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Review

Ascophyllum nodosum (L.) Le Jolis, a Pivotal Biostimulant toward Sustainable Agriculture: A Comprehensive Review

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Abstract: Algae are existing macroscopic materials with substantial benefits, including as important growth regulators and macronutrients and micronutrients for the growth of healthy crop plants. Biofertilizers obtained from algae are identified as novel production fertilizers or innovative biofertilizers without the detrimental impacts of chemicals. Seaweeds contain many water-soluble minerals and nutrients that plants can easily absorb and that are valuable for crop plants' growth. At present, *Ascophyllum nodosum* (L.) Le Jolis extract outperforms chemical fertilizers in terms of increasing seed germination, plant development, and yield, as well as protecting plants from severe biotic and abiotic stresses. *A. nodosum* contains bioactive compounds that exhibit an array of biological activities such as antibiotic, anti-microbial, antioxidant, anti-cancer, anti-obesity, and anti-diabetic activities. *A. nodosum* extract (AnE) contains alginic acid and poly-uronides that improve soil's water-carrying ability, morsel structure, aeration, and capillary action, stimulating root systems in plants, increasing microbial activity in soil, and improving mineral absorption and availability. The scientific literature has comprehensively reviewed these factors, providing information about the different functions of *A. nodosum* in plant growth, yield, and quality, the alleviation of biotic and abiotic stresses in plants, and their effects on the interactions of plant root systems and microbes. The application of AnE significantly improved the germination rate, increased the growth of lateral roots, enhanced water and nutrient use efficiencies, increased antioxidant activity, increased phenolic and flavonoid contents, increased chlorophyll and nutrient contents, alleviated the effects of abiotic and biotic stresses in different crop plants, and even improved the postharvest quality of different fruits.

Keywords: *Ascophyllum nodosum* (L.) Le Jolis; biofertilizer; biostimulants; plant growth; seaweeds

1. Introduction

The existing global scenario decisively highlights the need to accept eco-friendly agricultural tools for sustainable development. Chemicals have adverse impacts on the soil and the valuable soil microbes and microbial communities and the plants cultivated on these soils. Organic farming is a therapy for the evils of modern chemical agriculture. Many viable alternatives must be explored to meet the increasing demand for organic inputs. One such alternative is the application of seaweed extracts as plant stimulants, sources of nutrients, and biofertilizers [1]. According to the European Union (EU) Regulation 2019/1009, a plant biostimulant is "a product stimulating plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following plant or plant rhizosphere characteristics: (a) nutrient use efficiency; (b) tolerance to abiotic stress; (c) quality traits; or (d) availability of confined nutrients in the soil or rhizosphere" [2]. Biostimulants may be any substance or microorganism. The immediate use of seaweed is in the production of hydrocolloids such as alginates, carrageenan, and agar [3]. Various structures of natural products or bioactive components have been established in seaweed, such as carotenoids, terpenoids, polyphenols, peptides, sulfated polysaccharides, and fibers. These bioactive products demonstrate an array of biological properties, for instance, antibiotic, antioxidant, cytotoxic, anti-inflammatory, anti-diabetic, and anti-cancer activities [3,4]. Unlike synthetic chemicals, biofertilizers composed of algae are eco-friendly, non-toxic, pollution-free, and harmless to plants [5].

In various parts of the globe, a continuous reduction in rainfall is generating a high frequency of drought stress, which is negatively manipulating crop productivity and food security. In addition to water stress, salinity, heat, nutrient, and oxidative stresses limit agricultural productivity [6]. Leaf area and photosynthetic activity are reduced by drought stress due to partial stomatal closure, resulting in reduced growth, development, and productivity of crop plants [7]. Salt stress has a negative impact on approximately 6% of the world's arable land area, including 30% of irrigated land [8]. Alleviating these abiotic stresses is a major challenge in various parts of the globe, mainly in arid and semi-arid regions [6].

Seaweed extracts are used as plant biostimulants and are considered the most economic and effective way to improve the growth, development, quality, and quantity of plants by increasing water and mineral use efficiencies under various environmental stresses [9]. The application of AnE significantly improved the germination rate, increased the growth of lateral roots, enhanced water and nutrient use efficiencies, increased antioxidant activity, increased phenolic and flavonoid contents, increased chlorophyll and nutrient contents, alleviated the effects of abiotic and biotic stresses in different crop plants, and even improved the postharvest quality of fruits [10].

Brassica napus, *Solanum lycopersicum*, *Daucus carota*, *Cucumis sativus*, *Glycine max*, *Spinacia oleracea*, and *Hordeum vulgare* were all stimulated by agricultural biostimulants (AnE) [10]. Seaweed extracts have the capacity to sustainably increase the quality and yield of crops with different soil types and farming systems; for example, foliar and soil applications of seaweed extract enhanced the yield and post-harvest qualities of strawberries, tomatoes, vegetables, and sugarcane [11,12]. Many other studies on the interactions of soil microbes showed that the application of seaweed extracts altered the microbial activity in the rhizosphere located in the soil, and these modifications coincided with improved plant development and yield [12,13]. According to the study by Renaut et al. [13], the effect of AnE on the soil and root microbiota diversity of pepper plants altered the bacterial diversity in the soil. AnE applied to tomato and sweet pepper crops significantly enhanced the upregulation of the gene transcripts Ga_2Ox, IAA, and IPT, which are involved in the biosynthesis of gibberellin, auxin, and cytokinin, respectively [14]. The foliar spray of AnE on *Paspalum vaginatum* during protracted irrigation intervals and under conditions of salinity improved lipid peroxidation by means of linoleic acid and DPPH assays and increased the activities of antioxidant enzymes such as SOD, CAT, and APX, leading to the depletion of reactive oxygen species in the AnE-treated plants [15].

Seaweed extracts are used in plants to protect them from pathogenic infections, either directly or indirectly. *A. nodosum* has the potential to act as a protectant to control plant diseases. Both foliar (spray) and soil applications of seaweed extract were found to be effective in reducing foliar and soil-borne pathogens against a variety of crops [16,17]. Bioactive compounds present in *A. nodosum* are also considered potent elicitors of plant defense responses against various pathogens. The AnE improved plant disease resistance against *Phytopthora melonis* in cucumber [18] and against *Phytophthora capsica* in tomato [19].

This review represents the current state of biostimulants and their effects on plant growth and development. Biostimulants could be a long-term and cost-effective tool for improving plant development and resistance to various stresses. Recent research has shown that biostimulants defend plants and crops from different biotic and abiotic stresses, suggesting their potential for field application and measurement as organic inputs as they are safe for human health and are cost-effective and environmentally friendly alternatives.

2. Seaweeds

There are about 9000 species of marine algae integrated into different algal groups, such as Phaeophyta (brown), Chlorophyta (green), and Rhodophyta (red), depending upon their pigments, such as chlorophylls, carotenoids, and phycobilins [5]. For a long time, industries have used seaweeds as edible sources, fodder, green compost, and unprocessed materials [20]. Seaweeds, as important oceanic assets, are used in soil reformation to improve the plant growth of crops. In horticulture, using seaweed products is becoming a time-honored practice [21]. Seaweed extract can improve plant growth, yield, and quality by containing different plant growth hormones and hormones such as growth regulators, auxins, abscisic acid, gibberellins, cytokinins, betaines, brassinosteroids, jasmonates, polyamines, salicylates, and signal peptides. In addition to this, trace elements such as iron (Fe), copper (Cu), zinc (Zn), cobalt (Co), molybdenum (Mo), manganese (Mn), and nickel (Ni), as well as vitamins, and amino acids [5,22], are also found in seaweeds. Seaweed extract highly influences the cellular metabolism of plants, and its application has been used to raise the uptake of essential macro- and micronutrients from the soil and to improve plant resistance to pests, diseases, and stresses [23]. Many algal products are significant sources of plant biostimulants and are extensively used to increase agricultural productivity [24]. The most studied seaweed is the brown intertidal alga *Ascophyllum nodosum* (L.) Le Jolis. It is used as a source of many industrial and commercial plant growth stimulators to improve the regulation of physiological, biochemical, and molecular processes to enhance plant defenses against biotic and abiotic stresses [25]. The significance of *Ascophyllum nodosum* Extract (AnE) in the improvement of plant growth via different modes of action is shown in Figure 1.

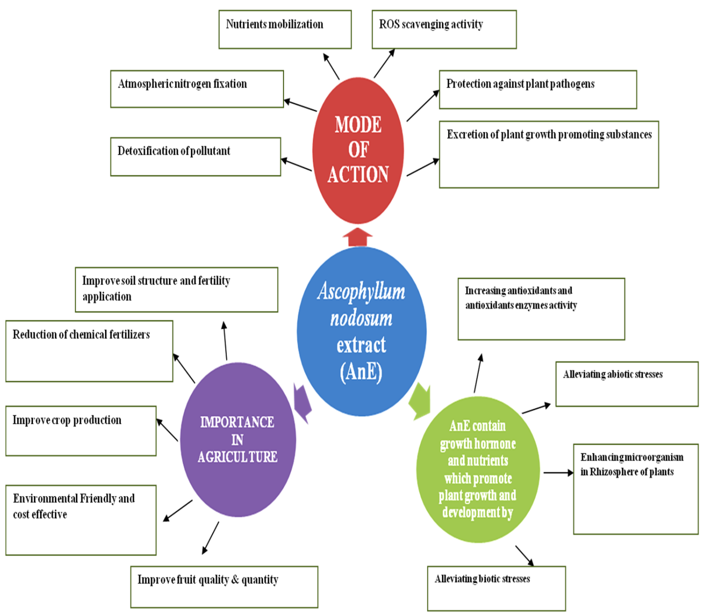

Figure 1. Significance of *Ascophyllum nodosum* extract (AnE) in improving plant growth via different modes of action.

In the subsequent sections, we provide a detailed and plant-centered review of the composition, commercial products, and effects of AnE on different plants under various environmental biotic and abiotic stresses. We also show tables that provide an overview of the morphological, physiological, and biochemical changes in plants in response to AnE treatment.

3. *Ascophyllum nodosum* (L.) Le Jolis and Its Composition

Ascophyllum nodosum (L.) Le Jolis belongs to the group Phaeophyta (brown algae), and it is the most studied seaweed among other groups of seaweeds [26]. It is primarily found in the cold water of the North Atlantic Ocean, which stretches from eastern Canada to parts of northern Europe [27]. *A. nodosum* is a brown alga that is edible and is also known as rockweed, knotted kelp, Norwegian kelp, and knotted wrack (egg wrack). *A. nodosum* seaweed extract has the potential to improve plant growth, yield, and quality as it contains plant growth regulators such as auxins, cytokinins, gibberellins, betaines, mannitol, organic acids, polysaccharides, amino acids, and proteins [28]. Phlorotannins are unique polyphenolic compounds found only in some brown algae and not in terrestrial plants. *A. nodosum* is one of the most significant sources of phlorotannins [29].

A. nodosum has bioactive biopolymers, including alginates, fucoidan, and laminarin, as well as non-polysaccharide bioactive components such as polyphenols [30]. *A. nodosum* contains sulfated polysaccharide chains known as fucoidans, which have alternate (1–3) and (1–4) linkages [31,32] with both disulfate and trisulfate sugars. Most of them have disulfated sugars [33]. Ascophyllan [34] is the common name for a fucoidan with a high amount of sulfur residue that is found in *Ascophyllum.* It has a molecular size of 390 kDa [35]. Brown algae, i.e., the Phaeophyceae family, reveal high levels of phlorotannins. Phlorotannins are a type of polyphenol that is unique to aquatic organisms. These are oligomers and polymers of phloroglucinol (1,3,5-trihydroxy benzene) [36] that are linked by the acetate malonate pathway and have molecular sizes ranging from 126 to 650 kDa [37–39].

Components of *A. nodosum* contain the following sulfated polysaccharides (fucoidans):

- Foley et al. [40] found a fucoidan with a dry weight of 1.75%, carbohydrates at 65.4%, polyphenols at 13.5%, and proteins at 18.5%. The carbohydrates comprise L-fucose (52.1%), glucose (21.3%), galactose (6.1%), and xylose (16.5%) at a molecular size of 420 kDa.
- Kloareg et al. [41] discovered sulfated polysaccharide, a fucoidan with 38.7% L-fucose and 33.7% sulfate by weight.
- Fucoidan sulfate at 26.1%, uronic acid at 5.7%, and L-fucose at 31.3% at 556 kDa [42].
- A fucoidan of 47% L-fucose, 30% sulfate, and 6% uronic acid at 25 kDa [43].
- A fucoidan of L-fucose (39.7%), sulfate (27%), and uronic acid (4.1%) with a molecular weight of 18.6 kDa [44].
- The fucoidan of L-fucose is 45.4%, sulfate is 22.1%, and uronic acid is 9.9% at 417 kDa [45].
- At 1323 kDa, the fucoidan of sulfate contains 19.4% sulfate, 28.4% L-fucose, and 5.8% uronic acid [45].

Other different, useful components are also found in *A. nodosum* (Table 1).

Table 1. Other components of *A. nodosum*.

Components	Quantity (%)	Reference
Water	70–85	[46,47]
Ash	15–25	
Alginic acid	15–30	
Laminarian	0–10	
Mannitol	5–10	
Fucoidan	4–10	
Protein	5–10	
Fat	2–7	

Table 1. *Cont.*

Components	Quantity (%)	Reference
Tannins	2–10	
Potassium	2–3	
Sodium	3–4	
Magnesium	0.5–0.9	
Iodine	0.01–0.1	
Other carbohydrates	0–10	
Choline	0.09–0.32	[48,49]
Betaine	0.04–0.12	
Butyric acid	-	[50]
Phenolics	-	[51,52]
Vanadium	-	[53]
Fucosterol	50	[50]
Glycolipids	32.6	[54]
Phospholipids	4.7	
Mannitol	8–10	[55]
Myristic, palmitic acid, stearic acid, oleic acid, linoleic acid, arachidonic acid, and eicosapentaenoic acid	-	[56]
Iodine	553 ± 186 μg/g dry weight	[57]
Carbohydrates	40–70	[22]
Proteins	3–10	
Polyphenols and pigments	4–8	
Phospholipids and glycolipids	2–4	
Hormone and vitamins	<1	
Alginate	30	[58]
Fucose	10	
Laminarin	7	

4. *Ascophyllum nodosum* Extract (AnE) Enhances Plant Morphological and Physiological Characteristics

Ascophyllum nodosum extract (AnE) commercial products have been confirmed to regulate growth-stimulating behaviors. When low concentrations of AnE are applied to plants, they are commonly referred to as “biostimulants”, “biostimulators”, “biofertilizers”, and “plant growth stimulators” [59] (Table 2). *A. nodosum* seaweed extract is a well-known growth promoter for vascular family plants due to its ability to improve nutrient absorption via root tissues, thereby increasing yield while reducing the damaging effects of biotic and abiotic stresses [5,22,60]. The development and efficiency of crops are improved by applying AnE, which increases nutrient uptake and availability at the plant roots [24].

Table 2. Commercial *A. nodosum* seaweed products utilized in farming and horticulture as biofertilizers and biostimulators for plant growth [59,60].

Sr. No.	Seaweed Used	Name of the Product	Action	Corporation/Industries
1	*A. nodosum*	Acadian®	Plant growth stimulator	Acadian Agritech, Dartmouth, NS, Canada
2		Actiwave®	Metabolic enhancer, biostimulant	Agro Exim, Ankeshwar, Gujarat, India
3		Agri-gro ultra	Plant growth stimulator	Agri-gro Marketing Inc., Doniphan, MO, USA
4		Agripower ®	---	Hindustan Agro, Delhi, India
5		Alg A Mic	Plant growth stimulator	Bio-Bizz Worldwide N.V., Groningen, The Netherlands
6		Algae green™	Biostimulant	Oilean Glas Teo Ltd., Donegal, Ireland

Table 2. *Cont.*

Sr. No.	Seaweed Used	Name of the Product	Action	Corporation/Industries
7		Algamare ®	Plant growth stimulator	Microquímica, Hortolândia - SP, Brazil
8		Algifert	Plant growth stimulator	Algae, Kristiansund - Omagata, Norway
9		Algifol	Biostimulator	Neomed Pharma GmbH, Germany
10	*L. digitata/A. nodosum*	Algovert ®	Biostimulator	Setalg, Pleubian, France
11	*A. nodosum*	Aquamax	Biostimulator	Aqua Maxx Inc., USA
12		Bio-Algen® S-90	Bioregulator	Shulze & Hermsen GmbH, Germany
13		Bio genesis™	Plant growth stimulator	Green Air Products Inc., Boring, OR, USA
14		Biopost AG200	Plant growth stimulator	Cofuna, Nousty, France
15		Biovita®	Plant growth stimulator	PI Industries Ltd., Sagar, Madhya Pradesh, India
16		Biozyme	Biostimulant, Bioregulator	Genesis Agro, Nashik, Maharashtra, India
17		Dalgin Active®	Growth regulator	Rhino AgriVantage, Wellington, South Africa
18		Espoma	Plant growth stimulator	Espoma Company, Millville, NJ, USA
19	*A. nodosum* and amino acid	Fylloton	Biostimulant	Biolchim, Warszawa, Poland
20	*A. nodosum*	Goemar, GA14®	Plant growth stimulator	Goemar, Saint-Malo, France
21		Goëmar BM86®	Fertilizer, biostimulator, and bioregulator	Parc Technopolitain, Atalante, France
22		GS 35	Plant growth stimulator	Micromix Plant Health Ltd., Nottingham, UK
23		Guarantee®	Plant growth stimulator	Maine Stream Organics, USA
24		HighTide™	---	Green Air Products Inc., Boring, OR, USA
25		ID-aIG™	Calorie reducer	Bio Serae Laboratories SAS, Bram, France
26		Kelpmeal	Plant growth stimulator	Acadian Sea Plants Ltd., Dartmouth, NS, Canada
27		Kelpro	Plant growth stimulator	Techniprocesos biologicos S.A. de C.A., USA
28		Kelpro soil	Plant growth stimulator	Productos del Pacifico, S.A. de C.A., Mexico
29	*A. nodosum/Possidonius australus*	Liquid kelp	Biostimulator	Sea Gold, Australia

Table 2. *Cont.*

Sr. No.	Seaweed Used	Name of the Product	Action	Corporation/Industries
30		Marmarine	Plant growth stimulator	IFTC™, Amman, Jordan
31		Maxicrop	Plant growth stimulator	Maxicrop Inc., Elk Grove Village, IL, USA
32		Nitrozime	Plant growth stimulator	Hydrodynamics International Inc., Lansing, MI, USA
33		Nitrozyme	Biostimulator	Agri-Growth International Inc., USA
34		OHM	Biostimulant	UPL AgroSolutions Canada Inc., Ontario, Canada
35		Plantin	Biostimulant	Plantin SARL, Courthézon, France
36		Proton®	Biostimulant	Zen Agrotech, Nagpur, Maharashtra, India
37		PSI-362	Biostimulant	Brandon Bioscience, Tralee, Ireland
38		RutfarmMaxifol	Biostimulant	Agromaster, Krasnodar Krai, Russia
39		Rygex	Biostimulator	Agriges S.R.L., Benevento, Italy
40	*A. nodosum* *A. nodosum*	SeaCrop	Biostimulant	Atlantic Laboratories Inc., Bensalem, PA, USA
41		Soluble seaweed extracts	Plant growth stimulator	Technaflora Plant Products Ltd., Mission, BC, Canada
42		Stella maris™	Plant growth stimulator	Acadian Sea Plants, Dartmouth, NS, Canada
43		Stimplex	Plant growth stimulator	Acadian Agritech, Dartmouth, NS, Canada
44		Super Fifty®	Biofertilizer	Bio Atlantis Ltd., Kerry, Ireland
45		Synergy	Plant growth stimulator	Green Air Products Inc., Boring, OR, USA
46		Tasco® -Forage	Plant growth stimulator	Acadian Sea Plants Limited, Dartmouth, NS, Canada
47		Thorvin	Biostimulator	Thorvin Inc., Norway
48		Wuxal®-Ascofol	Biostimulator	Aglukon, Düsseldorf, Germany
49	Liquid seaweed extract	WAVE™	Biostimulant	UPL Agro Solutions Canada Inc., Ontario, Canada

Commercial seaweed products significantly enhanced the yield and quality of citrus fruit [21] and grapes [61]. For example, a representative AnE-based biostimulant produced by PI Industries Ltd., India, BIOVITA, an agriculture product, is shown in Figure 2. Using seaweed extracts in *Petunia* and *Ageratum* improved vegetative plant growth, stomatal conductance, photosynthesis, transpiration rate, the water potential of leaves, and the relative water content (RWC) under prolonged irrigation conditions [62]. AnE transforms the concentration and localization of auxins, and it serves as a plant hormone that enhances plant growth [63]. AnE treatments extensively improve the number of leaves and their area, the height and dry weight of plants, antioxidant activity, and the phenolic, flavonoids, and tannin contents of *Calibrachoa* × *hybrida* (an ornamental plant) [64]. Crops treated with Bio-Algeen® have been accounted for in the yield, as in clover [65], sugar beet [66], tomatoes [67,68], and carrot [69]. Macro- and micronutrients in tomato fruit were increased using two commercial products derived from AnE, Rygex®, and Super Fifty® [70].

Figure 2. Example of biostimulant (AnE) produced by PI Industries Ltd., Sagar, Madhya Pradesh, India.

In another study, Danesh et al. [71] observed that *Ascophyllum* seaweed extract affected the growth parameters of tropical crops. When treated with AnE, tomato plants (*Lycopersicum esculentum* Mill.) showed an increase in plant height and root and shoot biomass, with a significant enhancement in numerous minerals and nutrients in the shoots and fruits of tomato plants at a concentration of 0.5%. The mineral nutrients of the fruits were significantly increased: nitrogen by 81%, phosphorus by 8%, potassium by 50%, calcium by 57%, iron by 25%, and zinc by 33%, and the intensity of sodium was reduced by 2% [71]. The AnE enhanced the yield and quality of the tomato fruit, as betaines in the extract enhanced the chlorophyll pigment in the tomato leaves and decreased its deterioration rate [72,73]. The seaweed-treated tomato plants exhibited improved concentrations of minerals in their shoots and a significant increase in fruit quality and other attributes, including size, color, total soluble solids, ascorbic acid, and minerals under tropical growing conditions [73]. Mohamed et al. [74] observed that the foliar application of AnE in the chickpea cultivar Giza 195 improved the seed quality and amino acid and mineral contents in the seeds and induced favorable changes in the protein profile.

Similarly, the foliar application of AnE influenced the growth, yield, and quality attributes in four onion cultivars; a 0.5% concentration of AnE caused a significant increase in total soluble sugar, mineral-like N, P, and K, bulb weight, and yield (Table 3). In contrast, at a concentration of 3%, AnE enhanced ascorbic acid content compared to the respective controls [75]. Likewise, an *A. nodosum*-based biostimulant enhanced the protein content and nutrition value of green beans [76].

Table 3. Physiological, morphological, and biochemical effects of *A. nodosum* extract (AnE) and commercial products of AnE on different plants.

Plants		Consequences of Treatment	Product	Reference
Scientific Name	**Common Name**			
Spinacia oleracea	Spinach	The use of foliar spray increased total fresh biomass.	Goemar, GA14®	[77]
Solanum Lycopersicum	Tomato	Greater chlorophyll content in sprayed plants.	Maxicrop®	[78]
Capsicum annuum	Pepper	Enhanced yield and quality.	Maxicrop®	[79]
Citrus unshiu	Satsuma orange	Early maturation of fruit.	Goemar®	[80]
Lilium	Lily	Foliar spray enhanced stems, leaves, and bulb weights.	AnE	[81]

Table 3. *Cont.*

Plants		Consequences of Treatment	Product	Reference
Scientific Name	**Common Name**			
Calendula officinalis	Marigold	Soil treated with seaweed before seeds were sown improved germination, leading to enhanced root length and shoot growth, and treated seedlings flowered earlier than non-treated seedlings.	AnE	[82]
Actinidia deliciosa	Kiwi	An AnE foliar spray after 5 and 10 days of flowering increased fruit weight and maturity.	AnE	[83]
Vitis vinifera	Grapevine	To increase fruit yield, spray the leaves five times.	WUAL	[84]
V. vinifera	Grapevine	Improved fruit quality and yield.	Acadian	[61]
V. vinifera	Grapevine	Grapevine copper uptake was improved.	Maxicrop, Proton, Algipower	[85]
V. vinifera	Grapevine	Multiple foliar sprays increased fruit setting.	AnE	[26]
Citrullus lantus	Watermelon	The use of ANE increased yield and quality significantly.	AnE	[86]
Vaccinium corymbosum	Blueberry	Foliar spray increased yield (15%) and berry size.	Ekologik	[87]
Citrus sinensis	Orange	Foliar spaying at budding improved bud sprouting, and full bloom enhanced the content of gibberellin and fruit yield (8–15%).	Goemar	[21]
Malus pumila	Apple	When applied to the soil as a liquid, it increased chlorophyll, fruit sugar content, and yield while decreasing biannual cropping.	Active	[88]
Fragaria × ananassa	Strawberry	It increases fruit yield and quality while also acting as an iron chelator.	Active	[89]
Malus pumila	Apple	Foliar sprays enhanced flowering and vegetative growth, yield, and quality.	Goemar	[90]
Olea europaea	Olive	A foliar application prior to full bloom improved yield and increased oil quality.	AnE	[91]
Solanum lycopersicum	Tomato	Drench or foliar spray with a commercial product increased chlorophyll content.	Algifert	[92]
S. oleracea	Spinach	Seaweed improved postharvest quality and storage time.	AnE	[93]
S. oleracea	Spinach	Improved yield and nutritional quality.	Acadian	[94]
Brassica oleracea	Cabbage	Increased the antioxidant and phenolic content of cabbage.	Acadian	[95]
Phaseolus vulgaris	French bean	Foliar application was minimal, but it improved betaine and chlorophyll contents.	Algifert	[92]
Solanum tuberosum	Potato	Foliar spray significantly improved the yields of three varieties.	AnE	[96,97]

Table 3. *Cont.*

Plants		Consequences of Treatment	Product	Reference
Scientific Name	**Common Name**			
Triticum	Wheat	Soil drenched with seaweed has increased chlorophyll content.	Algifert	[92]
Hordeum vulgare	Barley			
Zea mays	Maize			
H. vulgare	Barley	Priming seeds with extracts enhanced the rate of seed germination, improved the availability of oxygen to the embryo, and decreased the microbial population by 86%.	AnE	[98]
H. vulgare	Barley	The treatment increased the yield of hydroponically grown spring barley.	Maxicrop	[99]
H. vulgare	Barley	Treatment of seaweed stimulated gibberellic acid (GA3)-independent amylase activity.	AnE	[100]
Cynodon dactylon	Bermuda grass	Late-term soil treatment (nitrogen, iron, and seaweed extract) had no regular impacts on proline concentration (cold tolerance).	AnE	[101]
Poa pratensis	Blue grass	Increased shelf life and transplant rooting.	Acadian	[102]
Brassica oleracea	Cabbage	Improved secondary metabolite biosynthesis.	AlgaeGreen	[103]
Picea abies	Spruce	Soil flooded with extracts at the 17-week stage of seedling development and improved spring root development.	AnE	[104]
V. vinifera	Grape	Improved vegetative growth.	AnE	[105]
Picea abies	Spruce	Drench treatment improved seedling growth.	Bio-Algeen	[106]
Kappaphycus alvarezii	Sea moss	Acadian marine plant extract is efficient for regenerating young plants using tissue culture.	Acadian	[107]
Brassica napus	Rapeseed	Enhance plant growth and nutrient uptake.	AZAL5	[108]
Petunia *Ageratum*	- -	Drench treatment improved plants' vegetative growth parameters.	AnE	[62]
Calibrachoa × *hybrida*	-	The seaweed treatment enhanced the number of leaves and leaf area, plant height, dry weight, and antioxidant capacity.	AnE	[64]
Solanum lycopersicum	Tomato	The use of seaweed increased chlorophyll content in leaves as well as plant height and fruit yield.	AnE	[73]
Prunus dulcis	Almond	Foliar application improved growth and potassium uptake.	AnE	[109]
Morus alba	Mulberry	Seaweed extract significantly increases both the quality and quantity of mulberry leaves.	AnE	[110]

Table 3. *Cont.*

Plants		Consequences of Treatment	Product	Reference
Scientific Name	**Common Name**			
Pyrus	Pear	Improved fruit diameter, weight, and yield and cells per area of parenchymatous tissues in fruits.	AnE	[111]
Mangifera indica	Mango	Enhanced area and N, P, K, Mg, Fe, Mn, and Zn content in leaves, and improved fruit weight, retention, yield, and soluble sugars.	AnE	[112]
Solanum melongena	Eggplant	A foliar spray of *Ascophyllum* extract showed increased fruit yield.	AnE	[113]
Malus domestica	Apple	Increased fruit setting, number, weight, and length without affecting maturity.	Algamare	[114]
Capsicum annuum L.	Pepper	In comparison to the control, improved plant height, stem diameter, number of leaves and leaf area, chlorophyll content, shoot fresh and dry weight, and root fresh and dry weight.	Stimplex®	[115]
Mangifera indica	Mango	Reduced fruit mass loss, interruption of pulp color angle deterioration, preservation of pulp rigidity and subsequent increase in fruit shelf life, and the preservation of pH and acidity, soluble solids, and sugar contents during postharvest storage.	AnE	[116]
Arabidopsis thaliana		Enhanced plant growth via localization and alteration of auxin concentration.	AnE	[63]
Allium cepa	Onion	Improved vegetative growth and yield of onions.	Premium liquid seaweed	[117]
Citrullus lanatus	Watermelon	Increases the following evaluated parameters significantly: fresh shoot weight, shoot and root length, fresh and dry root weight.	Acadian®	[118]
Brassica oleraceae	Cabbage	Total phenolic content was higher in all seaweed-treated plants.	AlgaeGreen	[103]
Cucumis sativus	Cucumber	Induced favorable effects on plant growth, fruit yield, and quality.	AnE	[119]
Zea mays	Maize	Improved root system development and plant nutrition.	AnE	[120]
Solanum melongena	Eggplant	Enhanced early crop yield, antioxidant activity, number of fruits per plant, and selected mineral contents under field conditions.	Göemar BM-86	[121]
Achillea millefolium	Yarrow	Application of seaweed enhances phenolic content and antioxidant activity.	AnE	[122]

Table 3. *Cont.*

Plants		Consequences of Treatment	Product	Reference
Scientific Name	**Common Name**			
Capsicum annuum	Chili	Different biozyme treatments improved the growth, quality, and yield.	Biozyme	[123]
V. vinifera	Grapevine	Enhanced growth, leaf nutrient content, berry quality, and yield.	AnE	[124]
V. vinifera	Grapevine	Improves the fruit quality of cultivated wine grapes.	AnE	[125]
Pyrus	Pear	Enhanced fruit diameter, weight, yield, and number of cells per area of parenchymatous fruit tissue.	AnE	[111]
Brassica napus	Rapeseed	Promoted the plant's growth.	AnE	[108]
Cicer arietinum	Chickpea	Stimulated favorable changes in the anatomical structure of the stem and leaves.	AnE	[74]
Fragaria ananassa	Strawberry	Increased growth response of strawberry roots.	Seasol	[126]
S. oleracea	Spinach	Increase the yield and quality of spinach.	AnE	[127]
Allium cepa	Onion	AnE improved seed germination and seedling growth and plays an effective role as a priming agent.	AnE	[117]
Phaseolus valgaris	Green Bean	Increased the yield and quality of the bean.	Fylloton	[76]
Glycine max L.	Soybean	Improved seed growth and yield without compromising nutritional quality or nutraceutical content.	Fylloton	[128]
Prunus avium	Cherry	The use of seaweed extract improved the quality of the fruit and its bioactive compounds.	AnE	[129]
Solanum tuberosum	Potato	Enhanced the starch content in potato tubers.	Bio-algeen S90	[130]
Rebutia heliosa	Cactus	Increased plant height, suckers, vegetative and root weights, plant circumference, flower number, flower time, and seed germination significantly.	AnE	[131]
Sulcorebutia canigueralli	Cactus	Increased the height of the plants, the vegetative and radical parts, the number of flowers, the duration of flowering, and the circumference of the plants.	AnE	[131]
Arabidopsis thaliana		Influenced the N uptake mechanism, enhanced the nitrogen use efficiency, and reduced the N application in both plants.	AnE based PSI-362	[132]
Hordeum vulgare	Barley			
Alibertia edulis		Treated seedlings showed the highest N use efficiency, N uptake, and nitrogen use.	AnE	[133]

5. *Ascophyllum nodosum* Extract (AnE) Promote Abiotic Stress Tolerance in Plants

A wide range of organic molecules such as alginates, fucoidan, laminarin, mannitol, polyphenols, and polysaccharides are present in AnE. These compounds could potentially promote stress tolerance and improve plant growth (Table 4) [60].

Table 4. Effects of commercial products and ANE (seaweed extract) derived from *A. nodosum* on different plants under abiotic stress.

Plants		Consequences of Treatment	Product	Reference
Scientific Name	Common Name			
Agrostis stolonifera	Creeping bentgrass	Foliar sprays of AnE and humic acid improved antioxidant activity, promoted growth, and improved drought tolerance.	AnE	[134]
Fragaria	Strawberry	Soil drip application alleviated high soil salinity.	Acadian	[135]
Fragaria	Strawberry	Foliar spray increased tolerance to iron deficiency and significantly increased fruit yield.	Actiwave	[89]
Citrus	–	Foliar or soil flooding under water shortage conditions improved growth and stem–water potential.	Stimplex	[136]
Lactuca sativa	Lettuce	Application of viable extract improved the early development of seedlings (shoot and root) and provided protection from water stress.	Acadian®	[137]
Piper nigrum	Pepper			
Solanum lycopersicum	Tomato			
Petunia	Petunia			
Viola tricolor	Pansy			
Agrostis stolonifera	Creeping bentgrass	Frequent foliar applications are efficient for improving heat stress tolerance and turfgrass performance.	AnE	[138,139]
Citrus sinensis	Sweet orange	Enhanced drought stress tolerance and maintained the growth of seedlings under drought conditions.	Stimplex	[140]
Pinus	Pine	Drenching the roots with extract improved spring root growth and drought stress tolerance.	ANE	[141]
A. thaliana		The lipophilic component of AnE improved freezing tolerance by defending membrane integrity and regulating the expression of freezing stress-responsive genes.	Acadian	[50,142]
Arabidopsis thaliana	-	Increased tolerance to freezing stress.	AnE	[63,143]
Lactuca sativa	Lettuce	Improved plant growth and tolerance to abiotic and biotic stresses.	Super Fifty	[144]
Brassica napus	Oilseed rape			

Table 4. *Cont.*

Plants		Consequences of Treatment	Product	Reference
Scientific Name	**Common Name**			
S. oleracea	Spinach	Enhanced growth, quality, and nutritional value of spinach grown under drought conditions.	AnE	[145]
Ulva lactuca	Sea lettuce	AMPEP decreased ionic liquid-stimulated oxidative stress in *Ulva lactuca*.	Acadian Marine Plant Extract Powder	[146]
Spiraea nipponica	Spirea	Improved drought resistance by producing phytochemicals and antioxidants.	Stimplex	[147]
Pittosporum eugenioides	Lemonwood			
Kappaphycus alvarezii	Elkhorn sea moss	*A. nodosum* was tested on seaweeds and was found to improve growth and inhibit epibiosis in seaweed cultivation.	Acadian marine plant extract powder (AMPEP)	[148]
Kappaphycus alvarezii	Elkhorn sea moss	Increase tolerance to cold stress.	Acadian marine plant extract powder	[149]
Medicago sativa	Alfalfa	A positive effect on alleviating salt stress.	AnE	[150]
A. thaliana		Acclimatize plants to drought stress by enhancing photosynthesis and water use efficacy and controlling stress-responsive gene expression.	Algae	[151]
Solanum lycopersicum	Tomato	Increased tolerance to drought stress.	AnE	[152]
Glycine max	Soybean	Increased tolerance to drought stress.	AnE	[153]
Solanum lycopersicum	Tomato	Plants showed improved accumulation of antioxidants, minerals, and necessary amino acids in fruits and increased water relations in stress treatment and fruit quality traits under salt stress.	Rygex, Super Fifty	[70]
Solanum lycopersicum	Tomato	AnE application stimulated the antioxidant system in Fe-deficient plants, increasing SOD and CAT activities.	AnE	[154]
Glycine max	Soybean	Treatment of plants with Acadian seaweed extract provided effective modification and plant survival under drought conditions.	Acadian	[155]
Paspalum vaginatum	Seashore paspalum	Greater plant growth under prolonged irrigation and salt stress conditions is regulated by osmotic adjustment and the antioxidant defense system.	Stella Maris^{TM}	[15]

Table 4. *Cont.*

Plants		Consequences of Treatment	Product	Reference
Scientific Name	**Common Name**			
Persea americana	Avocado	Application of seaweed diminished the effect of salt stress in the early stages.	AnE	[156]
Phaseolus vulgaris	Green bean	Improved tolerance to drought stress by affecting proline metabolism.	AnE	[157]
P. vulgaris	Green bean	Reduced water stress.	Biostimulant	[158]
Lactuca sativa	Lettuce	ANE application altered the negative effects of potassium deficiency during the growth and storage of processed products.	AnE	[159]
Glycine max	Soybean	Enhanced salinity stress.	AnE	[153]
V. vinifera	Grapevine	Enhanced water stress tolerance in grapes.	AnE	[160]
Solanum lycopersicum	Tomato	Improved heat stress tolerance at the reproductive stage.	AnE	[161]
Corylus	Hazelnut	Protect trees from heat and drought stress during the summer.	AnE	[162]
Solanum lycopersicum	Tomato	Alleviated water stress by lowering the ABA and MDA contents.	ERANTHIS®®	[163]
Solanum lycopersicum	Tomato	Application of the extract modulated amino acid and potassium levels and improved osmotic imbalance and nitrate uptake under saline conditions.	Superfifty	[164]
Citrullus lanatus	Watermelon	Reduced the negative effects of drought stress.	AnE	[165]

Ascophyllum products may assist in stress alteration because of betaines' presence in the seaweed. Betaines serve as osmotic-compatible solutes under stress conditions [5]. *Ascophyllum* also contains mannitol, which facilitates osmotic adaptation [166]. AnE application alleviates drought stress in growing plants [140,141]. Several reports prove that the drought-stressed *Arabidopsis thaliana* plants can sustain strong stomatal conductance, water use efficiency (WUE), and mesophyll conductance after the application of AnE. The pre-treatment of *A. thaliana* plants with seaweed extract induced stomatal closure and changed the gene expression level involved in abscisic acid (ABA) response and antioxidant system pathways [151]. Shukla et al. [153] found that plants treated with AnE had a greater RWC, high stomatal conductance, and antioxidant activity under drought stress. Commercial seaweed extracts significantly improve the drought stress tolerance in grasses [167] crops, vegetables, ornamental plants [137], and container-grown "Hamlin" sweet orange trees [140]. Seaweed AnE has been applied to ornamental plants, such as *Spiraea nipponica* (Snow mound) and *Pittosporum eugenioides* (Variegatum), to increase drought stress tolerance. Under drought conditions, AnE improved the leaf gas exchange parameters, leaf water potential, and the RWC and increased the number of leaves and the dry weight and height of plants in *Spiraea nipponica* and *Pittosporum eugenioides* [147]. According to Elansary et al. [15], seaweed extract increases the turfgrass quality, the photochemical efficiency of leaves, root length, dry weight, and the total carbohydrates, potassium, calcium, and proline contents in supplemented *Paspalum vaginatum* (turfgrass) plants under extended irrigation and salt stress conditions. AnE alleviated the effect of salt stress on the growth and efficiency of *Persea americana* Mill. (avocado) by improving nutrient absorption and showing higher Ca^+ and K^+ ion contents [156]. Used as a biostimulant, seaweed AnE alleviated the water stress effect and improved the yield and nutrient content of *Phaseolus vulgaris* [158]. AnE also improved heat stress tolerance as it enhanced CO_2 assimilation, rate of transpiration, and stomatal conductance and reduced the leaf temperature [168].

The application of alkaline AnE, Acadian (a commercial product), in drought-stressed *Glycine max* L. (soybean) altered the expression of *GmCYP707A1a* and *GmCYP707A3b*, genes that are implicated in the catabolism of ABA [153]. It was also noticed that the AnE-treated plants changed their expression of the "*GmRD22*, *GmRD20*, *GmDREB1B*, *GmERD1*, *GmNFYA3*, *FIB1a*, *GmPIP1b*, *GmGST*, *GmBIP*, and *GmTp55*" stress-responsive genes [153]. AnE improved the expression of diverse miRNAs related to nutrient uptake and enhanced salt stress tolerance in *A. thaliana* [169]. Bioactive organic compounds of AnE have been reported to regulate the union and communication of different transcription factors such as "DREB/CBF, COR47, NF-YA, COR15A, AGF2, CCA1, and LHY1," which improve stress tolerance in plants [170,171]. Rayirath et al. [50] observed that AnE application in *A. thaliana* stimulated the cold-responsive genes "*COR15A*, *RD29A*, and *CBF3*" and improved the plant's cold stress tolerance. Stimplex, an AnE-based commercial product, upregulated 635 genes and downregulated 456 genes and strongly influenced the expression of genes involved in CO_2 fixation, glutathione, phenyl propanoid, stilbenoid metabolism, and plant–pathogen interactions [172]. In AnE, the upregulation of defense pathway genes such as *PinII* (jasmonic acid), *Etr1* (ethylene), and *PR-1a* (salicylic acid) enhanced the auxin-responsive proteins such as SAUR21 and indole-3-acetic acid-amido synthetase in AnE-treated tomatoes [172]. It was observed that the AnE alleviated the effect of heat stress by activating heat shock proteins (HPS), which mainly influenced the AtHSP17 family, particularly AtHPS17.4 and AtHPS17.6A and B, confirming the most significant changes [173].

6. *Ascophyllum nodosum* Extract (AnE) Reduced Oxidative Stress

Stress causes the production of reactive oxygen species (ROS), which damage the structures of proteins, lipids, carbohydrates, and DNA, impairing plant growth and development [174]. Under stress, enzymatic and non-enzymatic mechanisms such as superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT), glutathione reductase (GR), and glutathione peroxidase (GPX) play critical roles in ROS scavenging. The application of AnE to bean (*P. vulgaris*) improved drought tolerance by reducing ROS, inducing lipid peroxidation (MDA content), improving CAT activity, and enhancing proline biosynthesis [157]. AnE increases flavonoid content, and flavonoids protect the roundworm *Caenorhabditis elegans* from oxidative and heat stress [175]. It was found that there was an increase in root growth of 58% and enhanced freezing tolerance in *A. thaliana* while using *A. nodosum* extract [63,143]. Burchett et al. [176] observed that using AnE increased barley's winter toughness and cold tolerance. It was reported that AnE improved the leaf water relations, maintained the cell turgor pressure, and enhanced the growth of spinach by reducing stomatal limitations under drought stress conditions [145]. The expression of glutathione-S transferase was elicited by bioactive substances of AnE, resulting in the reduction of salinity-induced oxidative damage in *A. thaliana* [177]. AnE reduces oxidative stress damage by altering the expression of miRNAs and targeting the copper–zinc SOD1 gene, AtCSD1, which is essential in superoxide radical detoxification [169]. Increases in the activities of antioxidant enzymes such as superoxide dismutase, catalase, ascorbate peroxidase, peroxidase, and reductase nitrate, as well as proline concentration, were observed following AnE concentration treatment [168]. The spray application of 0.3% AnE enhanced the chlorophyll content and the activities of anthocyanin, proline, and antioxidant enzymes [172].

7. *Ascophyllum nodosum* Extract (AnE) Induced Defense Enzymatic Activity

A. nodosum contains laminarans with low and high molecular weights. Laminarans are intracellular water-soluble β-D-(1--3) glucan and β-D-(1--3) oligoglucans known as elicitors of phytoalexins. Laminarans are competent in eliciting D-glycanase activities such as "laminaranase, α-amylase" in *Rubus fruticosus* suspended cell cultures [178]. Applying seaweed extract induced peroxidase activity in the *Capsicum annuum* plant [179]. Laminaran and fucoidan exhibit a sample array of elicitor and growth-development activities [45]. Carrot and cucumber plants accumulated high levels of defense-related gene transcripts, received higher activity from defense-related enzymes, and showed increased levels of phenols when treated with AnE. Seaweed extract significantly increased chitinase, glucanase, peroxidase (PO), polyphenol oxidase (PPO), phenylalanine ammonia-lyase (PAL), and lipoxygenase enzyme activities [16–18]. The AnE treatment of postharvest plums increased polygalacturonase (PG) activity [180].

8. *Ascophyllum nodosum* Extract (AnE) Improves Disease Resistance in Plants

In recent years, environmental conditions and exhaustive agricultural practices have increased the occurrences of highly infectious diseases in plants, reducing crop productivity [181]. Due to their effectiveness in controlling microbial infections in crop plants, the use of chemical-based fungicides in cultivation has become limited over time. As a result, researchers must explore alternatives to improve crop health that involve priming the defense systems of plants to enhance their resistance levels against microbial or pathogenic infections. Modern-day crop protection strategies and signaling biomolecules or elicitors are promising biological and eco-friendly practices [182]. Bioactive organic molecules present in AnE elicit defense reactions against the pathogens that cause plant diseases [60]. AnE has been formerly reported to decrease the severity of pathogens, including viruses [183], bacteria [184], and fungi [185].

Seaweed extracts are used in plants to protect them from pathogenic infections, either directly or indirectly. *A. nodosum* has the potential to act as a protectant to control plant diseases. Both foliar (spray) and soil applications of seaweed extract were found to be effective in reducing foliar and soil-borne pathogens against a variety of crops [16,17]. Cucumber plants sprayed with an *A. nodosum* commercial seaweed extract (Stimplex^{TM}) showed significant reductions in fungal pathogen inoculation levels with *Alternaria cucumerinum*, *Didymella applanata*, *Fusarium oxysporum*, and *Botrytis cinerea* [17]. Comparable results were obtained when carrot plants treated with AnE demonstrated prominently lower rates of infection from *Alternaria radicina* and *B. cinerea* fungi compared with control plants [16]. In *Capsicum annuum*, treatment with AnE increased foliar resistance to *Phytophthora capsici* [179]. The application of AnE to greenhouse cucumber plants revealed a considerable decline in damping-off disease caused by *Phytophthora melonis* [18]. The use of a commercial AnE significantly suppressed the infection of broccoli by *Plasmodiophora brassicae* [186]. Seaweed-supplemented *A. thaliana* plants elicited defense responses against the necrotrophic pathogen *Sclerotinia sclerotiorum,* and jasmonic-acid-dependent systemic resistance in the leaves was induced against the hemibiotrophic pathogen *Pseudomonas syringae* [187]. Radwan et al. [188] observed the consequences of algae (*A. nodosum*) on the root-nematode *M. incognita* in a tomato crop, finding a reduced number of root galls and a better growth of infected plants. Drenching *Brassica oleracea* with AnE stimulated microbes more than *Pythium ultimum*, resulting in a lower frequency of damping-off disease in seedlings [189]. In tropical tomato plants, using AnE via foliar application increased disease suppression frequency caused by *Alternaria solani* and *Xanthomonas campteris* and subsequently increased the fruit yield [190]. Ajah [191] found that *A. nodosum* possesses an antifungal activity against *Candida albicans.* Ali et al. [14] discovered that a 0.5% concentration of seaweed extract reduced the severity of bacterial spot disease and the early blight of tomato and sweet pepper in tropical conditions as an AnE biostimulant induced plant growth and a defense mechanism against foliar diseases caused by *X. campestris* pv. *vesicatoria* and *A. solani* [14]. The rigorousness of *Fusarium* head blight, which is caused by *Fusarium graminearum* (Gibberella zeae), was decreased by the application of AnE to *Triticum aestivum* (wheat) [89]. Similarly, at a concentration of 0.4 mL/L, AnE reduced brown rot disease in the plum fruits by 50%, a disease which is caused by members of the *Monilinia* genus: *M. fructicola, M. laxa*, and *M. frutigena* [180]. Paiva et al. [192] reported that at a concentration of 40 mL/L of AnE, the mycelia growth of the fungus *Rhizopus stolonifer* was significantly reduced, ultimately decreasing the incidence of soft rot by up to 22.3% in postharvest *Fragaria ananassa* (strawberry). Islam et al. [193] reported that the pretreatment of *A. thaliana* roots with alkaline AnE reduced the extent of *Phytophthora cinnamomi* colonization.

9. *Ascophyllum nodosum* Extract (AnE) Has Antimicrobial Activity

A. nodosum has anti-microbial activity: it reduces the growth of *Escherichia coli, Streptococci,* and *Lactobacilli* [194]. The soil application of AnE enhanced the antifungal activities of *Calibrachoa × hybrida* against *Aspergillus flavus*, *Candida albicans*, *Penicillium funiculosum*, and *Penicillium ochrochloron* [64]. *A. nodosum* has anti-microbial activity against pathogens such as *E. coli*, *Murococcus pyogenes* var. *aureus*, *Streptococcus pyogenes*, and *Salmonella typhosa* [195]. Laminarin shows antibacterial activity, and it inhibits the activities of *E. coli, Listeria monocytogenes*, *Salmonella typhimurium*, and *Staphylococcus aureus* [196]. Ascophyllan, an organic compound present in AnE, showed antibacterial [197] and antiviral [198] activities. The acetone extract of *A. nodosum* demonstrated significant antibacterial activity and was more effective against Gram-positive bacteria such as *Micrococcus luteus* and *Staphylococcus aureus* than against Gram-negative bacteria such as *E. coli* and *Enterococcus aerogenes* [199]. In another study, Frazzini et al. [200] reported that AnE inhibited the activity of *E. coli* more significantly in comparison to other seaweed extracts.

10. *Ascophyllum nodosum* Extract (AnE) Stimulates the Production and Antioxidant Activities of Secondary Metabolites

Secondary metabolites are phenolic compounds that play a vital role in plants as they have antioxidant potential. Flavonoids comprise an essential group of polyphenolic compounds in plants and demonstrate more potent antioxidant activities [201]. The use of the commercial product "Tasco-Forage", a feed supplement derived from dried *A. nodosum*, increased the activities of the antioxidant enzymes SOD, GR, and APX and non-enzymatic antioxidants such as ascorbic acid, α-tocopherol, and β-carotene, in forage grasses and turf [202]. *A. nodosum* (AnE) stimulates flavonoid synthesis and increases the total phenolic content (TPC), total flavonoid contents (TFCs), and total antioxidant activities in *Spinacia oleracea*, thus enhancing its nutritional value [175]. In *A. nodosum*-treated plants of *Calibrachoa*, Elansary et al. [64] found enhanced phytochemical compositions. Similarly, the regular application of seaweed can potentially improve phytochemicals and significantly increase the TPC and TFC in cabbage [103]. Frioni et al. [125] observed that the application of seaweed extract significantly increased anthocyanin in the three most crucial grapevine cultivars. *Spiraea nipponica* and *Pittosporum eugenioides* showed higher phenolic and proline concentrations and flavonoid contents under drought stress when treated with AnE [147]. Under the conditions of prolonged irrigation gaps and salt stress, seaweed-treated turfgrass increased CAT, SOD, and APX activities and non-enzymatic antioxidants and also reduced lipid peroxidation [15]. Phlorotannins are central antioxidant molecules in the hydroalcoholic extracts of *Ascophyllum* [203]. Phlorotannins are important polyphenols for the biological activity of an organism [37–39]. Polymeric phlorotannins inhibit enzymes such as phospholipase, lipoxygenase, cyclooxygenase-1 [204] and hyaluronidase [205]. Phlorotannins isolated from *A. nodosum* with molecular weights ranging from 30 to 100 kDa inhibited α-amylase and trypsin in a noncompetitive manner [206]. Fucoidan from *A. nodosum* inhibited α-amylase and α-glucosidase enzymes effectively [207]. Chrysargyris et al. [159] observed that the foliar application of 1% biopost-AG200 biweekly for up to five weeks increased the comparative growth and postharvest quality of lettuce in a potassium-deficient condition by enhancing antioxidant activity. Applying *Ascophyllum nodosum* to postharvest plums increased the total phenolic content (TPC) in “Irati” plums [180]. The treatment of broccoli florets with *A. nodosum* and amino acid-based filtrate increased the TPC, sinapic acid, and quercetin levels [208]. AnE-treated okra plants showed significantly increased carotenoid contents under drought stress [172].

11. *Ascophyllum nodosum* Extract (AnE) Regulates the Biosynthesis of Growth Hormones in Plants

Growth hormones, also known as “phytohormones”, are low-molecular-weight compounds formed in very minute quantities. They regulate several physiological, morphological, and growth-developmental processes in plants [209]. Auxins, gibberellins, cytokinins, abscisic acid, ethylene, jasmonic acid, salicylic acid, brassinosteroids, and strigolactones are the major plant hormones [210]. Growth and development-supporting results of AnE in plants were recognized due to the different types of “phytohormone-like substances” present in *A. nodosum* [5,22,60,166]. Khan et al. [5] reported about a dry extract concentration of about 50 mg/g of indole-acetic acid (IAA) in *A. nodosum*. According to the results presented by Castaings et al. [211] and Krouk et al. [212], AnE upregulates the expression of the nitrate transporter gene (*NRT1.1*), which induces nitrogen (N_2) sensing and the transport of auxins; consequently, the development of lateral roots improved, and nitrogen assimilation was enhanced. The findings of Rayorath et al. [63] proposed that the organic fraction of AnE regulates the auxins’ responsive promoter elements (*AuxRE)*, which help in the regulation of the auxin activity of *A. thaliana*. At a concentration of 0.2%, the foliar application of neutral and alkaline-based AnE upregulated the expression of *SAUR33*, *SAUR59*, and *SAUR71*, whereas *SAUR1* and *SAUR50* were downregulated [213]. Small, auxin-induced RNAs, also called small auxin-up RNAs (SAURs), play a significant role in growth, physiological, morphological, and developmental procedures in plants [214]. A commercial product of AnE, Seamac, induced maximum callus formation in soybean, which indicates that AnE has cytokinin activity [215]. The root application of alkaline AnE triggered the cytokinin-responsive promoter *ARR5* [209]. According to Wally et al. [209], AnE stimulated the expression of the *IPT3, IPT4*, and *IPT5* genes, which regulate the activities of isopentenyl transferases (IPTs), which are involved in the biosynthesis of cytokinin in *A. thaliana*. Similarly, AnE stimulated the regulation of the gene involved in the synthesis of gibberellic acid (GA) when applied to roots [209]. The expressions of gibberellic-acid-responsive genes, *GASA1* and *GASA4*, in *A. thaliana* were regulated by the foliar spray of AnE at a concentration of 0.2% [213].

12. *Ascophyllum nodosum* Extract (AnE) Improves the Soil Health and Rhizospheric Microbial Population

Soil health is the capability of the soil to function as an essential, living ecosystem that maintains animals, plants, and humans. The alginic acid and poly-uronides in AnE improve soil water retention, crumb organization, aeration, and capillary action, stimulating plant root systems, increasing soil microbial activity, and improving mineral accessibility and assimilation [216]. They also increase the movement of carbohydrates and other organic compounds inside the plant [217]. A commercial seaweed extract from *A. nodosum* applied to the roots of hydroponically grown *Hordeum vulgare* increased plant growth by 56–63% over the control [99]. It was found that the bioactive substances and organic sub-fractions reported in *A. nodosum* affected the rhizobia–legume signaling process, resulting in more functional, healthy nodules and enhancing the growth of the *Medicago sativa* plant [26]. A commercial product of AnE, Active, was used as a natural iron chelator, which increased the rhizospheric microbial population and productivity in the strawberry crop [218]. *A. nodosum’s* commercial product Acadian increased the number of microbes in the rhizosphere of a ten-day-old alfalfa plant prior to inoculation with *Sinorhizobium meliloti* [26]. *A. nodosum* increased soil microbial activity in treated strawberries and carrot roots, and the alginates in AnE improved the soil’s physical condition by binding with metal ions in the soil and forming high-molecular-weight polymers that took up moisture from the soil and increased soil aeration and water-holding capacity [5,166,218,219] (Table 5).

Table 5. Effects of commercial products and *Ascophyllum nodosum* seaweed extract (AnE) derived from different plants under biotic stress.

Plants		Consequences of Treatment	Disease	Product	Reference
Scientific Name	**Common Name**				
Fragaria × ananassa	Strawberry	Diminished the population of two-spotted red spider mites *Tetranychus urticae* on plants treated with product.	Two-spotted red spider mite	Maxicrop	[220]
Arabidopsis		Reduced the number of females of *Meloidogyne javanica.*	Root-knot	Maxicrop	[221]
Daucus carota	Carrot	Foliar sprays that control *Alternaria radicina* and *Botrytis cinerea* infections, induced the manifestation of defense-related proteins or genes.	Black rot; Botrytis blight	AnE	[16]
Solanum tuberosum	Potato	Soil treatment for potato cyst nematodes (PCN), control, and nematicide was better than seaweed extract.	-	Algifol	[222]
Kappaphycus alvarezii	Elkhorn sea moss	*Polysiphonia subtilissima* reduced the growth of the epiphyte.	Ice–ice; goose bumps		[223]
Cucumis sativus	Cucumber	Reduction in *Phytophthora melonis* that caused damping-off disease.	Damping-off	AnE	[18]
Solanum tuberosum	Potato	Foliar-spray-controlled soil-borne Verticillium wilt via *Verticillium* spp.	Verticillium wilt	AnE	[224]
Agrostis stolonifera	Creeping bentgrass	Foliar disease (*Sclerotinia homeocarpa*) is notably decreased by seaweed with humic acid treatment at concentrations of 16 mg/m^2 and 38 mg/m^2, respectively.	Dollar spot	AnE	[102]
A. thaliana		AnE-application-induced resistance against *Pseudomonas syringae* and *Sclerotinia sclerotiorum* pathogens.	Bacterial speck; stem rot	AnE	[187]
Cucumis sativus	Cucumber	Plants treated with seaweed products developed a significant decline in the occurrence of disease from fungal pathogens, *viz.*, *Alternaria cucumerinum*, *Botrytis coinerea*, *Didymella applanata*, and *Fusarium oxysporum.*	Alternaria blight. Botrytis blight, Fusarium root; stem rot; Gummy stem blight	Stimplex™	[17]
Capsicum annuum	Pepper	Incorporation caused a delayed and reduced incidence of *Verticillium* wilt.	Verticillium wilt	AnE	[225]
Brassica oleracea var. italic	Broccoli	Seaweed extract significantly suppressed the infection of the plant by *Plasmodiophora brassicae.*	Clubroot	AnE	[186]
S. lycopersicum	Tomato	Produced the expression of defense-related genes or proteins against the *Phytophthora capsici* pathogen.	Damping-off	Dalgin	[19]
Kappaphycus alvarezii	Elkhorn sea moss	*A. nodosum*, tested on seaweeds, showed promising results in growth improvement and epibiosis prevention during the cultivation of seaweed.	--	Acadian marine plant extract powder (AMPEP)	[148]

Table 5. *Cont.*

Plants		Consequences of Treatment	Disease	Product	Reference
Scientific Name	Common Name				
S. lycopersicum	Tomato	Reduced number of root galls produced by the root nematode *Meloidogyne incognita.*	Root gall	Algaefol	[188]
S. lycopersicum	Tomato	In plants, reduced incidences of diseases caused by *Alternaria solani* and *X. campestris pv vesicatoria* through ethylene upregulation or the JA pathway.	Alternaria blight; bacterial leaf spot	AnE	[73]
K. alvarezii	Elkhorn sea moss	Decreased the biotic stress produced by endophyte *Neosiphonia apiculate.*	Ice–ice	AMPEP	[226]
A. thaliana		Constrained the growth of bacterial pathogens such as *Pseudomonas syringae* and *Xanthomonas campestris* by stimulating the expression of WRKY30, PR-1, and CYP71A12 genes.	Cankers; Black rot	Stella Maris™	[227]
Triticum aestivum	Wheat	Triggers defense mechanisms and confers protection against *Zymoseptoria tritici*	Septoria tritici blotch	Dalgin active	[228]
Pisum sativum	Pea	ANE and chitosan-induced transcripts of the JA- and SA-dependent plant defense genes and a decrease in powdery mildew infection caused by *Erisyphe pisi.*	Powdery mildew	AnE and chitosan	[229]
Prunus salicina	Plum	Diminished the disease caused by *M. fructicola*, *M. laxa*, and *M. frutigena* in the plum fruits up to 50%.	The brown rot	AnE	[180]
Quercus robur	Oak	Infection by *Erysiphe alphitoides* diminished in plants treated with AnE.	powdery mildew	AnE	[230]
Pisum sativum	Pea	AnE at 3% has a promising and improved biocontrol activity against *Rhizoctonia solani.*	Rhizoctonia root rot	AnE	[231]

13. Conclusions

The world's population is increasing every day, and food demands are also increasing. Therefore, to maintain the increasing population, agriculture must be supplementary and more fruitful than ever. In modern agricultural practices, the cultivation of crops is dependent on synthetic fertilizers. To combat abiotic and biotic stresses and improve plant health, chemical fertilizers and pesticides are constantly used. To decrease dependence on elementary fertilizers and pesticides, it is essential to include natural resources and compounds in agricultural practices that promote the growth of crop plants under apparently poor growing conditions without adverse side effects on the surrounding ecosystems.

This review emphasized the significant role of AnE in various crops, vegetables, fruits, pulses, etc. The application of AnE significantly improved the germination rate, increased the growth of lateral roots, enhanced water and nutrient use efficiencies, increased antioxidant activity, increased phenolic and flavonoid contents, increased chlorophyll and nutrient contents, alleviated the effects of abiotic as well as biotic stresses in different crop plants, and even improved the postharvest quality of different fruits and vegetables. The applications of *A. nodosum*-based commercial products as plant biostimulants are diverse, as they promote plant growth while reducing the negative effects of biotic and abiotic stresses. In addition, AnE has been observed to perform as a biocontrol mediator and improve soil health and the rhizospheric bacterial population. Although the present situation for AnE as a biostimulator in agriculture shows potential and affects forward progress toward achieving goal of sustainability, it is essential to thoroughly focus the research on the saturation of these commercial AnE extracts in agricultural practices. Further identification of the mechanism of action of AnE on the plants will enhance the extension of AnE applications into many other fields of agriculture.

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References

1. Zodape, S.T. Seaweeds as a Biofertilizer. *J. Sci. Ind. Res.* **2001**, *60*, 378–382.
2. European Union. Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 Laying Down Rules on the Making Available on the Market of EU Fertilising Products and Amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and Repealing Regulation (EC) No 2003/2003. 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri\protect$\relax\protect{\begingroup1\endgroup\@@over4}$OJ:L:2019:170:FULL&from\protect$\relax\protect{\begingroup1\endgroup\@@over4}$EN (accessed on 4 October 2020).
3. Smit, A.J. Medicinal and pharmaceutical uses of seaweed natural products: A review. *J. Appl. Phycol.* **2004**, *16*, 245–262. [CrossRef]
4. Blunt, J.W.; Copp, B.R.; Hu, W.P.; Munro, M.H.; Northcote, P.T.; Prinsep, M.R. Marine natural products. *Nat. Prod. Rep.* **2008**, *25*, 35–94. [CrossRef]
5. Khan, W.; Rayirath, U.P.; Subramanian, S.; Jithesh, M.N.; Rayorath, P.; Hodges, D.M.; Critchley, A.T.; Craigie, J.S.; Norrie, J.; Prithiviraj, B. Seaweed Extracts as Biostimulants of Plant Growth and Development. *J. Plant Growth Regul.* **2009**, *28*, 386–399. [CrossRef]
6. Francini, A.; Sebastiani, L. Abiotic stress effects on performance of horticultural crops. *Horticulturae* **2019**, *5*, 67. [CrossRef]
7. Basu, S.; Ramegowda, V.; Kumar, A.; Pereira, A. Plant Adaptation to Drought Stress. *F1000Research* **2016**, *5*, 1554. [CrossRef] [PubMed]
8. Fahad, S.; Hussain, S.; Matloob, A.; Khan, F.A.; Khaliq, A.; Saud, S.; Hassan, S.; Shan, D.; Khan, F.; Ullah, N.; et al. Phytohormones and plant responses to salinity stress: A review. *Plant Growth Regul.* **2015**, *75*, 391–404. [CrossRef]
9. Ronga, D.; Biazzi, E.; Parati, K.; Carminati, D.; Carminati, E.; Tava, A. Microalgal biostimulants and biofertilisers in crop productions. *Agronomy* **2019**, *9*, 192. [CrossRef]
10. De Saeger, J.; Van Praet, S.; Vereecke, D.; Park, J.; Jacques, S.; Han, T.; Depuydt, S. Toward the molecular understanding of the action mechanism of *Ascophyllum nodosum* extracts on plants. *J. Appl. Phycol.* **2020**, *32*, 573–597. [CrossRef]
11. Arioli, T.; Hepworth, G.; Farnsworth, B. Effect of seaweed extract application on sugarcane production. *Proc. Aust. Soc. Sugar Cane Technol.* **2020**, *42*, 393–396.
12. Hussain, H.I.; Kasinadhuni, N.; Arioli, T. The effect of seaweed extract on tomato plant growth, productivity and soil. *J. Appl. Phycol.* **2021**, *33*, 1305–1314. [CrossRef]
13. Renaut, S.; Masse, J.; Norrie, J.; Blal, B.; Hijri, M. A commercial seaweed extract structured microbial communities associated with tomato and pepper roots and significantly increased crop yield. *Microb. Biotechnol.* **2019**, *12*, 1346–1358. [CrossRef]
14. Ali, O.; Ramsubhag, A.; Jayaraman, J. Biostimulatory activities of *Ascophyllum nodosum* extract in tomato and Sweet pepper crops in a tropical environment. *PLoS ONE* **2019**, *14*, e0216710. [CrossRef]
15. Elansary, H.O.; Yessoufou, K.; Abdel-Hamid, A.M.E.; El-Esawi, M.A.; Ali, H.M.; Elshikh, M.S. Seaweed extracts enhance Salam turfgrass performance during prolonged irrigation intervals and saline shock. *Front. Plant Sci.* **2017**, *8*, 830. [CrossRef]
16. Jayaraj, J.; Wan, A.; Rahman, M.; Punja, Z.K. Seaweed extract reduces foliar fungal diseases on carrot. *Crop Prot.* **2008**, *27*, 1360–1366. [CrossRef]
17. Jayaraman, J.; Norrie, J.; Punja, Z.K. Commercial extract from the brown seaweed *Ascophyllum nodosum* reduces fungal diseases in greenhouse cucumber. *J. Appl. Phycol.* **2011**, *23*, 353–361. [CrossRef]

18. Abkhoo, J.; Sabbagh, S.K. Control of *Phytophthora melonis* damping-off, induction of defence responses, and gene expression of cucumber treated with a commercial extract from *Ascophyllum nodosum*. *J. Appl. Phycol* **2016**, *28*, 1333–1342. [CrossRef]
19. Panjehkeh, N.; Abkhoo, J. Influence of marine brown alga extract (*Dalgin*) on damping-off tolerance of tomato. *J. Mater. Environ. Sci.* **2016**, *7*, 2369–2374.
20. Sathya, B.; Indu, H.; Seenivasan, R.; Geetha, S. Influence of seaweed liquid fertilizer on the growth and biochemical composition of legume crop, *Cajanus cajan* (L.) Mill sp. *J. Phytol.* **2010**, *2*, 50–63.
21. Fornes, F.; Sánchez-Perales, M.; Guardiola, J.L. Effect of a Seaweed Extract on the Productivity of 'de Nules' Clementine Mandarin and Navelina Orange. *Bot. Mar.* **2002**, *45*, 486–489. [CrossRef]
22. Craigie, J.S. Seaweed extracts stimuli in plant science and agriculture. *J. Appl. Phycol.* **2011**, *23*, 371–393. [CrossRef]
23. Verkleij, F.N. Seaweed extracts in agriculture and horticulture: A review. *Biol. Agric. Hortic.* **1992**, *8*, 309–324. [CrossRef]
24. Van Oosten, M.J.; Pepe, O.; De Pascale, S.; Silletti, S.; Maggio, A. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. *Chem. Biol. Technol. Agric.* **2017**, *4*, 5. [CrossRef]
25. Shukla, P.S.; Mantin, E.G.; Adil, M.; Bajpai, S.; Critchley, A.T.; Prithiviraj, B. *Ascophyllum nodosum* Based Biostimulants: Sustainable Applications in Agriculture for the Stimulation of Plant Growth, Stress Tolerance, and Disease Management. *Front. Plant Sci.* **2019**, *10*, 655. [CrossRef] [PubMed]
26. Khan, A.S.; Ahmad, B.; Jaskani, M.J.; Ahmad, R.; Malik, A.U. Foliar application of mixture of amino acids and seaweed (*Ascophylum. nodosum*) extract improve growth and physicochemical properties of grapes. *Int. J. Agric. Biol.* **2012**, *14*, 383–388.
27. Cardozo, K.H.; Guaratini, T.; Barros, M.P.; Falcão, V.R.; Tonon, A.P.; Lopes, N.P.; Pinto, E. Metabolites from algae with economical impact. *Comp. Biochem. Physiol. Part C Toxicol. Pharmacol.* **2007**, *146*, 60–78. [CrossRef]
28. Norrie, J. Seaweed extract research and applications in agriculture. *Agro. Food Ind. Hi-Tech.* **1999**, *10*, 15–18.
29. Connan, S.; Goulard, F.; Stiger, V.; Deslandes, E.; Gall, E.A. Interspecific and temporal variation in phlorotannin levels in an assemblage of brown algae. *Bot. Mar.* **2004**, *47*, 410–416. [CrossRef]
30. Chater, P.I.; Wilcox, M.; Cherry, P.; Herford, A.; Mustar, S.; Wheater, H.; Brownlee, I.; Seal, C.; Pearson, J. Inhibitory activity of extracts of Hebridean brown seaweeds on lipase activity. *J. Appl. Phycol.* **2016**, *28*, 1303–1313. [CrossRef]
31. Chevolot, L.; Foucault, A.; Chaubet, F.; Kervarec, N.; Sinquin, C.; Fisher, A.M.; Boisson-Vidal, C. Further data on the structure of brown seaweed fucans: Relationships with anticoagulant activity. *Carbohydr. Res.* **1999**, *319*, 154–165. [CrossRef]
32. Chevolot, L.; Mulloy, B.; Ratiskol, J.; Foucault, A.; Colliec-Jouault, S. A disaccharide repeat unit is the major structure in fucoidans from two species of brown algae. *Carbohydr. Res.* **2001**, *330*, 529–535. [CrossRef] [PubMed]
33. Cumashi, A.; Ushakova, N.A.; Preobrazhenskaya, M.E.; D'Incecco, A.; Piccoli, A.; Totani, L.; Tinari, N.; Morozevich, G.E.; Berman, A.E.; Bilan, M.I.; et al. A comparative study of the anti-inflammatory, anticoagulant, antiangiogenic, and antiadhesive activities of nine different fucoidans from brown seaweeds. *Glycobio* **2007**, *17*, 541–552. [CrossRef] [PubMed]
34. Jiang, Z.; Okimura, T.; Yamaguchi, K.; Oda, T. The potent activity of sulfated polysaccharide, ascophyllan, isolated from *Ascophyllum nodosum* to induce nitric oxide and cytokine production from mouse macrophage RAW264. 7 cells: Comparison between ascophyllan and fucoidan. *Nitric Oxide* **2011**, *25*, 407–415. [CrossRef] [PubMed]
35. Wang, Y.; Jiang, Z.; Kim, D.; Ueno, M.; Okimura, T.; Yamaguchi, K.; Oda, T. Stimulatory effect of the sulfated polysaccharide ascophyllan on the respiratory burst in RAW264. 7 macrophages. *Int. J. Biol. Macromol.* **2013**, *52*, 164–169. [CrossRef]
36. Heffernan, N.; Brunton, N.P.; FitzGerald, R.J.; Smyth, T.J. Profiling of the molecular weight and structural isomer abundance of macroalgae-derived phlorotannins. *Mar. Drugs* **2015**, *13*, 509–528. [CrossRef]
37. Bocanegra, A.; Bastida, S.; Benedi, J.; Rodenas, S.; Sanchez-Muniz, F.J. Characteristics and nutritional and cardiovascular-health properties of seaweeds. *J. Med. Food* **2009**, *12*, 236–258. [CrossRef]
38. Wijesekara, I.; Yoon, N.Y.; Kim, S.-K. Phlorotannins from *Ecklonia cava* (Phaeophyceae): Biological activities and potential health benefits. *Biofactors* **2010**, *36*, 408–414. [CrossRef]
39. Lee, S.H.; Jeon, Y.J. Anti-diabetic effects of brown algae derived phlorotannins, marine polyphenols through diverse mechanisms. *Fitoterapia* **2013**, *86*, 129–136. [CrossRef]
40. Foley, S.A.; Szegezdi, E.; Mulloy, B.; Samali, A.; Tuohy, M.G. An unfractionated fucoidan from *Ascophyllum nodosum*: Extraction, characterization, and apoptotic effects in vitro. *J. Nat. Prod.* **2011**, *74*, 1851–1861. [CrossRef]
41. Kloareg, B.; Demarty, M.; Mabeau, S. Polyanionic characteristics of purified sulphated homofucans from brown algae. *Int. J. Biol. Macromol.* **1986**, *8*, 380–386. [CrossRef]
42. Nardella, A.; Chaubet, F.; Boisson-Vidal, C.; Blondin, C.; Durand, P.; Jozefonvicz, J. Anticoagulant low molecular weight fucans produced by radical process and ion exchange chromatography of high molecular weight fucans extracted from the brown seaweed *Ascophyllum nodosum*. *Carbohydr. Res.* **1996**, *289*, 201–208. [CrossRef] [PubMed]
43. Daniel, R.; Berteau, O.; Jozefonvicz, J.; Goasdoue, N. Degradation of algal (*Ascophyllum. nodosum*) fucoidan by an enzymatic activity contained in digestive glands of the marine mollusc *Pecten maximus*. *Carbohydr. Res.* **1999**, *322*, 291–297. [CrossRef]
44. Haroun-Bouhedja, F.; Ellouali, M.; Sinquin, C.; Boisson-Vidal, C. Relationship between sulfate groups and biological activities of fucans. *Thromb. Res.* **2000**, *100*, 453–459. [CrossRef] [PubMed]
45. Rioux, L.E.; Turgeon, S.L.; Beaulieu, M. Characterization of polysac-charides extracted from brown seaweeds. *Carbohydr. Polym.* **2007**, *69*, 530–537. [CrossRef]
46. Baardseth, E. *Synopsis of Biological Data on Knobbed Wrack Ascophyllum nodosum (Linnaeus) Le Jolis*; FAO Fisheries: Synopsis; Food and Agriculture Organization of the United Nations: Rome, Italy, 1970; Volume 38, pp. 1–38.

47. Indergaard, M.; Minsaas, J. Animal and human nutrition. In *Seaweed Resources in Europe: Uses and Potential*; Guiry, M.D., Blunden, G., Eds.; John Wiley & Sons: Chichester, UK, 1991; pp. 21–64.
48. DaSilva, E.; Jensen, A. Benthic marine and blue-green algal species as a source of choline. *J. Sci. Food Agric.* **1973**, *24*, 855–861. [CrossRef] [PubMed]
49. Blunden, G.; Currie, M.; Mathe, J.; Hohmann, J.; Critchley, A. Variations in betaine yields from marine algal species commonly used in the preparation of seaweed extracts used in agriculture. *Phycologist* **2009**, *76*, 14.
50. Rayirath, P.; Benkel, B.; Mark Hodges, D.; Allan-Wojtas, P.; MacKinnon, S.; Critchley, A.T.; Prithiviraj, B. Lipophilic components of the brown seaweed, *Ascophyllum nodosum*, enhance freezing tolerance in *Arabidopsis thaliana*. *Planta* **2009**, *230*, 135–147. [CrossRef]
51. Audibert, L.; Fauchon, M.; Blanc, N.; Hauchard, D.; Ar Gall, E. Phenolic compounds in the brown seaweed *Ascophyllum. nodosum*: Distribution and radical-scavenging activities. *Phytochem. Anal.* **2010**, *21*, 399–405. [CrossRef]
52. Apostolidis, E.; Lee, C.M. In vitro potential of *Ascophyllum nodosum* phenolic antioxidant-mediated α-glucosidase and α-amylase inhibition. *J. Food Sci.* **2010**, *75*, H97–H102. [CrossRef]
53. Hartung, J.; Brücher, O.; Hach, D.; Schulz, H.; Vilter, H.; Ruick, G. Bromoperoxidase activity and vanadium level of the brown alga *Ascophyllum nodosum*. *Phytochemistry* **2008**, *69*, 2826–2830. [CrossRef]
54. Tutour, B.; Benslimane, F.; Gouleau, M.P.; Gouygou, J.P.; Saadan, B.; Quemeneur, F. Antioxidant and pro-oxidant activities of the brown algae, *Laminaria digitata*, *Himanthalia elongata*, *Fucus vesiculosus*, *Fucus serratus* and *Ascophyllum nodosum*. *J. Appl. Phycol.* **1998**, *10*, 121–129. [CrossRef]
55. Moen, E.; Horn, S.; Østgaard, K. Biological degradation of Ascophyllum nodosum. *J. Appl. Phycol.* **1997**, *9*, 347–357. [CrossRef]
56. Van Ginneken, V.J.; Helsper, J.P.; Visser, W.; Van Keulen, H.; Brandenburg, W.A. Polyunsaturated fatty acids in various macroalgal species from north Atlantic and tropical seas. *Lipids Health Dis.* **2011**, *10*, 104. [CrossRef] [PubMed]
57. Kundel, M.; Thorenz, U.R.; Petersen, J.H.; Huang, R.J.; Bings, N.H.; Hoffmann, T. Application of mass spectrometric techniques for the trace analysis of short-lived iodine-containing volatiles emitted by seaweed. *Anal. Bioanal. Chem.* **2012**, *402*, 3345–3357. [CrossRef]
58. Kandasamy, S.; Khan, W.; Kulshreshtha, G.; Evans, F. The fucose containing polymer (FCP) rich fraction of *Ascophyllum nodosum* (L.) Le Jol. Protects *Caenohabditis elegans* against *Pseudomonas aeruginosa* by triggering innate immune signalling pathways and suppression of pathogen virulence factors. *Algae* **2015**, *30*, 147–161. [CrossRef]
59. Khan, W.; Palanisamy, R.; Hankins, S.D.; Critchley, A.T.; Smith, D.L.; Papadopoulos, Y.A.; Prithiviraj, B. *Ascophyllum nodosum* (L.) Le Jolis extract improves root nodulation in alfalfa. *Can. J. Plant Sci.* **2008**, *88*, 728.
60. Sharma, H.S.; Shekhar, C.F.; Selby, C.; Rao, J.R.; Trevor, M. Plant Biostimulants: A Review on the Processing of Macroalgae and Use of Extracts for Crop Management to Reduce Abiotic and Biotic Stresses. *J. Appl. Phycol.* **2014**, *26*, 465–490. [CrossRef]
61. Arioli, T.; Mattner, S.W.; Hepworth, G.; McClintock, D.; McClinock, R. Effect of seaweed extract application on wine grape yield in Australia. *J. Appl. Phycol.* **2021**, *33*, 1883–1891. [CrossRef]
62. Elansary, H.O. Green roof Petunia, Ageratum, and Mentha responses to water stress, seaweeds, and trinexapac-ethyl treatments. *Acta Physiol. Plant.* **2017**, *39*, 145. [CrossRef]
63. Rayorath, P.; Jithes, M.N.; Farid, A.; Khan, W.; Palanisamy, R.; Hankins, S.D.; Critchley, A.T.; Prithiviraj, B. Rapid bioassays to evaluate the plant growth promoting activity of *Ascophyllum nodosum* (L.) Le Jol. using a model plant, *Arabidopsis thaliana* (L) Heynh. *J. Appl. Phycol.* **2008**, *20*, 423–429. [CrossRef]
64. Elansary, H.O.; Norrie, J.; Ali, H.M.; Salem, M.Z.M.; Mahmoud, E.A.; Yessoufou, K. Enhancement of *Calibrachoa* growth, secondary metabolites and bioactivity using seaweed extracts. *BMC Complement. Altern. Med.* **2016**, *16*, 341. [CrossRef] [PubMed]
65. Sawicki, B.; Szymona, J. Yielding of permanent meadows under the influence of fertilization accepted as organic. In *Integrating Efficient Grassland Farming and Biodiversity, Proceedings of the 13th International Occasional Symposium of the European Grassland Federation, Integrating Efficient Grassland Farming and Biodiversity, Volume 10: Grassland Science in Europe, Tartu, Estonia, 29–31 August 2005*; Lillak, R., Viiralt, R., Linke, A., Geherman, V., Eds.; Estonian Grassland Society: Tartu, Estonia, 2005; pp. 409–412.
66. Pospíšil, M.; Pospíšil, A.; Gunjača, J.; Husnjak, S.; Hrgović, S.; Redžepović, S. Application of the growth stimulant Bio-algeen S 90 increases sugar beet yield. *Int. Sugar J.* **2006**, *108*, 576–581.
67. Dobromilska, R.; Mikiciuk, M.; Gubarewiczi, K. Evaluation of cherry tomato yielding and fruit mineral composition after using of Bio-algeen S-90 preparation. *J. Elementol.* **2008**, *13*, 491–499.
68. Mikiciuk, M.; Dobromilska, R. Assessment of yield and physiological indices of small-sized tomato cv. Bianka F-1′ under the influence of biostimulators of marine algae origin. *Acta Sci. Pol. Hortorum Cultus* **2014**, *13*, 31–41.
69. Kwiatkowski, C.A.; Kołodziej, B.; Woźniak, A. Yield and quality parameters of carrot (*Daucus carota* L.) roots depending on growth stimulators and stubble crops. *Acta Sci. Pol. Hortorum Cultus* **2013**, *12*, 55–68.
70. Di Stasio, E.; Van Oosten, M.J.; Silletti, S.; Raimondi, G.; Carillo, P.; Maggio, A. *Ascophyllum nodosum*-based algal extracts act as enhancers of growth, fruit quality, and adaptation to stress in salinized tomato plants. *J. Appl. Phycol.* **2018**, *30*, 2675–2686. [CrossRef]
71. Danesh, R.K.; Bidarigh, S.; Azarpour, E.; Moraditochaee, M.; Bozorgi, H.R. Study effects of nitrogen fertilizer management and foliar spraying of marine plant *Ascophyllum nodosum* extract on yield of cucumber (*Cucumis sativus* L.). *Int. J. Agric. Crop. Sci.* **2012**, *4*, 1492–1495.
72. Blunden, G.E.R.A.L.D.; Gordon, S.M. Betaines and their sulphonio analogues in marine algae. *Prog. Phycol. Res.* **1986**, *4*, 39–80.

73. Ali, N.; Farrell, A.; Ramsubhag, A.; Jayaraman, J. The effect of *Ascophyllum nodosum* extracts on the growth, yield and fruit quality of tomato grown under tropical conditions. *J. Appl. Phycol.* **2016**, *28*, 1353–1362. [CrossRef]
74. Mohamed, S.B.; Dalia, A.H.S.; Rania, M.A.N.; Azza, M.S. Influence of foliar spray with seaweed extract on growth, yield and its quality, the profile of protein pattern and anatomical structure of chickpea plant (*Cicer arietinum* L.). *Middle East J. Appl. Sci.* **2016**, *6*, 207–221.
75. Abbas, M.; Anwar, J.; Zafar-ul-Hye, M.; Iqbal Khan, R.; Saleem, M.; Rahi, A.A.; Danish, S.; Datta, R. Effect of seaweed extract on productivity and quality attributes of four onion cultivars. *Horticulturae* **2020**, *6*, 28. [CrossRef]
76. Kocira, A.; Lamorska, J.; Kornas, R.; Nowosad, N.; Tomaszewska, M.; Leszczyńska, D.; Kozłowicz, K.; Tabor, S. Changes in biochemistry and yield in response to biostimulants applied in bean (*Phaseolus vulgaris* L.). *Agronomy* **2020**, *10*, 189. [CrossRef]
77. Cassan, L.; Jeannin, I.; Lamaze, T.; Morot-Gaudry, J.F. The effect of the *Ascophyllum nodosum* extracts Goëmar GA 14 on the growth of spinach. *Bot. Mar.* **1992**, *35*, 437–440. [CrossRef]
78. Whapham, C.A.; Blunden, G.; Jenkins, T.; Hankins, S.D. Significance of betaines in the increased chlorophyll content of plants treated with seaweed extract. *J. Appl. Phycol.* **1993**, *5*, 231–234. [CrossRef]
79. Eris, A.; Sivritepe, H.Ö.; Sivritepe, N. The effect of seaweed (*Ascophyllum nodosum*) extracts on yield and quality criteria in peppers. In *I International Symposium on Solanacea for Fresh Market*; Fernández-Muñoz, R., Cuartero, J., Gómez-Guillamón, M.L., Eds.; ISHS: Malaga, Spain, 1995; Volume 412, pp. 185–192. [CrossRef]
80. Fornes, F.; Sánchez-Perales, M.; Guardiola, J.L. Effect of a seaweed extract on citrus fruit maturation. *Acta Hortic.* **1995**, *379*, 75–82. [CrossRef]
81. De Lucia, B.; Vecchietti, L. Type of biostimulant and application method effects on stem quality and root system growth in LA Lily. *Eur. J. Hortic. Sci.* **2012**, *77*, 10–15.
82. Russo, R.; Poincelot, R.P.; Berlyn, G.P. The use of a commercial organic biostimulant for improved production of marigold cultivars. *J. Home Consum. Hortic.* **1994**, *1*, 83–93. [CrossRef]
83. Chouliaras V, Gerascapoulos D, Lionakis S Effect of seaweed extract on fruit growth, weight, and maturation of 'Hayward' kiwifruit. *Acta Hortic.* **1997**, *444*, 485–489.
84. Colapietra, M.; Alexander, A. Effect of foliar fertilization on yield and quality of table grapes. *Acta Hortic.* **2006**, *721*, 213–218. [CrossRef]
85. Turan, M.; Köse, C. Seaweed extracts improve copper uptake of grapevine. *Acta Agric. Scand. Sect. B Soi. Plant Sci.* **2004**, *54*, 213–220. [CrossRef]
86. Abdel-Mawgoud, A.M.R.; Tantaway, A.S.; Hafez, M.M.; Habib, H.A.M. Seaweed extract improves growth, yield and quality of different watermelon hybrids. *Res. J. Agric. Biol. Sci.* **2010**, *6*, 161–168.
87. Loyola, N.; Munoz, C. Effect of the biostimulant foliar addition of marine algae on cv O'Neal blueberries production. *J. Agric. Sci. Technol.* **2011**, *1*, 1059–1074.
88. Spinelli, F.; Fiori, G.; Noferini, M.; Sprocatti, M.; Costa, G. Perspectives on the use of a seaweed extract to moderate the negative effects of alternate bearing in apple trees. *J. Hortic. Sci. Biotechnol.* **2009**, *84*, 131–137. [CrossRef]
89. Gunupuru, L.; Patel, J.; Sumarah, M.; Renaud, J.; Mantin, E.; Prithiviraj, B. A plant biostimulant made from the marine brown algae *Ascophyllum nodosum* and chitosan reduce *Fusarium* head blight and mycotoxin contamination in wheat. *PLoS ONE* **2019**, *14*, e220562. [CrossRef]
90. Basak, A. Effect of preharvest treatment with seaweed products, Kelpak and Goemar BM 86 on fruit quality in apple. *Int. J. Fruit Sci.* **2008**, *8*, 1–14. [CrossRef]
91. Chouliaras, V.; Tasioula, M.; Chatzissavvidis, C.; Therios, I.; Tsabolatidou, E. The effects of a seaweed extract in addition to nitrogen and boron fertilization on productivity, fruit maturation, leaf nutritional status and oil quality of the olive (*Olea europaea* L.) cultivar Koroneiki. *J. Sci. Food Agric.* **2009**, *89*, 984–988. [CrossRef]
92. Blunden, G.; Jenkins, T.; Liu, Y.W. Enhanced leaf chlorophyll levels in plants treated with seaweed extract. *J. Appl. Phycol.* **1996**, *8*, 535–543. [CrossRef]
93. Fan, D.; Kandasamy, S.; Hodges, D.M.; Critchley, A.T.; Prithiviraj, B. Pre-harvest treatment of spinach with *Ascophyllum nodosum* extract improves post-harvest storage and quality. *Sci. Hortic.* **2014**, *170*, 70–74. [CrossRef]
94. Fan, D.; Hodges, D.M.; Critchley, A.T.; Prithiviraj, B. A commercial extract of Brown Macroalga (*Ascophyllum. nodosum*) affects yield and the nutritional quality of Spinach in vitro. *Commun. Soil Sci. Plant Anal.* **2013**, *44*, 1873–1884. [CrossRef]
95. Lola-Luz, T.; Hennequart, F.; Gaffney, M. Effect on yield, total phenolic, total flavonoid and total isothiocyanate content of two broccoli cultivars (*Brassica oleraceae* var italica) following the application of a commercial brown seaweed extract (*Ascophyllum nodosum*). *Agric. Food Sci.* **2014**, *23*, 28–37. [CrossRef]
96. Blunden, G.; Wildgoose, P.B. Effects of aqueous seaweed extract and kinetin on potato yields. *J. Sci. Food Agric.* **1977**, *28*, 121–125. [CrossRef]
97. Kuisma, P. The effect of foliar application of seaweed extract on potato. *J. Agric. Sci.* **1989**, *61*, 371–377. [CrossRef]
98. Moller, M.; Smith, M.L. The effects of priming treatments using seaweed suspensions on the water sensitivity of barley (*Hordeum. vulgare* L.) caryopses. *Ann. Appl. Biol.* **1999**, *135*, 515–521. [CrossRef]
99. Steveni, C.M.; Norrington-Davies, J.; Hankins, S.D. Effect of seaweed concentrate on hydroponically grown spring barley. *J. Appl. Phycol.* **1992**, *4*, 173–180. [CrossRef]

100. Rayorath, P.; Khan, W.; Palanisamy, R.; MacKinnon, S.L.; Stefanova, R.; Hankins, S.D.; Critchley, A.T.; Prithiviraj, B. Extracts of the brown seaweed *Ascophyllum nodosum* induce gibberellic acid (GA3)-independent amylase activity in barley. *J. Plant Growth Regul.* **2008**, *27*, 370–379. [CrossRef]
101. Munshaw, G.C.; Ervin, E.H.; Shang, C.; Askew, S.D.; Zhang, X.; Lemus, R.W. Influence of late-season iron, nitrogen, and seaweed extract on fall colour retention and cold tolerance of four bermudagrass cultivars. *Crop Sci.* **2006**, *46*, 273–283. [CrossRef]
102. Zhang, X.Z.; Ervin, E.H.; Schmidt, R.E. Physiological effects of liquid applications of a seaweed extract and a humic acid on creeping bentgrass. *J. Am. Soc. Hortic. Sci.* **2003**, *128*, 492–496. [CrossRef]
103. Lola-Luz, T.; Franck, H.; Michael, G. Enhancement of Phenolic and Flavonoid Compounds in Cabbage (*Brassica Oleraceae*) Following Application of Commercial Seaweed Extracts of the Brown Seaweed, (*Ascophyllum Nodosum*). *Agric. Food Sci.* **2013**, *22*, 288–295. [CrossRef]
104. Mac, J.E.; Hacking, J.; Weng, Y.; Norrie, J. Effects of *Ascophyllum nodosum* extract application in the nursery on root growth of containerized white spruce seedlings. *Can. J. Plant Sci.* **2013**, *93*, 735–739.
105. Popescu, G.C.; Popescu, M. Effect of the brown alga *Ascophyllum nodosum* as biofertilizer on vegetative growth in grapevine (*Vitis. vinifera* L). *Curr. Trends. Nat. Sci.* **2014**, *3*, 61–67.
106. Lorenc, F.; Pešková, V.; Modlinger, R.; Podrázský, V.; Baláš, M.; Kleinová, D. Effect of Bio-Algeen® preparation on growth and mycorrhizal characteristics of Norway spruce seedlings. *J. For. Sci.* **2016**, *62*, 285–291. [CrossRef]
107. Hurtado, A.Q.; Yunque, D.A.; Tibubos, K.; Critchley, A.T. Use of Acadian Marine Plant Extract Powder from *Ascophyllum nodosum* in Tissue Culture of *Kappaphycus* Varieties. *J. Appl. Phycol.* **2009**, *21*, 633–639. [CrossRef]
108. Jannin, L.; Arkoun, M.; Etienne, P.; Laîné, P.; Goux, D.; Garnica, M. *Brassica. napus* growth is promoted by *Ascophyllum nodosum* (L). Le Jol. seaweed extract: Microarray analysis and physiological characterization of N, C, and S metabolisms. *J. Plant Growth Regul.* **2013**, *32*, 31–52. [CrossRef]
109. Sebastian, S.; Olivos-Del Rio, A.; Castro, S.; Brown, P.H. Foliar application of microbial and plant-based biostimulants increases growth and potassium uptake in almond (*Prunus. dulcis* [Mill.] D. A. Webb). *Front. Plant. Sci.* **2015**, *6*, 87.
110. Pappachan, A.; Lungjo, B.; Kanika, T. Effect of application of *Ascophyllum nodosum* extract on the yield and quality of Mulberry leaves. *Biosci. Discov.* **2017**, *8*, 235–240.
111. Colavita, G.M.; Spera, N.; Blackhall, V.; Sepulveda, G.M. Effects of seaweed extract on pear fruit quality and yield. *Acta Hortic.* **2011**, *909*, 601–607. [CrossRef]
112. Mohamed, A.Y.; El-Sehrawy, O.A.M. Effect of seaweed extraction fruiting of Hindy Bisinnara mango trees. *J. Am. Sci.* **2013**, *9*, 537–544.
113. Bozorgi, H.R. Effects of Foliar Spraying with Marine Plant *Ascophyllum nodosum* Extract and Nano Iron Chelate Fertilizer on Fruit Yield and Several Attributes of Eggplant (*Solanum. melongena.* L.). *J. Agric. Biol. Sci.* **2012**, *7*, 357–362.
114. Ayub, R.A.; Sousa, A.M.D.; Viencz, T.; Botelho, R.V. Fruit set and yield of apple trees cv. Gala treated with seaweed extract of *Ascophyllum nodosum* and thidiazuron. *Rev. Bras. Frutic.* **2019**, *41*, 1–12. [CrossRef]
115. Ozbay, N.; Demirkiran, A.R. Enhancement of growth in ornamental pepper (*Capsicum. annuum* L.) Plants with the application of a commercial seaweed product, stimplex®. *Appl. Ecol. Environ. Res.* **2019**, *17*, 4361–4375. [CrossRef]
116. Melo, T.A.D.; Serra, I.M.R.D.S.; Sousa, A.A.; Sousa, T.Y.O.; Pascholati, S.F. Effect of *Ascophyllum nodosum* seaweed extract on post-harvest' Tommy Atkins' mangoes. *Rev. Bras. Frutic.* **2018**, *40*, 1–12. [CrossRef]
117. Hidangmayum, A.; Sharma, R. Effect of different concentrations of commercial seaweed liquid extract of *Ascophyllum nodosum* as a plant biostimulant on growth, yield and biochemical constituents of onion (*Allium cepa* L). *J. Pharmacogn. Phytochem.* **2017**, *6*, 658–663.
118. De Júnior, A.F.; Dos Santos Rodrigues, A.P.M.; Júnior, R.S.; Negreiros, A.M.P.; Bettini, M.O.; Freitas, C.D.M.; Da Silva França, K.R.; Gomes, T.R.R. Seaweed Extract *Ascophyllum nodosum* (L.) on the growth of watermelon plants. *J. Exp. Agric. Int.* **2019**, *31*, 1–12. [CrossRef]
119. Valencia, R.T.; Acosta, L.S.; Fortis Hernández, M.; Rangel, P.P.; Robles, M.Á.G.; Del Antonio Cruz, R.C.; Vázquez, C.V. Effect of Seaweed Aqueous Extracts and Compost on Vegetative Growth, Yield, and Nutraceutical Quality of Cucumber (*Cucumis sativus* L.) Fruit. *Agronomy* **2018**, *8*, 264. [CrossRef]
120. Ertani, A.; Francioso, O.; Tinti, A.; Schiavon, M.; Pizzeghello, D.; Nardi, S. Evaluation of seaweed extracts from *Laminaria* and *Ascophyllum nodosum* spp. as biostimulants in *Zea mays* L. using a combination of chemical, biochemical and morphological approaches. *Front. Plant Sci.* **2018**, *9*, 428. [CrossRef]
121. Pohl, A.; Grabowska, A.; Kalisz, A.; Sekara, A. Preliminary screening of biostimulative effects of Goemar BM-86 on eggplant cultivars grown under field conditions in Poland. *Acta Agrobot.* **2018**, *71*, 1–10. [CrossRef]
122. Pacheco, A.C.; Sobral, L.A.; Gorni, P.H.; Carvalho, M.E.A. *Ascophyllum nodosum* extract improves phenolic compound content and antioxidant activity of medicinal and functional food plant *Achillea millefolium* L. *Aust. J. Crop Sci.* **2019**, *13*, 418–423. [CrossRef]
123. Manna, D.; Sarkar, A.; Maity, T.K. Impact of biozyme on growth, yield and quality of chilli (*Capsicum. annuum* L.). *J. Crop Weed* **2012**, *8*, 40–43.
124. Sabir, A.; Yazar, K.; Sabir, F.; Kara, Z.; Yazici, M.A.; Goksu, N. Vine growth, yield, berry quality attributes and leaf nutrient content of grapevines as influenced by seaweed extract (*Ascophyllum nodosum*) and nanosize fertilizer pulverizations. *Sci. Hortic.* **2014**, *175*, 1–8. [CrossRef]

125. Frioni, T.; Sabbatini, P.; Tombesi, S.; Norrie, J.; Poni, S.; Gatti, M.; Palliotti, A. Effects of a biostimulant derived from the brown seaweed *Ascophyllum nodosum* on ripening dynamics and fruit quality of grapevines. *Sci. Hortic.* **2018**, *232*, 97–106. [CrossRef]
126. Mattner, S.W.; Milinkovic, M.; Arioli, T. Increased growth response of strawberry roots to a commercial extract from *Durvillaea potatorum* and *Ascophyllum nodosum*. *J. Appl. Phycol.* **2018**, *30*, 2943–2951. [CrossRef]
127. Rouphael, Y.; Giordano, M.; Cardarelli, M.; Cozzolino, E.; Mori, M.; Kyriacou, M.; Bonini, P.; Colla, G. Plant-and seaweed-based extracts increase yield but differentially modulate nutritional quality of greenhouse spinach through biostimulant action. *Agronomy* **2018**, *8*, 126. [CrossRef]
128. Kocira, S.; Szparaga, A.; Kocira, A.; Czerwińska, E.; Wójtowicz, A.; Bronowicka-Mielniczuk, U.; Findura, P. Modeling biometric traits, yield and nutritional and antioxidant properties of seeds of three soybean cultivars through the application of biostimulant containing seaweed and amino acids. *Front. Plant Sci.* **2018**, *9*, 388. [CrossRef] [PubMed]
129. Gonçalves, B.; Morais, M.C.; Sequeira, A.; Ribeiro, C.; Guedes, F.; Silva, A.P.; Aires, A. Quality preservation of sweet cherry cv.'staccato'by using glycine-betaine or *Ascophyllum nodosum*. *Food Chem.* **2020**, *322*, 126713. [CrossRef] [PubMed]
130. Wadas, W.; Dziugieł, T. Quality of new potatoes (*Solanum. tuberosum* L.) in response to plant biostimulants application. *Agriculture* **2020**, *10*, 265. [CrossRef]
131. Prisa, D. *Ascophyllum nodosum* extract on growing plants in *Rebutia. heliosa* and *Sulcorebutia caniguerallі*. *GSC Biol. Pharm. Sci.* **2020**, *10*, 039–045. [CrossRef]
132. Goñi, O.; Łangowski, Ł.; Feeney, E.; Quille, P.; O'Connell, S. Reducing Nitrogen Input in Barley Crops While Maintaining Yields Using an Engineered Biostimulant Derived From *Ascophyllum. nodosum* to Enhance Nitrogen Use Efficiency. *Front. Plant Sci.* **2021**, *12*, 664682. [CrossRef]
133. Bernardes, R.D.S.; Santos, S.C.; Santos, C.C.; Heid, D.M.; Vieira, M.D.C.; Torales, E.P. *Ascophyllum nodosum* seaweed extract and mineral nitrogen in *Alibertia edulis* seedlings. *Rev. Bras. Eng. Agrícola Ambient.* **2023**, *27*, 173–180. [CrossRef]
134. Zhang, X.; Schmidt, R.E. Hormone-containing products' impact on antioxidant status of tall fescue and creeping bentgrass subjected to drought. *Crop Sci.* **2000**, *40*, 1344–1349. [CrossRef]
135. Ross, R.; Holden, D. Commercial extracts of the brown seaweed *Ascophyllum nodosum* enhance the growth and yield of strawberries. In *Hortscience*; American Society for Horticultural Science: Alexandria, VA, USA, 2010; Volume 45, p. S141.
136. Little, H.; Spann, T.M. Commercial extracts of *Ascophyllum nodosum* increase growth and improve the water status of potted citrus rootstocks under deficit irrigation. In *Hortscience*; American Society for Horticultural Science: Alexandria, VA, USA, 2010; Volume 45, p. S63.139.
137. Neily, W.; Shishkov, W.; Nickerson, S.; Titus, D.; Norrie, J. Commercial extract from the brown seaweed *Ascophyllum nodosum* (Acadian®) improves early establishment and helps resist water stress in vegetable and flower seedlings. *Hortscience* **2010**, *45*, S105–S106. [CrossRef]
138. Zhang, X.Z.; Ervin, E.H. Impact of seaweed extract-based cytokinins and zeatin riboside on creeping bentgrass heat tolerance. *Crop Sci.* **2008**, *48*, 364–370. [CrossRef]
139. Zhang, X.Z.; Wang, K.H.; Ervin, E.H. Optimizing dosages of seaweed extract based cytokinins and zeatin riboside for improving creeping bentgrass heat tolerance. *Crop Sci.* **2010**, *50*, 316–320. [CrossRef]
140. Spann, T.M.; Little, H.A. Applications of a commercial extract of the brown seaweed *Ascophyllum nodosum* increases drought tolerance in container-grown "hamlin" ANEet orange nursery trees. *HortScience* **2011**, *46*, 577–582. [CrossRef]
141. MacDonald, J.E.; Hacking, J.; Weng, Y.; Norrie, J. Root growth of containerized lodgepole pine seedlings in response to *Ascophyllum nodosum* extract application during nursery culture. *Can. J. Plant Sci.* **2012**, *92*, 1207–1212. [CrossRef]
142. Nair, P.; Kandasamy, S.; Zhang, J.; Ji, X.; Kirby, C.; Benkel, B.; Hodges, M.D.; Critchley, A.T.; Hiltz, D.; Prithiviraj, B. Transcriptional and metabolomic analysis of *Ascophyllum nodosum* mediated freezing tolerance in *Arabidopsis thaliana*. *BMC Genom.* **2012**, *13*, 643. [CrossRef]
143. Nair, P.; Kandasamy, S.; Zhang, J.; Ji, X.; Kirby, C.; Benkel, B.; Hodges, M.D.; Critchley, A.T.; Hiltz, D.; Prithiviraj, B. Transcriptional and metabolomic analysis of *Ascophyllum nodosum* mediated freezing tolerance in *Arabidopsis thaliana*. *BMC Genom.* **2012**, *13*, 643. [CrossRef]
144. Guinan, K.J.; Sujeeth, N.; Copeland, R.B.; Jones, P.W.; O'brien, N.M.; Sharma, H.S.S.; Prouteau, P.F.J.; O'sullivan, J.T. Discrete roles for extracts of *Ascophyllum nodosum* in enhancing plant growth and tolerance to abiotic and biotic stresses. In *I World Congress on the Use of Biostimulants in Agriculture*; ISHS: Leuven, Belgium, 2012; Volume 1009, pp. 127–135.
145. Xu, C.; Leskovar, D.I. Effects of *A. nodosum* seaweed extracts on spinach growth, physiology and nutrition value under drought stress. *Sci. Hortic.* **2015**, *183*, 39–47. [CrossRef]
146. Kumar, M.; Reddy, C.R.K.; Jha, B. The ameliorating effect of Acadian marine plant extracts against ionic liquids-induced oxidative stress and DNA damage in marine macroalga *Ulva lactuca*. *J. Appl. Phycol.* **2013**, *25*, 369–378. [CrossRef]
147. Elansary, H.O.; Skalicka-Wo'zniak, K.; King, I.W. Enhancing stress growth traits as well as phytochemical and antioxidant contents of *Spiraea* and *Pittosporum* under seaweed extract treatments. *Plant Physiol. Biochem.* **2016**, *105*, 310–320. [CrossRef]
148. Marroig, R.G.; Loureiro, R.R.; Reis, R.P. The effect of *Ascophyllum nodosum* (Ochrophyta) extract powderon the epibiosis of *Kappaphycus. alvarezii* (Rhodophyta) commercially cultivated on floating rafts. *J. Appl. Phycol.* **2016**, *28*, 2471–2477. [CrossRef]
149. Loureiro, R.R.; Reis, R.P.; Marroig, R.G. Effect of the commercial extract of the brown alga *Ascophyllum nodosum* Mont. on *Kappaphycus alvarezii* (Doty) Doty ex P.C. Silva in situ submitted to lethal temperatures. *J. Appl. Phycol.* **2014**, *26*, 629–634. [CrossRef]

150. El-Sharkawy, M.; El-Beshsbeshy, T.; Al-Shal, R.; Missaoui, A. Effect of Plant Growth Stimulants on Alfalfa Response to Salt Stress. *Agric. Sci.* **2017**, *8*, 267–291. [CrossRef]
151. Santaniello, A.; Scartazza, A.; Gresta, F.; Loreti, E.; Biasone, A.; Di Tommaso, D.; Piaggesi, A.; Perata, P. *Ascophyllum nodosum* seaweed extract alleviates drought stress in *Arabidopsis* by affecting photosynthetic performance and related gene expression. *Front. Plant Sci.* **2017**, *8*, 1362. [CrossRef] [PubMed]
152. Goni, O.; Quille, P.; OConnell, S. *Ascophyllum nodosum* extract biostimulants and their role in enhancing tolerance to drought stress in tomato plants. *Plant. Physiol. Biochem.* **2018**, *126*, 63–73. [CrossRef] [PubMed]
153. Shukla, P.S.; Shotton, K.; Norman, E.; Neily, W.; Critchley, A.T.; Prithiviraj, B. Seaweed extract improve drought tolerance of soybean by regulating stress-response genes. *AOB Plants* **2018**, *10*, 51. [CrossRef] [PubMed]
154. Carrasco-Gil, S.; Hernandez-Apaolaza, L.; Lucena, J.J. Effect of several commercial seaweed extracts in the mitigation of iron chlorosis of tomato plants (*Solanum. lycopersicum* L.). *Plant Growth Regul.* **2018**, *86*, 401–411. [CrossRef]
155. Martynenko, A.; Shotton, K.; Astatkie, T.; Petrash, G.; Fowler, C.; Neily, W.; Critchley, A.T. Thermal imaging of soybean response to drought stress: The effect of *Ascophyllum nodosum* seaweed extract. *SpringerPlus* **2016**, *5*, 1393. [CrossRef]
156. Bonomelli, C.; Celis, V.; Lombardi, G.; Mártiz, J. Salt Stress Effects on Avocado (*Persea americana* Mill.) Plants with and without Seaweed Extract (*Ascophyllum nodosum*) Application. *Agronomy* **2018**, *8*, 64. [CrossRef]
157. Carvalho, M.E.A.; De Camargo, E.; Castro, P.R.; Gaziola, S.A.; Azevedo, R.A. Is seaweed extract an elicitor compound? Changing proline content in drought-stressed bean plants. *Comun. Sci.* **2018**, *9*, 292–297. [CrossRef]
158. Spyridon, P.A.; Fernandes, Â.; Plexida, S.; Chrysargyris, A.; Tzortzakis, N.; Barreira, J.C.M.; Barros, L.; Ferreira, I.C.F.R. Biostimulants Application Alleviates Water Stress Effects on Yield and Chemical Composition of Greenhouse Green Bean (*Phaseolus vulgaris* L.). *Agronomy* **2020**, *10*, 181. [CrossRef]
159. Chrysargyris, X.P.; Anastasiou, M.; Pantelides, I.; Tzortzakis, N. Effects of *Ascophyllum nodosum* seaweed extracts on lettuce growth, physiology and fresh-cut salad storage under potassium deficiency. *J. Sci. Food Agric.* **2018**, *98*, 5861–5872. [CrossRef] [PubMed]
160. Linda, S.; Cecilia, B.; Eleonora, C.; Paolo, S.; Giovan, B.M. Eco-Physiological Traits and Phenylpropanoid Profiling on Potted *Vitis vinifera* L. cv Pinot Noir Subjected to *Ascophyllum nodosum* Treatments under Post-Veraison LowWater Availability. *Appl. Sci.* **2020**, *10*, 4473.
161. Carmody, N.; Goñi, O.; Łangowski, Ł.; O'Connell, S. *Ascophyllum nodosum* Extract Biostimulant Processing and Its Impact on Enhancing Heat Stress Tolerance During Tomato Fruit Set. *Front. Plant Sci.* **2020**, *11*, 807. [CrossRef]
162. Cabo, S.; Morais, M.C.; Aires, A.; Carvalho, R.; Pascual-Seva, N.; Silva, A.P.; Gonçalves, B. Kaolin and seaweed-based extracts can be used as a middle and long-term strategy to mitigate negative effects of climate change in physiological performance of hazelnut tree. *J. Agron. Crop Sci.* **2020**, *206*, 28–42. [CrossRef]
163. Campobenedetto, C.; Agliassa, C.; Mannino, G.; Vigliante, I.; Contartese, V.; Secchi, F.; Bertea, C.M. A Biostimulant Based on Seaweed (*Ascophyllum nodosum* and *Laminaria digitata*) and Yeast Extracts Mitigates Water Stress Effects on Tomato (*Solanum lycopersicum* L.). *Agriculture* **2021**, *11*, 557. [CrossRef]
164. Dell'Aversana, E.; Cirillo, V.; Van Oosten, M.J.; Di Stasio, E.; Saiano, K.; Woodrow, P.; Ciarmiello, L.F.; Maggio, A.; Carillo, P. Ascophyllum nodosum Based Extracts Counteract Salinity Stress in Tomato by Remodeling Leaf Nitrogen Metabolism. *Plants* **2021**, *10*, 1044. [CrossRef]
165. Bantis, F.; Koukounaras, A. *Ascophyllum. nodosum* and Silicon-Based Biostimulants Differentially Affect the Physiology and Growth of Watermelon Transplants under Abiotic Stress Factors: The Case of Drought. *Horticulturae* **2022**, *8*, 1177. [CrossRef]
166. Battacharyya, D.; Babgohari, M.Z.; Rathor, P.; Prithiviraj, B. Seaweed extracts as biostimulants in horticulture. *Sci. Hortic.* **2015**, *196*, 39–48. [CrossRef]
167. Zhang, X.; Ervin, E.H. Cytokinin-containing seaweed and humic acid extracts associated with creeping bentgrass leaf cytokinins and drought resistance. *Crop Sci.* **2004**, *44*, 1737–1745. [CrossRef]
168. Repke, R.A.; Silva, D.M.R.; Dos Santos, J.C.C.; De Almeida Silva, M. Increased soybean tolerance to high-temperature through biostimulant based on *Ascophyllum nodosum* (L.) seaweed extract. *J. Appl. Phycol.* **2022**, *34*, 3205–3218. [CrossRef]
169. Shukla, P.S.; Borza, T.; Critchley, A.T.; Hiltz, D.; Norrie, J.; Prithiviraj, B. *Ascophyllum nodosum* extract mitigates salinity stress in *Arabidopsis thaliana* by modulating the expression of miRNA involved in stress tolerance and nutrient acquisition. *PLoS ONE* **2018**, *13*, e206221. [CrossRef] [PubMed]
170. Faisal, M.; Faizan, M.; Tonny, S.H.; Rajput, V.D.; Minkina, T.; Alatar, A.A.; Pathirana, R. Strigolactone-Mediated Mitigation of Negative Effects of Salinity Stress in *Solanum lycopersicum* through Reducing the Oxidative Damage. *Sustainability* **2023**, *15*, 5805. [CrossRef]
171. Akhtar, M.; Jaiswal, A.; Taj, G.; Jaiswal, J.P.; Qureshi, M.I.; Singh, N.K. DREB1/CBF transcription factors: Their structure, function and role in abiotic stress tolerance in plants. *J. Genet.* **2012**, *91*, 385–395. [CrossRef]
172. Ali, O.; Ramsubhag, A.; Benn, D., Jr.; Ramnarine, S.; Jayaraman, J. Transcriptomic changes induced by applications of a commercial extract of *Ascophyllum nodosum* on tomato plants. *Sci. Rep.* **2022**, *12*, e11263. [CrossRef] [PubMed]
173. Cocetta, G.; Landoni, M.; Pilu, R.; Repiso, C.; Nolasco, J.; Alajarin, M.; Ugena, L.; Levy, C.C.B.; Scatolino, G.; Villa, D.; et al. Priming Treatments with Biostimulants to Cope the Short-Term Heat Stress Response: A Transcriptomic Profile Evaluation. *Plants* **2022**, *11*, 1130. [CrossRef]

174. Karuppanapandian, T.; Moon, J.C.; Kim, C.; Manoharan, K.; Kim, W. Reactive oxygen species in plants: Their generation, signal transduction, and scavenging mechanisms. *Aust. J. Crop Sci.* **2011**, *5*, 709–725.
175. Fan, D.; Hodges, D.M.; Zhang, J.; Kirby, C.W.; Ji, X.; Locke, S.J.; Critchley, A.T.; Prithiviraj, B. Commercial extract of the brown seaweed *Ascophyllum nodosum* enhances the phenolic antioxidant content of spinach (*Spinacia oleracea* L) which protects *Caenorhabditis elegans* against oxidative and thermal stress. *Food. Chem.* **2011**, *124*, 195–202. [CrossRef]
176. Burchett, S.; Fuller, M.P.; Jellings, A.J. Application of seaweed extract improves winter hardiness of winter barley cv Igri. In *The Society for Experimental Biology, Annual Meeting, The York University*; Experimental Biology Online; Springer: Berlin/Heidelberg, Germany, 1998; pp. 22–27. ISSN 1430-34-8.
177. Jithesh, M.N.; Shukla, P.S.; Kant, P.; Joshi, J.; Critchley, A.T.; Prithiviraj, B. Physiological and transcriptomics analyses reveal that *Ascophyllum nodosum* extracts induce salinity tolerance in *Arabidopsis* by regulating the expression of stress responsive genes. *J. Plant Growth Regul.* **2019**, *38*, 463–478. [CrossRef]
178. Patier, P.; Yvin, J.C.; Kloareg, B.; Liénart, Y.; Rochas, C. Seaweed liquid fertilizer from *Ascophyllum nodosum* contains elicitors of plant d-glycanases. *J. Appl. Phycol.* **1993**, *5*, 343–349. [CrossRef]
179. Lizzi, Y.; Coulomb, C.; Polian, C.; Coulomb, P.J.; Coulomb, P.O. Seaweed and mildew: What does the future hold? *Phytoma La Def. Des Veg.* **1998**, *5*, 29–30.
180. Viencz, T.; Ires Cristina, R.O.; Ricardo, A.A.; Cacilda, M.; Duarte, R.F.; Renato, V.B. Postharvest quality and brown rot incidence in plums treated with *Ascophyllum nodosum* extract. *Semin. Ciências Agrárias* **2020**, *41*, 753–766. [CrossRef]
181. Ayliffe, M.A.; Lagudah, E.S. Molecular genetics of disease resistance in cereals. *Ann. Bot.* **2004**, *94*, 765–773. [CrossRef] [PubMed]
182. Burketová, L.; Trdá, L.; Ott, P.G.; Valentová, O. Bio-based resistance inducers for sustainable plant protection against pathogens. *Biotechnol. Adv.* **2015**, *33*, 994–1004. [CrossRef]
183. Klarzynski, O.; Descamps, V.; Please, B.; Yvin, J.C.; Kloareg, B.; Fritig, B. Sulfated fucan oligosaccharides elicit defence responses in tobacco and local and systemic resistance against tobacco mosaic virus. *Mol. Plant Microbe Interact.* **2003**, *16*, 115–122. [CrossRef]
184. Kandasamy, S.; Khan, W.; Evans, F.; Critchley, A.T.; Prithiviraj, B. Tasco®: A Product of *Ascophyllum nodosum* Enhances Immune Response of *Caenorhabditis elegans* against *Pseudomonas aeruginosa* Infection. *Mar. Drugs* **2012**, *10*, 84–105. [CrossRef] [PubMed]
185. Hernández-Herrera, R.M.; Santacruz-Ruvalcaba, F.; Ruiz-López, M.A.; Norrie, J.; Hernández-Carmona, G. Effect of liquid seaweed extracts on growth of tomato seedlings (*Solanum lycopersicum* L.). *J. Appl. Phycol.* **2014**, *26*, 619–628. [CrossRef]
186. Wite, D.; Mattner, S.W.; Porter, I.J.; Arioli, T. The suppressive effect of a commercial extract from *Durvillaea potatorum* and *Ascophyllum nodosum* on infection of broccoli by *Plasmodiophora brassicae*. *J. Appl. Phycol.* **2015**, *27*, 2157–2161. [CrossRef] [PubMed]
187. Subramanian, S.; Sangha, J.S.; Gray, B.A.; Singh, R.P.; Hiltz, D.; Critchley, A.T.; Prithiviraj, B. Extracts of the marine brown macroalga, *Ascophyllum nodosum*, induce jasmonic acid-dependent systemic resistance in *Arabidopsis thaliana* against *Pseudomonas. syringae* pv. *tomato DC3000 and Sclerotinia. sclerotiorum. Eur. J. Plant Pathol.* **2011**, *131*, 237–248. [CrossRef]
188. Radwan, M.A.; Farrag, S.A.A.; Abu-Elamayem, M.M.; Ahmed, N.S. Biological control of the root-knot nematode, Meloidogyne incognita on tomato using bioproducts of microbial origin. *Appl. Soil Ecol.* **2012**, *56*, 58–62. [CrossRef]
189. Dixon, G.R.; Walsh, U.F. Suppressing Pythium ultimum induced damping-off in cabbage seedlings by biostimulation with proprietary liquid seaweed extracts. *Acta Hortic.* **2002**, *635*, 103–106. [CrossRef]
190. Nerissa, A.; Ramkissoon, A.; Ramsubhag, A.; Jayaraj, J. *Ascophyllum* Extract Application Causes Reduction of Disease Levels in Field Tomatoes Grown in a Tropical Environment. *Crop Prot.* **2016**, *83*, 67–75. [CrossRef]
191. Ajah, H.A. In vitro and in vivo studies on the antifungal activity of probiotics and Seaweed extract (*Ascophyllum. nodosum*). *Int. J. Innov. Sci. Eng. Technol.* **2016**, *3*, 306–312.
192. Paiva, K.D.; Martins, F.A.; Dos Santos, T.A.; Rezende, D.C.; Boas, B.M.V.; Xavier-Mis, D.M. *Ascophyllum nodosum* Seaweed Extract As an Alternative for Control of Post-Harvest Soft Rot in Strawberries/Extrato De Alga Marinha De *Ascophyllum nodosum* Como Alternativa Para Controle Da podridão Mole pós-Colheita Em Morangos. *Braz. J. Dev.* **2020**, *6*, 13531–13543. [CrossRef]
193. Islam, M.T.; Gan, H.M.; Ziemann, M.; Hussain, H.I.; Arioli, T.; Cahill, D. Phaeophyceaean (brown algal) extracts activate plant defence systems in Arabidopsis thaliana challenged with *Phytophthora cinnamomi*. *Front. Plant Sci.* **2020**, *11*, 852. [CrossRef] [PubMed]
194. Dierick, N.; Ovyn, A.; De Smet, S. Effect of feeding intact brown seaweed *Ascophyllum nodosum* on some digestive parameters and iodine content in edible tissues in pigs. *J. Sci. Food Agric.* **2009**, *89*, 584–594. [CrossRef]
195. Vacca, D.D.; Walsch, R.A. The antibacterial activity of an extract obtained from *Ascophyllum nodosum*. *J. Am. Pharm. Assoc.* **1954**, *43*, 24–26. [CrossRef]
196. Shannon, E.; Abu-Ghannam, N. Antibacterial Derivatives of Marine Algae: An Overview of Pharmacological Mechanisms and Applications. *Mar. Drugs* **2016**, *14*, 81. [CrossRef]
197. Yu, G.; Chen, Y.; Bao, Q.; Jiang, Z.; Zhu, Y.; Ni, H.; Li, Q.; Oda, T. A low-molecular-weight ascophyllan prepared from *Ascophyllum nodosum*: Optimization, analysis and biological activities. *Int. J. Biol. Macromol.* **2020**, *153*, 107–117. [CrossRef]
198. Ueno, M.; Nogawa, M.; Siddiqui, R.; Watashi, K.; Wakita, T.; Kato, N.; Ikeda, M.; Okimura, T.; Isaka, S.; Oda, T.; et al. Acidic polysaccharides isolated from marine algae inhibit the early step of viral infection. *Int. J. Biol. Macromol.* **2019**, *124*, 282–290. [CrossRef]
199. Jimenez, J.; O'Connell, S.; Lyons, H.; Bradley, B.; Hall, M. Antioxidant, antimicrobial, and tyrosinase inhibition activities of acetone extract of *Ascophyllum nodosum*. *Chem. Pap.* **2010**, *64*, 434–442. [CrossRef]

200. Frazzini, S.; Scaglia, E.; Dell'Anno, M.; Reggi, S.; Panseri, S.; Giromini, C.; Lanzoni, D.; Sgoifo Rossi, C.A.; Rossi, L. Antioxidant and Antimicrobial Activity of Algal and Cyanobacterial Extracts: An In Vitro Study. *Antioxidants* **2022**, *11*, 992. [CrossRef] [PubMed]
201. Wang, X.; Li, C.; Liang, D.; Zou, Y.; Li, P.; Ma, F. Phenolic compounds and antioxidant activity in red-fleshed apples. *J. Funct. Foods* **2015**, *18*, 1086–1094. [CrossRef]
202. Allen, V.G.; Pond, K.R.; Saker, K.E.; Fontenot, J.P.; Bagley, C.P.; Ivy, R.L.; Evans, R.R.; Schmidt, R.E.; Fike, J.H.; Zhang, X.; et al. Tasco: Influence of brown seaweed on antioxidants in forages and livestock—A review. *J. Animal. Sci.* **2001**, *79*, E21–E31. [CrossRef]
203. Blanc, N.; Hauchard, D.; Audibert, L.; Gall, E.A. Radical-scavenging capacity of phenol fractions in the brown seaweed Ascophyllum nodosum: An electrochemical approach. *Talanta* **2011**, *84*, 513–518. [CrossRef]
204. Shibata, T.; Nagayama, K.; Tanaka, R.; Yamaguchi, K.; Nakamura, T. Inhibitory effects of brown algal phlorotannins on secretory phospholipase A2s, lipoxygenases and cyclooxygenases. *J. Appl. Phycol.* **2003**, *15*, 61–66. [CrossRef]
205. Shibata, T.; Fujimoto, K.; Nagayama, K.; Yamaguchi, K.; Nakamura, T. Inhibitory activity of brown algal phlorotannins against hyaluronidase. *Int. J. Food Sci. Techcol.* **2002**, *37*, 703–709. [CrossRef]
206. Barwell, C.J.; Blunden, G.; Manandhar, P.D. Isolation and characterization of brown algal polyphenols as inhibitors of α-amylase, lipase and trypsin. *J. Appl. Phycol.* **1989**, *1*, 319–323. [CrossRef]
207. Kim, K.T.; Rioux, L.E.; Turgeon, S.L. Alpha-amylase and alpha-glucosidase inhibition are differentially modulated by fucoidan obtained from *Fucus vesiculosus* and *Ascophyllum nodosum*. *Phytochemistry* **2014**, *98*, 27–33. [CrossRef]
208. Franzoni, G.; Cocetta, G.; Prinsi, B.; Ferrante, A.; Espen, L. Biostimulants on Crops: Their Impact under Abiotic Stress Conditions. *Horticulturae* **2022**, *8*, 189. [CrossRef]
209. Wally, O.S.; Critchley, A.T.; Hiltz, D.; Craigie, J.S.; Han, X.; Zaharia, L.I.; Abrams, S.R.; Prithiviraj, B. Regulation of phytohormone biosynthesis and accumulation in Arabidopsis following treatment with commercial extract from the marine macroalga *Ascophyllum nodosum*. *J. Plant Growth Regul.* **2013**, *32*, 324–339. [CrossRef]
210. Wani, S.H.; Kumar, V.; Shriram, V.; Sah, S.K. Phytohormones and their metabolic engineering for abiotic stress tolerance in crop plants. *Crop J.* **2016**, *4*, 162–176. [CrossRef]
211. Castaings, L.; Marchive, C.; Meyer, C.; Krapp, A. Nitrogen signalling in Arabidopsis: How to obtain insights into a complex signalling network. *J. Exp. Bot.* **2011**, *62*, 1391–1397. [CrossRef] [PubMed]
212. Krouk, G.; Lacombe, B.; Bielach, A.; Perrine-Walker, F.; Malinska, K.; Mounier, E.; Hoyerova, K.; Tillard, P.; Leon, S.; Ljung, K.; et al. Nitrate-regulated auxin transport by NRT1. 1 defines a mechanism for nutrient sensing in plants. *Dev. Cell* **2010**, *18*, 927–937. [CrossRef] [PubMed]
213. Goni, O.; Fort, A.; Quille, P.; McKeown, P.C.; Spillane, C.; O'Connell, S. Comparative transcriptome analysis of two *Ascophyllum nodosum* extract biostimulants: Same seaweed but different. *J. Agric. Food Chem.* **2016**, *64*, 2980–2989. [CrossRef]
214. Ren, H.; Gray, W.M. SAUR proteins as effectors of hormonal and environmental signals in plant growth. *Mol. Plant* **2015**, *8*, 1153–1164. [CrossRef]
215. Stirk, W.A.; Van Staden, J. Comparison of cytokinin- and auxin-like activity in some commercially used seaweed extracts. *J. Appl. Phycol.* **1996**, *8*, 503–508. [CrossRef]
216. Moore, K.K. Using seaweed compost to grow bedding plants. *BioCycle* **2004**, *45*, 43–44.
217. Mohanty, D.; Adhikary, S.P.; Chattopadhyay, N. Seaweed liquid fertiliser (SLF) and its role in agricultural productivity. *Ecosan* **2013**, *3*, 147–155.
218. Spinelli, F.; Fiori, G.; Noferini, M.; Sprocatti, M.; Costa, G. A novel type of seaweed extract as a natural alternative to the use of iron chelates in strawberry production. *Sci. Hortic.* **2010**, *125*, 263–269. [CrossRef]
219. Illera-Vives, M.; López-Fabal, A.; López-Mosquera, M.E.; Ribeiro, H.M. Mineralization dynamics in soil fertilized with seaweed–fish waste compost. *J. Sci. Food Agric.* **2015**, *95*, 3047–3054. [CrossRef]
220. Hankins, S.D.; Hockey, H.P. The effect of a liquid seaweed extract from *Ascophyllum nodosum* (Fucales, Phaeophyta) on the two-spotted red spider mite *Tetranychus urticae*. *Hydrobiologia* **1990**, *204*, 555–559. [CrossRef]
221. Wu, Y.; Jenkins, T.; Blunden, G.; Von Mende, N.; Hankins, S.D. Suppression of fecundity of the root-knot nematode, *Meloidogyne. javanica*, in monoxenic cultures of *Arabidopsis thaliana* treated with an alkaline extract of *Ascophyllum nodosum*. *J. Appl. Phycol.* **1998**, *10*, 91. [CrossRef]
222. Martin, T.J.G.; Turner, S.J.; Fleming, C.C. Management of the potato cyst nematode (*Globodera pallida*) with bio-fumigants/stimulants. *Commun. Agric. Appl. Biol. Sci.* **2007**, *72*, 671–675. [PubMed]
223. Loureiro, R.R.; Reis, R.P.; Critchley, A.T. In vitro cultivation of three *Kappaphycus. alvarezii* (Rhodophyta, Areschougiaceae) variants (green, red and brown) exposed to a commercial extract of the brown alga *Ascophyllum nodosum* (Fucaceae, Ochrophyta). *J. Appl. Phycol.* **2010**, *22*, 101–104. [CrossRef]
224. Uppal, A.K.; El Hadrami, A.; Adam, L.R.; Tenuta, M.; Daayf, F. Biological control of potato Verticillium wilt under controlled and field conditions using selected bacterial antagonists and plant extracts. *Biol. Control* **2008**, *44*, 90–100. [CrossRef]
225. Goicoechea, N.; Aguirreolea, J.; Garcıa-Mina, J.M. Alleviation of verticillium wilt in pepper (*Capsicum. annuum* L.) by using the organic amendment COA H of natural origin. *Sci. Hortic.* **2004**, *101*, 23–37. [CrossRef]

226. Ali, M.K.M.; Yasir, S.M.; Critchley, A.T.; Hurtado, A.Q. Impacts of *Ascophyllum* marine plant extract powder (AMPEP) on the growth, incidence of the endophyte *Neosiphonia apiculata* and associated carrageenan quality of three commercial cultivars of Kappaphycus. *J. Appl. Phycol.* **2018**, *30*, 1185–1195. [CrossRef]
227. Cook, J.; Zhang, J.; Norrie, J.; Blal, B.; Cheng, Z. Seaweed extract (*Stella Maris* R.) activates innate immune responses in *Arabidopsis thaliana* and protects host against bacterial pathogens. *Mar. Drugs* **2018**, *16*, 221. [CrossRef]
228. Somai-Jemmali, L.; Siah, A.; Randoux, B.; Magnin-Robert, M.; Halama, P.; Hamada, W.; Reignault, P. Brown alga *Ascophyllum nodosum* extract-based product, Dalgin Active®, triggers defence mechanisms and confers protection in both bread and durum wheat against Zymoseptoria tritici. *J. Appl. Phycol.* **2020**, *32*, 3387–3399. [CrossRef]
229. Patel, J.S.; Selvaraj, V.; Gunupuru, L.R.; Rathor, P.K.; Prithiviraj, B. Combined application of *Ascophyllum nodosum* extract and chitosan synergistically activates host-defence of peas against powdery mildew. *BMC Plant Biol.* **2020**, *20*, 113. [CrossRef]
230. Tkaczyk, M.; Szmidla, H.; Sikora, K. The use of biostimulants containing *Ascophyllum nodosum* (L.) Le Jolis algal extract in the cultivation and protection of English oak *Quercus robur* L. seedlings in forest nurseries. *Sylwan* **2022**, *166*, 244–252.
231. Rashad, Y.M.; El-Sharkawy, H.H.A.; Elazab, N.T. *Ascophyllum nodosum* Extract and Mycorrhizal Colonization Synergistically Trigger Immune Responses in Pea Plants against Rhizoctonia Root Rot, and Enhance Plant Growth and Productivity. *J. Fungi* **2022**, *8*, 268. [CrossRef] [PubMed]