CHAPTER- VI

SUMMARY AND CONCLUSION

Economical and social development lead to the gradual transformation of agriculture, characterized by rising labour productivity, declining shares of population working in agriculture and rising urbanization. New modes of transportation, leisure employment and work within the home cause people to lead more sedentary lifestyles and to demand more convenient food. These changes in activity and dietary patterns are part of a “nutrition transition”. Agricultural productivity growth contributes to better nutrition through raising income, and by reducing the cost of food for all consumers. It is however, important to realize that the impact of agricultural growth is slow and may not be sufficient to cause a rapid reduction in malnutrition. Beyond staple food, healthy diets are diverse, containing a balanced and adequate combination of energy, fat and protein, as well as micronutrients. Therefore research and development priorities must be made with a stronger focus on nutrient dense food. Seaweeds have been a staple food since ancient times in countries located by the sea, viz., U.K, Ireland, Norway, the pacific Islands, African countries and the American countries. Seaweeds are considered to be the food supplement for 21st century and as source for proteins, lipids, polysaccharides, minerals, vitamins and enzymes. In India, seaweeds are generally being used as raw materials for the production of agar, alginates and seaweed liquid fertilizer, in spite of their great potential as therapeutic health booster, beauty enhancer and the source of nutrition. Hence it becomes essential to popularise and to establish seaweeds as health food which will help to feed undernourished people in India. The study on the nutraceutical value of seaweeds revealed that seaweeds belonging to Rhodophyceae contained the maximum
amount of carbohydrate, followed by members of Phaeophyceae and Chlorophyceae. Higher amount of dietary fiber was noted in Rhodymenia palmata, Sargassum ilicifolium, Padina tetrastromatica and Hypnea musciformis. The maximum level of protein was estimated in Colpomenia sinuosa (105.87 ± 3.01 mg/g DW). Other species like Turbinaria conoides (95.75±0.03 mg/g DW) and H. musciformis (78.74 ± 0.592 mg/g DW) also contained good amount of protein in all seasons. Among three groups of seaweeds Phaeophycean members were found to be enriched with protein. The relative digestibility of alkali- soluble proteins from Sargassum tenerrimum (69.7%) is higher than other seaweed proteins. Red seaweed was noted for its amino acids with highest amount in Gracilaria pygmaea (29.20 ±0.697 mg/g DW). Seasonal variation in carbohydrate, protein and lipid level was clearly noticed among different groups of seaweeds. Post monsoon season was found to be more suitable for seaweed harvest. The non-essential amino acids namely asparatic acid, glutamic acid, asparagine, serine, glutamine, glycine, alanine, cysteine and proline and essential amino acids like threonine, arginine, alanine, tyrosine, histidine, methionine, isoleucine, phenylalanine, leucine, lysine, were found in varying amount in all the seaweeds analysed. The present investigation exhibited the maximum lipid level in Kappaphycus alvarezii (34.4 ± 0.11 mg/g DW). The fatty acids detected commonly in all seaweeds were palmitic acid, margaric acid, stearic acid, oleic acid, linolenic acid, α linolenic acid and morotic acid. Highest amount of total fatty acids was present in Spathoglossum asperum and K. alvarezii. Relatively higher amount of saturated fatty acids were recorded in K. alvarezii (6.707 mg/100g DW) in the present study. Poly unsaturated fatty acids such as linoleic acid and α-linolenic acid that cannot be synthesized by human beings and other vertebrates were detected in S. asperum in an appreciable level. Maximum amount of magnesium in Sargassum cinereum (67.6 mg/100g DW)
and zinc in *S. asperum* (2.8399 mg/100g DW) were recorded. Minerals such as iron and copper were present in seaweeds at higher levels than in many well-known terrestrial sources of minerals, such as meat and spinach. Iron and copper was observed in highest level from green alga *Enteromorpha intestinalis*. Based on the abundance of nutritive components viz., carbohydrate, protein, lipid, amino acids, fatty acids and vitamins, the study suggest that seaweeds like *Enteromorpha intestinalis, Sargassum ilicifolium, Sargassum tenerrimum, Colpomenia sinuosa, Padina tetrastratica, Spathoglossum asperum, Turbinaria conoides, Hypnea musciformis, Rhodymenia palmata, Gracilaria pygmaea* and *Kappaphycus alvarezi* could be substituted with terrestrial vegetables for human consumption with proper processing. However, palatability, acceptability and incompatible problems must be analyzed before consumption.

Oxidative stress has been suggested to be the cause for series of events that deregulate the cellular functions, destroying biological molecules such as lipids, proteins, enzymes and nucleic acids and leading to various pathological conditions. Antioxidants are secondary metabolites with great diversity, synthesized by plants and seaweeds that enable the body to maintain the oxidant level and mediating normal functioning on consumption. The antioxidant chemicals such as phenol, flavonoid and tannin were abundantly present in the members of Phaeophyceae. In brown seaweeds the phenol level was 4-5 folds greater than green and red seaweed. Among the brown seaweeds studied, *Spathoglossum asperum, Stoechospermum marginatum, Padina pavonia, Padina tetrostratica* and *Sargassum wightii* were enriched with flavonoid, however other species like *Colpomenia sinuosa, Sargassum ilicifolium* and *Turbinaria conoides* also contained significant amount. The present study exemplified
that the red and green species contained lower total condensed tannin than the brown seaweeds. Results indicated that *Acanthophora spicifera* is overall a good source of water soluble vitamins, containing thiamine, riboflavin, niacin and pyridoxine. Of the Chlorophycean members, *Ulva reticulata* was seemed to be a rich source of thiamine (0.334 mg/100g DW), riboflavin (0.437 mg/100g DW), niacin (0.734 mg/100g DW) and pyridoxine (0.117 mg/100g DW). Vitamin C was found in twenty nine species studied. *S. marginatum* (26.56 ± 4.10 mg/g DW) was noted for its higher vitamin C level. Present study revealed that brown seaweeds contained higher levels of vitamin E than green and red seaweeds. Among all the seaweeds *Stoechospermum marginatum* (58.37 ± 1.55 %) showed maximum DPPH (2, 2-diphenyl-1-picrylhydrazyl reagent) radical scavenging activity. Superoxide anion radical scavenging was found to be more in *Gracilaria corticata* and *Amphiroa anceps*. Significant level of reducing power was noted in green and brown seaweeds with the highest value in *Caulerpa scalpelliformis* (58.1±0.012 %). The highest total antioxidant activity was observed in *Sargassum tenerrimum*. Karl Pearson’s correlation analysis between antioxidant chemicals and antioxidant activities revealed that besides phenols, flavonoid and tannin other seaweed components such as low molecular weight polysaccharides, pigments, and protein have contributed to the antioxidant activities / radical scavenging activities of seaweeds.

It is known that most of the secondary metabolites produced by seaweeds have bactericidal or fungicidal properties. The antifungal property of the hexane, benzene, methanol, petroleum ether, chloroform and aqueous extract of seaweeds, against human pathogens (*Candida albicans*, *Trichophyton simii* and *Trichophyton rubrum*) and plant pathogens (*Aspergillus niger* and *Curvularia lunata*) were analysed by disc
diffusion method. Antifungal activities of seaweed extracts were notably higher in Rhodophyceen members. The maximum being found in ethanol extract of *Hypnea musciformis* (24.33 mm) against *Trichophyton rubrum*. Of the four species of brown seaweeds tested, hexane extract of *Sargassum tenerrimum* was most active against *Trichophyton rubrum* (22.33 mm). It was remarkable to note that petroleum ether extract of *Caulerpa scalpelliformis* inhibited the growth of *Trichophyton rubrum* by exhibiting 22.33 mm inhibition zone. Red and brown seaweeds such as *Hypnea musciformis* and *Sargassum tenerrimum* exhibited higher antifungal activity against *Aspergillus niger*. The maximum antifungal activity was observed with hexane extract of *Spathoglossum asperum* (brown) and *Acanthophora spicifera* (red) against *Curvularia lunata*. Further, all the brown and red seaweeds in hexane exerted antagonistic effect on *Curvularia lunata*, however green algae in the same solvent were found ineffective. Green seaweeds such as *Ulva lactuca* and *Ulva reticulata* exhibited higher antifungal actively against *Aspergillus niger*, but it was comparatively lesser than the control.

Life threatening diseases and high rate of mortality occur in animal and human population due to bacterial infection. Many bacteria, both Gram positive and Gram negative contaminate food, water, air, soil, etc. cause biological / microbial pollution. *Bacillus subtilis* is responsible for causing food borne gastroenteritis, *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa* cause diseases like mastitis, abortion and upper respiratory complication while *Salmonella typhi* cause diarrhoea and typhoid fever. Hence, in this investigation bactericidal property of ten seaweeds, extracted with various solvents were tested against human pathogens *Escherichia coli, Bacillus subtilis, Salmonella typhi, Pseudomonas aeruginosa* and
Klebsiella pneumoniae. Methanolic extract of Padina pavonia was apparently more detrimental to Escherichia coli, whereas chloroform and benzene extract was very active against Bacillus subtilis and Salmonella typhi, Pseudomonas areuginosa. All the solvent extracts of Padina pavonia apart from water, produced inhibition zone more or less similar to the synthetic antibiotic, streptomycin. Among the three green seaweeds, Caulerpa scalpelliformis was found to be more effective in controlling the human pathogens studied. Methanol extract of Stoechospermum marginatum was more active against Escherichia coli. Similarly Pseudomonas areuginosa and Klebsiella pneumoniae were also effectively controlled by Sargassum tenerrimum extracts. Among all the brown seaweeds analysed Padina pavonia was found to have more antibacterial potential. Further, all the brown seaweed extracts were substantially reactive against all the pathogens used in the study. Petroleum ether and hexane extract of Acanthophora spicifera was assessed to be more antagonistic against Salmonella typhi and Klebsiella pneumoniae respectively. Perusal of data indicated that methanolic extract of A. spicifera was more detrimental to all the pathogens studied. More or less, all the solvents were proven to be suitable for isolation of bioactive, bactericidal compounds.

It was found that among the various seaweeds, Padina pavonia and Acanthophora spicifera were found to be more effective in mediating the formation of silver nanoparticles. Silver nanoparticles were further confirmed by UV-visible spectrophotometric analysis. The peak occurred at 420 nm corresponds to the absorbance by silver nanoparticles. The scanning and transmission electron microscopy images confirmed that the silver nanoparticles obtained by the reduction of silver by seaweed extracts were predominantly spherical shaped. The silver nanoparticles
produced by Padina pavonia and Acanthophora spicifera extract showed maximum antibacterial activity against E. coli. In order to ascertain the compounds with different functional groups behind antifungal and antibacterial potential, seaweeds, such as Ulva lactuca, Caulerpa scalpelliformis, Sargassum tenerrimum, Padina pavonia and Gracilaria verrucosa were subjected to FTIR spectroscopic analysis. The FTIR spectrum was used to identify the functional group of the active components based on the peak value in the region of infrared radiation. It confirmed the presence of compounds with functional groups such as primary amines, alkanes, secondary amines, aliphatic aldehydes, tertiary butyl aromatic esters, cycloalkanes, heterocyclic monosubstituted benzenes, flavonoids and xanthophylls. Hare Island part of Gulf of Mannar, National Marine Reserve Park is a rich repository of diversified marine flora and fauna. The study indicated that, Hare Island was endowed with numerous taxa belonging to Chlorophyceae (30 species) Phaeophyceae (28 species) and Rhodophyceae (32 species). Seventeen taxa were found as most abundant in this area. Seaweeds were abundant during post monsoon followed by monsoon and pre monsoon season. The study suggested that post monsoon season is more appropriate for seaweeds harvest.

The present study proposed that consumption of seaweeds such as Rhodymenia palmata, Colpomenia sinuosa, kappaphycus alvarezii, Sargassum illicifolium, Padina tetrastromatica, Gracilaria pygmaea, Ulva reticulata and Hypnea musciformis as a dietary supplement or as part of a balanced diet would meet the recommended daily intake of essential mineral nutrients, vitamins, protein, dietary fibre, essential amino acids, poly unsaturated fatty acids and antioxidants. Regular use of seaweeds as food supplement prevents malnutrition, obesity and also regulate cell
functions, protect from degenerative diseases. More over these seaweeds were found to possess antiphytopathogenic potentials and thus could be effectively explored as ecofriendly biopesticides in the field of agriculture. As organic solvent extracts of seaweeds namely *Ulva lactuca, Ulva reticulata, Caulerpa scalpelliformis, Padina pavonia, Sargassum tenerrimum, Stoechospermum marginatum, Spathoglossum asperum, Acanthophora spicifera, Gracilaria verrucosa* and *Hypnea musciformis* were highly reactive against human fungal pathogens (*Candida albicans, Trichophyton simii* and *Trichophyton rubrum*) and bacterial pathogens like *Escherichia coli, Bacillus subtilis, Salmonella typhi, Pseudomonas areuginosa* and *Klebsiella pneumoniae* these seaweeds could be exploited as a natural cost effective alternative resource for the development of antifungal and antibacterial drugs. Silver nanoparticles synthesized using seaweeds were smaller with high purity, further entrench advantage of deployment of seaweeds in drug development. However proper planning, husbanding and cultivation of these seaweeds are necessary for sustainable utilization. Hare Island provides a conducive environment and habitat for establishment of seaweeds. As nature’s wealth, seaweeds have to be used to promote future health.