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Review Article *Open Access*

COMPARISION OF NUTRITIVE VALUE OF SEAWEED WITH OTHER TERRESTRIAL FOODS—A REVIEW

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Seaweeds are low calorie food from nutritional point of view as they have high concentration of minerals, vitamins, proteins and indigestible carbohydrates. They have low content of lipids but they are of high quality in terms of nutritional value. Seaweeds also exhibit antioxidant; antimutagenic, anticoagulant, antitumor and they also play important role in modification of lipid metabolism in the human body. Seaweed, being a rich source of structurally diverse bioactive compounds with valuable nutraceutical properties, can be used as an ingredient to supplement food with functional compounds. Seaweed gums exploit for their multifunctional properties such as thickeners, stabilizers and gelling agents in milk products, sweets and confectionary, meat products, beverages and bakery industries. As seaweeds and seaweed isolates have the potential to both benefit health and improve food acceptability, seaweeds and seaweed isolates offer exciting potential as ingredients in the development of new food products. This article presents information on comparison of nutrient level of seaweeds with terrestrial foodstuffs with respect to selected nutrients.

Keywords: Seaweed, Bioactive compounds, Terrestrial foods, Nutrients

INTRODUCTION

Seaweeds are macroalgae living in sea or brackish water, often called as ocean kelps or benthic marine algae which means attached algae that live in the sea (Chandini *et al.,* 2008). Seaweeds possess a good nutritional quality and could be used as an alternative source of dietary fiber, protein, and minerals. Moreover, bioactive sulfated polysaccharides are the main components of soluble fiber in seaweeds and also bioactive peptides can be prepared from seaweed protein (Paul *et al.,* 2007; and Jimenez-Escrig *et al.,* 2011). About 150 species of seaweeds are used as food worldwide and over 100 species for seaweed gums production. Seaweeds are rich and diverse sources of raw material for the manufacture of Seaweed gums/ Phycocolloids/Hydrocolloids. Seaweeds are great potential producer of secondary metabolites that responsible for bioactivities which have commercial application in pharmaceutical, medical, cosmetic, nutraceutical and agricultural industries (Noer *et al.*, 2016).

Nowadays, seaweeds consumption is increasing due to their natural composition. They were recorded to have many beneficial nutritive bioactive compounds such as vitamins (ascorbic and â carotene), polyphenols, pigments, minerals, fibers and polysaccharides (Lahaye, 1991). They were also low in fat and in calorific value with high levels of essential fatty acids and essential amino acids in addition to about 80-90% water. In many studies, these bioactive compounds confirmed antioxidant, antimicrobial, antitumor and antiviral activities (Mabeau and Fleurence, 1993; Ortiz*et al.*, 2006; and Seenivasan *et al.*, 2012).

The present article quantifies the nutritional impact of seaweeds as a source of essential nutrients as well as their

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key bioactive molecules and activities; it also describes the individual benefits ascribed to the main types of edible seaweeds with other foods. The nutrient levels of seaweeds are also shown in comparison with terrestrial foodstuffs with respect to selected nutrients.

Classification of Seaweed

Seaweeds are classified taxonomically as algae and they represent a food group that is not normally ingested in unprocess form to any great extent in Western societies. Biologically, seaweeds are classified as macroalgae, with subclassification as brown (Phaeophyta), red (Rhodophyta) or green algae (Chlorophyta) (Gomez *et al.*, 2010).

SEAWEED RESOURCES

Brown Seaweeds: The brown colour of these algae results from the dominance of the xanthophylls pigment fucoxanthin, which masks the other pigments, chlorophyll a and c, beta carotene and other xanthophylls.

Green Seaweeds: 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.

Red Seaweeds: 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 (Oritz *et al.*, 2006; and Shahin *et al.*, 2016). Some examples of these edible algae are outlined in Table 1.

Table 1: Examples of Edible Algae

Subclassificaton	Genus/Latin Name	Common Name*
Brown algae (Phaeophyta)	*Alaria*	Kelp/bladderlocks
	Himanthalia elongata/ Bifurcaria	Sea spaghetti, fucales
	Laminaria digitata	Kelp/kombu/ kumbu/sea tangle
	Saccharina	Sugar wrack
	Undaria pinnatifida	wakame
	Ascophyllum nodosum	Egg wrack
	Fucus	Bladder wrack, rockweed
	Sargassum wightii	Mojaban/Indian brown seaweed
	Hizikia	Hijiki
Red algae (Rhodophyta)	*Rhodymenia/ Palmaria palmata*	Dulse or Dillisk
	Porphyra umbilicalis	Nori/haidai/kim/gim
	Chondrus crispus	Irish moss or Carrigeen
	Mastocarpus/ Gigartina	Stackhouse, Guiry
	Gracilaria Asparagopsis	Limu Kohu
Green algae (Chlorophyta)	*Ulvaria actuca/ Enteromorpha*	Laver/sea lettuce/ sea grass/nori
	Caulerpa racemosa, Caulerpa taxifolia	

Note: * Data from Paul *et al.* (2007), Gomez *et al.* (2010), Romarís *et al.* (2010) and Murugaiyan *et al.* (2012).

ASSESSMENT OF NUTRIENT VALUE OF SEAWEEDS WITH TERRESTRIAL FOODS

The nutrients in our daily diet or those synthesized in the human body using the precursor molecules play a vital role in regulating the body functions, essential for normal growth and development. Carbohydrates, proteins, lipids, and vitamins are provided to the human body through different food sources. Like most of the terrestrial plants, marine algae are also a rich source of above nutritional elements. In comparison with many common vegetables, high levels of fiber, minerals, ω-3 fatty acids and moderate concentrations of lipids and proteins available in most of the edible seaweed help it to be considered as an important food source for human nutrition. However, the available amounts of the above nutrients may vary basically depending on the variety, season, and the area of production (Murata and Nakazoe, 2001).

Since seaweeds are normally consumed and tested as a dried foodstuff, this can make comparison with land-based foodstuffs difficult. Thus, the present analysis consists of two forms: 1) a comparison of 100 g wet-weight seaweeds with 100 g of common foods, and 2) the nutrient levels found in an g/100 g dry-weight with g/100g of common foods. Generally eight grams of seaweed is a typical daily portion size consumed in Asian cuisine (Paul *et al.,* 2007).

Dietary Fibre

The fibre content in various seaweeds are compared with terrestrial foods are presented in Table 2. The main components in seaweeds are depends upon the type of seaweed. Red seaweeds varieties consist of different typical carbohydrates kinds including: floridean starch (α-1, 4-bindingglucan), cellulose, xylan, and mannan. Moreover, their water-soluble fiber fraction is formed by sulfur-containing galactans, e.g., agar and carrageenan (Jimenez-Escrig and Sanchez-Muniz 2000). On the other hand, the typical carbohydrates in brown seaweeds varieties consist of fucoidan, laminaran (β-1, 3-glucan), cellulose, alginates, and mannitol. Brown seaweeds, fibers are mainly cellulose and insoluble alginates. In contrast, the amorphous, slimy fraction of fibers consists mainly of water-soluble alginates and/or fucoidan. The typical seaweeds' carbohydrates are not digestible by the human gastrointestinal tract and,

Table 2: Fiber Content of Seaweeds Compared to Terrestrial Foods

Food Type	Total Fiber	Soluble Fiber	Insoluble Fiber	Carbohydrate
Seaweed (g/100 g Wet Weight)*				
Ascophyllum nodosum	8.8	7.5	1.3	13.1
Laminaria digitata	6.2	5.4	0.8	9.9
Himanthalia elongate	9.8	7.7	2.1	15
Undaria pinnatifida	3.4	2.9	0.5	4.6
Porphyra umbilicalis	3.8	3	1	5.4
Palmaria palmate	5.4	3	2.3	10.6
Ulva sp.	3.8	2.1	1.7	4.1
Enteromorpha sp.	4.9	2.9	2.1	7.8
Whole Food (g/100 g Weight)†				
Rice dry	1.3	1	0.3	80
Peas, green frozen	3.5	3.2	0.3	14
Kidney beans, canned	6.3	4.7	1.6	23
Potato no skin	1.3	1	0.3	22
Spinach raw	2.6	2.1	0.5	11
Tomato raw	1.2	0.8	0.4	6
Apple, unpeeled	2	1.8	0.2	15
Bananas	1.7	1.2	0.5	24
Peanut, dry roasted	8	7.5	0.5	21
Cashew, oil roasted	6	-	-	28

Note: * Values for seaweeds from the Institut de Phytonutrition (2004); † Value for whole food from Punna *et al.* (2003) and Devinder *et al.* (2012).

therefore, they are dietary fiber (Ghada and Amany, 2013). In addition, the fibers can increase feelings of satiety and aid digestive transit through their bulking capacity. (Brownle *et al.*, 2005).

Himanthalia elongate (brown algae), when compared with other selected whole foods contains slightly more fibre than Kidney beans canned, Peanut, dry roasted and Cashew oil roasted (9.8% versus 6.3%, 8.0% and 6.0%) respectively. By comparing *Laminaria digitata* (brown algae) contain more fibre content than rice dry, potato without skin, tomato raw and bananas (6.2% versus 1.3%, 1.3%, 1.2% and 1.7%) respectively. The seaweeds also rich in soluble fibre and insoluble fibre (*Himanthalia elongate*.7.7 and 2.1) when compared with terrestrial foods. According to the guideline daily amount of dietary fiber is 25 g per day (Susan and Robin, 2002). Based on this amount, seaweeds can provide up to 12.5% of a person's daily fiber needs in an 8 g serving. This is relatively large amount when compared with other terrestrial foods.

PROTEIN

Indian seaweeds are of great food value and certain of them contain 16-30% protein on dry weight basis and have all essential amino acids which are not available in vegetable food materials (Murugaiyan *et al.*, 2012). In general, seaweed protein is rich in glycine, arginine, alanine, and glutamic acid, and contains all the essential amino acids, the levels of which are comparable to those of the FAO/WHO requirements of dietary proteins (Anonymous, 2006). However, when compared with the other protein-rich food sources, seaweed is appeared to be limiting with lysine and cystine. With respect to the protein level and amino acid composition, the amino acid score and the essential amino acid index were higher in red seaweed than those in brown and green seaweeds (Holdt and Kraan, 2011).

The Protein content of brown seaweeds is generally low (5-15% of the dry matter), whereas higher protein contents are recorded for green and red seaweeds (10-30% of the dry weight) (Chandini *et al.*, 2008). In some red seaweeds, such as *Porphyra tenera* (47%) and *Palmaria palmata* (35%) of the dry matter. These levels are comparable to those found in soybean. Protein content varied among different genera and also in different species of the same genus. These levels varied depending on algal species, season and environment (Rajasulochana *et al.*, 2012). Red seaweed contains the highest protein content, which is comparable in quantitative terms to legumes at 30-40% of dry matter, and brown and green seaweeds contain only 15% and 30%, respectively (Murata and Nakazoe, 2001). The protein content of brown seaweeds *Laminaria japonica* and *Undaria pinnatifida* ranged from 7% to 16% (Marsham *et al.*, 2007).

From the Table 3 the seaweeds exhibit amino acid composition close to that of traditional proteins from cereals and leguminous plants. Essential amino acids such as histidine, leucine, isoleucine, and valine are present in many seaweeds, such as *Palmaria palmata* (Dillisk/Dulse) and *Ulva* spp. (sea lettuce). The levels of isoleucine and threonine in *Palmaria palmata* are similar to the levels found in legumes, and histidine is found in *Ulva pertusa* at levels similar to those found in egg proteins (Paul *et al.*, 2007).

Lipids

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 (Paul *et al.*, 2007; and Misurcova *et al.*, 2011). Seaweed lipids consist of 1-3% of dry algal matter. Glycolipids a formed the major lipid class in all seaweeds.

When compared with other whole foods as presented in Table 4 seaweeds are rich in PUFA. The major commercial sources of ω-3 PUFAs are fish, but their wide usage as food additives is limited for the typical fishy smell, unpleasant taste, and oxidative nonstability. Nevertheless, growing requirements of healthy functional foods have led to produce PUFAs as nutraceuticals in controlled batch culture of marine microalgae, especially Thraustochytrium and Schizochytrium strains. PUFAs are the important components of all cell membranes and precursors of eicosanoids that are essential bioregulators of many cellular processes. PUFAs effectively reduce the risk of cardiovascular diseases, cancer, osteoporosis, and diabetes. Because of the frequent usage of seaweeds in Asia and their increasing utilization as food also in other parts of the world, seaweeds could contribute to the improvement of a low level of ω-3 PUFAs, especially in the Western diet (Misurcova *et al.*, 2011).

Minerals

Marine algae contain more than 60 trace elements in a concentration much higher than in terrestrial plants and have various pharmacological activities (Jimenez *et al.*, 2011;

Table 3: Essential Amino Acid Composition of Different Seaweeds and Some Terrestrial Foods

Type of Food	Essential Amino Acids								
	1	2	3	4	5	6	7	8	9
Seaweeds*									
Ulva pertusa #	4	3.5	6.9	4.5	1.6	3.9	3.1	0.3	4.9
Ulva armoricana #	2.1	3.6	6.7	4.4	2.6	7.1	6.8	-	5.2
Undaria pinnatifida $	2.5	3.3	5.9	5.6	1.7	4.7	4.4	0.7	5.2
Laminaria sp$	2.2	2.7	4.9	3.9	0.9	3.2	3.5	0.5	3.8
Poryphera sp$	2.6	3.1	5.5	4.9	1.8	3.3	5.3	0.7	5.2
Whole Foods g/100 g Protein**									
Wheat (hard)	2	3	6.3	2.3	1.2	4.6	2.4	2.4	3.6
Brown Rice	2.5	4.1	8.6	4.1	2.4	5.2	4	1.4	5.8
Barley	2.1	3.6	6.6	3.5	2.2	5.2	3.2	1.5	5
Oats	2.4	4.2	7.5	4.2	2.3	5.4	3.3	-	5.8
Leguminous plants	4	3.6	7.3	6.5	1.4	2.4	4	1.9	4.5
Ovalabumin	4.1	4.8	6.2	7.7	3.1	4.1	3	1	5.4

Note: 1: Histidine; 2: Isoleucine; 3: Leucine; 4: Lysine; 5: Methionine; 6: Phentyalanine; 7: Threonine; 8: Tryptophan; 9: Valine. #: g per 100 g dry weight, $: g per 16 g nitrogen.* Mabeau and Fleurence (1993), Sanchez-Machado *et al.* (2004), Ortiz *et al.* (2006) and Dawczynski (2007). ** Macrae *et al.* (1993) and Chandini *et al.* (2008).

Table 4: Fatty Acid Composition of Different Seaweeds and Some Terrestrial Foods

Type of Food	Fatty Acids				
	Saturated (%)	MUFA (%)	PUFA (%)	ω6 PUFAs	ω3 PUFAs
Seaweed*					
Ulva Lactuca	23.5	38.8	13.7	8.3	4.4
Porphyra sp	33.5	2.2	43.1	7.97	7.2
Palmaria sp	60.5	10.5	24.1	2.14	25.52
Sargassum marginatum	50	17.8	24.1	4.9	-
Laminaria ochroluca	33.5	19.2	45.6	20.99	25.08
Himanthalia elongate	39.06	22.75	38.16	15.08	18.7
Udaria pinnatifida	20.39	10.5	69.11	22.1	44.7
Whole Food (g/100 g Food) †					
Barley, pearl, raw	0.29	0.14	0.77	0.7	0.07
Oat meal	1.61	3.34	3.71	3.52	0.19

Table 4 (Cont.)

Wheat flour	0.16	0.13	0.51	0.48	0.03
Brown rice	0.74	0.66	0.98	0.94	0.04
Apple	0.1	Traces	0.1	-	-
Bananas	0.2	Traces	0.1	-	-
Spinach raw	1.3	2.2	5.4	-	-
Peanut dry roasted	10.1	36	22.9	15.69	0
Tomatos raw	Traces	0.1	0.1	-	-

Note: * Values for Seaweed from Sanchez-Machado *et al.* (2004), Oritz *et al.* (2006) and Dawezynski *et al.* (2007). †**:** Values for whole food from Macrae (1993) and Brigid (2004).

and Noer *et al.*, 2016). The rich mineral and trace element content of seaweed compared to terrestrial plant foods Moreover, because of their minerals presence (Na, K, Ca, Mg, Fe, Zn, Mn, etc.) they are needed for human nutrition. As illustrated in Table 5 seaweeds are one of the most important vegetable sources of calcium than terrestrial foodstuffs. At 7% calcium, a typical daily portion size of seaweed (8 g dry weight) provides 560 mg of calcium which is a considerable amount compared to its recommended daily allowance (800-1000 mg) (Anonymous, 2006). In seaweeds, calcium is available as calcium phosphate, and that is more bioavailable than the form of calcium in milk, which is calcium carbonate. Sodium and potassium are also present at relatively high levels.

Table 5: Minerals Content of Different Seaweeds and Some Terrestrial Foods

Type of Food	**Ca**	K	**Mg**	**Na**	**Cu**	**Fe**	**Zn**	**I**
Seaweed (mg/100 g Wet Weight)*								
Laminaria digitata	364.7	2013.2	403.5	624.6	0.3	45.6	70	1.6
Himanthalia elongata	30	1351.4	90.1	600.6	0.1	5	10.7	1.7
Porphyra umbilicalis	34.2	302.2	108.3	119.7	0.1	5.2	1.3	0.7
Palmaria palmata	148.8	1169.6	97.6	255.2	0.4	12.8	10.2	0.3
Ulva spp.	325	245	465	340	0.3	15.3	1.6	0.9
Enteromorpha spp.	104	351.1	455.1	52	0.1	22.2	97.9	1.2
Whole Food (mg/100 g Weight)†								
Bovine milk	120	157	12	48	0.12	0.046	4	0.6
Cheddar cheese	720	77	25	670	0	0.3	39	2.3
Bananas	6	396	34	0.84	0.1	0.33	8	0.2
Peanuts	54	658.2	210	6.16	1	2.5	20	3.5
Brown rice	110	1160	520	28	1.3	12.9	NA	16.2
Spinach	145	554	54	65	0	3.8	2	0.7

Note: * Values for seaweeds from the Institut de Phytonutrition (2004). † Values for whole foods from Belitz (2009), Susan and Robin (2002) and Paul *et al.* (2007). Abbreviations: NA, no data available.

Minerals such as iron and copper are present in seaweeds at higher levels than in many well-known terrestrial sources of minerals, such as cheese, bananas, spinach. Iodine is an important nutrient in metabolic regulation and growth patterns and is abundant in most seaweed. The role of seaweed as a rich source of iodine is particularly relevant in the UK, where recent surveys have highlighted insufficiency in different groups of the population, with iodine being an essential component of thyroid hormones, which are essential for neuro development in utero and after birth (Paul *et al.*, 2007; and Maria and Emilie, 2015).

Vitamins

Seaweeds are a good source of some water-(B_1, B_2, B_{12}, C) and fat-soluble (β-carotene with vitamin A activity, vitamin E) vitamins. To ensure that the adequate intake of all vitamins is received in the diet, people (especially people on special diet, strict vegetarians, and vegans) can consume foods enriched with vitamins, for example, in the form of functional foods with vitamins as nutraceuticals, extracted from natural sources such as seaweeds. Seaweed vitamins are important not only due to their biochemical functions and antioxidant activity but also due to other health benefits such as decreasing of blood pressure (vitamin C), prevention of cardiovascular diseases (β-carotene), or reducing the risk of cancer (vitamins E and C, carotenoids) (Skrovankova, 2011).

From the Table 6 *Laminaria digitata* and *Ulva spp* are good sources for vitamin B_3 and C than other terrestrial foods. Seaweeds are also one of the few vegetable sources of vitamin B_{12}. This may provide an alternate source of vitamin B_{12} for vegetarians or vegans.

Antioxidant and Bioactive Compounds

Antioxidants play an important role in inhibiting and

Table 6: Vitamin Composition of Different Seaweeds and Some Terrestrial Foods

Seaweed	B1	B2	B3	B6	B9	C	E	B12†
(mg per 8 g Dry Portion)*								
Laminaria digitata	0.011	0.011	4.896	0.513	0	2.842	0.275	0.495
Porphyra umbilicalis	0.077	0.274	0.761	0.119	1.003	12.885	0.114	0.769
Ascophyllum nodosum	0.216	0.058	0	0.001	3.648	0.654	0.029	0.131
Undaria pinnatifida	0.403	0.936	7.198	0.259	0.528	14.779	1.392	0.345
Palmaria palmata	0.024	0.08	0.8	0.002	0.021	5.52	1.296	1.84
Ulva spp .	0.06	0.03	8	NA	0.012	10	NA	6.3
Whole Food$ (mg/100 g Edible Portion)								
Bovine milk	0.04	0.18	0.09	0.04	0.08	1.7	0.07	0.4
Emmental cheese	0.02	0.04	0.17	0.01	0.08	6.5	0.28	0.05
Whole wheat	0.48	0.09	5.1	0.27	0.58	-	1.4	-
Carrots	0.07	0.05	0.6	0.27	0.17	7.1	0.47	-
Tomatos	0.06	0.04	0.5	0.1	0.33	19	0.81	-
Spinach	0.09	0.2	0.6	0.22	0.145	2.5	2.5	-
Apple	0.035	0.032	0.3	0.1	0.05	12	0.49	-
Orange	0.08	0.04	0.3	0.1	0.22	5	0.32	-

Note: * Values for seaweeds from the Institut de Phytonutrition (2004). $ Values for whole foods from Belitz (2009). **†:** Values expressed in µg/100 g wet weight. Abbreviations: NA, no data available.

scavenging radicals and thus providing protection to humans against infections and degenerative diseases. A number of marine algae were reported to possess antioxidant properties (Hanan and Mohamed, 2015).

Antioxidant compounds act as free radical scavengers to protect living organisms from the systemic production of Reactive Oxygen Species (ROS), lipid peroxidation, protein damage and DNA breaking (Kokilam and Vasuki, 2014). Many seaweed species verified natural antioxidant capacity that can protect the human body from free radicals and retard the progress of many chronic diseases such as hypertension, heart diseases, diabetes and cancer (Gehan, 2017).

Phenolic and flavonoid compounds were broadly recognized in seaweeds confirming their potent role in chelating metal ions, preventing radical formation and improving the internal antioxidant system under stress environmental conditions. These activities protect the body from progressive diseases caused by the adverse effects of Reactive Oxygen Species (ROS) (Chakraborty *et al.*, 2013). Similar attitude was reported for carotenoid pigments of seaweeds, especially â carotene, for which activity against cancer diseases was postulated (Jane, 2013; and Gehan, 2017).

Extracts from macroalgae or seaweeds are rich in polyphenolic compounds. Which have well documented antioxidant properties. They also have antimicrobial activities against major food spoilage and food pathogenic micro-organisms (Hanan *et al.*, 2015).

CONCLUSION

Seaweeds as a new source of valuable nutrients, food additives nutraceuticals, and nutritional supplements for human and animal consumption. Microalgae and seaweeds have important amounts of macronutrients (proteins, carbohydrates and lipids), vitamins (fat soluble (A and E) and water soluble (C, B_1, B_3, nicotinate, panthotenic acid, biotin, folic acid, B_{12}) minerals, essential and non-essential aminoacids, chlorophylls, carotenoids, polyphenols, polysaccharides, and minerals, although the concentration varies widely among the different species. Specifically, trace elements and minerals are abundant in seaweeds compared to terrestrial foodstuffs, and their non animal nature lends them to use in many food products.

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