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Evaluating Seaweed as a Source of Protein in the Future of Food Production Worldwide

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Abstract: *Alternative protein sources are constantly explored to secure the future food and protein demand. Among these sources, biomasses originating from algae[1]. Building on the United Nations Food and Agriculture Organization's (FAO) food demand projections, it's estimated that the world needs to close a 70 percent "food gap" between the crop calories available in 2006 and expected calorie demand in 2050 [12], in this review we evaluate seaweed as a source of protein as the future of food production worldwide. It is clear that seaweeds (microalgae) represent a sustainable source of various bioactive natural carotenoids and proteins [6,10]. However, several studies show that safety hazards for seaweed may include iodine, ANFs, heavy metals, radioactive isotopes, ammonium, dioxins, and pesticides[20, 21, 22]. At very high levels, most heavy metals can cause health problems. However, this is very uncommon [42]. Thus, this review suggest more research for cultivating seaweed without the presence of heavy metals or to experiment on how to extract heavy metals from seaweed. As seaweed is a very sustainable source of protein, we could use Seaweed as a source of protein for human consumption worldwide, however we need more research in the health hazards of heavy metals in seaweed and more research in techniques to prevent healthhazardsfrom the use of seaweed.*

Keywords*: Seaweed, protein, food cap, nutrition, heavy metals, health hazards, human consumption, harmful algal blooms, algae.*

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I. Introduction

Alternative protein sources are constantly explored to secure the future food and protein demand.Among these sources, biomasses originating from algae [1]. Algae can be distinguished as microalgae and seaweed [2, 3]. Microalgae are single-celled organisms that can grow over a wide range of environmental conditions, whereas seaweeds are complex multicellular organisms growing in salt water or a marine environment [4, 5]. Marine microalgae and seaweeds (microalgae) represent a sustainable source of various bioactive natural carotenoids, including β-carotene, lutein, astaxanthin, zeaxanthin, violaxanthin and fucoxanthin [6].

There are three types, brown, red and green algae. The brown algae include some of the largest and most complex seaweeds: the kelps, wracks and sargassums. Brown algae belong to the Phylum Phaeophyta and are particularly common in the temperate zones of the world, although many species of sargassum grow in warmer waters[7].Brown seaweeds are rich in sulfated polysaccharides that could potentially be exploited as functional ingredients for human health [8].

Classification:	
KINGDOM:	Protoctista
PHYLUM:	Phaeophyta: Brown Algae

Table 1 classification brown algae [7].

The red algae are seaweeds belonging to the PhylumRhodophyta that are distinguished from other seaweeds bythe presence of unique red and blue pigments, phycocyaninand phycoerythrin. The redand blue pigments are a great advantage to these seaweeds as they can absorb blue-green light in deep water,passing the energy to chlorophyll for food productionby photosynthesis[7].For example, Porphyraumbilicalis (laver) belongs to an ancient group of red algae (Bangiophyceae), and is harvested for human food, and thrives in the harsh conditions of the upper intertidal zone [9].

Classification:	
KINGDOM: PHYLUM:	Protoctista Rhodophyta: Red Algae

Table 2 classification red algae [7].

The green algae are common inhabitants of both salt and fresh water. Green algae belong to the Phylum Chlorophyta and are thought to be the ancestors of land plant[7].

Classification:	
KINGDOM: PHYLUM:	Protoctista Chlorophyta: Green Algae

Table 3 classification green algae [7].

The seaweeds are simpler than land plants. Being emerged inwater, they can simply absorb nutrients, water, dissolvedgasses and sunlight through the entire surface of the plant.They have no need for roots, leaves and a complex networkto transport food and water around the plant, as land plantsdo [7].

Table 4 Examples of seaweed species used in food industry [10].

Species or genus	Common name	Uses	Annual world seaweed production 1995 (tons of dry weight)
Laminaria japonica	Kombu	Sea vegetables, colloids	682,600
Laminaria digitata	Kombu breton	Sea vegetables, colloids	13,400
Undaria pinnatifida	Wakame	Sea vegetables	127,708
Ulva sp (lactuca or pertusa)	Sea lettuce, Aosa, Aonori	Sea vegetables	1500
Chondrus crispus	Irish moss, pearl moss	Sea vegetables, *colloids*	12,213
Porphyra tenera or *yezoensis*	Amanori laver	Sea vegetables	130,622
Palmaria palmata	Dulse	Sea vegetables	130

In recent years, use of seaweeds as a functional or nutritional ingredient in food products is gaining importance among the researchers worldwide [11].

Importance seaweed as a source of protein

Building on the United Nations Food and Agriculture Organization's (FAO) food demand projections, it's estimated that the world needs to close a 70 percent "food gap" between the crop calories available in 2006 and expected calorie demand in 2050.The food gap stems primarily from population growth and changing diets.

The global population is projected to grow to nearly 10 billion people by 2050, with two-thirds of those people projected to live in cities. In addition, at least 3 billion people are expected to join the global middle class by 2030.As nations urbanize and citizens become wealthier, people generally increase their calorie intake and the share of resource-intensive foods—such as meats and dairy—in their diets. At the same time, technological advances, business and economic changes, and government policies are transforming entire food chains [12].Thus it's important to focus in the production of food with a low impact for the environment. This review aims to evaluate the seaweed as a source of future protein production worldwide.

Picture 1, (sargassumsp) brown algae in the red sea.

Picture 2, (sargassumsp) brown algaein the red sea.

For example, sargassum algae (see picture 1 and 2) are brown free-floating seaweed found worldwide in temperate and tropical regions and provide shelter and food for many animal species. In recent years, their wide-spread presence has gone out of control, leaving dense clumps of rotting weeds and toxic waste along urban beaches. Howeverthis harmful brown seaweed is a valid source of sodium alginate (SA), a well-known biodegradable and biocompatible polysaccharide, and so can be widely used in food, pharmaceutical and biomedical applications due to its stabilizing and gelling properties[13].

With the continuous development ofeconomy and human activities, harmful algal blooms (HABs) caused by eutrophication occur more and more frequently [14]. HABs have been considered as ocean disasters that can destroy the marine ecological environment, affect the survival of marine organisms, damage coastal aquaculture industries and even threaten human health [15].

Compared with the physical and chemical methods, biocontrol technologies for the regulation of HABs have become the research hotspots because of their potential effectiveness, species specificity, and eco-friendly characteristics. There are two ways about how microorganisms act on target algal cells: direct attack, which needs cell-to-cell contact [16]; indirect attack, where the interaction between microorganisms and algal cells is mediated by the algicidal compounds, such as antibiotics from actinomycete and fungi [17, 18]. However, instead of fighting/killing the algae bloom, in this review we like to aim to use the algae as a food source for human consumption.

Evaluating proteins in seaweed

Novel protein sources (like insects, algae, duckweed, and rapeseed) are expected to enter the European feed and food market as replacers for animal-derived proteins. However, food safety aspects of these novel protein sources are not well-known[19].Several studies show that safety hazards for seaweed may include iodine, ANFs, heavy metals, radioactive isotopes, ammonium, dioxins, and pesticides[20, 21, 22].

Edible seaweed products have been consumed in many Asian countries. Edible seaweeds accumulate iodine from seawater, and are therefore a good dietary source of iodine. An adequate consumption of seaweed can eliminate iodine deficiency disorders, however excessive iodine intake is not good for health.To prevent excessive consumption, it is imperative for consumers to be knowledgeable about the iodine contents in different food groups. Adequate consumption of seaweed is beneficial for health. Iodine fortification with seaweeds of high iodine content will not cause hyperthyroidism if the seaweed is prepared by boiling in soup with abundant goitrogenic vegetables [23].

Seaweeds can be harvested from the sea, but they are also increasingly cultivated [24].For example, the Norwegian seaweed industry is expanding and there is a need for accurate estimates of protein content of seaweed species from Norwegian waters [25].

A study discovered that seaweed, Gracilariachangiiis high in dietary fibre (64.74 ± 0.82%), low in fat (0.30 ± 0.02%) and Na/K ratio (0.12 ± 0.02). The total amino acid content is 91.90 ± 7.70% mainly essential amino acids (55.87 ± 2.15 mg g^{-1}) which are comparable to FAO/WHO requirements. The physicochemical properties of this seaweed namely the water holding and the swelling capacity are comparable to some commercial fibre rich products. G. changii could be potentially used as ingredients to improve nutritive value and texture of functional foods for human consumption [26].

The total content of amino acids in A protein extract from the brown seaweed Himanthaliaelongata (Linnaeus) S. F. Gray, is determined as 54.02 ± 0.46 g amino acids/kg dry weight, with high levels of the essential amino acids lysine and methionine. SDS-PAGE showed 5 protein bands with molecular weights of 71.6, 53.7, 43.3, 36.4 and 27.1 kDa. The water holding capacity and oil holding capacity were determined as 10.27 ± 0.09 g H_2O/g and 8.1 ± 0.07 g oil/g respectively.These results demonstrate the potential use of Himanthaliaelongata protein extract in the food industry [27].

Table 5 Protein levels of some seaweeds consumed as foods in human nutrition [10].

	Phaeophyta			*Chlorophyta*			*Rhodophyta*	
Seaweed species	*Laminariadigitata* (1)	*Ascophyllumnodosum* (2)	*Undaria pinnatifida* (3,4)	*Ulva lactuca* (5)	*Ulva pertusa* (6)	*Palmariapalmata* (7)	*Porphyra tenera* (3)	*Chondrus crispus* (8)
Protein content (% of dry weight)	8.0–15.0	3.0–15.0	11.0–24.0	8.7–32.7	17.5–26.0	8.0–35.0	33.0–47.0	21.4

Therefore it is clear that seaweeds (microalgae) represent a sustainable source of various bioactive natural carotenoids. Although conventional processing technologies, based on solvent extraction, offer a simple approach to isolating carotenoids, they suffer several, inherent limitations, including low efficiency (extraction yield), selectivity (purity), high solvent consumption, and long treatment times, which have led to advancements in the search for innovative extraction technologies [6].

Evaluating the quantities of heavy metals in seaweed

Heavy metals is the generic term for metallic elements having an atomic weight higher than 40.04 (the atomic mass of Ca) [28].The toxicity of these metals is in part due to the fact that they accumulate in biological tissues, a process known as bioaccumulation[29].

Though seaweed consumption is growing steadily across Europe, it's important to know that relatively few studies have reported on the quantities of heavy metals they contain and/or their potential effects on the population's health.For example: A study focuses on the first topic and analyses the concentrations of six typical heavy metals (Cd, Pb, Hg, Cu, Zn, total As and inorganic As) in 52 samples from 11 algae-based products commercialised in Spain for direct human consumption (Gelidium spp.; Eiseniabicyclis;Himanthaliaelongata;Hizikiafusiforme; Laminaria spp.; Ulva rigida; Chondruscrispus;Porphyraumbilicales and Undariapinnatifida).This results that the Hizikiafusiforme samples contained the highest values of total and inorganic As and that most Cd concentrations exceeded the French Legislation. The two harvesting areas (Atlantic and Pacific oceans) were differentiated using both univariate studies (for Cu, total As, Hg and Zn) and a multivariate discriminant function (which includes Zn, Cu and Pb) [30].

Another study reports that the total and bio accessible concentrations of heavy metals (Mn, Fe, Cu, Zn, Cd and Pb) in the seaweed Caulerparacemosa var.corynephora collected from local markets along the Andaman coast of Krabi Province, Thailand. The total, gastric phase, and residual fraction concentration are determined by inductively coupled plasma-optical emission spectrometry (ICP-OES). The total amounts found in the seaweed samples, in ascending order were $Cd < Pb < Cu < Zn < Mn < Fe$ with the mean concentrations of 0.89, 0.97, 17.4, 59.0, 63.4, and 450 mg/kg dry weight, respectively. High bioaccessibility percentages for Mn (71.8–85.3%) were observed alongside moderate bioaccessibility percentages for Cu (44.3–56.3%), Zn (37.7–47.4%), and Cd (41.8–46.7%), a low bioaccessibility percentage for Pb (22.3–32.0%), and a very low bioaccessibility percentage for Fe (11.5–16.5%) [31].

When discussing the possibility to use seaweed as source of protein for consumption we must know about the risk of heavy metals in seaweed because many algae species absorb heavy metals that are caused by the industry [32, 33, 34].

The concentration of Fe, Mn, Zn, Cu, Pb, Ni, Cr, Cd, and Ag were determined in the brown alga Fucusvesiculosus and intertidal surface sediments from coastal locations of northeast England. Levels of heavy metals similar to those of polluted areas of the British coastline were detected.Aqua regia-extracted Zn, Cu, and Pb in sediments are significantly correlated with those in seaweed. Despite the closure of all base metal and coal mines, and the cessation of many industrial activities in the region, sediments and brown algae are contaminated with heavy metals[35].

Side effects of heavy metals in human health

Heavy metals are individual metals and metal compounds that can impact human health [36].Of the 92 naturally occurring elements, approximately 30 metals and metalloids are potentially toxic to humans, Be, B, Li, Al, Ti, V, Cr, Mn, Co, Ni, Cu, As, Se, Sr, Mo, Pd, Ag, Cd, Sn, Sb, Te, Cs, Ba, W, Pt, Au, Hg, Pb, and Bi [37].Generally, humans are exposed to these metals by ingestion (drinking or eating) or inhalation (breathing) [38].Concern has been raised about possible heavy metals contamination in seaweeds. Anthropogenic sources of metals derived from mining, petrochemical industry, printing, electronic industry and municipal waste are ultimately discharged into the marine environment [39].

A study in south eastern Chinaresearched the distribution of 10 metals and metalloids in 295 dried seaweeds (brown and red) and estimated the possible health risk via hazard index (HI). Elements in seaweeds can be sequenced in descending order by mean values:$Al > Mn > As > Cu > Cr > Ni > Cd > Se > Pb > Hg$. The levels of Cd, Cu, Mn and Ni in red seaweeds were significantly higher than those in brown seaweeds ($P < 0.01$). Correlation analysis showed contents of Ni-Cr ($r = 0.59$, $P < 0.01$) in seaweeds had moderate positive correlations. Seaweeds from different geographical origins had diverse element distribution. Risk assessment showed that HI at mean level was less than the threshold of 1. It indicates that for the general people there is low health risk to these elements by the intake of seaweeds. Furthermore, in terms of the confirmative toxicity of some metals, such as Cd, Pb and Hg, surveillance of metals in seaweeds should be performed continuously[40].For example; Cadmium (Cd) is a pollutant with multiple adverse health effects: cancer, renal dysfunction, osteoporosis and fracture, and cardiovascular disease [41].

At very high levels, most heavy metals can cause health problems. However, this is very uncommon. There is growing evidence that “chronic” or long-term exposure to lower levels of heavy metals also causes health problems.Symptoms of chronic heavy metal toxicity can include:Headache; Weakness; Muscle and joint pains; Constipation;Feeling tired. However, True chronic heavy metal poisoning is rare[42].

Hence, there is a need for proper understanding of mechanism involved, such as the concentrations and oxidation states, which make them harmful. It is also important to know their sources, leaching processes, chemical conversions and their modes of deposition in polluting the environment, which essentially supports life[43].

Effective legislation, guidelines and detection of the areas where there are higher levels of heavy metals are necessary. Failure to control the exposure will result in severe complications in the future because of the adverse effects imposed by heavy metals.However, occupational exposure to heavy metals can be decreased by engineering solutions. Monitoring the exposure and probable intervention for reducing additional exposure to heavy metals in the environment and in humans can become a momentous step towards prevention. National as well as international co-operation is vital for framing appropriate tactics to prevent heavy metal toxicity [44].

II. Discussion

Building on the United Nations Food and Agriculture Organization's (FAO) food demand projections, it's estimated that the world needs to close a 70 percent "food gap" between the crop calories available in 2006 and expected calorie demand in 2050 [12]. Algae has been existing on earth since its beginning but its prospective advantages have recently been understood and hence it is now being considered to play a major role in solving some of the most critical problems of the world. However the high cost of algae production is an obstacle in making algae a mainstream candidate for the development of various products.An economic analysis of algae growth through fish excreta reduced the cost of algae production to 45% as compared to algae grown in MBBM [45].

Edible seaweed products have been consumed in many Asian countries. Edible seaweeds accumulate iodine from seawater, and are therefore a good dietary source of iodine [22]. However, Several studies show that safety hazards for seaweed may include iodine, ANFs, heavy metals, radioactive isotopes, ammonium, dioxins, and pesticides[20, 21, 22].

A study discovered that seaweed, Gracilariachangiiis high in dietary fibre (64.74 ± 0.82%), low in fat (0.30 ± 0.02%) and Na/K ratio (0.12 ± 0.02) [26]. The total content of amino acids in A protein extract from the brown seaweed Himanthaliaelongata (Linnaeus) S. F. Gray, is determined as 54.02 ± 0.46 g amino acids/kg dry weight, with high levels of the essential amino acids lysine and methionine. SDS-PAGE showed 5 protein bands with molecular weights of 71.6, 53.7, 43.3, 36.4 and 27.1 kDa [27].

It is clear that seaweeds (microalgae) represent a sustainable source of various bioactive natural carotenoids and proteins [6,10]. Although conventional processing technologies, based on solvent extraction, offer a simple approach to isolating carotenoids, they suffer several, inherent limitations, including low efficiency (extraction yield), selectivity (purity), high solvent consumption, and long treatment times, which have led to advancements in the search for innovative extraction technologies [6].

When discussing the possibility to use seaweed as source of protein for consumption we must know about the risk of heavy metals in seaweed because many algae species absorb heavy metals that are caused by the industry [32, 33, 34]. At very high levels, most heavy metals can cause health problems. However, this is very uncommon [42].

III. Conclusion

Building on the United Nations Food and Agriculture Organization's (FAO) food demand projections, it's estimated that the world needs to close a 70 percent "food gap" between the crop calories available in 2006 and expected calories demand in 2050 [12], we are evaluating seaweed as a source of protein as the future of food production worldwide. In this review we found the high nutritious values of proteins in Seaweed, however we also found the concentrations of heavy metals present.It is clear that seaweeds (microalgae) represent a sustainable source of various bioactive natural carotenoids and proteins [6,10]. However, Several studies show that safety hazards for seaweed may include iodine, ANFs, heavy metals, radioactive isotopes, ammonium, dioxins, and pesticides[20, 21, 22]. At very high levels, most heavy metals can cause health problems. However, this is very uncommon [42]. Thus, this review suggest more research for cultivating seaweed without the presence of heavy metals or to experiment on how to extract heavy metals from seaweed. As seaweed is a very sustainable source of protein, we could use seaweed as a source of protein for human consumption worldwide, however we need more research in the health hazards of heavy metals in seaweed and more research in techniques to prevent healthhazards from the use of seaweed. If we could useseaweed as a sustainable source of protein we should continue the research to use the harmful algal blooms as a source of protein for human consumption.

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