The review of literature pertaining to the study on “Nutrient Composition, Antioxidant Activity and Therapeutic Use of Selected Seaweeds”, is presented under the following headings.

2.1 Seaweeds - An overview
2.2 Seaweeds - Power house of Nutrients
2.3 Seaweeds - Functional food and Therapeutic uses

2.1 Seaweeds - An overview

Algae are relatively simple photosynthetic plants with unicellular reproductive structures. They range from unicellular organisms to non vascular filamentous or thaloid plants (Druehl, 2000).

Seaweeds are large algae (macro algae) that grow in salt water or marine environment and lack true stems, roots and leaves (Krishnamurthy, 1996).

Seaweeds commonly grow on coral reefs or in rocky landscape or can grow at great depths if sunlight can penetrate through the water (Mateljan, 2006). Most of the seaweeds can be seen thriving in underwater beds floating along the sea surface attached to rocks (Collen, 2001).

Seaweeds play an important and vital role in the marine ecosystem, providing food and shelter for host of creatures, such as sea urchins, lobsters and young fishes.

2.1.1 Types of seaweed

Three major groups of seaweeds are recognized according to their pigments that absorb light of particular wavelengths and give them their characteristic colors of green, brown or red (Collins, 2001).
The green algae (Chlorophyta) are truly green with no pigments to mask the chlorophyll. The green algae are very diverse and range from microscopic free-swimming single cells to large membranous, tubular and bushy plants (Davies, 2002).

Brown algae (Phaeophyta) are multi-cellular and are found in a variety of different physical forms including crusts and filaments. Like all photosynthetic organisms, brown algae contain the green pigment chlorophyll. They also contain other gold and brown pigments, which mask the green colour of chlorophyll. The dominant pigment found in brown algae is called fucoxanthin (Bartle, 2005).

The red algae (Rhodophyta) in addition to chlorophyll contain the pigments phycocyanin and phycoerythrin which give the red colouration. Red algae are found in a variety of physical forms, including simple and branched filaments (Harbo, 1999).

2.1.2 Morphology of seaweeds

Seaweeds do not require support structures. Figure 1 shows the structure of seaweeds.

Instead of roots seaweeds have holdfasts, which attach them to the sea floor. A holdfast is not necessary for water and nutrient uptake, but is needed as an anchor. The stalk or stem of seaweed is called as stipe. The function of the stipe is to support the rest of the plant. The structure of the stipe varies among seaweeds and they can be flexible, stiff, solid, gas-filled, very long (20 metres), short or completely absent (Druehl, 2000).
The leaves of seaweeds are called blades. The main function of the blades is to provide a large surface for the absorption of sunlight. In some species the blades also support the reproductive structures of the seaweed. Some seaweeds have only one blade, which may be divided, while other species have numerous blades (Harbo, 1999).

Many seaweeds have hollow, gas-filled structures called floats or pneumatocysts. These help to keep the photosynthetic structures of the seaweed buoyant so they are able to absorb energy from the sun (Turner, 2003).

Absorption of nutrients takes place directly through the walls of the thallus. The thallus may be simple filament of cells or columns of cells, a flattened membrane of one or several layers of cells or a complex set of organs including stipe holding photosynthetic frond and reproductive organs (Tudge, 2000).

### 2.1.3 Biodiversity of seaweeds in the Indian coastline

Jha *et al.* (2009) reports that India is bestowed with a long coastline (7,516 Km) and sizeable (2.5 million sqkm) Exclusive Economic Zone (EEZ) which is about two third of the main land area. The seaweed flora of India is highly diversified and comprises mostly of tropical species.

According to Untawale *et al.* (1983) Indian coastline has 844 species of marine algae belonging to 215 genera and 64 families. Gulf of Mannar stands first in terms of diversity and density (302 species), followed by the Gulf of Kutch (202 species). The biodiversity of seaweeds in Gulf of Mannar is due to the large extent of coral reefs, which provide suitable substrate for its growth (Kannan *et al.*, 2006).

Figure 2 shows the biodiversity of seaweeds in the Indian coastline

Seaweed diversity is prominent in Gulf of Mannar, Gulf of Kutch, Lakswadeep and Andaman and Nicobar Islands (Kaliyaperumal *et al.*, 2001).
2.1.4 Consumption pattern of seaweeds

Young et al. (2006) reported that almost everyone in the world from ancient times have been consuming marine algae. The Chinese, Japanese, Filipinos and Hawaiians considered seaweed as a food of great delicacy and have been using in
their diets for centuries. Seaweed is a dietary staple, enjoyed in Iceland, Scotland, Hawaii and other Pacific Islands and coastal regions of the United States (Webb, 1997). In California large farmers harvest giant kelp mechanically, preparing it for human and livestock consumption.

In Asia, seaweeds have been consumed as a vegetable since the beginning of time. On an average, the Japanese eat 1.4 kg per person per year (Funahashi et al., 1999).

Smith (1992) reported that many plants from the sea have been staples in the diets of many cultures. Twentyfive per cent of all food Japan consume is seaweed. In Canada, seaweed is used in bread and soups. Other species often called Laver are eaten in the British Isles. Irish moss (Chondrus crispus), a red algae, is consumed in the United States.

Think Quest (2006) reported that seaweeds, especially species of the red algae Porphyra (Nori and Chondrus), form an important part of the diet and are used for food in China and Japan.

Krishnamurthy (1996) reported that in Hawaiian Islands, edible seaweeds are called Limu and these are grown in royal gardens to provide food to the royal family. In Japan, number of seaweeds is used as food and the most common one is Porphyra species. Similarly a number of seaweeds are used as sources of drugs. Such seaweeds are mentioned in the Chinese Materia Medica and algae are also mentioned in Ayurvedic texts like Bhava and Rakasa.

### 2.1.5 Uses of seaweeds

Bilan et al. (2007) indicated that algin is a polysaccharide derived from the brown seaweeds or Phaeophyceae. Its derivatives have wide application in the food industry as gelling, water holding, emulsifying and stabilizing agents.
Hydrocolloids

A hydrocolloid is a non crystalline substance with very large molecules which dissolves in water to give thickened (viscous) solution. Various red and brown seaweeds are used to produce hydrocolloid namely agar, alginate and carageenan. These are water soluble carbohydrates that are used to thicken (increase the viscosity of) gels, jellies of varying degree of firmness, to form water soluble films and to stabilize some products such as ice cream so that the ice cream can retain a smooth texture (Kaladharan et al., 1998). Seaweed has been as a source of phycocolloids (alginate, carageenan and agar) thickening and gelling agents for various industrial applications, including uses in food (Wantanabe et al., 1999).

Two genera, *Gelidium* and *Gracilaria* account for most of the raw material used for the extraction of agar. Extractions from *Gelidium* species gives higher quality agar and are called agarophytes; brown seaweeds like *Laminaria* and *Undaria* are used for the extraction of alginates and are called alginophytes. The red seaweeds *Chondrus crispus* (Irish moss) and *K. alverezii* are used for carrageenan extraction and are called carrogeenophytes (Kaliyaperumal, 2003).

Carrageenans are phycocolloids obtained from members of the *Hypneaceae*. Carrageenan is used in the food and pharmaceutical industry as an emulsifier, as a sizing ingredient in the textile and leather industries (Subbarao et al., 2001).

Antimicrobial activity

Algae species have been shown to have bactericidal or bacteriostatic substances (Glombitza, 1979; Caccamese et al., 1980). The antibacterial agents found in the algae include aminoacids, terpenoids, phlorotannins, acrylic acid, phenolic compounds, steroids, halogenated ketones, alkanes, cyclic polysulphides and fatty acids. In large number of marine algae antimicrobial activities are attributed to the presence of acrylic acid., phlorotannins, terpenoids and steroids (Glombitza, 1979 and Arnico et al., 1978).
The antimicrobial activities exhibited by the seaweeds are due to the capacity of the seaweeds to synthesize bioactive secondary metabolites (González del Val et al., 2001). There are numerous reports on compounds derived from macroalgae with a broad range of biological activities, such as antibacterial (Oranday et al., 2004) antiviral, antitumor and anticoagulant (Athukorala et al., 2006 and Farias et al., 2000).

Antibacterial activity of seaweeds varies with season (Moreau et al., 1984). Antibacterial effects of crude methanol extracts obtained from 32 marine macroalgae species (13 Chlorophyceae and 19 Phaeophyceae) harvested from the Atlantic and Mediterranean coast of Morocco were found to be effective against pathogenic bacteria namely Escherichia coli, Staphylococcus aureus, Klebsiella pneumoniae and Enterococcus faecalis (Chiheb, 2009).

Vallinayagam et al. (2009) reported the antibacterial activities of four seaweeds namely Ulva lactuca, Padina gymnospora, Sargassum wightii and Gracilaria edulis against human bacterial pathogens Staphylococcus aureus, Vibrio cholerae, Shigella dysentriae, Shigella bodii, Salmonella paratyphi, Pseudomonas aeruginosa and Klebsiella pneumonia. The maximum activity (8.8 mm inhibition zone) was recorded from the extract of Gracilaria edulis against Staphylococcus aureus and (11.2 mm) by Ulva lactuca against Pseudomonas aeruginosa.

Karthikadevi et al. (2009) studied the antibacterial activity of some commonly occurring green algae Codium adherens, Ulva reticulata and Halimeda tuna. The maximum antibacterial activity was noted in ethanol extracts of Ulva against Staphylococcus (13 mm of inhibition zone) and the minimum antibacterial activity was recorded in methanol extracts of Codium against Escherichia coli (8 mm), Staphylococcus (5 mm) and proteus (2 mm), Streptococcus (2 mm) and Enterococci (3mm).
Kim et al. (2005) studied the *invitro* antimicrobial activity of the marine green algae *Ulva lactuca* by testing against gram-positive bacteria, gram-negative bacteria and a fungus. The ethyl-ether extract of algae exhibited a broad-spectrum of antibacterial activity. *Ulva lactuca* extract showed strong activity against the bacterium methicillin-resistant *Staphylococcus aureus* (MRSA). This result confirms the potential use of seaweed extracts as a source of antibacterial compound and as a healthy feed for aquatic animals.

Tadahiko et al. (2007) recognized the antimicrobial properties of seaweeds by extracting the essential oils from seaweeds *Laminaria japonica, Kjellmaniella crassifolia, Gracilaria verrucosa* and *Ulva pertusa*. The results indicated that α, β-unsaturated carbonyl compounds from seaweeds strongly inhibited tyrosinase activity. Thus indicating that the flavor compounds that are found in seaweeds are valuable antimicrobial and browning-inhibitory agents.

Kandhasamy et al. (2008) stated that the marine green alga, *Ulva lactuca*, contain 3-O-β-D glucopyranosyl-stigmasta-5,25-dien. The antimicrobial activity of the isolated compound was tested against ten various microorganisms (G+, G-, fungi and yeast strains) and found to be very effective.

Hari et al. (1992) reported that green algae *Ulva fasciata* found in the west coast of India showed an *invitro* and *invivo* antiviral activity. The potent antiviral activity was found to be due to the compound N-palmitoyl-amino-1,3,4,5-tetra-hydroxyoctadecane present in the selected seaweed.

The *invitro* antibacterial activities of seaweeds of Chlorophyceae (*Caulerpa racemosa* and *Ulva lactuca*), Rhodophyceae (*Gracillaria folifera* and *Hypnea muciformis*) and Phaeophyceae (*Sargassum myricocystum, Sargassum tenneerimum* and *Padina tetrastomatica*) were studied against both gram-negative and gram-positive pathogenic bacteria. Chlorophyceae members showed high
antibacterial activity than other members of the red and brown algae tested (Selvi et al., 2001).

2.2 Seaweeds - Power house of Nutrients

Ali (2009) reported macroalgae are considered as the most important source of many biologically active metabolites.

2.2.1 Proximate Composition

Algae contain 80–90 per cent water and on a dry weight basis approximately 50 per cent are carbohydrates, 1–3 per cent are lipids and 7–38 per cent minerals. Protein content is highly variable (10–47 per cent) with a high proportion of essential amino acids. Algae have high concentration of vitamins and minerals that provide an obvious health benefit. Algae contain more vitamin A, B-12, C, β-carotene, pantothenate, folate, riboflavin and niacin than fruits and vegetables (Keiji Ito et al., 2000).

Nirmal et al. (2010) studied the biochemical constituents of eighteen species of marine macroalgae belonging to Chlorophyta, Phaeophyta and Rhodophyta collected from Okha coast, Gulf of Kutch, India and compared their biochemical composition. The carbohydrate, amino acid, protein, lipid and ash contents were in the range of 16–45 per cent, 9–20 per cent, 10–35 per cent, 8–34 per cent and 0.4–14 per cent on fresh weight basis, for all the selected seaweeds respectively.

Arporn et al. (2006) studied the nutritional qualities of two edible green seaweeds, Caulerpa lentillifera and Ulva reticulata. Caulerpa lentillifera and Ulva reticulata contained 12.49 per cent and 21.06 per cent protein and 24.21 per cent and 17.58 per cent ash based on dry weight respectively. Caulerpa lentillifera was found to be rich in phosphorus, calcium, magnesium and copper while Ulva reticulata was rich in potassium, manganese and iron.
Manivannan et al. (2006) studied the nutrient composition of different seaweeds like green (Ulva reticulata, Enteromorpha compressa, Cladophora glomerata, Halimeda macroloba and Halimeda tuna) brown (Dictyota dichotoma, Turbinaria ornata and Padina pavonica) and red (Gelidiella acerosa, Gracilaria crassa and Hypnea musciformis) collected from Vedalai coastal waters, Southeast coast of India. The highest protein content was found in G. acerosa and Ulva and lowest in D. dichotoma. Highest carbohydrate level was observed in T. ornata and lowest in P. pavonica. The lipid content was high in H. tuna and low in H. macroloba.

Mohd Norziah et al. (1999) reported that Gracilaria changgi an edible seaweed contained, 74 per cent of unsaturated fatty acids mainly the omega fatty acids and 26 per cent of saturated fatty acids (mainly palmitic acid) and also relatively high levels of calcium and iron. Major amino acid components were glycine, arginine, alanine and glutamic acid. This study also had aimed at popularizing the consumption and utilization of Gracilaria changgi in Malaysia.

Wong et al. (2000) studied the proximate composition and amino acid profile of two subtropical red seaweeds (Hypnea charoides and Hypnea japonica) and one green seaweed (Ulva lactuca). The total dietary fiber ranged from 50.3 to 55.4 per cent dry weight and ash ranged from 21.3 to 22.8 per cent. The crude lipid contents of the three seaweeds were very low and ranged from 1.42 to 1.64 per cent.

Kamatham et al. (1994) evaluated the food safety and nutritional quality of Indian seaweed species Enteromorpha linza, Enteromorpha prolifera, Ulva fasciata, Caulerpa taxifolia and Sargassum johnstonii collected from natural and cultivated populations. Among the above seaweeds Enteromorpha prolifera of natural habitat showed the highest caloric value and protein content and these values were lowest in Sargassum johnstonii species of natural habitat. The lipid content was high in cultivated seaweeds of E. linza and U. fasciata species.
Sanchez-Machado et al. (2004) reported that polysaccharide (ulvan) and glucuronic acid are major constituents of *Ulva* species. Glucuronic acid is an important component of chondroitin, a mucopolysaccharide that act as the flexible connecting matrix between collagen filaments in cartilage to form a polymeric system.

Edible seaweeds are rich in non-starch polysaccharides (dietary fibre) (Lahaye, 1991; Montserrat and Goni, 2002). Benefits are realized from the sulfated galactan and porphyran, which are similar to agar and occur in relatively large quantities in *Porphyra*. The water-soluble dietary fiber present in seaweeds has functional activities such as an anti-blood coagulant, antihypercholesterolemic, anti-tumor and anti-oxidizing activity (Zhang et al., 2003).

*Porphyra* contains nearly seventeen types of free amino acids and the protein content of *Porphyra* species is comparable with that of high-protein plant foods such as soybean (Sanchez- Machado et al., 2004). Furthermore, the digestible proportion (69 – 75 per cent) of the protein and carbohydrates is very high in *Porphyra* species (Turner, 2003).

The fatty acids of seaweeds generally have linear chains containing an even number of carbon atoms with one or more double bonds (Shameel, 1990). Polyunsaturated fatty acids content are high as those of terrestrial vegetables (Darcy-Vrillon 1993). Lipids comprise 2-3 per cent of dry weight of *Porphyra* (Noda 1993).

Sevim et al. (2008) analysed the proximate analysis and the fatty acid profile of brown algae (*Stypopodium schimperii*) and red algae (*Spyridia filamentosa, Acanthophora nayadiformis* and *Halymenia floresii*). The highest protein content was seen in *H. floresii* (3.05 per cent on a dry weight basis) whereas the lowest protein content was seen in *S. schimperii* (1.12 per cent dry weight). The lipid content was found to be 1.10 per cent for *S. filamentosa* and 11.53 per cent for
S. schimperii. The ash content of all the selected algal species ranged from 17.98 to 27.15 per cent on a dry weight basis.

2.2.2 Mineral and vitamin content of seaweeds

Ortega-calvo et al. (1993) reported that seaweed mineral content is higher than that of land plants and animal products. Ryan drum, (2005) reported that most of the seaweed are excellent sources of vitamins A, B, C, D, E and K as well as essential fatty acids. Shirley (2006) reported that a good source of trace minerals such as chromium and iodine are present in seaweeds.

News target (2006) pointed that seaweed contains trace elements chromium and zinc which influences the way insulin behaves in the body and helps with healing properties respectively.

Wanatabe et al. (1999) reported that seaweeds contain vitamin B₁₂, which is particularly recommended in the treatment of ageing, chronic fatigue syndrome (CFS) and anaemia.

Noda (1993) found that Nori contains up to 12.0 - 68.8 µg/100g of dry weight of vitamin B₁₂ and this is roughly comparable to that amount of vitamin B₁₂ from animal sources. Watanabe et al. (1999) reported that only two or three sheets of Nori (3g) are sufficient to satisfy the recommended daily intake of vitamin B₁₂ for a normal adult (2µg/day).

Jimenez Es cring (2000) found that seaweeds contain a high concentration of minerals such as magnesium, calcium, phosphorus, potassium and iodine. Soja (2006) stated that some variety of seaweeds is even richer in calcium than milk and the human body can utilise nutrients from seaweed without wastage.

Burtin (2003) found that seaweeds are also one of the most important sources of calcium and their content may be as high as 34 per cent dry weight.
Seaweed consumption may thus be useful in the case of expectant mother, adolescents and elderly who are all exposed to risk of calcium deficiency.

Le Tutour (1990) stated that lipid extracts of some edible seaweed showed antioxidant activity and synergistic effect with tocopherol. Erhart Shep (2001) reported that sea vegetables are good source of magnesium, which has also been shown to reduce high blood pressure and prevent heart attack. Folic acid in seaweed helps to remove homocysteine. If present in the human body it can increase the risk of coronary heart disease (Matelijan, 2006).

Malea et al. (2001) made an analysis of the levels of iron, copper, zinc, cadmium, lead, sodium, potassium, calcium and magnesium in three green seaweeds namely Ulva sps, Caulerapa and Enteromorpha collected from Antikyra Gulf (Viotia, Greece). The minerals namely iron, potassium, magnesium and sodium was high in Ulva species. Cadmium content was low in all the three species.

Eun Kyoung et al. (2008) reported that the nutritive value of Capsosiphon fulvescens, a new developing species of marine macroalgae in Korea was compared with common edible green seaweed Ulva species collected from Korea and Japan. The main minerals analysed in Capsosiphon and Ulva were sodium, magnesium, manganese, potassium, calcium, aluminium and cobalamin.

The content of sodium and potassium of Capsosiphon were significantly greater than those of Ulva, while manganese and calcium were significantly lower in Capsosiphon. Ulva had a higher amount of cobalamin. These results suggest that both Ulva and C. fulvescens has greater potential to be used as human food and as an ingredient in formulated food.

MacArtain et al. (2007) studied the nutritional aspects of seaweeds in terms of fiber, mineral, lipids and vitamin contents. The results of the study indicated that
a daily intake of eight gram dry weight of seaweed can be consumed for potential nutrient supply.

Dang et al. (2004) studied the nutrient composition of Vietnamese edible marine. Fifteen species of edible seaweeds were studied and reported to contain higher levels of ash, protein, lipid, carbohydrate, fatty acids, vitamins, pigments and minerals.

Abulude et al. (2009) studied the phytate and mineral content of twenty two different varieties of aquatic seaweeds using standard methods. Phytate contents expressed on a dry matter (DM) basis ranged from 394-490mg/100g. The seaweeds also contained sodium (168-32 mg/100g), potassium (408-1110 mg/100g), magnesium (102-401 mg/100g) and calcium (223-460 mg/100g).

Rupérez (2002) stated the mineral content of several brown (Fucus vesiculosus, Laminaria digitata, Undaria pinnatifida) and red (Chondrus crispus, Porphyra tenera) edible marine seaweeds. The selected red seaweeds had high content of ash (21.1–39.3 per cent) and sulphate (1.3–5.9 per cent). Brown seaweeds had ash content (30.1–39.3%) higher than that of red algae. Ash content of selected marine seaweeds had higher amounts of both macro and micro minerals and trace elements than those reported for edible land plants.

Cristina Taboada et al. (2009) reported that the commonly consumed algae Ulva rigida had good quality protein since it contains all the essential amino acids.

2.3 Seaweeds - Functional food and Therapeutic uses

2.3.1 Phytochemicals

Karl Abrams (2000) reported that chlorophyll present in algae is the highest known source of chlorophyll. This green pigment is reported to be vital for rapid assimilation of amino acids.
Piovetto *et al.* (2000) reported that red and green seaweeds contain carotenoids such as beta carotene, lutein, violaxanthin and fucoxanthin in brown seaweeds.

Yan *et al.* (2001) found that the main carotenoids present in the red algae are beta-carotene, alpha carotene and their dihydroxylated derivatives such as zeaxanthin and lutein.

Nakumura *et al.* (1996) revealed that algal polyphenol are called phlorotannin. Phlorotannin ranges from five to 15 per cent of dry weight in seaweeds. It plays an essential role in preventing disease linked to oxidative stress.

### 2.3.2 Antioxidant activity of seaweed

Lipid peroxidation mediated by free radicals is considered to be the major mechanism of cell membrane destruction and cell damage. Free radicals are formed in both physiological and pathological conditions in tissues (Tas *et al.*, 2005).

The uncontrolled production of free radicals is considered as an important factor in the tissue damage induced by several pathophysiologys (Yeh *et al.*, 2005).

Oxidative stress is brought about due to damage by free radicals and this also is known to influence the response of patients to therapy. Moreover the body’s defense mechanisms would play a role in the form of antioxidants and would try to minimize the damage by adapting itself to the stressful situation. Antioxidants are compounds that dispose, scavenge and suppress the formation of free radicals or oppose their actions (Sie, 1988).

Two main categories of antioxidants are the ones which prevent the generation of free radicals and the other that intercept any free radicals that are generated (Cotgreave *et al.*, 1988).
Yuan et al. (2005) reported that algae are also being studied as a source of antioxidants. Epidemiological data obtained in rodents showed the protective effect of red and green algae against intestinal, skin and breast cancer.

Kumar et al. (2008) reported the antioxidant activity of three selected Indian brown seaweeds namesly *Sargassum marginatum*, *Padina tetrastomatica* and *Turbinaria conoides*. Ethyl acetate fraction of *Sargassum marginatum* exhibited highest total antioxidant activity of 39.62 mg ascorbic acid equivalent/g extract. Petroleum ether fraction of *Turbinaria conoides* exhibited lower deoxyribose activity of 47.81 per cent.

Ganesan et al. (2008) studied the invitro antioxidant activities of three Indian red seaweeds namely *Euchema kappaphycus*, *Gracilaria edulis* and *Acanthophora spicifera* and reported that ethanol fraction of *Acanthophora spicifera* exhibited higher total antioxidant activity (32.01 mg ascorbic acid equivalent/g extract) among all the fractions. Higher phenolic content (16.26 mg gallic acid equivalent/g) was noticed in petroleum ether fraction of *Gracilaria edulis*.

Marlène et al. (2009) investigated the effects of *Ulva* on hypercholesterolemic hamsters. Three groups of 12 hamsters were fed with a high cholesterol diet for 12 week and the high cholesterol diet was replaced for an equivalent fibre weight of *Ulva*. Plasma cholesterol, non-HDL cholesterol and triglycerides were reduced in hamsters with *Ulva* dietary treatments and increased the liver glutathione peroxidase activity and showed thiobarbituric acid reactive substances compared with control which was fed with cellulose. Plasma antioxidant capacity increased with the treatment and aortic fatty streak area was noticed to be decreased by 70 per cent in *Ulva* dietary rats.

Huimin et al. (2010) studied the antioxidant activity of sulfated polysaccharide (ulvan) extracted from *Ulva pertusa*. The results showed that ulvan
showed significant inhibitory effects on superoxide and hydroxyl radicals with IC$_{50}$ values of 22.1 µg mL$^{-1}$ and 2.8 mg mL$^{-1}$. The results indicated that *Ulva pertusa* has a stronger antioxidant activity.

Yvonne *et al.* (2006) described that the *Laminaria* and *Porphyra* species has the potential to reduce the risk of intestinal or mammary cancer in animal studies. Evaluation of the effect of red alga, Dulse (*Palmaria palmata*) and three Kelp varieties (*Laminaria setchellii*, *Macrocystis integrifolia*, *Nereocystis leutkeana*) their extracts on human cervical adenocarcinoma cell line (HeLa cells) were studied. The antiproliferative activity exhibited by the seaweed extracts were positively correlated with the total polyphenol contents ($p < 0.05$) suggesting a link related to the content of phlorotannins and polyphenols including mycosporine-like amino acids and phenolic acids present in dulse and kelp.

Soo-Jin *et al.* (2005) reported the potential antioxidative activities of enzymatic extracts from seven species of brown seaweeds. The enzymatic extracts exhibited more prominent effects in hydrogen peroxide scavenging activity (approximately 90 per cent) and their activity was even higher than that of the commercial antioxidants.

Sachindra *et al.* (2010) extracts from brown and red seaweeds of Indian origin were evaluated for their ability to scavenge different radicals and quench singlet oxygen. The methanol extract from brown seaweed exhibited higher 2,2′-azinobis (3-ethyl benzothizoline-6-sulfonic acid) radical scavenging activity and the activity is correlated to the high polyphenol content in the seaweeds.

Meenakshi *et al.* (2009) in their study evaluated the total flavonoid and *invitro* antioxidant activity of two seaweeds *Ulva lactuca* and *Sargassum wightii*. The total flavanoid content and antioxidant activity of methanolic extract was 2.02±0.07 mg GAE/g and 1.16±0.11 mg GAE/g respectively in *Ulva lactuca* and *Sargassum wightii* respectively.
Xiaolin-Hou (2000) described that twenty seven species of Chinese seaweed were tested for antioxidant activity. Among them 15 seaweeds had significant antioxidant activity in at least one of the organic solvent extracts. The antioxidant activity was high in seaweed species namely *Gloiosiphonia capillaries*.

Cox *et al.* (2010) studied the antioxidant activity of six species of edible Irish seaweeds *Laminaria digitata*, *Laminaria saccharina*, *Himanthalia elongata*, *Palmaria palmata*, *Chondrus crispus* and *Enteromorpha spirulina*. The total phenolic contents of dried methanolic extracts were significantly different among the different seaweeds. *Himanthalia elongata* had the highest phenolic content of 151.3 mg GAE/g and also had the highest DPPH scavenging activity with a 50 per cent inhibition (EC50) level at 0.125µg/ml of extract.

Chew *et al.* (2008) evaluated the Total Phenolic Content (TPC) and Antioxidant Activity (AOA) of 50 per cent aqueous methanol extracts of the marine algae, *Padina antillarum*, *Caulerpa racemosa* and *Kappaphycus alvarezzi*. *Padina antillarum* was found to have the highest total phenolic content, 2430±208 mg gallic acid equivalents (GAE) per 100 g dried sample and ascorbic acid equivalent antioxidant capacity (AEAC) of 1140±85 mg AA/100 g.

**2.3.3 Therapeutic value of seaweeds**

Susun Weed (2002) found that seaweeds are an everyday miracle. The benefit of including seaweeds in our daily diet increases longevity, enhances immune functioning, revitalize the cardiac system, endocrine, digestive and nervous systems. Seaweed has also been found traditionally useful to cure a variety of maladies.

**2.3.3.1 Cancer**

News target (2006) stated that in Japan the low rate of breast cancer can be traced to the fact that the Japanese eat a great deal of seaweed. A diet containing kelp lowers the level of the sex hormone oestradiol (a form of oestrogen) in rats and
might also decrease the risk of oestrogen dependent disease such as breast cancer in human beings.

Mateljan (2006) found that seaweeds contain good amounts of lignans, plant compounds with cancer protective properties. Louis (2000) revealed that edible brown seaweeds have anti-tumour activity and inhibit cancers of colon cancer, brain and sarcoma by boosting the immune system. Seaweeds contain powerful antioxidant and anti cancer properties to arrest the proliferation of cancer cells (Cousens, 2000).

Hiroomi Funahashi et al. (2001) investigated the chemopreventive effects of Wakame seaweed on breast cancer and reported a suppressive effect on the proliferation of DMBA (DiMethylBenz (a) Anthracene) induced rat mammary tumors. These effects were better than that of a chemotherapeutic agent widely used to treatment of human breast cancer.

2.3.3.2 Cardiovascular disease

Solibami et al. (1985) explains that brown algae contain alpha, beta and gamma tocopherol while the green and red algae contain only the alpha tocopherol. It was shown that the gamma and alpha tocopherol play an important role in the prevention of cardiovascular disease.

Renaud et al. (1999) described that lipids represent only 1.5per cent of algal dry matter and has shown interesting polyunsaturated fatty acid composition of omega 3 and omega 6 fatty acids which play a role in the prevention of cardiovascular diseases.

Matelijan (2006) found that folic acid in seaweeds helps to remove homocysteine, which otherwise increase the risk of cardiovascular diseases. Seaweeds are also very good source of magnesium, which has also been shown to reduce high blood pressure and prevent heart attack.
Kyeung-Soon Lee (2004) reported that the therapeutic potential of Low Molecular Weight (LMW) fucoidan, a sulfated polysaccharide extracted from brown seaweed. *Invitro* results showed improvement in tissue blood flow along with tissue regeneration in rat models. The Low Molecular Weight (LMW) fucoidan supplementation also initiated angiogenesis in rat model.

Ara *et al.* (2004) studied the ethanol extracts of five seaweed species *Solieria robusta, Iyengaria stellata, Colpomenia sinuosa, Spatoglossum asperum* and *Caulerpa racemosa* at 10 mg/200 g body weight for their hypolipidemic activity. All the species significantly decreased the total cholesterol, triglyceride and low density lipoprotein levels to normal.

### 2.3.3.3 Thyroid dysfunction

Remirez *et al.* (1999) reported that brown seaweeds have traditionally been used for treating goitre.

Seaweeds, especially Kelp are nature’s richest sources of iodine, which as a component of thyroid hormones thyroxine (T4) and triiodothyroid glands adds iodine to the amino acid tyrosine to create hormone secretion (Mateljan, 2006).

Ron Roberts (1997) stated that seaweeds stimulate the immune system and in folk medicine, it is used to treat respiratory and gastrointestinal problem and maintain thyroid activity.

Yaychuk *et al.* (2006) reported that the amount of iodine found in seaweeds exceeds that found in land plants by as much as 20,000 per cent. It also helps to nourish the thyroid gland and maintain good thyroxine levels.

### 2.3.3.4 Weight Imbalances

Shirley (2006) reported that obesity is rare among the Polynesians and other races that incorporate seaweeds as a regular part of their daily diet.
Guiry (2010) reported that seaweed has been promoted for weight loss, boosting the immune system. Seaweeds were also found to decrease blood sugar and cholesterol levels and improved gastro-intestinal tract function.

2.3.3.5 Other Disorders

Yay Chuk (2006) opined that seaweeds provides organic chlorine component that are important in the manufacture of hydrochloric acid in the stomach. The mucilage in seaweed is soothing to the intestinal tract and promotes peristalsis. The gel in sea vegetables are nutritious and provide roughage as well. Vitamin A, D and C found in seaweeds help to rebuild the mucous membranes of the intestinal tract.

Recent studies showed that phycobiliproteins present in seaweeds are beneficial in the prevention or treatment of neuro-degenerative diseases caused by oxidative stress (Gonzalez et al., 1999; Padula et Boiteux 1999 and Remirez et al., 1999). Erhart Shep (2001) reported that seaweeds have traditionally been used in Asia to treat heart disease, hypertension, cancer and thyroid problems.

Seaweed consumption may be useful for expectant mothers, adolescents and elderly to overcome the risk of calcium deficiency (Gonzates et al., 1999; Padula and Boiteux, 1999). Richards (2010) revealed that consuming seaweeds helps to boost health and immune system of an individual.

Brenden et al. (2008) reported that use of extract from algae is beneficial for enhancing the skin barrier and act as a photo protector for skin and prevents skin cancer. Seaweeds are also used in the treatment of Human Immuno Virus (HIV) and called as poor mans “HAART” (Jane et al.1981).

2.3.4 Bioavailability of seaweed nutrients

Nutrients in seaweeds have a higher bioavailability than nutrients of land plants. When used in dishes they can increase the concentration of nutrients ability to absorb the nutrients from the dishes (Rising tide www.loveseaweed.com).
Natural foods rich in iron provide an alternative choice other than iron fortification for improving iron nutrition. However, plant foods usually have components that inhibit iron absorption (Hallberg, 1981) so availability of iron from laver was evaluated in a rat hemoglobin regeneration bioassay (AOAC, 1995; Fritz et al., 1974; Rotruck and Luhrsen, 1979).

*Porphyra* is rich in iron (Shaw and Liu 2000) and zinc (Nisizawa et al. 1987). Haemoglobin regeneration assays demonstrated that the amount of available iron from *Porphyra* (0.28 mg to 0.91 mg Fe/g dry matter) was comparable to many iron-fortified foods (Amine and Hegsted, 1974). *Porphyra* also contains relatively high contents of essential trace elements including copper (Cu), manganese (Mn) and selenium (Se) (Noda 1993).

Maria et al. (2009) reported that marine algae are easily produced and are good sources of iron. Algae consumption could help to combat iron deficiency and anaemia worldwide. A total of eighty-three subjects were fed with maize-or wheat-based meals containing marine algae (*Ulva* species, *Sargassum* species and *Porphyra* species). The results showed that algae significantly increased iron absorption in maize or wheat-based meals. All three seaweeds were reported to be good sources of bioavailable iron.

Mohamed-Fayaz et al. (2005) studied the iron bioavailability of *Kappaphycus alvarezi*, edible seaweed from the west coast of India and were analyzed for its chemical composition. It was found that *Kappaphycus alvarezi* is rich in protein (16.24 per cent w/w) and contains a high amount of fiber (29.40 per cent w/w) and carbohydrates (27.4 per cent w/w). *Kappaphycus alvarezi* showed vitamin A activity of 865µg retinal equivalents/100g. *Kappaphycus alvarezi* was also found to be good source of minerals namely 0.16 per cent of calcium, 0.033 per cent of iron, and 0.016 per cent of zinc, which are essential for various vital biological activities. Bioavailability of iron by invitro
methods showed a higher efficiency in intestinal conditions than in stomach conditions.

Wong et al. (2000) reported the nutritional values of seaweed Protein Concentrates (PCs) isolated from two red seaweeds (Hypnea charoides and Hypnea japonica) and one green seaweed (Ulva lactuca) and also evaluated for their *invitro* protein digestibility and amino acid profiles. Both protein extractability and *invitro* protein digestibility of the red seaweed Protein Concentrates (88.7–88.9 per cent) were significantly (*P*<0.05, ANOVA, Tukey-HSD) higher than those of green seaweed Protein Concentrates (85.7 per cent).