Bioactive Properties in Brown Algae

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Brown algae are a source of interesting natural bioactive compounds that could be employed in the development of new industrial applications. However, the bioactive compound content in algal extracts is highly dependent on the extraction method applied. Our research was focused on the effect of five different extracting solvents: EtOH, AcO, EtAc, Chl, and Hex, on the extraction yield, polyphenolic content, and antioxidant and antimicrobial activities of nine brown algae from the NW coastal region of the Iberian Peninsula. As expected, all parameters were significantly affected by the species and the nature of the extracting solvent. In fact, the highest extraction yield was achieved when ethanol was used as solvent. Nevertheless, regarding TPC, DPPH-RSA, and FRAP values, EtAc and AcO were reported to be the most effective solvents, depending on the algae assessed, which suggests a differential composition of brown macroalgae in terms of phenolic compounds with antioxidant activity. Concerning the extracts, the highest TPC and FRAP values were found for Ascophyllum nodosum using EtAc as solvent, showing a possible correlation between polyphenol production and antioxidant activity in terms of reducing power, while the highest DPPH-RSA values were achieved by Bifurcaria bifurcata extracted with hexane, thus suggesting the hydrophobic nature of the antioxidant produced by this species.

Keywords: macroalgae ; brown algae ; phenolic content ; antioxidants ; bioactive compounds ; antimicrobial activity

1. Overview

Algae are an underexploited source of natural bioactive compounds in Western countries, so an increasing interest in the valorization of these marine organisms has emerged in recent years. In this work, the effect of extracting solvent on the extraction yield, phenolic content, antioxidant capacity, and antimicrobial activity of nine brown macroalgae species (*Ascophyllum nodosum*, *Himanthalia elongata*, *Undaria pinnatifida*, *Pelvetia canaliculata*, *Saccharina latissima*, *Bifurcaria bifurcata*, *Laminaria ochroleuca*, *Sargassum muticum*, and *Fucus spiralis*) was assessed. Total phenolic content (TPC) and the antioxidant properties of extracts by different assays: radical scavenging activity (DPPH-RSA) and ferric reducing antioxidant power (FRAP) were performed. The antimicrobial activity of extracts was studied against six different foodborne microorganisms: *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Bacillus cereus*, *Escherichia coli*, *Salmonella enteritidis*, and *Pseudomonas aeruginosa.* The highest extraction yield was achieved in ethanolic extracts. However, the highest TPC and FRAP values were obtained on the ethyl acetate extracts, especially from *A. nodosum*. Concerning algal species, the highest TPC and FRAP values were found in *A. nodosum*, while the highest DPPH-RSA values were achieved in the hexane extracts of *B. bifurcata*. The antimicrobial activity of algal extracts varied according to the solvent and alga selected, suggesting the species- and solvent-dependent behavior of this property, with *B. bifurcata* extracts showing the highest results for a wide range of bacteria.

2. Macroalgae

The topic of food safety is one of the most widespread concerns, as the European Food Safety Authority and the European Centre for Disease Prevention and Control reported the occurrence of 91,662 confirmed cases of disease just from salmonellosis in Europe [1]. Some foodborne microorganisms, for instance *Bacillus cereus*, can be found in different matrices, like soil and plants, being able to thrive in the intestinal tract of animals and further cause major health problems [2]. Consequently, the control of pathogenic microorganisms in food products is a major issue for this industry. Recently, consumer pressure and environmental awareness have led to a trend to opting for more natural ingredients. Thus, marine algae can be considered as functional foods and ingredients of natural origin, since they are used in food and cosmetic products, as well as in traditional remedies in Asian countries. Nevertheless, macroalgae are still underestimated in Western cultures, despite the numerous scientific studies that have proved their biological activities (**Figure 1**). Such health-promoting properties associated with macroalgae have prompted their use in various new industrial applications, also motivated by their chemical and nutritional composition and their high availability in coastal ecosystems [3][4].

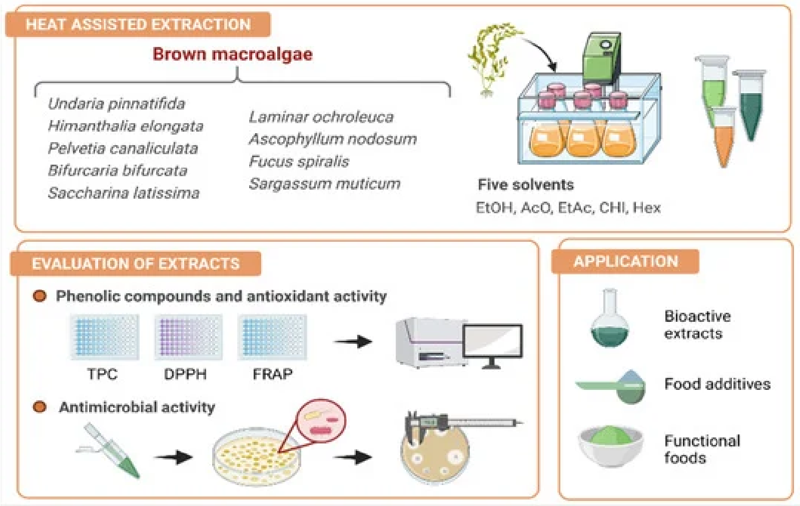

Figure 1. Schematic representation of the main goals of the present study. The nine selected species were extracted by heat-assisted extraction using five different solvents and the obtained extracts were evaluated in terms of phenolic content and antioxidant and antimicrobial properties. These bioactive extracts could have different applications such as food additives of functional foods.

Among the different groups of macroalgae, brown algae have gained attention due to the numerous biological properties and bioactive compounds that have been attributed to these organisms [5][6][7]. *Himanthalia elongata* (L.) S. F. Gray, *Undaria pinnatifida* (Harvey) Suringar, 1873, *Pelvetia canaliculata* (L.) Decne. and Thur., *Laminaria ochroleuca* Bach. Pyl., *Saccharina latissima* L., *Bifurcaria bifurcata* R. Ross, 1958, *Fucus spiralis* L., and *Ascophyllum nodosum* (L.) Le Jolis and the invasive species *Sargassum muticum* (Yendo) Fensholt are brown macroalgae species that can be found in the Northwestern coasts of the Iberian Peninsula. Besides their widespread distribution, these species were widely reported for their high nutritional value and associated beneficial properties to human health [8]. Some activities that have been recognized to brown macroalgae include antioxidant [5][9], anti-inflammatory [10][11], or antimicrobial [12][13], among others. Several studies have reported that the presence of phenolic compounds is linked to the biological properties attributed to these organisms, as it is the case of the antioxidant, antimicrobial, and cytotoxic activities [5][11][14]. Nevertheless, the chemical composition of macroalgae presents great variations depending on different factors, like species, geographical region, seasonal variations, and other environmental factors [15][16][17]. Despite these health-promoting properties, macroalgae are still considered as underexploited resources and greater efforts are needed to achieve their chemical and bioactive characterization, facing their large-scale application by different industrial sectors.

The chemical composition of macroalgae presents great variations depending on different factors, like species, geographical region, seasonal variations, and other environmental factors [15][16][17]. Thus, to achieve such goal, the development of efficient experimental procedures to maximize the extraction of bioactive compounds from brown macroalgae is of great interest for both the food and cosmetic industries, throughout the optimization of critical factors involved in this process, such as extraction method, solvent polarity, incubation time, etc. Among them, the chemical nature of the solvent used for extraction plays a fundamental role, as it should promote the solubility of target compounds and respond to other additional concerns, including safety and environmental features [18].

3. Conclusions

Brown algae are a source of interesting natural bioactive compounds that could be employed in the development of new industrial applications. However, the bioactive compound content in algal extracts is highly dependent on the extraction method applied. Our research was focused on the effect of five different extracting solvents: EtOH, AcO, EtAc, Chl, and Hex, on the extraction yield, polyphenolic content, and antioxidant and antimicrobial activities of nine brown algae from the NW coastal region of the Iberian Peninsula. As expected, all parameters were significantly affected by the species and the nature of the extracting solvent. In fact, the highest extraction yield was achieved when ethanol was used as solvent. Nevertheless, regarding TPC, DPPH-RSA, and FRAP values, EtAc and AcO were reported to be the most effective solvents, depending on the algae assessed, which suggests a differential composition of brown macroalgae in terms of phenolic compounds with antioxidant activity. Concerning the extracts, the highest TPC and FRAP values were found for *Ascophyllum nodosum* using EtAc as solvent, showing a possible correlation between polyphenol production and antioxidant activity in terms of reducing power, while the highest DPPH-RSA values were achieved by *Bifurcaria bifurcata* extracted with hexane, thus suggesting the hydrophobic nature of the antioxidant produced by this species.

On the other hand, the antimicrobial activity of algal extracts was also reported, also showing a strong dependence on the species and the nature of the extracting solvent, reinforcing the idea that the extraction of bioactive compounds should be individually optimized. In general, *Bifurcaria bifurcata* extracts showed the highest rates of antimicrobial activity against the whole panel of bacteria evaluated in this study, except for *E. coli*. Moreover, the use of AcO as solvent promoted a significant increase in the inhibitory effectiveness against *B. cereus*, *S. enteritidis*, and *P. aeruginosa*, thus proposing that *B. bifurcata* should be considered as a powerful candidate for its large-scale application by industrial sectors. Furthermore, considering the screening results, different strategies should be explored in the next future to the most significantly performing algae, including the optimization of the extraction parameters and the application of different extraction techniques such as ultrasound- and microwave-assisted extraction.

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