Invasive Algae Species

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seaweeds aquaculture feed invasive macroalgae species

1. Introduction

Invasive alien species (IAS), also known as exotic or non-native species, are plants or animals that have been introduced, intentionally or not, into regions where it is not usual to find them [1][2]. This situation often leads to negative consequences for the new host ecosystem, generally related to the community biodiversity reduction, changes in the abundance of the species and in the population's configuration across the habitats, as well as trophic displacements that can trigger other cascade effects [3]. Spanish law 42/2007, of 13 December, on Natural Heritage and Biodiversity, defines IAS as "species that are introduced and established in an ecosystem or natural habitat, which are an agent of change and a threat to native biological diversity, either by their invasive behavior, or by the risk of genetic contamination". IAS usually present high growth and reproduction rates, the ability to prosper in different environments, the capacity to use several food sources, and the ability to tolerate a wide range of environmental conditions. All these factors, along with the lack of natural predators, make these organisms more difficult to control and allow them to succeed in colonizing new ecosystems [3][4]. In addition, these species may feed on natural species or may carry pathogens for native organisms and even humans [5]. The invasion of non-native species also entails economic cost, which have been estimated at $1.4 trillion in the last decade [6].

Among marine IAS declared in Europe, around 20–40% are macroalgae (seaweeds) [7], a term that refers to several species of multicellular and macroscopic marine algae, including different types of Chlorophyta (green), Phaeophyta (brown), and Rhodophyta (red) macroalgae. Non-native seaweeds are particularly prone to become invasive due to their high reproductive rates, the production of toxic metabolites, and their perennial status that makes them more competitive than native species [1]. Several species periodically become a major problem, causing red tides, fouling nets, clogging waterways, and changing nutrient regimes in areas near to fisheries, aquaculture systems, and desalination facilities [1][4]. In the last years, the presence of invasive macroalgae in the northwestern marine areas of Spain has become a common problem due to growing globalization, climate change, aquaculture, fisheries, and marine tourism [8]. However, their proliferation could also offer new opportunities since the recovery of the algal biomass and their novel applications in different economic sectors could increase their added value. Obtaining natural compounds with biological properties of interest for both the food and the pharmaceutical industries is one of these possible applications.

2. Possible Exploitation of the Invasive Species

The exploitation of macroalgae is a growing industry with several applications, including human food and animal feed, biorefinery, fertilizers, production of phycocolloids, and obtaining compounds with biological properties [6][9]. Several applications are briefly discussed below.

2.1. Food Industry

Macroalgae have been consumed since ancient times in many countries around the world, mainly in the Asian regions. Nevertheless, their consumption has increased in the last decades in western countries, which has been attributed to the high nutritional values of macroalgae and their health benefits [10][11]. Some of the most consumed macroalgae are nori or purple laver (*Porphyra* spp.), kombu (*Laminaria japonica*), wakame (*Undaria pinnatifida*), Hiziki (*Hizikia fusiforme*), or Irish moss (*Chondrus crispus*), which can be consumed in different food formats (salads, soups, snacks, pasta, etc.) [11][12]. Still, most of them are considered an innovative niche product. Macroalgae are also widely used in the food industry to produce phycocolloids (polysaccharides of high molecular weight composed mostly of simple sugars), mainly alginates, agars, and carrageenans, which are frequently used as thickeners, stabilizers, as well as for probiotics encapsulation, gels, and water-soluble films formation [6][13]. Furthermore, diverse molecules present in algae have been shown to exert several bioactivities, such as antioxidant, anti-inflammatory, antimicrobial, and antiviral effects. These bioactive compounds (mainly proteins, polyunsaturated fatty acids, carotenoids, vitamins, and minerals) may play important roles in functional foods (e.g., dairy products, desserts, pastas, oil derivatives, or supplements) with favorable outcomes on human health [14]. Other applications of algae in the food industry include their use as colorant agents and the extraction of valuable oils (such as eicosapentaenoic acid, docosahexaenoic acid, and arachidonic acid) [15].

2.2. Biofuel

The development of algal biofuels (“third-generation biofuels”) has been considered an option to reduce the use of petroleum-based fuels and avoid competition between food and energy production for arable soil, since macroalgae grow in water. These organisms do not contain lignin, thus they are good substrates for biogas production in anaerobic digesters, while fermentable carbohydrates are fit for bioethanol production. Although the production of bioenergy from macroalgae is not economically feasible nowadays, several measures have been proposed to achieve a rational production cost in the future [16]. On the other hand, microalgae are considered a more suitable source to produce biodiesel due to the greater ease of controlling the life cycle and increasing the reproduction rate [17]. Microalgae biomass can be used for electricity generation or biofuel production after the lipid extraction. It has shown 80% of the average energy content of petroleum. The lipid content is highly dependent on the microalgae species and the cultivation conditions, thus not all species will be profitable, and choosing appropriate microalga strain is crucial [18]. Some microalgae used to produce biofuel are *Chlorella* spp., *Dunaliella salina, Haematococcus pluvialis*, *Spirulina platensis*, *Porphyridium cruentum*, *Microcystis aeruginosa*, and *Scenedesmus obliquus* [19].

2.3. Therapeutic and Cosmetic Products

The use of macroalgae for therapeutic purposes has a long history, but the search for biologically active substances from these organisms is quite recent. Numerous studies have demonstrated the biological properties of macroalgae extracts and compounds, including antioxidant, anti-inflammatory [20], antithrombotic, anticoagulant and coagulant [21], antimicrobial [22], and anticancer [23]. In addition, macroalgae have been demonstrated to exert biological properties applicable to cosmetic products, such as photo-protection, anti-aging, or anti-cellulite (Table 1). Considering this range of activities, macroalgae extracts and compounds have been considered for different pharmacologic and cosmetic products [24]. Regarding cosmetics, brown and red seaweeds are usually employed. The interest of these species lies in their content in cosmeceuticals ingredients, such as phlorotannins, polysaccharides, and carotenoid pigments [25]. These compounds are incorporated into cosmetics due to their bioactivities, their capacity to improve organoleptic properties, and their capacity to stabilize and preserve the products [26].

Table 1. Properties and applications of extracts and compounds isolated from algae in the cosmetic field.

Treatment	Specie	Compound	Result	Ref.
Skin aging	*Alaria esculenta*	Extract	Decline the amount of progerin in aged fibroblasts at the lowest tested concentration (not for younger cells)	[27]
	Phaeodactylum tricornutum	Ethanol extract	Protecting the skin from the adverse effects of UV exposure; preventing and/or delaying the appearance of skin aging effects	[28]
	Hizikia fusiformis	Fucosterol	Inhibit metalloproteinase-1 expression	[29]
	Ecklonia stolonifera	Phlorotannins	Inhibit metalloproteinase-1 expression	[30]
Sunscreen	*Halidrys siliquosa*	Phlorotannins	UV-filter activity	[31]
	Brown seaweeds	Phlorotannins	Protective effect against photo-oxidative stress	[32]
	Corallina pilulifera	Phenolic compounds	Anti-photoaging activity and inhibition of matrix metalloproteinase	[33]
	Sargassum spp.	Fucoxanthin	Protective effect on UV-B induced cell damage	[34]
	Sargassum confusum	Fucoidan	Suppress photo-oxidative stress and skin barrier perturbation in UVB-induced human keratinocytes	[35]
	Macrocystis pyrifera,	Acetone extracts	In vivo UVB-photoprotective activity	[36]

Treatment	Specie	Compound	Result	Ref.
	Porphyra columbina			
Moisturizer	*Fucus vesiculosus*	Fucoidan	Inhibition of hyaluronidase enzyme	[37]
	Laminaria japonica	5% water:propylene glycol (50:50) extracts	Hydration with the alga extract increased by 14.44% compared with a placebo	[38]
	Rhizoclonium hieroglyphicum	Polysaccharides and amino acids	Similar moisturizing effects to hyaluronic acid and glycerin	[39]
Whitening	*Nannochloropsis oculata*	Zeaxanthin	Antityrosinase activity	[40]
	Laminaria japonica	Fucoxanthin	Antityrosinase activity	[41]
	Arthrospira platensis	Ethanol extract	Antityrosinase activity	[42]
Hair care	*Chlorella* spp.	Intact microalga cells	Soften and make flexible both skin and hair	[43]
	Ecklonia cava	Dioxinodehydroeckol	Promote hair growth	[44]

Currently, the negative environmental impacts of synthetic fertilizers have been identified. Thus, the use of organic fertilizers, including macroalgae, has been proposed as a suitable alternative to reduce the impact on the environment [45][46]. In fact, macroalgae have been used since ancient times as fertilizers, and several beneficial effects have been described, such as enhancement of crops growth and yield, increased resistance against abiotic and biotic stresses, or nutrient intake [46][47][48]. The biostimulant effects of macroalgae have been attributed to diverse biological compounds such as plant hormones, phlorotannins, and oligosaccharides [48].

Regarding animal feed, macroalgae have been employed for this purpose since ancient times as feed but also as nutritious supplements [49]. Several studies have evaluated the positive effects of macroalgae-enriched food, both for terrestrial animals [50] and specially in aquaculture animals [51][52][53][54].

3. Main Invasive Species of Northwest Spain and Their Bioactive Compounds

According to the Spanish Catalogue of IAS of Algae [55], there are 14 species of invasive seaweeds in Spain which can be divided into: (i) red species: *Acrothamnion preissii*, *Asparagopsis armata*, *Asparagopsis taxiformis*, *Grateloupia turuturu*, *Lophocladia lallemandii*, and *Womersleyella setacea*; (ii) brown species: *Gracilaria vermiculophylla*, *Sargassum muticum*, *Stypopodium schimper*, and *Undaria pinnatifida;* and (iii) green species: *Caulerpa taxifolia*, *Codium fragile*, and *Caulerpa racemosa*. In addition, there are also invasive diatoms, such as the *Didymosphenia geminata*, also known as rock snot or didymo (Table 2). However, it should be noted that this catalogue is a dynamic instrument subjected to continuous changes and updating. Most of these invasive species are originally from the Indo-Pacific Ocean (Western Australia, New Zealand, and Japan), and it is thought that they have been introduced into the Spanish coasts through the Suez Canal. Maritime traffic, ballast water, fishing nets, trade of oysters, aquaculture, and fouling are considered the main routes of dispersion [8][56][57][58].

Table 2. Invasive algae species in Spain: taxonomy, origin, geographical distribution, and principal uses.

Specie	Taxonomy	Native Distribution	Distribution in Spain	Other Regions in Which They are Invasive	Principal Uses
		Red species			
Acrothamnion preissii	Phylum: *Rhodophyta* Class: *Florideophyceae* Orden: *Ceramiales* Family: *Ceramiaceae*	Western Australia	All Spain	Temperate coastlines on the Pacific coast of North America and western coasts of Europe	- Unknown
Asparagopsis armata	Phylum: *Rhodophyta* Class: *Florideophyceae* Orden: *Bonnemaisoniales* Family: *Bonnemaisoniaceae*	Indo-Pacific Ocean	All Spain	Mediterranean, Portugal, and Ireland	- Pharmaceutical potential as antibiotic
Asparagopsis taxiformis	Phylum: *Rodophyta* Class: *Rhodoplayceae* Orden: *Nemaliales* Family: *Bonnemaisoniaceae*	Australia and New Zealand	Except Canarias	Portugal	- Human consumption - Antifungal
Grateloupia turuturu	Phylum: *Rhodophyta* Class: *Florideophyceae* Orden: *Halymeniales* Family: *Halymeniaceae*	Pacific Ocean	All Spain	North America, Europe, and Oceania	- Human consumption - Fertilizer
Lophocladia lallemandii	Phylum: *Rhodophyta* Class: *Florideophyceae* Order: *Ceramiales* Family: *Rhodomelaceae*	Indo-Pacific Ocean	All Spain	Mediterranean	- Unknown
Womersleyella setacea	Phylum: *Rhodophyta* Class: *Rhodophyceae* Order: *Ceramiales*	Indo-Pacific Ocean	All Spain	Mediterranean	- Unknown

Specie	Taxonomy	Native Distribution	Distribution in Spain	Other Regions in Which They are Invasive	Principal Uses
	Family: *Rhodomelaceae*				
			Brown species		
Gracilaria vermiculophylla	Phylum: *Rhodophyta* Class: *Florideophyceae* Orden: *Gracilariales* Family: *Gracilariaceae*	North-east Pacific	All Spain	Europe and North America	- Animal feed - Biofuels - Fertilizer - Human consumption
Sargassum muticum	Phylum: *Ochrophyta* Class: *Phaeophyceae* Order: *Fucales* Family: *Sargassaceae*	Indo-Pacific Ocean	All Spain	Pacific Coast of North America, North Sea, Portugal, and the Mediterranean	- Animal feed - Food additive - Pesticide
Stypopodium schimperi	Phylum: *Ochrophyta* Class: *Phaeophyceae* Order: *Dictyotales* Family: *Dictyotaceae*	Indo-Pacific Ocean and Red Sea	All Spain	Africa and Southwest Asia	- Unknown
Undaria pinnatifida	Phylum: *Heterokontophyta* Class: *Phaeophyceae* Order: *Laminariales* Family: *Alariaceae*	Asia	All Spain	Europe	- Human consumption - Animal feed
			Green species		
Caulerpa taxifolia	Phylum: Chlorophyta Class: Bryopsidophyceae Orden: Bryopsidales Family: Caulerpaceae	Tropical area	All Spain	Mediterranean, California, and southern Australia	- Laboratory use
Codium fragile	Phylum: Chlorophyta Class: Chlorophyceae Orden: Codiales Family: Codiaceae	North of the Pacific Ocean and coast of Japan	All Spain	Widespread in the Mediterranean	- Human consumption
Caulerpa racemosa	Phylum: Chlorophyta Class:	Tropical areas	Except Canarias	Mediterranean: from Spain to	- Human consumption

Specie	Taxonomy	Native Distribution	Distribution in Spain	Other Regions in Which They are Invasive	Principal Uses
[59][60]	Bryopsidophyceae Orden: Bryopsidales Family: Caulerpaceae			Turkey	
Diatoms					
Didymosphenia geminata	Phylum: Ochrophyta Class: Bacillariophyceae Orden: Cymbellales Family: Gomphonemataceae	Boreal and alpine[61] regions of North America and Northern Europe	All Spain	New Zealand and Patagonia, South America	- Ornamental

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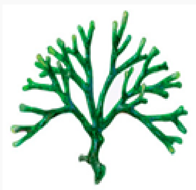
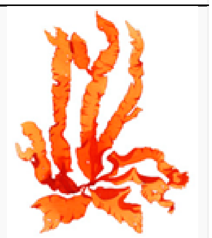
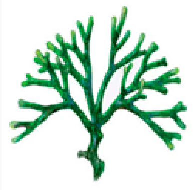
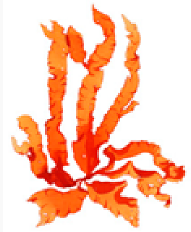
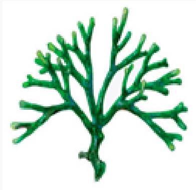
invasive macroalgae, is currently the focus of several industries, such as pharmaceutical, food, cosmetic, and biotechnological industries, due their biological activities, e.g., antioxidant, antimicrobial, anti-inflammatory, anticancer. The aim of these industries is to revalorize invasive macroalgae as a source of extracts and compounds with industrial interest [8]. Although many studies have evaluated the biological properties of various extracts of *A. armata*, *C. fragile*, *G. turuturu*, *S. muticum*, and *G. verniculophylla*, in some cases, the bioactive compounds responsible for this activity have not yet been identified. In the following paragraphs, the current knowledge about target compounds for industrial applications and the bioactive compounds identified in the macroalgae species considered invasive in Galicia are compiled. They are also summarized in Table 3.

Table 3. Main compounds and bioactive compounds reported for the invasive macroalgae in northwest Spain.

Bioactive compounds	**Invasive Macroalgae**				
					
	Asparagopsis armata	***Codium fragile***	***Gracilaria vermiculophylla***	***Sargassum muticum***	***Grateloupia turuturu***
Polysaccharides	Sulphated galactan derivatives, Mannitol	Sulphated polysaccharides		Fucoidans, Alginate, Glucuronic acid, Mannuronic acid, Laminarin	
Lipids	Cholestanol, Cholesta-5,25-diene-3,24 -diol, Palmitic acid, Stearic acid	Clerosterol	Cholesterol, 1-tetradecanol, 1-hexadecanol, 1-octadecanol, 1-eicosanol, 1-docosanol,	α -Linolenic acid	Phospholipids, Glycolipids, Eicosapentaenoic acid

Bioactive compounds	Invasive Macroalgae				
					
	Asparagopsis armata	***Codium fragile***	***Gracilaria vermiculophylla***	***Sargassum muticum***	***Grateloupia turuturu***
			Sterols, Monoacylglycerol		
Proteins			Mycrosporine-like aminoacids*		
Pigments		β-carotene, Siphonaxanthin		Fucoxanthin	R-phycoerythrin
Vitamins		α, β, γ, δ-tocopherol, γ-tocotrienol	α-tocopherol	α, γ-tocopherol	α-tocopherol, Phytonadione (vitamin K1)
Phenolic compounds	Not specified	Flavonoids, tannins	Gallic acid, Protocatechuic acid, Gentisic acid, Hydroxybenzoic acid, vVnillic acid, Syringic acid	Hydroxybenzoic acid, Gallic acid, Vanillic acid, Protocatechuic acid, Caffeic acid, Syringic acid, Chlorogenic acid, Coumaric acid, Phlorotannins, Fuhalols, Phlorethols, Hydroxyfuhalols, Monofuhalol A,	
Other compounds	Halogenated compounds, *Halogenated ketones*, 1,1-dibromo-3-iodo-2-propanone, 1,3-dibromo-2- propanone, 1,3-dibromo-1-chloro-2- propanone (±) form, [72] *Halogenated carboxylic acids*, Dibromoacetic acid, Bromochloroacetic acid, Dibromoacrylic acid, *Halogenated*	Serine protease [73]	Long chain aliphatic alcohols	Tetrapernyltaluquinol meroterpenoid with a chrome moiety [71]	Squalene

...al effects ...ibition of ... authors ...buted to ...*ata*, in a ... ...Ps). The ...itus and obesity in several animal models without any cytotoxic effect [74][75]. Recently, a study stated that SPs from *C. fragile* scavenge effectively freed radicals in vitro and suppressed the oxidative damage caused by H_2O_2 in Vero cell cultures and in zebrafish [76]. It has also been reported that SPs from *C. fragile* increased the coagulation time of human blood in a dose-dependent manner according to the methods activated partial thromboplastin time (APTT) [77][78], thrombin time (TT), and prothrombin time (PT) [78]. SPs from *C. fragile* inhibited HeLa cells proliferation [79] by stimulating tumor necrosis factor (TNF)-related apoptosis-inducing ligand, a promising anticancer target [80].

Bioactive compounds [81][82][83]	Invasive Macroalgae				
			 [84]		
	Asparagopsis armata	*Codium fragile*	*Gracilaria vermiculophylla*	*Sargassum muticum*	[85] *Grateloupia turuturu*
	alkanes, Bromoform, Dibromochloromethane				
Reference	[62][63][64]	[65][66] [86]	[67]	[68]	[69][70]

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anticancer properties, stimulating cell death in A549 cells (epithelial lung adenocarcinoma), PSN1 cells (pancreatic adenocarcinoma), HCT- 116 cells (colon carcinoma), and T98G cells (glioblastoma) [87].

Finally, G. *vermiculophylla* and *G. turuturu* are being used in the phycocolloid industry for obtaining agar and carrageenan, respectively, turning them into valuable matrixes [88][89]. Recently, polysaccharide extracts from *G. turuturu* have shown antimicrobial properties against *Escherichia coli* and *Staphylococcus aureus* [90].

3.2. Lipids

Starting with *A. armata*, it has been reported that these macroalgae contain some sterols such as cholesta-5,25-diene-3,24-diol, (3β,24*S*)-form [91], palmitic and stearic fatty acids, and cholestanol [73]. Recently, different crude extracts and fractions of this species were demonstrated to present antibacterial and antifouling properties. In the crude extract and most active fractions, several compounds were identified, including hexadecanoic, dodecanoic, octadecanoic, and tetradecanoic acids, which may be involved in this activity [92][93].

Regarding *C. fragile*, clerosterol (a derivative of cholesterol) was found in several extracts. This compound shows antioxidant properties, since it attenuated UVB-induced oxidative damage in human immortalized keratinocyte HaCaT cells and BALB/c mice models, reducing lipid and protein oxidation [94]. In addition, clerosterol stimulated apoptosis in A2058 human melanoma cells [95] and modulated several apoptotic factors in human leukemia cells [96]. Recently, a study observed that *C. fragile* displayed neuroprotective effects on neuroblastoma cell line SH-SY5Y. In the most bioactive fractions, several lipid compounds, among others, were identified. Although more research is needed, the authors considered that lipids are involved in the neuroprotective effect [97].

G. vermiculophylla contains high quantity of cholesterol (473.2 mg/kg dry weight), cholesterol derivatives, long-chain aliphatic alcohols, and monoglycerides, including 1-tetradecanol, 1-hexadecanol, 1-octadecanol, 1-eicosanol, and 1-docosanol [67]. Other lipids of great interest for nutraceutical and biotechnological industries include phospholipids, glycolipids, and eicosapentaenoic acid, present in high levels in this alga [69]. For example, three sphingolipids (gracilarioside, and gracilamides A and B) isolated from *G. vermiculophylla* (accepted name of *G. asiatica*) showed moderate cytotoxic effects against human A375-S2 melanoma cell line [98].

3.3. Proteins

To our knowledge, only *G. vermiculophylla* presents bioactive compounds of protein nature. This alga can absorb UV-A and UV-B radiations and decrease free radicals-induced effects, resulting from its high content in mycosporine-like amino acids [99].

3.4. Pigments

Siphonaxanthin from *C. fragile* has shown anticancer properties, stimulating the apoptosis of A549 lung cancer cells and modulating apoptotic factors in human leukemia cells [95][96]. Moreover, the anti-angiogenic effect of siphonaxanthin has been described in human umbilical vein endothelial cells as well as in a rat aortic ring angiogenic model [100], which suggests that this biomolecule could be an alternative to prevent pro-angiogenic diseases such as cancer. In addition, this alga also contains β-carotene [66].

In recent years, fucoxanthin has received a great deal of interest from the scientific community and industry due to the many beneficial health properties attributed to it, including anti-inflammatory [101]. Fucoxanthin extracted from *S. muticum* inhibited the lipopolysaccharide-induced nitric oxide production in RAW 264.7 macrophages and inhibited the expression of pro-inflammatory cytokines [102][103].

At industrial scale, *G. turuturu* is also used to produce R-phycoerythrin, a pink-purple pigment soluble in water present in large quantities, which presents diverse biological properties and potential industrial applications [89][104].

3.5. Vitamins

Different vitamins have been identified in the selected macroalgae, except in *A. armata*. In *C. fragile*, high levels of tocopherols have been reported (1617.6 µg/g lipid), including α, β, γ, and δ tocopherol and γ-tocotrienol [66]. *G. vermiculophylla* showed a considerable α-tocopherol content (28.4 µg/g of extract) [105]. Regarding *G. turuturu*, a chemical analysis revealed the presence of α-tocopherol and phytonadione (vitamin K1) [70]. Finally, *S. muticum* contains high amounts of α- and γ- tocopherol, 218 and 20.8 µg/g of extract, respectively [105].

3.6. Phenolic Compounds

Phenolic content has been evaluated in several species, although not all the studies have identified the target compounds. In the case of *A. armata*, phenolic content was determined by the Folin–Ciocalteu spectrophotometry method, which showed that it represented 1.13 ± 0.05% of dry weight [106]. Different extracts of *C. fragile* also contain phenolic compounds, mainly flavonoids and, to a lesser extent, tannins. These compounds showed a correlation with the antioxidant activity of the macroalgae [65]. The previous study of Farvin and Jacobsen (2013) identified several phenolic acids in both *G. vermiculophylla* aqueous extracts (gallic, protocatechuic, hydroxybenzoic, vanillic, syringic, and salicylic acids) and ethanolic extracts (gallic, protocatechuic, and gentisic acids). In correspondence with its content in phenolic compounds, a high antioxidant capacity has been demonstrated for these macroalgae according to the 2,2-Diphenyl-1-picrylhydrazyl (DPPH) and the ferric antioxidant power (FRAP) methods. In addition, *G. vermiculophylla* extracts inhibited lipid peroxidation [105]. Finally, some authors have reported the presence of phenolic compounds in *S. muticum*, including (ordered from highest to lowest concentration): hydroxybenzoic and gallic acids, *p*-hydroxybenzaldehyde, vanillic acid, 3,4-dihydroxybenzaldehyde and protocatechuic, ferulic, *p*-coumaric, caffeic, syringic, and chlorogenic acids [107]. Several bioactivities of *S. muticum*, such as antioxidant, antimicrobial, anticancer, or anti-inflammatory, have been attributed to the presence of phenolic compounds with high antioxidant capacity, particularly to phlorotannins (e.g., phloroglucinol, diphlorethol, bifuhalol), which are exclusively found in marine seaweed [68][108][109][110][111].

3.7. Other Minor Compounds

The invasive species *A. armata* presents high levels of halogenated secondary metabolites with recognized antibiotic activity [112]. They act as chemical defense against grazers and epibiota [113] and may be suitable for a wide range of applications [114][115]. For instance, the major metabolites bromoform and dibromoacetic acid, along with dibromochloromethane, bromochloroacetic acid, and dibromoacrylic acid, have shown high antifouling potential [62][63][64]. They can decrease the density of six bacteria strains on the algae surface: two marine (*Vibrio harveyii* and *V. alginolyticus*) and four biomedical strains (*Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Staphylococcus epidermis*, and *Escherichia coli*) [116]. Recently, several brominated compounds, such as tribromomethanol, were found in the crude extract and fractions of *A. armata*, which showed antimicrobial antifouling potential [92][93].

A serine protease extracted from *C. fragile* was demonstrated to exert in vitro and in vivo anticoagulant and fibrinogenolytic activity [117]. Finally, it was found that *G. turuturu* contains squalene, which was reported to exert several beneficial activities [70].

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