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Evaluation of Seaweed Resources as Functional Food in Turkey

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Abstract: Seaweeds are primary producers in marine environments and they are rich in proteins, minerals, vitamins, polyunsaturated fatty acids, soluble dietary fibers and bioactive antioxidants. Since they contain valuable substances, seaweeds have been used for functional food sources in recent years. These special foods may provide a health benefit beyond nutrition and they could reduce the risk of disease. In Turkish coastal waters, having wide biodiversity, the genus of *Gracilaria* (Rhodophyceae), *Cystoseira* (Phaeophyceae), and *Ulva* (Chlorophyceae) can be evaluated as functional foods. However, there isn't any industry on culturing and/or processing of these valuable seaweeds. This study review that seaweeds which could be evaluated as functional food industry in Turkey.

Keywords: Seaweed, Macro algae, Functional Food, Proximate contents, Pigments.

Introduction

Seaweeds are found in all coastal areas of the world, in all climatic zones from the warm tropics to the icy Polar Regions and they are by far the most abundant primary producers (Mouritsen, 2013). Seaweeds (macro algae) are traditionally classified according to chemical and morphological characteristics, with special relevance to the presence of specific pigments, which determine the inherence to one of the three algal divisions: brown, red and green algae (Van Den Hoek et al., 1995; Barsanti and Gualteri, 2006). A greater diversity in biochemical composition of seaweeds paves the path to explore variety of compounds in their composition with a wide range of physiological and biochemical characteristics, many of which are rare or absent in other taxonomic groups (Holdt and Kraan, 2011). Knowing the benefits associated with the seaweeds through the experience, seaweed has been used as an important dietary component for centuries in countries like China, Japan, and Korea. In addition, seaweeds are an important source of hydrocolloids: agar and carrageenan obtained from Rhodophyta and alginate obtained from Phaeophyceae. These hydrocolloids are widely used, mainly in the food industry, as thickeners and gelling agents (Freile-Pelegrin and Robledo, 1997). Seaweeds are attracting as a food source in other parts of the world, and growing interest is developing to explore all possible seaweed intervention including functional food product development (Mendis and Kim, 2011).

Functional foods defined as foods or dietary components that may provide a health benefit beyond basic nutrition (Hanninen and Sen, 2008). The beneficial effects could be either maintenance or promotion of a state of wellbeing or health and/or a reduction of risk of a pathologic process or a disease (Roberfroid, 1999). Functional foods include everything from natural foods, such as fruits and vegetables endowed with antioxidants and fiber, to fortified and enriched foods, such as orange juice with added calcium or additional carotenoids, to formulate ready to drink beverages containing antioxidants and immune-supporting factors (Wildman and Kelley, 2007). The global market for functional foods is expected to reach USD264.4 billion in 2013, with a compound growth rate of 7.4% (Abu-Ghannam and Cox, 2014). This situation has created a surge of research activity in identifying new ingredients and raw materials with beneficial health properties for the development of functional foods from both terrestrial and marine sources (Walsh and Watson, 2011). This study review that seaweeds which could be evaluated as functional food industry in Turkey.

Seaweeds as Functional Foods in Turkey

Turkey is surrounded by four seas (Mediterranean Sea, Aegean Sea, Sea of Marmara and Black Sea) and it has a diverse seaweed flora. Total number of seaweed species along the Turkish coasts is about 586 (Taşkın, 2014). Although there are so many species, the number of studies on biochemical composition of seaweeds are limited. Studies are usually focused on taxonomy and distribution of seaweeds.

Marine algae have been identified as a major potential source for growth in the functional food sector. They are rich proteins, minerals, lipids, pigments, polysaccharides and poly unsaturated fatty acids (Dere et al., 2003; Holdt and Kraan, 2007; Ak et al., 2015; Yenigül, 1993). But, environmental conditions such as inorganic nutrients, light intensity, water temperature and season affects nutrient composition of seaweeds (Cirik et al., 2010b). In addition, biochemical composition of seaweeds show differences between natural populations and cultivated ones (Hafting et al., 2012).

Proteins and Amino Acids

Macro algae are excellent source of protein and their derivatives (Samarakoon and Jeon, 2012). Protein content of seaweed ranges between about 1% 50% (dw) (Dere et al., 2003, Ak et al.2015, Cirik et al.2010a, Holdt and Kraan, 2011, Hafting et al., 2012).We explain this gap with several reasons. Protein content of seaweeds show differences between species but generally high in red seaweeds (Holdt and Kraan, 2011). Among macro algae divisions, red algae are rich for proteins. *Laurencia papillosa* has maximal content of 34.65% (dw), followed by *Graciliaria verrucosa* with maxima around 27% (dw) (Polat and Özoğul, 2009; Ova Kaykaç, 2007). But, calcareous red algae such as *Jania rubens* (~7% dw) are poor for proteins (Polat and Özoğul, 2009). Green macro algae are good sources of protein. The highest protein level of *Ulva rigida* was recorded as 21.20% dw (Ova Kaykaç, et al., 2008). The proteins of edible brown algae is low. It changes from 5.18 to 18.73% dw in Cystoseira barbata (Table 1) which is an important edible seaweed for Black Sea Region (Cirik et al., 2010a; Ova Kaykaç, 2007). But, some of non-edible brown algae have high protein levels. And, it can be reach up to 30.43% and 35.40% dw in *Cystoseira coniculata* and *Padina pavonica* (Polat and Özoğul, 2009). Also, culturing techniques and culture media affects protein content of seaweed. The proximate composition of cultured seaweed in Turkey is summarized in Table 2. Protein content of cultured *G. verrucosa* change from 20.28% to 42.6% dw while *C. barbata* vary from 8.13% to 22.70 dw (Cirik et al., 2010a; Topçu et al., 2013; Öztaşkent et al., 2013; Ak et al., 2011a, b). The highest protein value was determined as 25.73% dw for cultured *U. rigida* (Ak et al., 2015).

Seaweeds species distributed in Turkey contain essential amino acids and are rich source of aspartic acid and glutamic acid (Table 3). The combined aspartic acid and glutamic acid concentration is about 35% total amino acids. Tryptophan, cysteine, tyrosine and methionine are limiting amino acids in algal proteins distributed Turkish coastal waters. But, the general levels in seaweed proteins are higher than those found in terrestrial plants (Galland-Irmouli et al., 1999).

Lipids and Fatty Acids

Lipid levels of seaweed are lower than micro algae but they are important source of essential fatty acids (Khotimchenko et al., 2002). Lipids represent up 6.73% dw of samples of seaweed collected in Turkish costs (Table 1). Like other proximate contents, total lipid level changes with species, seasons and other environmental factors. The maximum content of lipids was found in *L. papillosa* (6.73% dw), *P. pavonica* (5.89% dw) and *U. rigida* (2.5% dw), respectively (Polat and Özoğul, 2009; Yıldırım et al., 2009).

Table 1. Proximate composition of seaweeds distributed along Turkish costs.

Species	Crude Protein (%) dw	Lipid (%) dw	Ash (%) dw
Gracilaria verrucosa	14.74 - 27.38[a]	0.37 – 1 04 [a]	19.13 – 28.71 [a]
G. bursa-pastoris	41.5[b]		
Laurencia papillosa	34.65[c]	6.73 [c]	44.05 [c]
Jania rubens	7.20 [c]	0.12 [c]	80.73 [c]
Ulva rigida	11.87 – 21.20[d]; 9.91[e]; 17.44[f]; 16.00[g]	0.78 – 1.25 [d]; 0.11 [e]; 2.5 [f]; 0.50 [g]	15.84 – 18.41 [d]; 26.67[e]; 32.85 [f]; 24.00 [g]
Enteromorpha intestinalis	15.02[h]	1.63[h]	1.92[h]
Enteromorpha linza	14.1 [f]	2.2 [f]	32.64 [f]
Cladophora glomerata	14.13 [h]	2.48 [h]	2.44 [h]
Cystoseira barbata	5.18[i]; 7.44 – 18.73[a]; 6.77 – 17.42[j]	1.44[i]; 0.46 – 1.75[a]; 0.79 – 5.05[j]	26.32[i]; 21.07 – 26.09[a]; 15.43 – 38.3[j]
Cystoseira coniculata	30.43[c]	5.45[c]	28.97[c]
Padina pavonica	35.40 [c]	5.89 [c]	44.92 [c]

[a]Ova Kaykaç, 2007; [b]Yıldız et al., 2011; [c]Polat and Özoğul, 2009; [d]Kaykaç et al., 2008; [e]Ergün et al., 2009; [f]Yıldırım et al., 2009;[g]Güroy, 2009; [h]Aköz et al., 2011; [i]Cirik et al., 2010a; [j]İrkin and Erduğan, 2014.

Table 2. Proximate composition of cultured species in Turkey

Species	Crude Protein (%) dw	Lipid (%) dw	Ash (%) dw
Gracilaria verrucosa	20.07 – 42.6[a]; 14.99 – 20.28[b]	4.5 – 7.6[a]; 2.9 – 2.66[b]	10 – 12.5[a]; 11.25 – 12.14[b]
Ulva rigida	16.21 – 24.55[c]; 18.26 – 25.73[d]	3.50 - 8.28[c]; 2.30 – 5.59[d]	16.14 – 33.25[c]; 22.92 – 35.24[d]
Cystoseira barbata	8.13 – 12.01[e]; 22.70[f]; 17.46[g]	1.59 – 1.68[e]; 3.51[f]; 6.15[g]	30.55 – 32.44[e]; 36.33[f]; 42.87[g]

[a]Ak et al., 2011a; [b]Cirik et al., 2010b; [c]Ak et al., 2011b; [d]Ak et al., 2015; [e]Cirik et al., 2010b; [f]Topçu et al., 2013; [g]Öztaşkent et al., 2013.

Also, lipid content of seaweeds improves with applying different culture techniques (Table 2). The highest lipid content was determined as 7.6% dw in *G. verrucosa* cultured at greenhouse conditions (Ak et al., 2011a).

There are very few studies on fatty acid composition of marine macro algae in Turkey (Ak et al., 2015; Yazıcı et al., 2009; Akgül et al., 2015b). According to these studies, total values of monounsaturated fatty acids (MFAs) and polyunsaturated fatty acids (PUFAs) are higher than saturated fatty acids (SFAs). The most abundant fatty acids (FA) for all seaweed is palmitic acid (C16:0). And, it varies between 26.50 (*Ulva* spp.) to 26.50% (Table 4). The fatty acid profiles of seaweed show differences between divisions. Red seaweed species contain significant quantities of PUFA. In accordance with Table 4, *Phyllophora crispa* has the highest PUFA content but, *U. rigida*, grown in tank systems, this level is low. It change from 12.30% to 18.91%. PUFAs are categorized as omega-3 (*n*-3) and omega-6 (*n*-6) fatty acids (Rustan and Drevon 2001). In generally, the total *n*-3 PUFA levels were higher than the total n-6 PUFA levels. The highest *n*6/*n*3 ratio find in *C. barbata* ant it change from 1.08% to 2.40% (Table 4).

Table 3. Amino acid composition of some edible seaweeds in Turkey

Amino Acid Names	*Ulva rigida*[a] (mg dw)	*Cystoseira barbata*[b] (mg dw)	*Phyllophora crispa*[c] (mg dw)
Histidine	5.64	4.494	2.985
Isoleucine	3.97	5.830	6.122
Leucine	9.13	9.264	7.682
Lysine	6.48	10.480	7.558
Methionine	1.68	2.078	2.029
Phenylalanine	7.05	4.940	5.170
Threonine	6.05	6.200	5.108
Valine	6.08	8.284	7.857
Alanine	9.27	17.848	6.762
Aspartic Acid	13.81	11.740	18.609
Glutamic Acid	15.50	32.500	17.579
Glycine	6.85	12.656	7.287
Proline	5.81	3.292	7.050
Serine	6.51	7.160	5.623
Tyrosine	3.02	2.600	6.334
Tryptophan	-	-	-
Cystine	4.65	-	4.512

[a]Ova Kaykaç et al., 2008; [b]Çetingül et al.,1996; [c]Akgül et al., 2015a.

Table 4. Fatty acid composition of some edible seaweeds in Turkey

Name	*Phyllophora crispa* [a]	*Ulva* spp.[b]	*Ulva rigida* (cultured) [c]	*Cystoseira barbata* [d]	*Cystoseira barbata*[a]
C14:0	1.513	2.00	0.38 - 0.47	7.1	2.898
C16:0	30.723	26.50	36.72 - 37.48	29.4	33.160
C18:0	6.749	8.00	1.06 - 0.47	1.2	1.586
ΣSFA	**42.69**	**38.50**	**41.93 - 40.81**	**37.7**	**38.59**
C16:1	2.397	12.10	5.86 - 10.27	5.3	5.870
C18:1	17,108	6.20	37.97 - 30.01	20.2	30.69
ΣMUFA	**20.87**	**19.50**	**45.78 - 40.29**	**25.5**	**36.49**
C18:2*n*6	0.970	2.23	2.95 - 3.45	7.3	4.095
C18:3*n*3	0.00	6.11	4.84 - 10.13	0.5	0.00
C20:4*n*6	15.424	0.13	0.00 - 0.18	16.1	8.821
C20:5*n*3	19.281	4.40	0.00 - 0.27	3.3	12.005
ΣPUFA	**36.44**	**33.76**	**12.30 - 18.91**	**36.8**	**24.92**
Total*n*3	19.28	24.35	9.16 - 15.46	10.8	12.01
Total*n*6	16.6	6.11	3.13 - 3.45	25.9	12.92
*n*6/*n*3	0.86	0.25	0.22 - 0.34	2.40	1.08

[a]Akgül et al., 2015b; [b] Durmaz et al., 2008;[c] Ak et al., 2015; [d] Yazıcı et al., 2007

Nutritional Elements

The ash content of seaweed is high compared to vegetables (Murata and Nakazoe 2001). Ash includes macro-minerals and trace elements. The highest ash content determines in *Jania rubens* (Table 1) because cell wall of this seaweed consist of calcium carbonate and calcific acid. Ash contents also influenced by seasons and nutrient concentration. Ash content of *G. verrucosa* range from 19.13% to 28.71% dw (Ova Kaykaç, 2007). Ash content of brown seaweeds change between 15.43% to 38.3% dw (İrkin and Erduğan, 2014). Also, culture practices effect the ash contents of seaweeds. Ash content of cultured seaweeds vary from 10.0% to 42.87% dw (Table 1).

Polysaccharides

Seaweeds contain large amount of polysaccharides, which are polymers of simple sugars (McHugh, 1987; Kumar et al., 2008). These polysaccharides are identified as economically most important among other ingredients found in seaweeds that have been used in industry for food and medicinal proposes (Mendis and Kim, 2011). Red and brown algae produce these contents in higher concentrations as form of agar and alginate, respectively. Agar content of *G. bursa-pastoris* and *Hypnea musciformis,* distributed in Turkish costs, is very high (Table 5) and they can be used for agar industry. Also, the agar content in *G. verrucosa,* can reach 43% (Table 5). Alginates are extracted from brown seaweeds and it is an important cell wall component for these seaweeds (Holdt and Kraan, 2011). Alginates are available in both acid and salt forms. Commercially, alginic acid is obtained from brown seaweeds as soluble sodium alginate (Mendis and Kim, 2011). Alginate content of *Padina pavonica, Scytosiphon lomentaria* and *Cystoseira barbata* raise up to 33%, 29% and 22%, respectively (Table 5).

Table 5. Agar and Alginate contents of seaweeds in Turkey

Agar Contents		Alginate Contents	
Species	Amount (% dw)	Species	Amount (% dw)
Gracilaria verrucosa	24.0 – 43.0[a]; 8.6 – 21.90[b]; 9.65 – 18.64[c]	*Cystoseira barbata*	3 – 22[e]; 14.00 – 26.70[f]; 17.85[g] – 19.98[h]
Gracilaria bursa-pastoris	13 –70[d]	*Sargassum vulgare*	2 – 6 [e]
Hypnea musciformis	28 – 64[d]	*Colpomenia sinuosa*	14 – 21[e]
Gelidium spinosum	7 – 23[d]	*Padina pavonica*	15 – 33[e]
Phyllophora crispa	6 – 13[d]	*Syctosiphon lomentaria*	16 – 29[e]
Ceramium spp.	15 – 54[d]	*Dictyota dichotoma*	5 – 32 [e]

[a]Yenigül, 1993; [b]Ak et al., 2011a. [c]Cirik et al., 2010b; [d]Sağbaş, 2011; [e]Koçoğlu, 2011; [f]Cirik et al., 2010a, [g]Öztaşkent et al., 2013; [h]Topçu et al., 2013.

Pigments

Chlorophylls are green lipid-soluble pigments found in all photosynthetic algae and plants to carry out photosynthesis (Holdt and Kraan, 2011). The chlorophyll *a* contents of seaweeds, distributed along Turkish costs, changes from 0.16 mg/kg to 2.187 mg/g (Table 6). Carotenoids as tetraterpenoids are simple or pure prenyl lipids and they classified according to their functions. The carotenoids of green, photosynthetically active plant tissue, which are needed for photosynthetic function, are classified as primary carotenoids, whereas those of red fruits and flowers have been termed secondary carotenoids (Lichtenthaler, 1987). Total carotenoid of seaweed varies from 0.01 mg/kg to 0.8 mg/kg (Table 6). According to previous studies, it was determined that total carotenoids content of brown algae are higher than the red algae.

Table 6. Pigments contents of seaweed in Tukey

Species	Chlorophyll *a* (mg/g)	Σ Carotenoids (mg/g)
Gracilaria verrucosa	0.16 [c]	0.01 [c]
Ceramium sp.	0.90 [c]	0.06 [c]
Ulva spp.	0.71 [b]	0.31 [b]
Ulva rigida	0.14 – 0.18 [c]	0.05 – 0.17 [c]
Ulva lactuca	0.22 – 0.39 [c]	0.05 – 0.08 [c]
Cystoseira barbata	1.056 [a] 0.71 – 1.53[c]	0.180 [a] 0.01 – 0.02 [c]
Cystoseira spp.	0.36[b]	0.81 [b]
Dictyota dichotoma	1.427 [a]	0.207 [a]
Padina pavonia	2.187 [a]	0.610 [a]

[a]Özgün et al., 2015; [b]Durmaz et al., 2008; [c]Dere et al., 2003

Conclusion

Seaweeds are valuable resource for functional foods. Their proteins, peptides and amino acids have shown positive bioactive effects in the treatment of diabetes, cancer, and AIDS and the prevention of vascular diseases. Also, lipids from seaweeds have high percentages of the omega-3 fatty acids and have been tested positive as immune stimulants, decreases the concentration of cholesterol in animal and humans. In addition, they accumulates the desired minerals and trace metals. From day to day, the number of functional foods obtained from seaweeds is increasing. In order for Turkey to be able to take its place in this market, culturing and processing technologies of seaweeds such as *Gracilaria*, *Cystoseira* and *Ulva* are planning to develop**.**

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