Marine macroalgae, which are the most conspicuous inhabitants of rocky shores, constitute an important marine living resource. They are used as human food, livestock feed and agricultural fertilizer in many countries. They also serve as sources of commercially and pharmaceutically important compounds. They are the sole source of commercial phycocolloids such as agars, carrageenans, alginites etc. The various uses of marine algae depend mainly on the richness of biochemical constituents such as proteins, lipids, carbohydrates, amino acids, fatty acids, vitamins, macrominerals, trace elements, bioactive compounds etc. The present study investigates the biochemical composition of some selected species of marine macroalgae from two locations (Ettikkulam and Narakkal) along Kerala coast. The study provides information on the potential of these algae as sources of food for human and animal consumption. In addition, it reveals the interspecies and interclass variability of various organic and inorganic constituents of algae on a spatial and temporal scale. The study gives information on the potential use of the different species of algae studied as bioindicators of heavy metal pollution. It also evaluates the quality and quantity of agar isolated from the agarophyte *Gracilaria*. The salient features of this study are summarized in the following paragraphs.
The different algal species studied during the present investigation were found to contain substantial amounts of proteins (average, 7 – 19%) and carbohydrates (average, 12 – 34%). In most cases, carbohydrates constituted the largest proportions of the dry weight of algae compared to proteins. There were a few exceptions with proteins showing the highest proportion. In the case of the chlorophyte Chaetomorpha antennina, fibres represented the largest component. In all the marine algae studied, lipids exhibited relatively smallest proportion (average, 0.4 – 2.2%). The average energy contents varied from 1.5 to 2.1 kcal g⁻¹.

In the present study, marine algae did not show any significant interspecies or interclass variations in the levels of proteins and lipids. Algae from Ettikkulam showed significant specieswise and classwise variations in the levels of carbohydrates including low-molecular-weight carbohydrates (LMWC) and polysaccharides. Rhodophyceae recorded higher values compared to chlorophyceae. Calorific values and fibre contents of algae from this location also exhibited significant variations among different species and classes. Marine algae from Narakkal showed statistically significant interspecies variations in fibre contents only. They did not exhibit any significant interclass variations in the major biochemical constituents.

The biochemical compositions of marine algae from Kerala coast exhibited considerable variations from those of marine algae from other parts of Indian coast. However, variations were not much pronounced between the locations selected for the present study. Significant spatial variations were observed only for the protein and carbohydrate (LMWC, polysaccharides and total carbohydrates) contents of rhodophyceae members. Rhodophyceae from Narakkal showed higher protein contents than those from Ettikkulam, while reverse was true for their carbohydrate contents.
All the algal species studied were found to exhibit considerable temporal variations in their biochemical compositions. Protein and carbohydrate levels were high in the summer monsoon and early winter monsoon seasons. Lipid levels were higher in the period from mid winter monsoon to mid hot season compared to other seasons. Biochemical constituents recorded comparatively low levels in the late hot season. Crude fibre contents of algae did not show any notable seasonal variations. Calorific values were high in the summer monsoon and early winter monsoon seasons and low in late hot seasons. Thus, with respect to the biochemical composition and calorific value, the best seasons for harvest of algae for food purposes appears to be summer monsoon and early winter monsoon seasons while the least suitable period is the late hot season. Considering the levels of major biochemical constituents and energy contents, Centroceras clavulatum, Grateloupia filicina, Gracilaria corticata and Ulva lactuca were found to have potential as food sources. Among the different species of marine algae studied, Chaetomorpha antennina with very high levels of crude fibre and low calorific value appeared to be least suitable for food purposes.

Study on the amino acid composition of marine algae from Kerala showed the presence of both essential and non-essential amino acids. The total amount of amino acids (both free and combined) varied in the range 85 – 211 mg g\(^{-1}\) on dry weight basis. Of these, about 20 – 37% was constituted by essential amino acids. The most dominant amino acid in most of the algae studied was aspartic acid. Arginine, cysteine and glutamic acid were also found to be major constituents. Glycine, histidine and tyrosine were found to present in fairly good quantities. Among the essential amino acids, leucine(s) and phenylalanine were found to be dominant compounds. Lysine and threonine were present in fairly high levels. However, methionine and
valine were found to be limiting amino acids in many cases. The amino acid compositions showed considerable temporal and spatial variations. The rhodophyceae members *Centroceras clavulatum* and *Grateloupia filicina* collected from Narakkal in the summer monsoon season were found to be more nutritive with respect to the amino acid contents than the other algal species studied. The chlorophyceae members were found to be limiting in methionine and valine. Thus, the rhodophytes of Narakkal especially, those available in the summer monsoon season can be exploited for use as an additional source of essential amino acids.

Marine algae from Kerala coast were found to contain considerable amounts of many of the essential trace elements needed for human and animal nutrition. The total mineral constituents of algae, represented by their ash contents, were found to show mean values varying in the range 7.8 – 21.5%. Only the rhodophyte *Gracilaria corticata* recorded ash contents below 10%, whereas all other species recorded average values above 12%. *Centroceras clavulatum* from Ettikkulam (21.5%) and *Enteromorpha intestinalis* from Narakkal (21%) recorded the highest values. Although class-wise variations in ash contents were not significant at both the locations, specieswise variations were observed to be significant at Ettikkulam. The ash content of rhodophyceae showed significant differences between the two locations, whereas that of chlorophyceae was statistically indistinguishable. Algae were found to show temporal variations in their ash content. Low values were observed in the summer monsoon and retreating monsoon seasons, whereas comparatively high values in the period from mid winter monsoon to hot season.

Among the various inorganic constituents of algae, chlorine and iodine were found to show mean values varying in the ranges 1.18 – 6.08
mg g\(^{-1}\) and 0.16 - 1.47 mg g\(^{-1}\) respectively. Iodine contents of algae from Ettikkulam showed highly significant interspecies variations, while their chlorine contents were not significantly different. A reverse case was observed at Narakkal. Here, iodine contents of different species were statistically indistinguishable, whereas chlorine contents showed significant specieswise variation. Both iodine and chlorine exhibited significant interclass variations at Narakkal, while differences were significant only for chlorine at Ettikkulam. Although significant spatial variations were not observed in the halogen contents, temporal variations were notable. All the algal species recorded lowest iodine contents in the summer monsoon season and most of them showed highest values in the mid hot season. Intermediate values were obtained in other seasons. Such a general trend was not observed in the chlorine content of algae. The period of minimum and maximum chlorine contents were found to differ from one species to another and also between locations. It was found that chlorine contents of all the algal species studied were higher than their iodine contents in all the seasons. However, chlorine was not concentrated by any of these species, whereas iodine was accumulated to several orders of magnitude compared to its concentration in the ambient seawater. The largest concentrator of iodine was found to be the rhodophyte *Centroceras clavulatum* followed by *Grateloupia filicina* and the lowest accumulation of iodine was shown by the chlorophyte *Enteromorpha intestinalis*. The former two species of algae can be considered for use as dietary sources of iodine.

Marine macroalgae from Kerala were observed to contain notable amounts of many of the essential trace metals. They were also found to accumulate toxic heavy metals such as Pb and Cd. Most of the metals studied showed high levels of accumulation. The levels of Cu, Zn and Co in
different species of algae were found to be of similar magnitude to those reported for algae from supposedly clean areas, while Fe, Cr and Cd contents were generally in accordance with those reported for algae from contaminated areas. Mn, Ni and Pb contents of algae were in agreement with those reported for algae from some polluted areas, but in other cases, values were lower than those from clean areas. Different species of algae were found to accumulate metals to different extent. Significant interspecies variations were observed in the accumulation of metals such as Fe, Cu, Zn, Sr, Mn and Cr. The rhodophyte Centroceras clavulatum showed highest accumulation of Fe and Cu, while Grateloupia filicina showed high accumulation of Zn and Sr. Gracilaria corticata accumulated highest level of Mn. The chlorophyte Chaetomorpha antennina showed highest accumulation of Cr. The least accumulation of most of the metals was shown by the chlorophyte Ulva lactuca. Interclass variations were significant only for the metals Cr, Sr, Mn and Cd. Chlorophyceae showed greater accumulation of Cr and Sr, while rhodophyceae accumulated more Mn and Cd. The general pattern of trace metal distribution in the two classes of marine algae from both Ettikkulam and Narakkal were found to be Fe > Mn > Zn/Sr > Ni/Pb > Cu > Co > Cd/Ag. The accumulation level of Cr was in between that of Mn and Cu. Algae were observed to show significant spatial variations in the levels of metals such as Fe, Zn, Cd, Mn and Ni. Other metals did not show any significant spatial variations. In general, metal contents were higher in algae from Narakkal, which may be due to the proximity of this site to the Cochin barmouth through which the intensely polluted Cochin backwaters open out into the Arabian Sea. The temporal variations in metal accumulation did not follow any general pattern and different metals were accumulated to different extents in various seasons.
Information obtained on the trace metal composition of marine algae from Kerala coast suggests a possible use of some of the species as bioindicators of trace metal levels in seawater. The rhodophyceae members *Gracilaria corticata*, *Centroceras clavulatum* and *Grateloupia filicina*, which were found to be good concentrators of trace metals can be considered for this purpose. *G. corticata* can be used for the monitoring of potentially toxic heavy metals, while *C. clavulatum* for the nutrient trace metals.

The qualitative and quantitative evaluation of agar isolated from *Gracilaria corticata* collected from Ettikkulam coast of Kerala showed that yield and gel strength of this agar was in accordance with those specified for agar from Grade-II *Gracilaria*. The average yield was 24% on dry weight basis and the gel strength was 76 g cm\(^{-2}\). The yield was high in summer and winter monsoon seasons and low in the retreating monsoon season. Gelling and melting temperatures showed average values of 44.8 and 86.2 °C respectively. Mean values of 3,6-anhydrogalactose and sulphate contents of agar were 30% and 4% respectively. Spectral studies revealed the presence of D-galactose-4-sulphate residues and possible absence of galactose-2-sulphate, galactose-6-sulphate and 3,6-anhydrogalactose-2-sulphate residues in the agar isolated in the present study. The physicochemical properties of this agar appeared to be far from those required for bacteriological purposes. However, this agar may be suitable for food industry, probably after enhancement of its quality, which may be carried out by techniques such as fractionation. Considering the gel regulating factors as well as the yield, the best time of the year to obtain a firmer and less viscous gel seems to be the early winter monsoon season. The late hot season and retreating monsoon season may also provide firm and rigid gel, but yield may be low.
In short, some of the algal species investigated during the present study, especially *Centroceras clavulatum* and *Grateloupia filicina* have potential as sources of proteins, carbohydrates, lipids, fibres, essential amino acids, iodine and trace metals, which are needed for human and animal nutrition. However, caution must be taken of toxic metals such as Cd and Pb. Since these heavy metals are usually detoxified in algae by adsorption onto charged polysaccharides in the cell wall and intercellular matrix, which are weakly fermented in the digestive tract, they may pose less threat to health. Nevertheless, considering the levels of trace metals – both nutrient and toxic – in marine algae from Kerala, their use as food supplement rather than as staple food item is recommended as a better means of introducing them into the diet. They can also serve as a source of minerals for plants whose products are eventually consumed by humans and animals. The rhodophyte *Gracilaria corticata* occurring at Ettikkulam can be used as a source of food-grade agar and the species such as *Gracilaria corticata*, *Centroceras clavulatum* and *Grateloupia filicina* can be considered for use as biomonitors of heavy metal pollution in coastal waters.