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Macroalgae in the Food Industry – Opportunities and Challenges

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Abstract

The industry recognized macroalgae not only as a very important source of bioactive compounds but also as 'super-foods' due to their nutritional value. They can be used as raw food acting as an alternative source of vegetable proteins, fibres, vitamins and minerals but also they can be commercialized in many forms and incorporated in other food products. The aim of this review is to emphasize the importance of macroalgae application in the food industry. They are already used for different purposes, from food products to medicine. Among mentioned compounds, the special emphasis was given to macroalgal polysaccharides that are present in many products consumed on daily basis. Their importance in texture stability of the food products, as well as their functional properties are evaluated.

Keywords: *macroalgae, food industry, high added-value products, macroalgal polysaccharides*

1. Introduction

Oceans are considered as the "lungs of the Earth" due to the presence of the algae and Cyanobacteria which provide up to 80 % of the atmospheric oxygen. Among organisms that provide oxygen, macroalgae are very important for human health as they are important for the Earth. Generally, they are divided into three groups based on the colour of the thallus, as follows: Chlorophyta (green algae), Rhodophyta (red algae), and Ochrophyta Phaeophyceae (brown algae) (Barsanti and Gualtieri, 2014). Since they are sessile organisms, they have to adapt to extreme and hostile environmental conditions such as temperature fluctuations, salinity, UV radiation and various pollutants. During the adaptation, they are producing a wide range of secondary metabolites, such as pigments, phenolic compounds, sterols and other bioactive agents. Besides, they represent a rich source of proteins, saturated/unsaturated fatty acids and polysaccharides which makes them important at the commercial level. A few years ago, interest in the exploitation of macro-algae increased and they are already used for various purposes (Pereira, 2016). Although there is still much to investigate about macroalgae and their compounds, it is known that several of the metabolites they synthesize have great potential to be used in pharmaceutical, cosmetics and the food industry. As their interest, cultivation and applications increase, their value in the market rises too. It is estimated that the value of the macroalgae market worldwide in 2024 will exceed twice the achieved in 2017 (Statista 2019). Recently, Europe has been highlighted as one of the most innovative regions regarding the use of macroalgae as a food ingredient with the exponential increment of new products on the European market by 147 % between 2011 and 2015 (Afonso et al., 2019).

This overview provides an insight into the importance of macroalgae as part of the human diet as well as into the components of food. The studies reported in this review showed that the addition of macroalgae, in powder or as extracts, can improve the nutritional and textural properties of food products. Macroalgal polysaccharides are the most important compounds incorporated into products so their role in the food industry is specially emphasized in this review.

2. Macroalgae as part of everyday diet

Since ancient times until the beginning of the 19th century, people in the East regarded seaweed as a food of great delicacy, while the Greeks and Romans thought differently. After 1800, the boom in the macroalgae industry began, especially in the 20th century (Zeneveld, 1959). It is recognised that edible macroalgae, which are categorised in more than 600 species, have a great nutritional value which can be influenced by geographical location, growth stage, season, etc. (Kim, 2011). Even though they are known as low caloric food, rich in vitamins and minerals, they need to be evaluated before being used as supplements (Leandro et al., 2020).

Although the consumption of macroalgae is not as widespread in Europe as in Asia, they have attracted attention because their bioactive compounds have earned them a reputation as the new 'superfoods' (Cofrades et al., 2017). Brown algae are the most consumed (66.5 %), followed by red (33 %) and green (5 %) (Lorenzo et al., 2017). Brown macroalgal species considered safe for human consumption are *Fucus vesiculosus, Fucus serratus, Himanthalia elongata, Undaria pinnatifida, Ascophyllum nodosum, Laminaria* *digitata, Laminaria saccharina, Laminaria japonica* and *Alaria esculenta* (CEVA, 2014). Studies have shown that the macroalgae contain a higher content of fibres (*Grateloupia filicina*, *Chondrus crispus*, *Ulva lactuca*) than the plants (Holdt and Kraan, 2001; Yuan et al., 2009) which can contribute to general human health. It is known that dietary fibres stimulate the growth of beneficial gut bacteria, reduce the risk of diabetes, obesity and hypercholesterolaemia due to their capacity for absorbing organic compounds such as glucose and cholesterol (Bocanegra et al., 2009). Macroalgae can be used as alternatives to vegetable sources of proteins (red algae: *Pyropia tenera*, *Grateloupia filicina*), as well as for the formation of protein balanced diets with low-costs due to their high content present in macroalgae, similar to those found in legumes such as peas and beans (Rodrigues et al., 2015; Yuan et al., 2009). Although a small amount of total lipids is present in macroalgae, their qualitative profile is of particular interest from the nutritional point of view due to the presence of ω-3 and ω-6 polyunsaturated fatty acids (PUFAs) which exhibit activities such as cardiovascular and coronary protection, reduction of arterioscelorsis, etc. (Khan et al., 2007; Plaza et al., 2008). It was found that the ashes of edible macroalgae contained higher contents of macro- and microelements than those reported for edible plants where the amounts of Na, K, Ca and Mg were in range of 8.083-17.875 mg/100 g and of Fe, Zn, Mn and Cu were between 5.1-15.2 mg/100 g. According to this fact, brown and red macroalgae can be used as food supplements to reach the recommended daily intake of minerals and trace elements. For instance, the consumption of 10 g of *Ulva lactuca* provides 70 % of the daily Mg and over a half of Fe requirements (Yuan et al., 2009; Ruperez, 2002). *Himanthalia elongata* is the most exploited due to its mineral composition and it is a good candidate for the salt replacer as it reduces high salt consumption and health-related complications (Circuncisao et al., 2018).

3. Macroalgae as functional health-promoting ingredients of food products

Because of the bioactivities mentioned for the fatty acids ω-3 and ω-6, they were used in infant foods and formulas, leading to an improvement in infants' cognitive performance and visual acuity (Jensen et al., 2005). Compounds derived from macroalgae can behave as functional ingredients of various food products which has been demonstrated in the production of fortified healthier snacks with algal oil. Healthy adults that consumed these snacks showed higher levels of docosahexaenoic acid (DHA; 22:6) in plasma (Arterburn et al., 2007). Algal oil was also added to ice creams to increase the ω-3 fatty acid content, but the results of the sensory evaluation showed that the fishy taste was stronger than ice cream taste (Chee et al., 2007). When the food is enriched with ω-3 fatty acids, its oxidative stability decreases and it can lead to the development of undesirable flavours and reduction of the shelf-life (Jacobsen et al., 2000). However, O'Sullivan et al. (2014, 2016) observed that the incorporation of *F. vesiculosus* ethanol extract improved the shelf-life of milk and yogurt which indicated the presence of the compounds with the ability to reduce lipid oxidation that is known as antioxidants.

Antioxidants present in macroalgae can serve as alternative replacements of synthetic antioxidants such as butylated hyroxyltoluene (BHT) and butylated hydroxianisole (BHA) without any side effects on human health (Roohinejad et al., 2017). Also, they have ability of the extension of shelf-life during storage by inhibition or postponement of lipid oxidation (Cornish and Garbary, 2010). The most known antioxidants of macroalgal origin are phlorotannins mostly present in brown macroalgae. *Fucus vesiculosus* has been found as the best source of phlorotannins and antioxidant compounds and because of that it is applied as functional ingredient in different food matrices to prevent spoilage and oxidative deterioration (Afonso et al., 2019). It was shown that the addition of *F. vesiculosus* commercial extract can be exploited as a food antioxidant agent due to the inhibition of formation of primary and secondary oxidation products, as well as the maintenance of the colour of pork liver pâté (Agregan et al., 2018). Carotenoids are as well added into the food products as antioxidants, but they have one more important role. They can serve as natural color enhancers and replace synthetically obtained which are known to cause liver and renal toxicity, as well as promote carcinogenesis. β-Carotene is the most applicable macroalgal derived pigment which has multiple activities, from color enhancer to anticancer agent that is absorbed 10 times more easily by the body than the synthetic one (Christaki et al., 2012). All the compounds discussed above with their properties when they are added into the food products are summarized in **Table 1**.

Table 1. Macroalgal compounds of interest in the food industry and their properties in the food products

Macroalgal compounds	Properties in the food products
Carotenoids Phlorotannins	Replacers of synthetically obtained antioxidants, Extension of shelf-life
Carotenoids	Colour enhancer
Phlorotannins	Prevention of spoilage and oxidative deterioration
Proteins	Nutritional value, Higher content than in legumes
Minerals	Higher content than in plants, Salt replacers, Food supplements for reaching the recommended daily intake
ω-3 and ω-6 Polyunsaturated fatty acids	Cardiovascular and coronary protection, Improvement of infant cognitive performances

Apart from the functional properties, macroalgal compounds can influence product texture and consistency. When 4 % of *Fucus vesiculosus* powder was added during bread preparation, it was observed that dough had increased viscosity and consistency, while porosity decreased that led to higher density and crumb firmness of the bread (Arufe et al., 2018). Also, better quality was achieved for pasta when two algal powders, *Sargassum marginatum* and *Undaria pinnatifida*, were added. Not only the fortified pasta exhibited better cooking and sensory characteristics, but also its nutritional quality was enhanced due to the higher protein content (Prabhasankar et al., 2009a; Prabhasankar et al., 2009b). When algal powders of *Undaria pinnatifida* and *Laminaria japonica* were added in the production of cottage cheese, its consistency and firmness were better (Lalić and Berković, 2005). The food products containing macroalgal derived compounds are listed in **Table 2**.

Table 2. Food products containing valuable macroalgal derived compounds

Food product	Macroalgal derived compounds or extracts	References
Pork liver pâté	*Fucus vesiculosus* commercial extract	Agregan et al., 2018
Pork patties	*F. vesiculosus* ethanol extract	Agregan et al., 2019
Snack bars	Docosahexaenoic acid (DHA)	Arterburn et al., 2007
Bread	Powder of *Fucus vesiculosus*	Arufe et al., 2018
Ice-cream	ω-3 Fatty acids	Chee et al., 2007
Meat products	Powder of *Himanthalia elongata*	Cofrades et al., 2017
Infant food	Docosahexaenoic acid (DHA)	Jensen et al., 2005
Cottage cheese	Powder of *Undaria pinnatifida* and *Laminaria japonica*	Lalić and Berković, 2005
Milk Yogurt	*F. vesiculosus* ethanol extract	O'Sullivan et al., 2014; 2016
Pasta	Powder of *Sargassum marginatum* and *Undaria pinnatifida*	Prabhasankar et al., 2009a; Prabhasankar et al., 2009b

Macroalgae can be commercialized and/or consumed in many forms; fresh, dried, as powder or incorporated in the food products that are called high added-value products (Leandro et al., 2020). They are already commercialized as healthier and natural substitutes of pasta (*Himanthalia elongata* as spaghetti) or bacon (*Palmaria palmata* as sea bacon). The red algae of genus *Porphyra* are used for the preparation of sushi rolls and crispy snacks, while wraps are made of *Undaria pinnatifida* (wakame) and *H. elongata*. The macroalgal products available on the market are labeled as "fat-free", "gluten-free", "mineral rich", "low carbohydrates" and "low calories". Seamore company is one of the most popular manufacturer of macroalgae products including wraps, bacon, pasta and bread (Seamore, 2020).

Challenges that need to be overcome when the algae are used as food ingredients go from the amount of needed biomass to sustain the market development, to the consistent research of their physiochemical characteristics and the impacts which they have on the food products when used as ingredients. The incorporation of macroalgae into the food usually leads to a deterioration of the sensory properties of the products. This can be overcome if more attention is paid to research into alternative approaches, such as the use of algae extracts consisting of whole algae or the encapsulation of algae or their extracts and the use of food flavourings to camouflage the undesirable flavourings. There is also a lack of information on the bioavailability of nutrients and/or phytochemicals, which is the decisive factor when macroalgae are presented in terms of their nutritional value. This will require more attention in future studies, as well as the potential functionality of macroalgae enriched products (Afonso et al., 2019).

4. Macroalgal polysaccharides as hidden food components

Polysaccharides isolated from macroalgae are the most implemented macroalgal derived compounds in food products. They are valuable additives such as stabilisers, thickening agents, texture modifiers and binders of ingredients thanks to their functions including water-binding capacity, gelation and formation of emulsions and foams. They have the ability to control starch retrogradation, replace fat, enhance flavour and improve fibre content when added in the food products (Menon, 2012). Macroalgal polysaccharides which are used in various food products are summarized in **Table 3**.

Carragenan is one of the main additives used in the food industry, from various dairy products (ice creams, milkshakes, yoghurts) to meat products (hams) as thickening and stabilizing agent or emulsifier (Pereira and van de Velde, 2011; Armisen, 1995). The molecular weight of the carragenan used in food products is regulated by Food and Drug Administration (FDA) where the minimum value of 100 kDa was established but the usual range is 400-600 kDa. There are three types of carragenan which can be used in food preparations differing in sulfation degree where kappa (κ) carragenan has one sulfate group per disaccharide, iota (ι) has two sulfates, while lambda (λ) has three sulfate groups. The used carragenan depend on the desired properties, ι- and κ-carragenans have gelling properties, while λ-carragenan is a thickener/viscosifier (Pereira et al., 2013).

Agar is frequently used as a thickener in food products, as well as a vegetarian substitute for gelatine. The difference between agar and carrageenan is that carrageenan gels by

Table 3. Polysaccharides utilized in food products and its properties

Compound	Macroalgae species	Application	Properties	Food additive code	References
		Ochrophyta, Phaeophycaea			
Alginate	*Laminaria hyperborea, Macrocystis pyrifera, Laminaria digitate, Ascophyllum nodosum* and *Laminaria japonica*	ice-cream, beer and soft drinks, meat products	emulsifier, stabiliser, foaming agent, thickener/ viscosifier, binder and filler	sodium alginate E-401, potassium alginate E- 402, ammonium alginate E-403, calcium alginate E-404, propylene glycol alginate E-405	Alba and Kontogio-rgos, 2019; Sartal et al., 2012; Cofrades et al., 2012
		Rhodophyta			
Carragenan	*Kappaphycus alvarezii* and *Eucheuma denticulatum*	dairy products: ice creams, yoghurt, cheese and milk, low-fat meat products, clarifying beer and fruit juices	gelling, stabilising and thickening agent	E-407	Sartal et al., 2012
Agar	*Gracilaria* and *Gelidium species*	pie filling, ice-creams, dairy products, wines, low fat products, icings and bakery glazes	thickener, stabiliser, clarification of wines, binder, crystallisa-tion prevention	E-406	Sartal et al., 2012

both ionic and hydrogen bonding, while agar gels only by hydrogen bonding (Kilinc et al., 2013; Pereira 2016).

Alginate is, next to cellulose, the most abundant biopolymer in the world. It acts as thickener, emulsifier and it needs no heat to gel. The spherification process, a technique used in molecular cooking, includes the addition of agar in combination with calcium lactate of calcium chloride (Leandro et al., 2020). Alginates are responsible for the interaction with cholesterol and facilitate its excretion (Cofrades et al. 2012).

Apart from commercially available macroalgae polysaccharides, scientists studied the addition of polysaccharides on the quality of foods such as bread, where Guarda et al (2004) added carragenan and sodium alginate to prevent dehydration of fresh bread during storage.When the powder of *Undaria pinnatifida* was added to meat products such as patties, less thawing and cooking losses and softer texture were observed when compared to the samples without the addition of macroalgae. It was explained by the microstructural changes caused by the formation of alginate chains (Lopez-Lopez et al., 2011). The firmer and chewier structure was accomplished due to better water and fat-binding properties of macroalgae that can be explained by the presence of polysaccharides (Cofrades et al., 2008; Cofrades et al., 2012). With the addition of *Laminaria digitata* extract (0.5 % w/w) containing polysaccharides to pork patties, the quality of the products in terms of oxidative stability increased by the reduction of lipid oxidation in the cooked samples, but the products were not very well accepted in the sensory analysis (Moroney et al., 2013). Similar observations occurred when laminaran and fucoidan from *L. digitata* were added to pork homogenates (Moroney et al., 2015).

Conclusions

Macroalgae as a source of bioactive compounds are widely applied in functional products so their positive influence on human health is inevitable. Antioxidants and pigments are important macroalgae constituents in the industrial range, but even more important are polysaccharides such as alginate, agar and carrageenan, which are already used in several food industries. With the exception of their functional properties, macroalgal polysaccharides have a significant influence on the texture of food products acting as emulsifiers, thickening and gelling agents. Most people are not aware that they consume macroalgae but many products, such as meat and dairy products, we consume on daily basis contain macroalgae derived compounds or their extracts. Also, macroalgae can be eaten as whole foods including more than 600 species known to have nutritional value higher than some plants and vegetables.

This review provided information that may help in the development of novel food products, but further research on the nutritional and functional value of macroalgae is still needed.

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References

[1] Afonso, N.C., Catarino, M.D., Silva, A.M.S., Cardoso, S.M. (2019). „Brown macroalgae as valuable food ingredients“, Antioxidants, 8:365

[2] Agregán, R., Barba, F.J., Gavahian, M., Franco, D., Khaneghah, A.M., Carballo, J., Ferreira, I.C.F., Barretto, A.C.S., Lorenzo, J.M. (2019). „*Fucus vesiculosus* extracts as natural antioxidants for improvement of physicochemical properties and shelf life of pork patties formulated with oleogels“, Journal of the Science of Food and Agriculture, 99:4561–4570

[3] Agregán, R., Franco, D., Carballo, J., Tomasevic, I., Barba, F.J., Gómez, B., Muchenje, V., Lorenzo, J.M. (2018). „Shelf life study of healthy pork liver pâté with added seaweed extracts from *Ascophyllum nodosum*, *Fucus vesiculosus* and *Bifurcaria bifurcata*“, Food Research International, 112:400–411

[4] Alba, K., Kontogiorgos, V. (2019) „Seaweed polysaccharides (agar, alginate, carragenan)“, in: Melton, L., Shahidi, F., Varelis, P. (Ed.) Encyclopedia of food chemistry. Elsevier, Amsterdam, Netherlands, pp. 240–250.

[5] Armisen, R. (1995). „World-wide use and importance of *Gracilaria*“, Journal of Applied Phycology, 7:231–243

[6] Arterburn, L.M., Oken, H.A., Hoffman, J.P., Bailey-Hall, E., Chung, G., Rom, D., Hamersley, J., McCarthy, D. (2017). „Bioequivalence of docosahexaenoic acid from different algal oils in capsules and in a DHA-fortified food“, Lipids, 42:1011–1024.

[7] Arufe, S., Della Valle, G., Chiron, H., Chenlo, F., Sineiro, J., Moreira, R. (2018). „Effect of brown seaweed powder on physical and textural properties of wheat bread“, European Food Research and Technology, 244:1–10

[8] Barbosa, M., Valentao, P., Andrade, P. (2014). „Bioactive compounds from macroalgae in the new millenium: implications for neurodegenerative diseases“, Marine Drugs, 12:4934–4972

[9] Barsanti, L., Gualtieri, P. (Ed.) (2014) Algae Anatomy, Biochemistry and Biotechnology, CRC Press: Boca Raton, FL, USA, 2014.

[10] Bocanegra, A., Bastida, S., Benedi, J., Rodenas, S., Sanchez-Muniz, F. (2009). „Characteristics and nutritional and cardiovascular-health properties of seaweeds“, Journal of Medicinal Food, 12:236–258

[11] Centre d’Étude et de Valorisation des Algues (CEVA): *Edible Seaweed and French Regulation* 2014. Available online: https://www.ceva-algues.com/en/document/edible-algae-regulatory-update/ (accesed 19 March 2020)

[12] Chee, C.P., Djordjevic, D., Faraji, H., Decker, E.A., Hollender, R., McClements, D.J., Peterson, D.G., Roberts, R.F., Coupland, J.N. (2007). „Sensory properties of vanilla and strawberry flavored ice cream supplemented with omega-3 fatty acids“, Milchwissenschaft, 62:66-69

[13] Christaki E., Bonos E., Giannenas I., Florou-Paneri P. (2012). „Functional properties of carotenoids originating from algae“, Journal of Science and Food Agriculture, 93:5–11

[14] Circuncisão, A.R., Catarino, M.D., Cardoso, S.M., Silva, A.M.S. (2018). „Minerals from Macroalgae Origin: Health Benefits and Risks for Consumers“, Marine Drugs, 16:400

[15] Cofrades, S., Lopez-Lopez, I., Jimenez-Colmenero, F. (2012) „Applications of seaweed in meat-based functional foods“, in: Kim, S.K. (Ed.) Handbook of marine macroalgae: biotechnology and applied phycology. Wiley-Blackwell, Hoboken, New Jersey, USA, pp. 491–499.

[16] Cofrades, S., López-Lopez, I., Solas, M., Bravo, L., Jimenez-Colmenero, F. (2008). „Influence of different types and proportions of added edible seaweeds on characteristics of low-salt gel/emulsion meat systems“, Meat Science, 79:767–776

[17] Cofrades, S., Benedi, J., Garcimartin, A., Sanchez-Muniz, F.J., Jimenez-Colmenero, F. (2017). „A comprehensive approach to formulation of seaweed-enriched meat products: From technological development to assessment of healthy properties“, Food Research International, 99:1084–1904

[18] Cornish, M.L., Garbary, D.J. (2010). „Antioxidants from macroalgae: potential applications in human health and nutrition“, Algae, 25:155–171

[19] Holdt, S.L., Kraan, S. (2011). „Bioactive compounds in seaweed: Functional food applications and legislation“, Journal of Applied Phycology, 23:543–597

[20] Guarda, A., Rosell, C.M., Benedito, C., Gaotto, M.J. (2004). „Different hydrocolloids as bread improvers and antistaling agents“, Food Hydrocolloids, 18:241-247

[21] Jacobsen, C., Hartvigsen, K., Lund, P., Thomsen, M.K., Skibsted, L.H., Adler-Nissen, J., Hølmer, G., Meyer, A.S. (2000). „Oxidation in fish oil-enriched mayonnaise. Assessment of the influence of the emulsion structure on oxidation by discriminant partial least squares regression analysis“, European Food Research and Technology, 211:86–98

[22] Jensen, C.L., Voigt, R.G., Prager, T.C., Zou, Y.L.L., Fraley, J.K., Rozelle, J.C., Turcich, M.R., Llorente, A.M., Anderson, R.E., Heird, W.C. (2005). „Effects of maternal docosahexaenoic acid intake on visual function and neurodevelopment in breastfed term infants“, The American Journal of Clinical Nutrition, 82:125–132

[23] Khan, M.N., Cho, J.Y., Lee, M.C., Kang, J.Y., Park, N.G., Fujii, H., Hong, Y.K. (2007). „Isolation of two anti-inflammatory and one pro-inflammatory polyunsaturated fatty acids from the brown seaweed *Undaria pinnatifida*“, Journal of Agricultural and Food Chemistry, 55:6984–6988

[24] Kilinc, B., Cirik, S., Turan, G., Tekogul, H., Koru, E. (2013). „Seaweeds for Food and Industrial Applications“, in: Muzzalupo, I. (Ed.) Food Industry. IntechOpen, London, United Kingdom, pp. 735-748.

[25] Kim, S.K. (Ed.) (2011) Handbook of Marine Macroalgae: Biotechnology and Applied Phycology. Wiley-Blackwell, Hoboken, New Jersey, USA,

[26] Lalić, L.M., Berković, K. (2005). „The influence of algae addition on physicochemical properties of cottage cheese“, Milchwissenschaft, 60:151-154

[27] Leandro, A., Pereira, L., Goncalves, A.M. (2020). „Diverse Applications of Marine Macroalgae“, Marine drugs, 18:17

[28] López-Lopez, I., Cofrades, S., Cañeque, V., Díaz, M., Lopez, O., Jimenez-Colmenero, F. (2011). „Effect of cooking on the chemical composition of low-salt, low-fat Wakame/olive oil added beef patties with special reference to fatty acid content“, Meat Science, 89:27–34

[29] Lorenzo, J.M., Agregán, R., Munekata, P.E.S., Franco, D., Carballo, J., Sahin, S., Lacomba, R., Barba, F.J. (2017). „Proximate Composition and Nutritional Value of three macroalgae: *Ascophyllum nodosum*, *Fucus vesiculosus* and *Bifurcaria bifurcata*“, Marine Drugs, 15:360

[30] Menon, V.V. (2012). „Seaweed polysaccharides – food applications“, in: Kim, S.K. (Ed.) Handbook of marine macroalgae: Biotechnology and applied phycology. Wiley-Blackwell, Hoboken, New Jersey, USA, pp. 541–556

[31] Moroney, N.C., O'Grady, M.N., Lordan, S., Stanton, C., Kerry, J.P. (2015). „Seaweed Polysaccharides (Laminarin and Fucoidan) as Functional Ingredients in Pork Meat: An Evaluation of Anti-Oxidative Potential, Thermal Stability and Bioaccessibility“, Marine Drugs, 13:2447–2464

[32] Moroney, N., O'Grady, M., O'Doherty, J., Kerry, J. (2013). „Effect of a brown seaweed (*Laminaria digitata*) extract containing laminarin and fucoidan on the quality and shelf-life of fresh and cooked minced pork patties“, Meat Science, 94:304–311

[33] O'Sullivan, A.M., O'Callaghan, Y.C., O'Grady, M.N., Waldron, D.S., Smyth, T.J., O'Brien, N.M., Kerry, J.P. (2014). „An examination of the potential of seaweed extracts as functional ingredients in milk“, International Journal of Dairy Technology, 67:182–193

[34] O'Sullivan, A., O'Grady, M., O'Callaghan, Y., Smyth, T., O'Brien, N., Kerry, J. (2016). „Seaweed extracts as potential functional ingredients in yogurt“, Innovative Food Science and Emerging Technologies, 37:293–299

[35] Pereira, L. (2016) Edible Seaweeds of the World, CRC Press: Boca Raton, FL, USA.

[36] Pereira, L., Gheda, S.F., Ribeiro-Claro, P.J.A. (2013). „Analysis by Vibrational Spectroscopy of Seaweed Polysaccharides with Potential Use in Food, Pharmaceutical, and Cosmetic Industries“, International Journal of Carbohydrate Chemistry, 1-7

[37] Pereira, L., Van De Velde, F. (2011). „Portuguese carrageenophytes: Carrageenan composition and geographic distribution of eight species (*Gigartinales*, *Rhodophyta*)“, Carbohydrate Polymers, 84:614–623

[38] Plaza, M., Cifuentes, A., Ibanez, E. (2008). „In the search of new functional food ingredients from algae“, Food Science and Technology, 19:31–39,

[39] Prabhasankar, P., Ganesan, P., Bhaskar, N. (2009a). „Influence of Indian brown seaweed (*Sargassum marginatum*) as an ingredient on quality, biofunctional and microstructure characteristics of pasta“, Food Science and Technology International, 15:471-479

[40] Prabhasankar, P., Ganesan, P., Bhaskar, N., Hirose, A., Stephen, N., Gowda, L.R., Hosokawa, M., Miyashita, K. (2009b). „Edible Japanese seaweed, wakame (*Undaria pinnatifida*) as an ingredient in pasta: chemical, functional and structural evaluation“, Food Chemistry, 115:501−508

[41] Rodrigues, D., Freitas, A.C., Pereira, L., Rocha-Santos, T.A.P., Vasconcelos, M.W., Roriz, M., Rodriguez-Alcala, L.M., Gomes, A.M.P., Duarte, A.C. (2015). „Chemical composition of red, brown and green macroalgae from Buarcos bay in Central West Coast of Portugal“, Food Chemistry, 183:197–207

[42] Rodrigues, D., Sousa, S., Silva, A., Amorim, M., Pereira, L., Rocha-Santos, T.A.P., Gomes, A.M.P., Duarte, A.C., Freitas, A.C. (2015). „Impact of enzyme- and ultrasound-assisted extraction methods on biological properties of red, brown and green seaweeds from the central west coast of Portugal“, Journal of Agricultural and Food Chemistry, 63:3177–3188

[43] Roohinejad, S., Koubaa, M., Barba, F.J., Saljoughian, S., Amid, M., Greiner, R. (2017). „Application of seaweeds to develop new food products with enhanced shelf-life, quality and health-related beneficial properties“, Food Research International, 99:1066–1083

[44] Rupérez, P. (2002). „Mineral content of edible marine seaweeds“, Food Chemistry, 79:23–26

[45] Ruperez, P., Saura-Calixto, F. (2001). „Dietary fibre and physicochemical properties of edible spanish seaweeds“, European Food Research and Technology, 212:349–354

[46] Sartal, C.G., Alonso, M.C., Barrera, P.B. (2012). „ Application of seaweeds in the food industry“, in: Kim, S.K. (Ed.) Handbook of marine macroalgae: Biotechnology and applied phycology. Wiley-Blackwell, Hoboken, New Jersey, USA, pp. 522–531

[47] Seamore. Seamore Products. Available online: https://seamorefood.com (accessed on 15 March 2020)

[48] Statista-The Statistic Portal: The Statistic Portal Value of the Seaweed MarketWorldwide in 2017 and 2024 (in Billion U.S. Dollars). Available online: https://www.statista.com/ (accessed on 4 March 2020)

[49] Wang, H.M.D., Li, X.C., Lee, D.J., Chang, J.S. (2017). „Potential biomedical applications of marine algae“, Bioresource Technology, 244:1407–1415

[50] Yuan, Y.V., Westcott, N.D., Hu, C., Kitts, D.D. (2009). „Mycosporine-like amino acid composition of the edible red alga, *Palmaria palmata* (dulse) harvested from the west and east coasts of Grand Manan Island, New Brunswick“, Food Chemistry, 112:321–328

[51] Zeneveld, J.S. (1959). „The utilization of marine algae in tropical South and East Asia“, Economic Botany, 89:131