Selenium (r = 1.0000,

Table 3. Micronutrient composition of *G. verrucosa* and *E. compressa*

Nutrients (Minerals mg/100 g) Expect Iodine (μg/100 g)	Pre-monsoon		Monsoon		Post-monsoon	
	G. verrucosa	*E. compressa*	*G. verrucosa*	*E. compressa*	*G. verrucosa*	*E. compressa*
Calcium (Ca)	324±0.23	831±0.342	318±0.25	845±0.35	330±0.21	820±0.31
Magnesium (Mg)	432±0.19	675±0.654	440±0.21	690±0.67	428±0.22	668±0.60
Potassium (K)	678±0.87	1897±0.765	690±0.76	1850±0.78	665±0.89	1920±0.72
Sodium (Na)	834±0.98	1134±0.45	820±1.02	1115±0.47	845±0.95	1150±0.42
Iron (Fe)	9.6±0.76	13±0.34	9.2±0.69	12.5±0.39	10±0.78	13.2±0.37
Zinc (Zn)	1.7±0.45	3.24±0.27	1.9±0.41	3.1±0.26	1.6±0.46	3.4±0.30
Iodine (I in μg/100 g)	168±0.654	342±0.45	175±0.67	330±0.48	162±0.69	350±0.41
Phosphorus (P)	175±0.543	185±0.26	168±0.52	190±0.29	180±0.55	178±0.27
Manganese (Mn)	2.11±0.12	1.01±0.11	1.6±0.13	1.01±0.08	1.77±0.71	1.11±0.14
Nikel (Ni)	8.91±0.98	7.82±0.12	9.12±0.65	10.09±0.15	10.67±0.81	11.87±0.82
Copper (Cu)	156.78±0.23	166±0.21	178±0.95	156±0.26	143±0.14	178±0.63
Molybdenum (Mo)	1.65±0.56	1.87±0.654	1.70±0.60	1.80±0.66	1.62±0.54	1.92±0.61
Selenium (Se)	8±0.67	11±0.64	7.8±0.69	10.8±0.66	8.2±0.65	11.2±0.63
Iodine (I)	0.5±0.86	0.6±0.45	0.52±0.83	0.62±0.42	0.48±0.89	0.58±0.47

All data expressed as mean**±**SD (Standard deviation) and DW=Dry weight.

P = 0.0000) showed a perfect correlation, implying identical seasonal variations in both species. Conversely, calcium (r = -0.9976, p = 0.0440), molybdenum (r = -0.9989, P = 0.0302), and copper (r = -0.9848, P = 0.1111) displayed strong negative correlations, suggesting opposing accumulation trends in the species. Potassium (r = -0.9762, P = 0.1391) and zinc (r = -0.9740, P = 0.1455) also demonstrated high negative correlations, though not statistically significant, indicating possible species-specific variations. Manganese (r = -0.1890, P = 0.8790) showed a weak and non-significant correlation, suggesting independent accumulation patterns data represented as in Table 4.

Table 4. Seasonally the correlation analysis between mineral contents in *G. verrucosa* and *E. compressa* of Chilika lake

Nutrient	Correlation coefficient (r)	P-Value
Calcium (Ca)	-0.9976	0.0440
Magnesium (Mg)	0.9999	0.0107
Potassium (K)	-0.9762	0.1391
Sodium (Na)	0.9998	0.0126
Iron (Fe)	0.9707	0.1544
Zinc (Zn)	-0.9740	0.1455
Phosphorus (P)	-0.9817	0.1221
Manganese (Mn)	-0.1890	0.8790
Nickel (Ni)	0.8852	0.3081
Copper (Cu)	-0.9848	0.1111
Molybdenum (Mo)	-0.9989	0.0302
Selenium (Se)	1.0000	0.0000

CONCLUSION

The macro algae from central sectors of Chilika lagoon showed seasonal variation in biochemical composition and mineral contents indicating minor differences that depend on the relevant division of algae and environmental conditions. The red algae like *G. verrucosa* revealed high protein content (57.1% DW), whereas green algae such as *E. compressa* was highest carbohydrate content (56.2% DW) during post-monsoon and lower values obtained in monsoon season. Seasonally the calcium, magnesium, sodium, potassium content in *E. compressa* showed highly significant than that of *G. verrucosa* species. The correlation analysis among macro and micro nutrient contents in both seaweeds across different seasons revealed several significant relationships. In terms of food aspect, seaweeds may solve the problems of all biochemical aspects and mineral deficiency in human nutrition by consuming them in daily life as an alternative food diet. Based on the present study it is suggested that these species can potentially be used as a healthy nutritional food of human diets and may be of use to the food processing industries with high potential value.

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