Chapter 2

Ulva Genus as Alternative Crop: Nutritional and Functional Properties

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Abstract

Use of seaweed by humans is an ancient practice. In Asian countries, the use of them in human and animal feed, traditional medicine, and compost in agriculture is well documented. Since the twenty-first century begins, the scientific interest for seaweed had increased in Occidental countries. *Ulva* or *Enteromorpha* is a green macroalgae genus that raises and cultivates around the world. It has salinity tolerance and growth with diverse nitrogen ratios, be able to farm them in aquaculture systems. Scientific studies seen in this genus an interesting profile of chemical compounds: The protein is similar in quantity and quality to soy or some animal products; dietetic fiber percentage is elevated (>40%), being around 40% soluble fiber of them. In addition, fiber fraction presents Ulvan, a complex sulfated polysaccharide that presents antiviral, antihyperlipidemic, and antidiabetic effect in animal assays. Moreover, antioxidant and phytochemical profile has not being totally elucidated, giving important opportunities to scientific community for explode consciously this biological resource.

Keywords: *Ulva* , *Enteromorpha* , algae, Ulvan, functional food

1. Introduction

For centuries, food has been used to promote health, but the knowledge of the relationship between food components and health is now being understanding, helping to improve food quality or discover new nutrient sources. Use of seaweed in human and animal feed, as natural medicine, is a practice that goes back many eras, mainly in Asian countries. In Occident, mostly they had been confined as raw material for obtaining phycocolloids. Since the twenty-first century initiates, the innovation of algae as a crop, predominantly *Ulva* species had made an increase in the possible uses in food and health industry. The evidence had showed *Ulva* species present agronomical and nutritional facts scientifically interesting. The *Ulva* genus is tolerant to environmental challenges, and the biomass increases in fast way. Nutritionally, the protein ratio is similar to some legumes and some varieties shown high digestibility (>90%). The lipid fraction contains polyunsaturated fatty acids (PUFA) and another fatty compounds of interest, as alpha linoleic acid (ALA). However, fiber fraction and antioxidant compounds would be the most interesting elements; which present antioxidant activity, support to decrease glucose, cholesterol, and triglycerides levels in blood, among other benefic health effects. The aim of this chapter is to review about *Ulva* as an alternative crop and its role as functional food and nutraceutical compounds source.

2. Biological characteristics of *Ulva*

The employment of seaweeds in human and animal nutrition had been practiced for centuries, principally in Oriental countries, mainly in China, Japan, and South Asia area. In the last decades, European and American countries as France, Scotland, Peru, and Chile had been added this crop as ingredient in traditional food [1]. However, the most part of the seaweed species founded in littoral areas around the world is used as a basis in phycocolloides extraction, utilized in textile, chemistry, and food industry; or as agronomic basis for fertilizes [2].

One cosmopolite green seaweed group is Ulvaceae family. The genus *Ulva* (subsequently denominated *Ulva* in text) has specific biological and physiological characteristics. *Ulva* frequently is distributed marine environment with its few freshwater representatives, with variation of salinity, temperature, water quality, and grow successfully in nutrient-rich habitats [3, 4]. Macroscopically shape is filament-like and membranous (leaf-like), growing in form of typical vividly green tube- or leaf-shaped thalli, often also with various types of branches, attached to the substrate by rhizoids, or later as free-floating intestinoid clusters [5]. *Ulva* forms morphologically similar haploid and diploid thalli, both of which produce asexual zoospores by mitotic division of vegetative cells [6], showing biflagellate or quadriflagellate gametes or zoospores. In addition, the cell has complex and thick cell wall made of microfibrils with irregular settled; containing one parietal and cup-shaped chloroplast with one or numerous pyrenoids [6, 7]. For these reasons, taxonomically *Ulva* is complicated macroalgal group and usually confused with *Enteromorpha* genus; they are used as synonyms. If the differentiation of both genus is required, it would be necessary genetic and/or ultrastructure studies [8].

2.1. *Ulva* as a crop: agronomical uses and advantages

Ulva is widely distributed around the world and tolerant to some environmental challenges, enabling the amount of biomass generated being in order of tons. Around 16 million tons of seaweeds (fresh weight basis) and other marine plants are annually produced or collected with an estimated value of 5575 million Euros worldwide [9]; at the same time, seaweeds are currently considered as an underexploited or barely not exploited natural resource [10–12]. In a Mexican report, the biomass generated by *Ulva* in Golfo de México littoral had been quantified, showing around 360–426 ton weight dry basis, mostly of them, being wasted or eliminated [13], due the deoxygenation of water and fish deaths, besides the unsightly and undesirable odor when in decomposition [14].

Most of the metric tons of seaweed are used as nutrient supplement or biostimulant/biofertilizer to increase plant growth and yield. Studies have revealed a wide range of beneficial effects of seaweed extract applications on agronomic plantation; helping to improve agriculture practices as seed germination, performance yield and decrease stress, and upgrade postharvest shelf-life of unpreserved products [11]. Seaweed components such as macroelement and microelement nutrients, amino acids, vitamins, cytokinins, auxins, and abscisic acid (ABA)—such as growth substances affect cellular metabolism in treated plants leading to enhanced growth and crop yield [15–17], but many of the action modes or biochemical pathways activated are unknown or barely elucidated [11].

Literature mentioned that *Ulva* contains some metabolites and polysaccharides would act as effective elicitors of plant defense against plant diseases. A study using extracts of *Ulva* spp. against *Colletotrichum trifolii* in *Medicago truncatula* showed disease resistance without the elicitation of necrotic lesions [18]. *Ulva* extract elicited the expression of the PR-10 gene. The PR-10 gene belongs to the group of pathogenesis-related genes (PR) important for active defense against diseases following pathogen attack [19], be able to up regulate until 152 genes related to plant defense [18].

As its know, the different algae species present alginates and another complex polysaccharides which retain water and minerals, helping to moisture and growing of plants. A mix of salts of alginic acid and metallic ions in the soil helps to absorb moisture and make and swelling effect, intensification mud structure, making a healthier soil for plant root system [20].

In other hand, cultivate seaweed, as *Ulva* could be a form to reduce aquaculture pollution, generating biomass utilizable for another industries. The aquaculture industry, predominantly land-based aquaculture, generates more than 65 million tons of organisms cultivated annually [9]. The intensive aquaculture production is reliant on high-protein feed to facilitate the rapid growth of animals. Nevertheless, the protein conversion ratio of aquatic organisms is relatively ineffective, resulting in nutrient-rich remaining [21]. If released directly into the environment, these waste nutrients can cause significant environmental degradation through nitrogen enrichment and lead to the proliferation of algal growth [22], producing an unbalance in oxygenation of water.

Seaweeds as *Ulva* can be cultivated in aquaculture wastewater to recover a high proportion of these waste nutrients, while simultaneously creating a biomass resource [23]. The integration of seaweed cultivation with land-based aquaculture for nutrient remediation has been successfully demonstrated at a research level numerous times [23–25], although rarely implemented commercially [26]. One of the major reasons for this is that the seaweed biomass produced requires a market, or on-site use; otherwise, the seaweed biomass itself can become a waste product and liability [27].

One of the lowest cost approaches to explode this biomass is composting, which is the aerobic decomposition of organic material by successive microbial communities. To successfully compost any organic waste, the carbon-to-nitrogen ratio of the material needs to be balanced. As seaweed is a relatively novel feedstock for composting, it is unknown as to how the initial C:N ratio of seaweed-based composts will influence the composting process and the quality of the mature compost, but studies had demonstrated that it is feasible, making a high-quality compost, with C:N ratio for seaweed-based composts to be 22:1, which corresponds to seaweed accounting for 82% of the compost on a fresh weight basis [27]. Another way of decrease nutrient waste in aquaculture by *Ulva* culture is through fluid systems, making possible remove total N in water, increasing optical transmittance of light [28]. Additionally, *Ulva* methanolic extract presents antialgal activity against red tide microalgae [29], which could act as biological contaminant in aquaculture.

2.2. Nutritional evidences of *Ulva* algae

At the same time, as food has long been used to improve health, our knowledge of the relationship between food components and health is now being used to improve food [30]. The foods that provide nutrients and additionally promote health had been denominated "functional food". Functional foods can provide health benefits by reducing the risk of chronic diseases and enhancing the ability to manage chronic diseases, thus improving the quality of life. Functional foods also can promote growth and development and enhance performance [30].

Seaweeds have become a valuable vegetable, fresh or dried, and an important food ingredient in the human diet [31], mainly in Oriental countries and lately in European and Latin American countries. They are identifiable by present protein, polysaccharides, mineral, and some vitamins in important percentages.

Interest in *Ulva* as a "newness food" is expanding in Western countries. The nutritional information about *Ulva* has been focused in: *Ulva lactuca*, *Ulva pertusa*, *Ulva fasciata*, *Ulva rigida*, *Enteromorpha* sp., *Enteromorpha flexuosa*, *Enteromorpha intestinalis*, and *Enteromorpha compressa* [32].

Normally, the chemical composition of *Ulva* has 9–14% protein; 2–3.6% ether extract (n-3 and n-6 fatty acids 10.4 and 10.9 g/100 g of total fatty acid); 32–36% ash. Alkaloids, cyanogenic

***Ulva* species**	**Protein (%)**	**Lipid (%)**	**Ash (%)**	**Total dietetic fiber (%)**	**Insoluble fiber (%)**	**Soluble fiber (%)**
Ulva spp. (as *Enteromorpha* spp.) [33]	9.45–14.10	2.20–3.60	32.64–36.38	–	–	–
Ulva clathrata [34]	13.13	2.92	18.36	44.44	–	–
Ulva clathrata [32]	21.9–26.9	2.5–3.5	44.8–49.6	24.8–26.3	8.7–10.7	15.6–16.6
Ulva lactuca [35]	8.46	7.87	19.59	54.90	34.27	20.53
Ulva spp. [30]	7–44	0.3–1.6	11–55	38	17	21
Ulva lactuca [36]	7.06	1.64	21.3	55.4	–	–

Table 1. Chemical composition of *Ulva* species

glucids, saponins, and tannic acid are near to null [33]. In **Table 1**, some *Ulva* species are titled by nutritional characteristics.

2.3. Protein of Ulvales: amino acidic profile and bioactive peptides

The protein ratio of Ulvales would oscillate by different factors, as the species is cultivated or marine source, changes in seasonal periods [31], principally. Generally, the highest protein value has been found during the period of winter–early spring and the lowest during summer–early autumn [37].

Diverse researchers had found interesting information about the *Ulva* protein, presenting an amino acidic profile comparable to soy or another legumes, peptides with bioactivity against inflammation processes, antivirals, among others. *Ulva* founded in Mexican littorals was analyzed, and the results for amino acids content shown 9 of the 10 considered essential for humans are present in protein of *Ulva* spp., a higher quantity than in an equivalent weight of soy [33]. The concentration of isoleucine, leucine, lysine, and threonine is higher to the FAO-OMS pattern [38]. Protein digestibility by enzymatic assay was 98% compared to the reference casein pattern. Anti-nutritional factors (tannins, alkaloids, cyanogenic glucids, and saponin) that could affect digestibility were scarce to none [33].

In Hong Kong and Tunisia areas had been reported similar results about amino acids for *Ulva*. The essential amino acid score analysis of *U. lactuca* shown seaweed samples contained all the essential amino acids (in different proportions, excluding tryptophan), which accounted for 42.1 ± 48.4% of the total amino acid content, being Leucine was limiting amino acid but to be able to contribute adequate levels of total EAA [35, 36]. *Ulva armoricana* contains high levels of the amino acid proline (approximately 5–11%) of total amino acids, while *U. pertusa* is reported to have an arginine content of 15% [39, 40].

For these reasons, *Ulva* protein had been used by the fortification in some reports. The results for bread shown that an *Ulva* and *Cladophora* spp. mixture increases the protein percentage with minimal variations in sensory and technological properties [14]. In case of maize tortilla, the protein percentage was significantly increased but in chemical compute, the *Ulva* protein was not complementary to maize protein. The rheological and sensorial properties in maize tortilla were slightly modified [34]. In addition, the free amino acid fraction of seaweed is mainly composed of alanine, arginine, aspartic, and glutamic acid; given the characteristic taste of "sea product" [34, 41] **(Table 2**).

A myriad of positive health beneficial properties is associated with bioactive peptides including antihypertensive, anti-diabetic, anti-obesity, immune-modulatory, relaxing, and satiety-inducing effects [42]. Bioactive peptides used as functional food ingredients do not accumulate in body tissue, and there are only a few reports regarding negative side effects when bioactive peptides are used for preventative healthcare purposes. In the case of *Ulva* genus had been isolated a mitogenic hexapeptide, SECMA 1. This peptide was shown to be involved in the modulation of cell proliferation-associated molecules, proteoglycans and glycosaminoglycans in human foreskin fibroblasts [43].

Amino acid	*Ulva* spp. flour
Taurine	0.09
Hydroxiproline	0.34
Aspartic acid	1.70
Threonine	0.71
Serine	0.69
Glutamic acid	1.73
Proline	0.50
Lantionine	0.02
Glycine	0.85
Alanine	1.28
Cysteine	0.30
Valine	0.80
Methionine	0.26
Isoleucine	0.48
Leucine	0.75
Tyrosine	0.31
Phenylalanine	0.64
Hydroxilysine	0.18
Ornithine	0.12
Lysine	0.48
Hystidine	0.12
Arginine	0.68
Tryptophan	0.10
Total	13.13
Protein crude (N × 6.25) grams	14.99

*Grams per 100 g sample. Extracted with the permission from Vázquez Rodríguez et al [34].

Table 2. Amino acids profile of *Ulva* spp.

In addition, *Ulva* presents bioactive lectins. These proteins interact with specific glycan structures, making glycoconjugates. The protein–carbohydrate interaction is responsible for participation in numerous biological and immunological processes [44]. Furthermore, lectin has been found to increase the agglutination of blood cells (erythrocytes) and is also useful in the detection of disease-related alterations of glycan synthesis, including infectious agents such as viruses, bacteria, fungi, and parasites [10, 45, 46]. Other bioactive properties exhibited by marine algal lectins include antibiotic, mitogenic, cytotoxic, anti-nociceptive, anti-inflammatory, anti-adhesion, and anti-HIV activities [45, 47, 48].

2.4. Dietary fiber in *Ulva*: Ulvan as bioactive polymer

Dietetic fiber is a complex mixture of polysaccharides no digestible. Structurally, polysaccharides are polymers of simple sugars (monosaccharides) linked together by glycosidic bonds, and this characteristic gives them numerous commercial applications in products such as stabilizers, thickeners, emulsifiers, and generally, food industry. The total polysaccharide concentrations in the seaweed species of interest range from 4 to 76% of dry weight; in *Ulva* species, the concentration would be until 65% of dry weight [9].

In algae, the cell wall polysaccharides mainly consist of cellulose and hemicelluloses, neutral polysaccharides, and are thought to physically support the thallus in water. The cellulose and hemicellulose content of *Ulva* species is around 9% both. Lignin is characteristic of *Ulva* sp., with concentrations of 3% dry weight [49]. As storage polysaccharides, green algae contain sulfuric acid polysaccharides, sulfated galactans, and xylans [30].

The seaweed dietary fibers contain some valuable nutrients and substances, and there has been a deal of interest in seaweed meal, functional foods, and nutraceuticals for human consumption by the presence of complex polysaccharides; shown antitumor and antiherpetitic bioactivity; they are potent as an anticoagulant and decrease low-density lipid (LDL)-cholesterols in rats (hypercholesterolemia); they prevent obesity, large intestine cancer, and diabetes; and they have antiviral activities [46, 50–54]. Moreover, glucose availability and absorption are delayed in the proximal small intestine after the addition of soluble fibers, thus reducing postprandial glucose levels [55]. Water-insoluble polysaccharides are mainly associated with a decrease in digestive tract transit time [41].

In the green algae, most work has focused on storage polysaccharides. In *Ulva* genus, these are known as Ulvan. Ulvan and derives display several biological activities of potential interest for therapeutic, nutraceutical, and personal care applications [42]. Ulvans are highly sulfated polysaccharides (189–8200 kDa [56]) composed by a mix of rhamnose, uronic acid, and xylose as the main monomers. Furthermore, the Ulvans containing a disaccharide, the aldobiuronic acid, [→4)-D-glucuronic acid-(1→4)-L-rhamnose3-sulphate-(1→], and iduronic acid. As dietary fiber, Ulvans contain a water-soluble fraction and insoluble material, similar to cellulose.

The mechanism of gel formation of Ulvan is exceptional between polysaccharide hydrogels and phycocolloids. The Ulvan rheology is compared with Arabic gum but presents another characteristics not fully understood due to its physicochemical interactions are very complex. Ulvans have thermoreversible behavior without thermal hysteresis, and its gelling properties are affected by boric acid, divalent cations as Ca^+ and pH. These properties perhaps of interest for chelating application [30, 56], among others.

These properties make to Ulvans highly water absorbent and under some conditions, biodegradable hydrocolloid; making desirable for some industries. Relationally to food industry, Ulvans can constitute an effective and low-cost alternative to meat-derived products because their rheological and gelling properties make them suitable substitutes for gelatin and related compounds [57].

Medical and pharmacologically, Ulvans and their oligosaccharides present anticoagulant, antioxidant, antiviral, anticancer, and immunomodulation activities [12]. They were able to modify the adhesion and proliferation of normal and tumoral human colonic cells as well as the expression of transforming growth factors and surface glycosyl markers related to cellular differentiation [58]. Ulvan is rich in iduronic acid. Iduronic acid is used in the synthesis of heparin fragment analogues with anti-thrombotic activities [56]. Oligosaccharides from *Ulva* could be used as reference compounds for analyzing biologically active domains of glycosaminoglycan-like heparin [59]. Ulvans possess immune-modulatory activities that may be of potential application in stimulating the immune response or controlling immune cell activity to mitigate associated negative effects, such as inflammation. It had been proved that low-Mw sulfated Ulvans from *U. lactuca* and their desulfated derivatives have anticancer activities because they can inhibit Caco-2 cell proliferation and/or differentiation in cell culture tests [60]. In reports had evaluated the effects of a water-soluble acidic polysaccharide from *U. rigida* on the activities of RAW264.7 murine macrophages. However, these effects considerably decreased after desulfation of the polysaccharides, which suggests that the sulfate group is essential for the stimulatory capacity of these molecules [61].

Furthermore, Ulvans present antiviral effects. Some research indicates that almost all Ulvan fractions from *E. compressa* shown potent anti-HSV-1 activity as well as low cytotoxicity to host cells [62]. Extracts from *U. lactuca* can inhibit Japanese encephalitis virus (JEV) infection in Vero cells because the SP can block JEV adsorption and thus hinder the entry of JEV into the cells [63].

Much of the characteristics mentioned before are due to antioxidant activity present in Ulvans. Ulvans have emerged as prospective candidates for effective, nontoxic substances [64, 65] with potent antioxidant activity [66, 67] because they generally act as free-radical inhibitors or scavengers and, therefore, primary antioxidants. These effects include superoxide radical scavenging, hydroxyl radical scavenging, DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging, total antioxidant capacity, power reducing ability, and ferrous chelating ability. However, in terms of antioxidant potential, some crude Ulvans show effects no greater than those from red or brown algae (carrageenan and fucoidan) [68]. Even that the enzymatic or chemical digestion of Ulvans is adept; obtaining in some cases, fractions with anti-hyperlipidemic effects [69] and a significantly effect of sulfated degree in antioxidant and quelant effect [70]. Ulvans from *U. pertusa* also show antihyperlipidemic activity, affecting total cholesterol and LDL-cholesterol in blood serum [71]. The causal mechanisms of this bioactivity are unclear, but bile acid sequestration is hypothesized [69]. Additionally, the particular chemical structure of Ulvan make complicated fermentation process by colonic bacterial [72].

The commercial limitation of Ulvan and dietetic fiber of *Ulva* is based in its diverse and complex structure [73, 74], making difficult the standardization of properties [52, 62, 68, 75–77]; and the fiber fraction, mainly the insoluble fraction, quelate lead and another heavy metals, highly toxic to human or another animals, due to its extraction and use should be managed with quality control measures [35].

2.5. *Ulva* as a source of phytochemicals: bioactivity and nutraceutical function

Many studies already demonstrated the promising properties of macroalgae extracts, as health promoters. Anticoagulant, anti-proliferative, antiviral, antimicrobial, among others bioactivities are some of his characteristics. Notwithstanding macroalgae are known to contain numerous phytochemicals such as terpenes, phenolics, sterols, vitamins, principally. Their detailed chemical characterization and the identification of bioactive action are still largely unexplored in many species [78].

For example, the lipoid fraction of *Ulva* is slightly minor than protein or fiber fractions, but the fatty acid compounds presents in their make it relevant. Some researchers had found in *U. lactuca* numerous fatty acids (saturated and unsaturated) and relative compounds as diacids, long-chain aliphatic alcohols, sterols, monoglycerides, diterpenes, and tocopheroles; all valuable lipophilic components with well-established nutritional and health benefits [78].

Ethanolic extract of *U. rigida* (4.31 ± 0.74 μmol gallic acid g-1) presented anti-hyperglycemic, anti-oxidative, and genotoxic/antigenotoxic capacity *in vivo* in diabetic mellitus-induced rats. The possible mechanisms by which *U. rigida* exerts its antihyperglycemic action in diabetic rats may be due to the regeneration of b-cells in the islets of pancreas and/or potentiating the insulin release [79]. *U. rigida* presents a vast quantity of antioxidant as chlorophyll a, b, carotenoids, vitamins A, C, and E, phenolic content, among others; all them with important bioactivity [42, 69, 79–82].

Also, *Ulva clathrata* shows an important antioxidant potential in comparison with other species. This detail could be explained by a high phenolic and flavonoid quantities [83]. The results suggest that these edible green seaweeds possess antioxidant potential which could be considered for future applications in medicine, dietary supplements, cosmetics, or food industries.

3. Conclusions

Ulva genus shows an interesting profile as an alternative crop. Filamentous species of the genus *Ulva* have desirable characteristics for year-round large-scale cultivation, including a broad tolerance of salinity and temperature with high growth rates, enabling production in enclosed and open waters. Relatedly to human and/or animal nutrition, *Ulva* presents a balance of nutrients, as protein with amino score similar to legume or animal protein, an important PUFA fraction, dietetic fiber with functional activity (technological and nutritionally); furthermore of an important presence of various antioxidants as polyphenols, flavonoids, and sulfated compounds, among others, which activate different biochemical pathways, shown beneficial effects to health. In summary, *Ulva* exhibits an interesting agronomic profile and beneficial biological effects, which promotes this alga as an alternative functional crop. Despite the demonstrated properties, the presence of heavy metals should be evaluated, especially lead, for not limiting its use as food or raw material in diverse industries.

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