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A REVIEW ON BIOCHEMICAL COMPOSITION AND NUTRITIONAL ASPECTS OF SEAWEEDS

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ABSTRACT:

Seaweeds have been consumed in Asia since ancient times. Marine algae have been utilized in Japan as raw materials in the manufacture of many seaweed food products, such as jam, cheese, wine, tea, soup and noodles and in the western countries, mainly as a source of polysaccharides for food and pharmaceutical applications. Seaweeds are an important source for food, fodder fertilizer and medicine from the ancient times. The earliest record of use of sea weed dates back to 2700 BC in the compilation of "Chinese herb" by Emperor Shen Nung. Because of their high protein content, Protein Concentrates (PCs) of seaweeds have become more important for the food industry, especially in developed countries. Their recent utilization as an animal feed is on the increase due to their nutritive importance. Generally most of the seaweeds contains high ash (indicates appreciable amount of diverse minerals), high fibers, low protein and moderate amount of fatty acids. The Rhodophyta members contain high protein content (32%), where as Chlorophyta members contain highest carbohydrate content (35%). The most common edible seaweeds in Asian countries are *Porphyra* Spp., *Padina* Spp., *Undaria* Spp., and *Laminaria* Spp. Sea weeds are good additive to improve the nutritive quality of various foods.

INTRODUCTION:

In marine ecosystems, macroalgae are ecologically and biologically important. Macroalgae communities provide nutrition, reproduction, and an accommodating environment for other living organisms. Because of these properties, macroalgae are some of the most important organisms maintaining the ecosystem's stability**.** Marine algae are an important source of dissolved organic carbon in coastal waters. The organic carbon is represented by carbohydrates, polysaccharides, nitrogenous and polyphenol materials. In addition to that they are also excellent source of bioactive compounds such as carotenoids, dietary fibers, proteins, essential fatty acids, vitamins and minerals and also important sources of medicine and fertilizer [7,10,11,17,21,46,47]**.**

Seaweeds have been an important dietary component since, at least fourth century in Japan and sixth century in China. In Korea also consumption of seaweeds is a common practice [44]. Nowadays residents of many countries like in Europe, Pacific Ocean and others are consuming the seaweeds. Its food value, flavor, colour and texture appearance favors the use of seaweed as food. Different species of seaweeds especially protein rich seaweeds are used as human food in different countries all over the world [13]. Certain edible seaweeds contain significant quantities of protein, lipids, minerals and vitamins [27]. Nutrient content of seaweeds vary with species, geographical location, season, humidity and temperature [14]. Seaweeds contain potential antibacterial, anti funagal, anti oxidant and anti Viral activities [44]. Algae are important in nature and in human life as sources of food for man and animals. Industrially many important items, such as agar-agar and gelatinous material for bacteriological culture, soups, deserts, shoe polishes. Cosmetics, shaving cream and laxatives are obtained from algae [13]. Macroalgae are nutritionally valuable as fresh or dried vegetables, salads, or as ingredients in a wide variety of prepared foods [35]. Sea weeds can play a vital role in various aspects compared to other aquatic resources. Much attention should be given on seaweed to compensate the food problem to some extent and fulfill the deficiency of nutrition for erecting the economy of several countries. The present study can be the future directions on the detailed study of specific seaweed [37].

Seaweeds are macro-algae or multi-celled marine algae which appear like terrestrial plants. Seaweeds are not classified as true plants because they lack an organized vascular system for absorbing nutrients. Each cell is in contact with the water and they can take up nutrients, gases and fluids directly. The root like part is called the holdfast, the stem is the stripe and the leaf of the seaweed is the blade or frond. Seaweeds are similar to flowering plants as they are able to use chlorophyll to conduct the process of photosynthesis and create food for growth. However, seaweeds differ from land plants in that the holdfast is used to primarily anchor or secure the seaweed to the substrate instead of absorbing water and nutrient. Rather, the blade or fronds absorbs nutrients for the seaweed to grow from the saltwater. In addition, seaweed have a process of sexual reproduction based upon either spores and gametes, or an asexual process based upon fragmentation [9].

CLASSIFICATION OF SEAWEEDS:

Macro-algae or "seaweeds" are multicellular plants growing in salt or fresh water. Based on their pigmentation they were classified in to Chlorophyta (green algae), Rhodophyta (Red algae) and Phaeophyta (Brown algae). The coastal zone of Eritrea lies in the southern part of the red Sea and it is just over 1000 km long. It has high salinity range around 40.5ppt and supports a relatively high level of endemism, including 9% for macro algae. According to Ateweberhan and Reire (2005), In the Eritrean coast of red sea recorded a total of 286 specific and infraspecific taxa of seaweeds including 50 Chlorophyta, 108 Phaeophyta and 128 Rhodophyta., that survey resulted in 36 new records for Eritrea (11 Chlorophyta, 7 Phaeophyta and 18 Rhodophyta). Of these Eritrean records, 26 are new for the Red Sea (5 Chlorophyta, 4 Phaeophyta and 17 Rhodophyta). According to the report Rhodophyta species are the most abundant in the red sea of Eritrea [1].

The Chlorophyta (Green algae):

The green algae are classified in the phylum Chlorophyta. Green seaweeds are usually found in the intertidal zone (between the high and low water marks) and in shallow water where there is plenty of sunlight. They are thought to be the algae most closely related to plants, due to the similarity of their pigments. Many species of green algae grow attached to rocky substrates on or near the ocean's surface. In general, because they are attached to a substrate, they are not tossed up on the beach by waves. However, some green algae may be torn from their substrates during storms and by heavy wave action. About 140 species have been recorded around the coast of world; about 50 species are present in the Eritrean coast of Red Sea. One of the easiest to recognise is sea lettuce (*Ulva lactuca*), which forms bright green sheets up to 30 centimetres in diameter. As its common name suggests, it is edible, although prolific growth often indicates sewage pollution. Gut weed (*Enteromorpha intestinalis*), a tubular green seaweed, also favors high-nutrient sites. Another common green seaweed is sea rimu (*Caulerpa brownii*), also edible, and looking very much like the foliage of the large tree rimu.

Halimeda macroloba

Ulva lactuca

Enteromorpha clathrata

Caulerpa trifara

Fig 1: common green algae present in Eritrean coast of Red Sea

The Rhodophyta (Red algae)

Red algae are the most abundant, and commercially valuable, of the marine algae. They are classified in the phylum Rhodophyta. The term Rhodophyta represents the group of algae which owns red color due to the accessory pigments phycoerythrin and phycocyanin; this masks the other pigments, chlorophyll a (no chlorophyll b), β - carotene and a number of unique xanthophylls [16]. Red algae are found on rocky shores from the intertidal to the sub tidal zones. Some species are found at much greater depths than either brown or green algae. There are 550 species of red seaweed were recorded in the world, making them the largest group. The main reserves are typically floridean starch, and floridoside. The walls are made of cellulose and agars and carrageenans, both long-chained polysaccharide in widespread commercial use. Some red algal cells can creep about in amoeboid fashion, but none are able to swim about rapidly, since no algae have flagella [45]. Red sea is diversified with a wide variety of Red algae; a total 128 varieties of red algae had been recorded so far [1].

Hypenia Spp.

Gracillaria Spp.

Fig 2: The most abundant Red algae species in Eritrean coast of red sea

The Phaeophyta (Brown algae)

The brown algae are classified in the phylum Phaeophyta. These medium to giant-sized seaweeds typically grow at depths below the greens and above the reds. They are very good source of iodine and the most commonly used species for alginates. Alginates from the macroalgae such as the *Laminaria* (kelp) family are also used as thickeners in lots of products from salad dressings to oil-drilling muds and fluids to coatings for welding rods and in paper manufacture. These algae have a brown or olive-green color. This color results from the mixture of pigments in the cells of the algae, particularly the green pigment chlorophyll and the yellow pigment xanthophylls. The variable blending of these pigments gives brown algae their characteristic range of colors [45]. There are 108 species of brown alage are present in red sea waters of Eritrean coast [1].

Padina boerengsnii

Dictyota ciliolata

Fig 3: most abundant brown algae in Eritrean Coast of Red sea

BIOCHEMICAL COMPOSITION OF SEAWEEDS:

The proximate composition of different species of seaweeds collected from Mandapam coastal regions, southeast coast of India was evaluated. The maximum protein content was recorded in Phaeophyceae member *Padina gymnospora* (17.08%) and the minimum protein concentrations was in Chlorophyceaean member *Ulva lactuca* (3.25%). Eventually the protein content of *Enteromorpha intestinalis* (16.38%) (Green algae), *Gracilaria folifera* (6.98%) (Red algae) *Sargassum tenerimum* (12.42%) (Brown algae), *Codium tomentosum* (6.13%) (Green algae), *Hypnea valentiae* (8.34%) (Red algae) [19]. Eventually the high protein content in the brown seaweed *Turbinaria ornate* (14.68%) and lower in the red seaweed *Gracilaria verrucosa* (9.47%) collected from the Tuticorin coast of Southeast India [30]. Protein content varied among different genera and also in different species of the same genus. This change may be of spatial or temporal in nature. However, it is largely attributed to the surrounding water quality as reported by Dave and Parekh (1975) [8].

The protein content of green seaweed *Ulva rigida* collected from the coastal region of Chilka Lake of India is 6.64% [37]. Similarly the total protein content of *Kappaphycus alvarezii,* a red alga collected from the sea coast of Rameshwaram, Tamil Nadu, India is 18.78% [33]. *Padina tetrastromatica* belongs to the order Dictyotales of Phaeophyta is rich in amino acids and total eighteen amino acids were reported. In addition to lysine, phenylelanine and aspartic acid, histidine too occurs as a major constituent [31]. The protein content of red algae *Gracillari canaliculata* from the Massawa region of Red sea was recorded as 8.51% [18].

The protein content of macro algae collected from the sea shore of Bay of Bengal in St. Martin's Island was investigated. Among all the species *Sargassum coriifolium* has the highest percentage of protein (16.07%), while lowest in *Padina tenuis*, which was estimated as 8.32% [13]. Similarly the total protein in the seaweeds collected from the Sea of Marmara which is located in the northwestern Turkey and recorded the highest total protein value among green algae in *U. rigida* 28.06% and lowest in *U. lactuca* 27.7% sampled from the surface at Karacaali station. Eventually the variations in total protein value depending on the depth of the sample collected. The highest total protein among the Rhodophyta is 31.03% in *Polysiphonia* spp. where as the lowest protein is in *G. verrucosa* (0.94%). In all *Ulva* spp. (Chlorophyta) except *U. rigida* total protein decreased significantly from 5 to 10 times according to depth at Ormanli. However, in *C. tomentosum* from Ormanli, there was no depth-dependent variation [7].

Chlorophycean members contain high carbohydrate content than Rhodophycean and Phaeophycean members [15, 30]. The maximum carbohydrate content was recorded in the green seaweed *E. intestinalis* 28.58 % and the brown seaweed *Dictyota dichotoma* 10.63% recorded the minimum value [30] in the green seaweeds *U. lactuca* (35.27%) and *E. intestinalis* (30.58%) [3]. The Sea weeds collected from the Maharashtra coast and Kovalam coast of India noted maximum value of carbohydrate content in Rhodophycean members than in Phaeophycean and Chlorophycean members. In the present study, the contrastingly the high content of carbohydrate in red algae might be due to higher phycocolloid content in their cell walls [8,40].

The carbohydrate content of sea weed collected from Mandapam coast varied from 20.47 to 23.9%, in that the maximum carbohydrate concentration was recorded from brown algae *Turbinaria conoides* (23.9%), *Sargassum tenerimum* (23.55%), *Sargassum wightii* (23.50%), followed by the green alga *E. intestinalis* (23.84%), and red algae *H. valentiae* (23.60%), *Acanthophora spicifera* (23.54%). The minimum carbohydrate content was observed from green alga *Codium tomentosum* (20.47%) followed by brown algae *Padina gymnospora* (21.88%), *Colpomenia sinuosa* (22.46%) and the red alga *Gracilaria folifera* (22.32%) [19]. Similarly the carbohydrate content of green seaweed *U. rigida* is 22% [37] and in *K. alvarezii* contains the minimum carbohydrate content of 2.67% [33]. The carbohydrate content of the seaweeds was richer than that of *Spirulina*. Carbohydrate content was lower (38.94%) in *Dictyota dichotoma,* but higher (56.29%) in *Hypnea musciformis* whereas, in *Spirulina* sp. it was only 10-20%. So, *Hypneu* sp. was rich in carbohydrate as compared to other species. [13].

Marine macro algae varieties contained low amount of lipids, they are the sources of poly unsaturated fatty acids. The fatty acid distribution of seaweed products showed high level of omega-3 fatty acids and demonstrated a nutritionally ideal omega-6/omega-3 free fatty acid ratio. The lipid content of seaweeds varied from 1.33 to 4.6; in that the maximum lipid content was observed from *E. clathrata* (4.6%) followed by *G. folifera* (3.23%), *C. tomentosum* (2.53%), *C. sinuosa* (2.337%) and *S. wightii* (2.337%). The minimum lipid concentration was recorded from *E. intestinalis* (1.33%) followed by *P. gymnospora* (1.4%), *S. tenerimum* (1.46%) and *U. lactuca* (1.6%) [19]. The total lipid content of U. rigida is 12% [37] and in *K. alvarezii* is 1.09% [33]. The Lipid content of seaweeds collected from Tuticorin coast of India varied from 3.15% to 5.30%. The maximum lipid content was recorded in green seaweed *E. intestinalis* and the red seaweed *G. verrucosa* recorded the minimum content. Similarly Chakraborthy and Santra (2008) have recorded higher lipid content in the same green seaweeds *E. intestinalis* (7.13%) [3]**.**

Padina tetrastromatica belongs to the order Dictyotales of Phaeophyta is rich in water soluble vitamins like vitamin B_1, B_2, B_6 and nicotinic acids. Gas chromatographic analysis was reported total sixteen fatty acids among which palmatic acid is huge in amount. Total thirteen mineral elements were reported among which calcium and Iron were found as major ones [31]. The green seaweed *U. rigida* contains the total free amino acid of 8.9% [37]. The ash contents in *Hypnea muscifȍrmis* were lower (11%) and higher (36%) in *Padina tenuis***.** All the minerals, such as calcium, magnesium, sodium, potassium, and iron were higher in *H. musciformis, H. pannosa, P. tenuis, Sargassum coriifolium* and *Dictyota dichotoma* than that of *Spirulina*. In *Padina* sp., calcium and magnesium contents per g were high, 48.00 and 44.13 mg, respectively. Whereas, in *Spirulina*, calcium, and magnesium contents per gram were recorded 4.00 and 4.80 mg, respectively. Even, the lowest contents of Ca and Mg in *D. dichotoma* (4.55 mg) and in *H. musciformis* (12.64 mg) were higher than that of *Spirulina*. Sodium contents were much higher (127.65 mg) in *H. pannosa* than that of *Spirulina* (7.3 mg) and other species. The potassium contents were 15.2 mg per gram in *Spirulina* whereas, *H. pannosa* and *P. tenuis* contained 31.91 and 30.00 mg of K. Iron contents were also higher in *P. tenuis* containing 6.64 mg/g whereas, in *Spirulina*, it was recorded 1.6 mg/g [13].

One of the major uses of the seaweeds is as dietary fiber, because of their high content of polysaccharides. Dietary fiber is a complex material consisting of the plant cell walls, structurally complex and chemically diverse polysaccharides and other associated substances. The fiber content was higher (8.5%) in *Hypnea pannosa* followed by *Dictyota dichotoma*, whereas it was much lower (2.5%) in case of *Padina tenuis* [13]. Fucan (polymer of fucose), ulvan (polymer of rhamnose), galactan (polymer of galactose) are the three important sulfated polysaccharides present in brown algae *Sargassum* sp, green algae *Ulva* sp., and red algae *Gelidium* sp. respectively. After extraction, total polysacharrides were estimated in the respective extracts as 33.24mg/ml, 25.6mg/ml, 48.83mg/ml respectively [29].

Now-a-days sea weeds have been widely accepted by the people of coastal region throughout the world due to their important sources of nutrients. Especially *Padina lenuis* and *Hypnea* spp. are usually eaten whole plants as a good source of minerals. In *Hypneu pannosa* Na contents (127.65 mg/g) were much higher, but Ca, Mg, and Fe were higher in *Padina tenuis*, which was 48.00 mg/g, 44.13 mg/g, and 6.64 mg/g, respectively. Though protein contents of these sea weeds are less, but carbohydrate and mineral contents are higher. These sea weeds may be used to solve the problems of carbohydrate and mineral deficiency. Red and brown algae have the ability to accumulate iodine and thus they may be regarded as a good source of concentrated iodine [13].

SEAWEEDS AS HUMAN FOODS:

For most populations, seafood means protein in the form of fish, prawns, oysters and other shellfish. However, there are many other food resources available from the sea. One such example is edible seaweeds. This major resource of the sea is largely ignored in typical western diets. By comparison, edible seaweeds are an integral part of the diet for people who live by the sea in such areas as Asia, Pacific Islands including Hawaii, South America and Africa. However, with the increasing focus upon consumer health and nutrition, seaweeds are now being reconsidered in many Western populations for their nutritional qualities. Seaweeds are nutritionally valuable as fresh or dried, or as an ingredient in processed foods. Edible seaweeds are very good sources of vitamins including A, B_1, B_2, B_6, B_{12}, niacin and C. They are also rich in iodine, potassium, iron, magnesium and calcium. [23, 28, 48]. *Hydroclathrus*, *Caulerpa*, *Eucheuma*, *Gracilaria* and *Acanthohora* spp. are used as green salad vegetables; where as coarser *Gracilaria* and *Eucheuma* spp. are pickled [44]**.**

FOOD PREPARED FROM RED ALGAE:

Nori

Nori is probably one of the most well-known and well-liked edible seaweeds throughout Asia and the Western world. The dried sheets are used as a 'wrap-up vegetable' to cover rice balls containing vegetables in sushi rice, or the Nori may also be used as food toppings or garnishes. In parts of Europe, nori may be more commonly known as 'purple laver'. While there are many species of *Porphyra*, for Nori the most commonly used species are *Porphyratenera*, *Porphyra yezoensis* and *Porphyra umbilicalis*.

Nori seaweed (*Porphyra* sp.) has been found to be especially rich in the B complex of vitamins including vitamins B_6 and B_{12} [26]. Generally B_{12} is not found in terrestrial plants, in western diets vitamin B_{12} is normally found in foods containing red meat, fish, dairy and egg products. Healthy levels of vitamin B_{12} are associated with the regeneration of red blood cells and a reduction in the potential for anemia. It also promotes body growth and healthy functioning of nervous system.

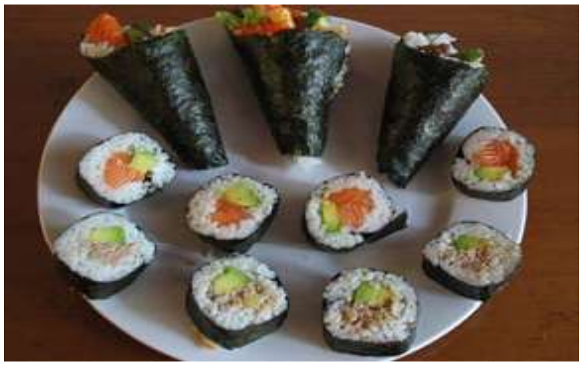

Fig 4: Food prepared from the Red algae, Nori or Purple Laver Sheets Wrap-Up' Vegetables

Foods prepared from green algae:

Sea Lettuce

These seaweeds include the many species of *Ulva Spp.*, and are found throughout the world including Australia. They are consumed raw or cooked in soups. *Ulva Spp.*, are high in protein, soluble dietary fiber and a range of vitamins and minerals especially iron. For this reason *Ulva* has apparently been used in multi-vitamins and health supplements. The similar in form *Monostroma* is commonly known as 'slender sea lettuce', and may also be commonly used in place of *Ulva.*

Foods prepared from brown algae:

Kombu

Kombu usually refers to large brown seaweeds or kelps such as species of *Laminaria*. Common species include *Laminaria japonica, Laminaria angustata, and Laminaria saccharina.* Most commercial Kombu or kelp products are sold dried as pieces or powder, and are re-hydrated in water before use. They are used commonly for salads and soups, and are used as a condiment. Kombu is a rich source of glutamic acid, an amino acid responsible for '*umami*' (as it is called in Japan), or a fifth taste or flavour beyond the basic tastes of sweet, sour, salty and bitter.

Fig 5: Food prepared from Brown algae (Kombu – Umami taste)

Wakame

Wakame or *Undaria pinnatifida* is kelp used widely in Japan, China and Korea for soups, as main -dishes and salads. Wakame has a subtle sweet flavour and a slippery texture. It is notable for its use in soups such as miso soup in Japan, and in salads especially with tofu. An example of this salad is Chuka. Wakame which consists of shredded wakame with a sesame seed and chili dressing. This product is imported into many western markets including Australia from countries such as Japan and Taiwan. As with Kombu, Wakame is rich in polysaccharides and a good source of soluble dietary fibre. *Undaria* is known also to be rich in compounds such as fucoxanthums and fucoidans, and these areused as supplements for anti-cancer and weight loss.

Fig 6: Chuka Wakame Salad an example of food prepared from brown algae (*P. gymnospora* and S. *tenerrimum)*

CONCLUSION:

Now-a-days sea weeds have been widely accepted by the people of coastal region throughout the world due to their important sources of nutrients and their applications in different work sectors. In terms of food aspect seaweeds may solve the problems of protein, carbohydrate and mineral deficiency in human nutrition by consuming them in daily life. Thus results of the present study conclude that seaweeds are a potential health food in human diets and may be of use to the food industry as a source of ingredients with high nutritional value. Seaweeds can provide a dietary alternative due to its nutritional and commercial value which enhanced by improving the quality and expanding the range of seaweed-based products. In case of Eritrea even though there is a great deal of the edible seaweeds but not many studies had been done on them. So at last but not least hence seaweeds are the "future medicines" of our world we have to play a great role on their study and preservation.

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