IOP Conf. Series: Materials Science and Engineering **231** (2017) 012126 doi:10.1088/1757-899X/231/1/012126

Seaweeds from the Portuguese coast: A potential food resource?

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Abstract. The Portuguese coast presents a large amount of potentially edible seaweeds that are underexploited. The identification of different macroalgae species and their availability in the northern and central coast of the continental territory was assessed. The nutritional value of seaweeds is discussed based on a literature review (when available) focused on data for species collected in Portugal with the aim to define the most important nutritional parameters that should be characterized in the samples. Possible health concerns related with the presence of contaminants are also considered.

1 Introduction

1.1 International and Portuguese seascape

Currently, seaweeds are used in many countries for several purposes: directly as food, and for phycocolloids extraction (carrageenan, agar, and alginate) used in the pharmaceutical, cosmetic, and food industries. Macroalgae or seaweeds, are mainly found in three of the algal taxonomic groups: Chlorophyta (green seaweeds), Rhodophyta (red seaweeds), and Phaeophyceae (brown seaweeds) [14].

The Portuguese coast presents a marked gradient in the distribution of the algal flora. The flora of the Northern plateau is similar to that found in Central Europe (Brittany and South of the British Isles). In the south, the algal flora is, however, quite different, with a clear influence of the Mediterranean and the North zone of the West African coast [1, 13]. Araújo et al. [1] presented an updated checklist for the benthic marine algae of the northern Portugal coast, reporting the identification of 346 species: 26 Cyanobacteria, 200 Rhodophyta, 70 Ochrophyta, and 50 Chlorophyta.

1.2 Production, consumption and uses of seaweeds

Portugal has one of the longest coastlines in the Eu-ropean Union, measuring approximately 2587 km, when including the continental territory (1242 km) and the archipelagos of Azores (943 km) and Madeira (402 km) [9]. The major economic activities related to the sea are shipbuilding, shipping, fishing and in a lesser extent aquaculture [9]. In the seventies, Portugal was one of the largest producers of agar in the world. Overuse of seaweeds and changes in the marine ecosystem provoked the downturn of this industry, but there is still a great potential for its recovery [9]. In Portugal, except for the Azores, where there are ancient reports of the consumption of certain macroalgae species [11], their use in food is sporadic and mainly related to the relatively recent consumption of Japanese food.

1.3 Nutritional value of seaweeds
Due to the nutritional value of seaweeds, namely their content in essential micronutrients and proteins of high biological value, its integration in food is very relevant not only because of the food challenge of an expanding population, but also because of the possibility of filling some deficiencies identified at world level. Emphasis is placed on the need to find alternative sources of iodine, since deficiency in this element covers an extremely large geographical area and has very harmful health. Iodine deficiency is the leading cause of brain damage in children [4].

The objective of this work was to identify and as-sess the availability of edible seaweeds harvested manually on the Portuguese coast. Based on a literature review, important parameters regarding the nutritional value (iodine, macro and micronutrients, protein content and amino acid profile, lipids and carbohydrates), and safety of seaweeds are discussed.

2 Methods

2.1 Sampling
An extensive list of the edible seaweeds of the Portuguese coast was compiled in a website (MACOI), and based on it and on scientific literature, a pre-selection of Portuguese macroalgae was established (Table 1). Although *Osmundea pinnatifida* is not on the list of edible seaweeds in the European Union [3], there is evidence of its consumption, namely in Azores [11]. Information on each species was analyzed in terms of availability in Portugal, facility of identification and harvest, harvest type (manual vs. dive), geographical distribution, commercial availability in well-established suppliers in Europe, seasonality and main uses, for example in the aquaculture. Criteria for closer selection considered the proximity of the seashore to the research Institute (located in the North of Portugal). Seaweeds in the north and central coast of Portugal were collected. The site choice was also dependent on the reports from IPMA (Portuguese Institute for Sea and Atmosphere) concerning the concentration of biotoxins, metals pollutants, toxic phytoplankton and microbiological contaminants, as well as the distance from seaports and industrial areas, which can represent potential sources of pollution.

Table 1. List of macroalgae considered edible in Europe [3] and indication of existing ones in Portugal (MACOI)

Scientific name	Sheashore
Brown seaweeds	
Ascophyllum nodosum	Praia do Norte
Fucus spiralis	Aguda, Apúlia, A Ver-o-Mar, Praia do Norte
Fucus vesiculosus	Praia do Norte
Undaria pinnatifida	Buarcos
Saccorhiza polyschides	Aguda, Apúlia, A ver-o Mar
Laminaria ochroleuca	Apúlia, Castelo do Neiva
Red seaweeds	
Porphyra umbilicalis	Aguda, Apúlia, A Ver-o-Mar
Osmundea pinnatifida	Aguda, Apúlia, Praia do Norte
Mastocarpus stellatus	Aguda, Apúlia
Chondrus crispus	Aguda, Apúlia, A Ver-o-Mar, Buarcos, Praia do Norte
Gracilaria sp.	Aguda, Buarcos
Green seaweeds	
Ulva sp.	Aguda, Apúlia, A Ver-o-Mar, Buarcos, Praia do Norte
Enteromorpha sp.	The same as *Ulva* sp.

In Figure 1, a map of Portugal with the seashores selected for sampling are presented.

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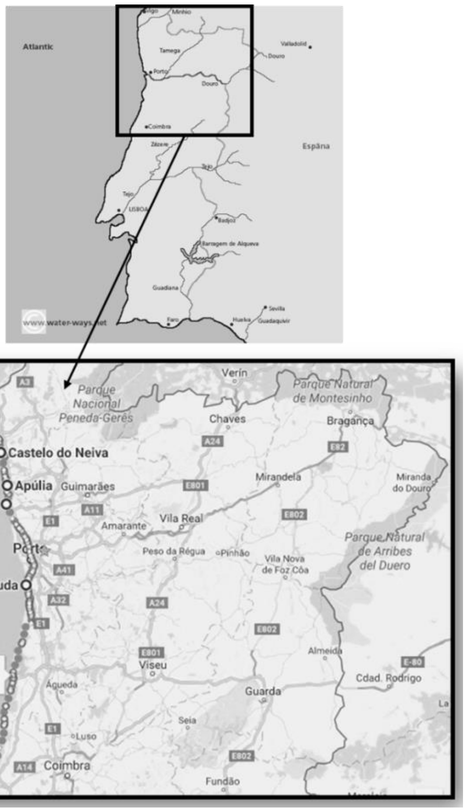

Figure 1. Map of Portugal and indication of the shores considered for seaweeds harvesting: Praia do Norte, Castelo do Neiva, Apúlia, A Ver-o-Mar, Aguda and Buarcos (sealine of almost 200 km).

2.2 Assessment of the nutritional value of seaweeds

The nutritional value of the seaweeds selected to be studied in this project was first assessed by researching scientific databases (Science Direct and Scopus) and by consulting repositories of Portuguese Universities and Research Institutes. An effort to find reports about seaweeds collected in the Portuguese coast was made. The information collected is discussed in the next sections.

3 Nutritional value of seaweeds from the portuguese coast

3.1 Minerals

Seaweeds present a huge variety of essential minerals and trace elements (sodium, calcium, magnesium, potassium, chlorine, sulphur and phosphorus); and micronutrients (iodine, iron, zinc, copper, selenium, molybdenum, fluoride, manganese, boron, nickel and cobalt) [17]. The brown algae *F. spiralis* and *L. ochroleuca* collected in the north and central Portuguese coast present higher levels of Ca (10.5 and 12.6 mg/kg respectively), while *Ulva* sp. shows high levels of Mg (19.5 mg/kg) and *Gracilaria vermiculophylla* the highest levels of Fe and Mn (1049 mg Fe /kg and 392.3 mg Mn/ kg) [2]. Rodrigues et al. [16] reported 91.1, 54.1 and 34.4 mg of Ca and 765.4, 261.0 and 651.0 mg of K per 10 g of sample for *S. polyschides*, *O. pinnatifida* and *Gracilaria gracilis*, respectively. These authors also reported high levels of Mg for *S. polyschides* (79.7 mg/10 g) and high levels of Fe for *G. gracilis* (14 mg/10 g of sample).

3.1.1 Iodine. Seaweeds have been described as an ideal food-safe natural source of iodine. Consumption of very large amounts could induce some undesirable effects but, overall, the effects of iodine consumption would be beneficial in metabolic regulation and growth patterns [10]. The iodine levels reported for Ulva sp., F. spiralis, L. ochroleuca and G. vermiculophylla were, respectively, 23.3, 232.7, 883.5 and 46.7 mg/kg dry weight (dw) [2].

3.1.2 Chloride. Ranger [15] reported that seaweeds contain sodium (2.7 g/100g dw); in the seaweeds, sodium is a chelated, soluble, colloidal mineral bound to protein ions. In fact, although the salt/sodium association is often used to cover the harmful effects of salt on cardiovascular health, there is evidence that the association should be made with salt and not necessarily with sodium itself [18]. Thus, it is very important to quantify the sodium and chloride content in the seaweeds. Although there is reference to the determination of chlorides in seaweeds [5, 6], there is no reference to chloride determination in seaweeds harvested on the Portuguese coast. According to one study with seaweeds collected in Coruña (Spain) the authors reported 34.8±0.5 and 4.1±0.1 % (ash dry weight) of chloride for Laminaria saccharina and M. stellatus, respectively [6]. For seaweeds harvested on the Italian coast, the contents of chloride of C. crispus, A. nodosum, U. pinnatifida and Ulva lactuca were, respectively, 7.5, 19.1, 78.3 and 12.5 mg/g dw [5].

3.2 Lipids
Lipid composition in marine seaweeds has been raising considerable interest due to its high content in polyunsaturated fatty acids (PUFA) particularly omega-3 and omega-6 acids, with proved beneficial effects in the prevention of cardiovascular diseases, osteoarthritis and diabetes [7]. The monounsaturated fatty acids (MUFA) of the macroalgae harvested on the Portuguese coast varied between 15.2 and 29.1 % (per total fatty acid content) for *G. gracilis* and *S. polyschides*, respectively. The PUFA contents ranged from 21.2 to 39.0% per total fatty acid content for *Gracilaria* sp. and *F. spiralis*, respectively [16]. For seaweeds harvested on the Azores coast, *F. Spiralis*, *Porphyra* sp. and *O. Pinnatifida* presented, respectively, PUFA and MUFA contents: 39.0 and 27.1%; 25.0 and 17.3%; and 22.2 and 2.6% per total fatty acid content [12].

3.3 Proteins
The protein content of seaweed varieties ranges greatly and demonstrates a dependence on seasonality and environmental growth conditions; the highest contents are generally found in red and green seaweeds. For Azores seaweeds, the protein content reported for *Porphyra* sp., *O. pinnatifida* and *F. spiralis* were, respectively, 24.8, 20.8 and 9.71% dw (Paiva et al., 2014). For the north and central shores, the protein contents of *S. polyschides*, *O. pinnatifida* and *G. gracilis* were respectively, 14.4, 23.8 and 20.2% dw [16].

3.4 Amino acids
Some free amino acids can influence taste. An example is glutamic acid, which is the basis of the basic taste, umami. Of the 20 natural amino acids, all the essential amino acids (EAA) valine, leucine, lysine, histidine, isoleucine, methionine, threonine, phenylalanine and tryptophan are present in the protein of seaweeds [10]. The amino acid profile of the Azores edible seaweeds *Porphyra* sp., *O. pinnatifida* and *F. spiralis* were reported by Paiva et al. [12]. *O. pinnatifida* presented 41.6% of EAA/protein, with higher contents of leucine (16.5 mg/g of protein), followed by proline (15.9 mg/g), aspartic acid (13.69 mg/g) and glutamic acid (12.2 mg/g). *Porphyra* sp. presented 56.7% of EAA/proteins, with higher concentration of leucine (18.5 mg/g of protein), followed by aspartic acid (13.7 mg/g), threonine (11.2 mg/g) and glutamic acid (10.3 mg/g). *F. spiralis* presented the highest amount of EEA/protein (63.5%) with leucine again showing the highest quantity (5.5 mg/g), followed by isoleucine (15.3 mg/g), lysine (12.5 mg/g), glutamic acid (12.1 mg/g), arginine (11.7 mg/g), serine (11.5 mg/g), valine (11.1 mg/g) and threonine (10.9 mg/g).

3.5 Carbohydrates
Three groups of carbohydrates are found in seaweeds: sugars, soluble dietary fiber, and insoluble dietary fiber. Sugars, including mannitol in brown seaweeds and sorbitol in red seaweeds, can constitute up to 20% dw of the seaweeds [10]. Soluble seaweed fiber includes agar, carrageenan, and alginate, and have many significant industrial and medical applications. The insoluble dietary fiber is indigestible, not caloric and enhances digestive function by absorbing water and thereby easing the passage of food through the intestines. Seaweeds have a much greater fiber content than vegetables and fruits [10]. The soluble carbohydrates reported for *F. spiralis*, *O. pinnatifida* and *Porphyra* sp. were respectively 17.6, 17.6 and 25.4% dw [12]. The total sugars contents reported for *S. polyschides*, *O. pinnatifida* and *G. gracilis* were, respectively, 45.5, 32.4 and 46.6% dw [16].

3.6 Contaminants
The group of potentially toxic trace elements that can be naturally present in seaweeds includes different metals, namely cadmium (Cd), mercury (Hg), lead (Pb), aluminum (Al) and the metalloid arsenic (As). The contents of these potentially toxic elements are usually higher in brown seaweeds [10]. The levels of As reported for *Ulva* sp., *F. spiralis*, *U. pinnatifida* and *G. vermiculophylla* seaweeds collected in the Portuguese coast were, respectively, 10.3, 38.6, 54.1 and 17.6 mg/kg dw [2]. These authors also reported that *G. vermiculophylla* presented the highest amounts of Pb (1.1 mg/kg dw) and that *F. spiralis* presented the highest amounts of Al (571.5 mg/kg dw). These authors concluded that these contaminants suggest a low toxicological risk associated to seaweed consumption.

4 Conclusions. Ongoing and future work
Seaweeds present a potential new source of food for the Portuguese population. The few available studies on the safety and nutritional value of Portuguese coastal seaweeds encourage us to further perform a comprehensive characterization of the available species. The seaweeds harvested during the different seasons of the year and in the different beaches are being the target of several studies that will allow us to obtain the nutritional composition of the seaweeds and their variability throughout the year.

Acknowledgements
This work received financial support from project iCanSea- Conservas com macroalgas para diferenciação nutricional e sensorial, by the consortium La Gondola, ISEP and WEDOTECH, sponsored by Portugal 2020 under the *Programa Operacional Competitividade e Internacionalização* (Ref. 3171/Portugal 2020).

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