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# ALGAE AS FUNCTIONAL FOOD: REVIEW

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**Abstract.** The main cultivated and consumed varieties are *Ulva lactuca*, *Undaria pinnatifida* and *Porphyra yezoensis*. Edible algae are also a type of low-calorie and low-fat food. Extracts from the most common edible seaweeds contained polyphenol content. *Ulva* has been found to have low polyphenol content compared to species of red and brown algae. Marine algae present a good antioxidant activity. Macroalgae have anti-inflammatory, anti-cancer (*Undaria pinnatifida*) and anti-obesity effect amongst many others. These characteristics coupled with many other make them a valuable ingredient in food products or as functional food.
***Keywords:*** algae, antioxidant, functional.

## Introduction

Edible seaweeds can be directly consumed or used as a material for preparing food. Nowadays, there are diverse species of edible seaweeds be cultured as large-scale including *Porphyra yezoensis, Saccharina japonica*, and *Undaria pinnatifida* Seaweeds contain a large amount of nutrient contents such as proteins, dietary fiber, vitamins, and minerals. Seaweeds are also rich in bioactive compounds including polyphenols, polysaccharides (Teng *et al.*, 2013), peptides, sterols, flavonoids, alkaloids, proteins, fatty acids, and other bioactive compounds (Jmel *et al.*, 2019; Burtin, 2003).

Regular consumption of seaweeds has many benefits. As an addition to these benefits, the medicinal properties of seaweed bioactive have been recognized. Seaweeds are used for treatment and or for prevention of goitre, which is caused by the lack of iodine in the diet. Several studies have shown various remedial effects of algal species against non-communicable diseases such as inflammation, obesity, diabetes, hypertension and viral infections (Shao *et al.*, 2017). A clinical study showed that regular consumption of *Undaria* seaweed can effectively minimise the risk of breast cancer in women, while an oral administration of seaweed extracts (*Fucus vesiculosus,*

*Macrocystis pyrifera* and *Laminaria japonica*) with zinc, manganese and vitamin B6, potentially decreased osteoarthritis symptoms in a mixed population. Seaweeds are well-known for their antioxidant capacities and bioactive polyphenolic compounds (Ganesan *et al.*, 2019).

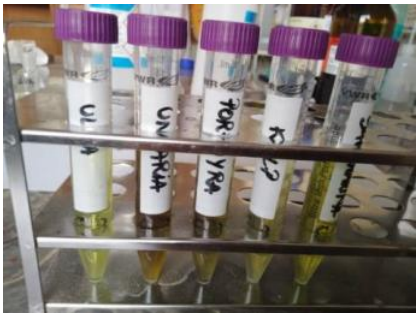

Fig. 1. Methanolic extracts of algae

## Algae species

From all the algae species that are commonly used as food or as food ingredient were chosen three most important.

### *1.Undaria pinnatifida*

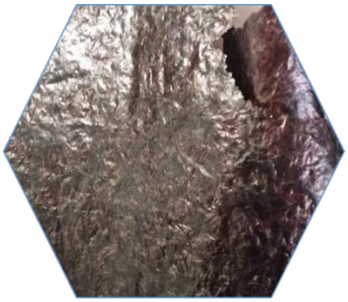

Fig. 2. *Undaria pinnatifida*

*Undaria pinnatifida* (Fig. 2) contains carbohydrates (a percentage of 9.14%) such as monosaccharides, polysaccharides (sacran, mannan and xylan), dietary fiber, lipid ( a percentage of 0.64%) such as unsaturated fatty acid and saturated fatty acid, protein composition (3.03%) such as peptides, vitamins, amino acids and its derivatives (methacrylic acid) and tauric acid, minerals, plus some phytochemicals including polyphenols, flavonoids, alkaloids and sterols (Chiu *et al.*, 2012; Gurpilhares *et al.*, 2019; Jun *et al.*, 2019).

Recently more and more research has focused on searching antioxidant agents for development of a therapeutic agent or functional food. Oxidative stress is an imbalance between reactive oxygen species (ROS) generation and scavenging by endogenous antioxidants. ROS are products in any living organisms. The excess of cellular ROS can lead to cellular damage of essential macromolecules such as DNA, protein, and lipid, cellular endomembrane system damage which affect cell function, apoptosis and necrosis. These facts tell us that oxidative stress promotes inflammation, tumour, obesity, diabetes, cardiovascular diseases and other chronic diseases (Han *et al.*, 2002).There were different studies performed on rats on the lipid peroxidation of the liver. It was proved to be decreased when polysaccharides were added to rats (in their feed) compared with the ones with high-fat diet only. *Undaria pinnatifida* has a proven antioxidant activity of the phenolic compound rich extract (30.85 mg of gallic acid equivalents/g of extract). The extract is rich in protocatechuic acid and syringic acid. Kang *et al.* (2008) reported that fucoidan isolated from *U. pinnatifida* (UPFE) has strong protective effects against carbon tetrachloride (CCl4)-induced oxidative stress in an in vivo rat model (Hata *et al.*, 2001).

*U. pinnatifida* also has an anti-inflammatory effect (Wang *et al.*, 2019). Inflammation is a multifactorial dynamic and complex physiological process, which occurs in the response to harmful stimuli or injury in the body, aiming to remove or control the harmful agent, or promote the injured tissue repair. Redness, swelling, heat and pain are the most representative symptoms of inflammation. Macrophages release various pro inflammatory molecules during the process of inflammatory response (Cheong *et al.*, 2016).

Some marine algae are also known for their anti-cancer activity. Tumour is an abnormal tissue mass existing as fluid-filled or solid form. Tumours are classified into three types (benign, pre-malignant and malignant) based on their characteristics. The malignant tumour is known as cancer, which grows rapidly and metastasizes. In recent years cancer has been the leading cause for death around the world (Samarakoon *et al.*, 2014). World Health Organization (WHO, 2018) reported that 9.6 million people died of cancer in 2018. Cancer has become the first leading cause of death in developed countries and the second in developing countries. Therefore looking for a safe and effective therapeutic agent for prevention and treatment of cancer has become a timing topic (Adrien *et al.*, 2019).

Yang *et al.* (2008) presented that the fucoidan isolated from the species *U. pinnatifida* shows anti-cancer activity in human lung cancer cell line (A549) by reducing cell growth by 37.6%. This growth inhibition was increased to 75.9%, when the fucoidans were hydrolyzed by boiling water with HCl for 5 min. The results suggest that about 40% of cell proliferation,

40% of cell migration, and 61% of tube formation were inhibited when cells were treated with a concentration of 400 μg/mL fucoidan (Boo *et al.*, 2011; Billakanti, *et al.*, 2013; Boo *et al.*, 2013).

Algae can also have effects against obesity, a medical condition in which a humans body weight is beyond their normal body mass index due to the accumulation of excess fat, which may have negative effects on health (liver steatosis, cardiovascular disease, osteoarthritis, type 2 diabetes, and some types of cancer)(Chandrasekaran *et al.*, 2012). Obesity has become a serious health issue in the recent years. Recent reports support that *U. pinnatifida* also possesses anti-obesity activity. Fucoxanthin and fucoxanthinol from *U. pinnatifida* suppress adipocyte differentiation and intercellular lipid accumulation through down-regulation of proliferator-activated receptor gamma. Fucoxanthinol has stronger effects than fucoxanthin on adipocyte differentiation (Jeon *et al.*, 2010).

Species like *Undaria pinnatifida* have a good potential to fight cardiovascular diseases (Cai, 2000) through the reduction of hypertension and prevention of blood-clotting. All of these seven peptides were shown to have potent ACE inhibitory activity. It was demonstrated that a daily dose of 5 g dried *U. pinnatifida* powder lowered the blood pressure and hypercholesterolemia levels of hypertensive patients (Hata *et al.*, 2001; Taboada et al, 2013; Song *et al.*, 2019; Hui *et al.*, 2019).

### *2. Ulva lactuca*

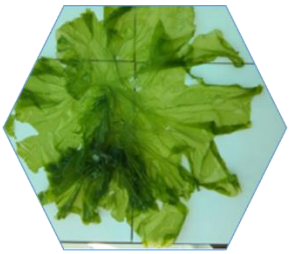

Fig 3. Fresh *Ulva lactuca*

*Ulva lactuca* (Linnaeus) (Fig. 3), commonly known as sea lettuce, is marine green seaweed. Morphologically, the colour has variations from green to dark green. Fronds are attached to rocks with the help of holdfast. It gains 20-30 cm diameter that is quite smaller (Pereira *et al.*, 2012; Tang *et al.*, 2016).The nutritional composition of *U. lactuca* includes dietary fiber, amino acid, and tocopherol compounds. There are 16.5% of water-soluble and 13.3% insoluble dietary fibers. Some substances isolated from these algae have proven to have pharmacological activities. Some studies revealed that

the heteropolysaccharides isolated from *U. lactuca* can stimulate macrophage - and T-cells in mice (El Sayed *et al.*, 2011).

Oligosaccharides from green algae *Ulva lactuca* and *Enteromorpha prolifera* were used for investigation of anti-ageing effects mechanism in mice. These oligosaccharides enhanced the glutathione, superoxide dismutase, catalase, and telomerase levels and total antioxidant capicity. They also decreased the levels of malondialdehyde and advanced glycation end products. To summarise the study, oligosaccharides from *U. lactuca* and *E. prolifera* play important anti-ageing roles by reducing oxidative damage, protecting brain neurons, reducing inflammatory factor levels, and regulating apoptosis-related genes. New evidence shows that *U. lactuca* oligosaccharides are highly efficient at preventing apoptosis and have excellent anti-ageing effects due to the high sulfated content (Xiao-yan *et al.*, 2019).

Significant anti-inflammatory activity of methanolic extract of *U. lactuca* (Fig. 1) (500 mg/kg b.wt) may be due to inhibition of the mediators of inflammation (histamine, serotonin, prostaglandin) (Athukorala *et al.*, 2007).

*U. lactuca* extract treatment significantly decreased the elevated serum pro-inflammatory cytokines stated that RA has been associated not only with free radical formation but also with low antioxidant status. It was proved that high lipid peroxidation was an indicator of increased oxidative stress and reduced antioxidant capacity. It was noticed that the superoxide radicals are the first product of molecular oxygen reduction (Osama *et al.*, 2017; Sanna *et al.*, 2019).

### *3. Porphyra yezoensis*

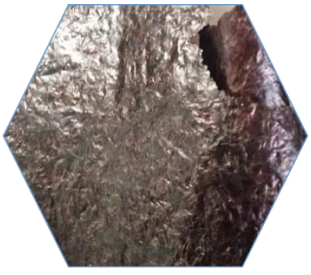

Fig. 4. *Porphyra yezoensis* (Nori sheet)

*Porphyra* is seaweed that is used as medicine. *Porphyra haitanensis* is known to contain large quantities of sulfated polysaccharides, proteins, minerals, and amino acids and many other active components (Zhao *et al.*, 2011).

The *in vitro* antioxidant activities were proved by different studies. Nori, a dried sheet product of *Porphyra yezoensis* (Fig. 4), is known to contain an exceptionally high (12.5-51.5% w/w) protein content among seaweeds and can be expected to produce a high quantity of free amino acids after degradation (Uchida *et al.*, 2017).

**Chlorophyll importance and cooking effects on the algae**

Chlorophyll pigments are one group of bioactive compounds present in edible seaweeds and have been proven to harbour important biological properties, such as antioxidant, antimutagenic and anti-inflammatory effects. The pigments are bioavailable and distributed in the serum. In fact, seaweed chlorophylls have been shown to be resistant to in vitro digestion and are potentially absorbed by the intestinal epithelium.

The phyla *Rhodophyta* and *Phaeophyta* mainly contain magnesium detached derivatives, including pheophorbides and pheophytins and phylum *Chlorophyta* mainly contain magnesium-containing chlorophyll derivatives (Chen *et al.*, 2017). Different chlorophyll compounds exhibit distinct functional properties and also different bioavailability characteristics.

Two most common cooking techniques are boiling and microwave treatment.

For Nori, the amount of total chlorophyll pigments is slightly reduced by the boiling process and microwave treatment. The fresh dried starting materials were mainly composed of pheophorbides and pheophytins of series a (> 97%) (Chen and Roca, 2018). For *Ulva lactuca* it can be stated that cooking caused the net degradation of total chlorophyll pigments, with a decrease of 28% and 14% after the boiling and microwave processes, respectively. This degradation affected series a chlorophyll more than series b (less than 10% for boiling and unchanged in net b series content after microwaving). The pheophytinisation reaction affected over 50% of chlorophyll b after *Ulva lactuca* cooking. For the brown algae Kombu, the cooking process had caused a loss of around 30% of the total chlorophyll pigments. This loss is even higher than for *Ulva lactuca*. The net degradation of chlorophyll affected the c series more than the a series of pigments. Cooking also caused the pheophytin a degradation of brown seaweeds. For the c series pigments, pheophorbide c1 was formed after the cooking of brown seaweed from chlorophyll c1, but the transformed amounts did not account for the total loss of chlorophyll c1, therefore suggesting a net degradation of chlorophyll c1(Chen and Roca, 2018).

Betaine lipids are widely distributed in algae, where they display different functions as donors of diacylglycerols and fatty acids to be used in the biosynthesis of other lipid classes (Rey *et al.*, 2019).

*Ulva pertusa* aldehydes were 54% of the total volatiles belonging to similar aliphatic compounds (Sugisawa *et al.*, 1990; Madhusudan *et al.*, 2011).

Alkaloids are very important compounds. They have rarely been isolated from macroalgae (mostly from plants). The main difference between the alkaloids present in plants and algae is that indoles and halogenated alkaloids are found specifically in algae. Marine algae contain 44 alkaloids, consisting of 1 phenylethylamine, 41 indole, and 1 naphthyridine derivates. In the halogenated alkaloid group, there can be found 25 bromine-containing compounds, among which 7 have chlorine and 5 have sulfur, additionally. In brown algae are rarely found but in red algae alkaloids are more abundant than in green algae.

Some alkaloids were produced by host organisms on algae. Like communesin which was isolated from the mycelium of a strain of *Penicillium* sp. on the *Enteromorpha intestinalis*, Ascosalipyrrolidinone was isolated from fungus *Ascochyta salicornia* on green alga *Ulva* sp. and citrinadin A was isolated from *Penicillium citrinum* separated from a marine red algae (Guven *et al.* ,2013).

*Gracilaria canaliculata* (Red algae) has a protein content of 8.51621% on an average and hence it is found to be the most suitable as an alternative additive for diet containing high protein content. This seaweed can be consumed it the form of powder added to food items and ready to use (Madhu *et al.*, 2011).

Polyunsaturated fatty acids (PUFA) are vital components in human nutrition and are known to have several beneficial effects for human health. A diet intake of PUFA, both *n*-3 and *n*-6 fatty acids, is well known to modulate inflammatory processes and other cell functions. Some Phaeophyta and Rhodophyta species exhibit higher concentrations of PUFA. Phylum Chlorophyta presents the lowest PUFA/SFA ratios (0.27–0.68). Many studies suggest that this phylum has a lower potential compared to the other two phyla.

Macroalgae can also be used for pharmaceutical purposes. Many of the PUFA detected in macroalgae are considered powerful molecules against several diseases. As a result several species of macroalgae are used in biomedical application. Several studies suggest that *n*-3 fatty acids, mainly EPA and DHA, may have a significant potential in the treatment of autoimmune and inflammatory diseases. Rhodophyta was the phylum with the highest percentage of *n*-3 fatty acids (16%–27% of total FAME), followed

by Phaeophyta (0%–15%). Aside from *Ulva* sp. that had 18% of *n*-3 FAME, Chlorophyta macroalgae presented the lowest values of *n*-3 fatty acids (1%–9%) (Pereira *et al.*, 2012)

Marine algae also possess antimicrobial activity (Sung *et al.*, 2012). *Ulva lactuca* L., in a concentration of 1%, extract in methanol 70%, presented a good antimicrobial activity against *Enterococcus faecalis*, *Staphylococcus aureus* and *Escherichia coli*. The best activity was against the *Enterococcus faecalis*. In lower concentrations the effect was diminished (Biriș-Dorhoi, 2018).

## Conclusions

Algae have an extraordinary wealth of mineral elements that can account up to 36% for its dry mass (sodium, calcium, magnesium, potassium and chloride as macronutrients and for micronutrients iodine, iron, zinc, selenium). Seaweeds are alkaline and have digestible sugars. Chlorophyll content is only slightly reduced by the cooking methods (exception green macroalgae). Seaweeds possess different types of alkaloids depending on the phylum, Rhodophyta having the highest number.

Seaweed characteristics present them with antioxidant, anti-obesity, anticancer and anti-inflammatory activity which makes them suitable for as a food or food related products.

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