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Bibliographic review

Algae as a natural alternative for the production of different crops

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ABSTRACT

Algae have achieved a high interest for their applications in the pharmaceutical, fish; animal and man feed industry as well as in agriculture. They have potential as biostimulants and biofertilizers; they can be applied in different ways such as foliar application, soil amendment and seed imbibition. They can be used in the production of different crops as an economic alternative, which allows for sustainable agriculture. Using them decreases the use of chemicals products and protects the environment. Algae bioproducts contain different metabolites, minerals and phytohormones that stimulate plant growth and yield, improve soil biological properties and increase productivity under conditions of abiotic and biotic stress. The objective of this review is investigate the potential role of macro and microalgae in the yield and protection of different crops.

Key words: microalgae, biofertilizers, biostimulants, protection

INTRODUCTION

In order to conserve the agroecosystem and taking into account the growing demand for food, it is necessary to look for new technologies to increase the production and quality of crops, as well as to offer products free of toxic waste to consumers [1,2]. Governments today reinstate the idea of efficient recycling of waste and the use of biological products such as biostimulants and biofertilizers, to minimize the use of chemicals that cause toxicity to human health and the agroecosystem. These bioproducts contain active ingredients, which act on the physiology of plants, increasing plant growth and development, as well as yield and quality of crops (1-3).

Among the bioproducts that have been evaluated are algae and derived products that have been used as human food, animal feed, fodder, paper production and other industries (4,5). In agriculture, the entire world has been used as biofertilizers and biostimulants to increase plant growth and yield (2,4,6-10). There are approximately 9,000 species of macroalgae classified into three main groups based on their pigmentation, Phaeophyta, Rhodophyta and Chlorophyta or brown, red and green algae, respectively (4,6). In addition, there are more than 50,000 different types of microalgae species present in oceans and freshwater (lakes, ponds and rivers) (2,11), among these species, only 30,000 have been studied (3,11).

The macroalgae most commonly used in agriculture are brown, including *Ascophyllum nodosum* (L.) (6,12,13). In addition to *A. nodosum*, other brown algae such as *Fucus* spp., *Laminaria* spp., *Sargassum* spp., *Turbinaria* spp. and *Ecklonia maxima* (Osbeck) Papenfuss are used as biofertilizers (6,12). Red algae such as *Corralina mediterranean Areschoug*, *Jania rubens* (L.) J.V. Lamouroux, *Pterocladia pinnata* (Hudson) Papenfuss and green algae such as *Cladophora dalmatica* Kützing, *Enteromorpha* intestinalis (L.) *Nees*, *Ulva lactuca* L. have also been used as plant growth biostimulants. (8,10,12). *Isochrysis* spp., *Chaetoceros* spp., *Chlorella* spp., *Arthrospira* spp. and *Dunaliella* spp., are species of microalgae that are commercially available and have been used in the food chain for marine ecosystems, in the pharmaceutical industry, human consumption (2,11) and in agriculture (2). The best-known cyanobacterium is *Arthrospira platensis* Gomont (spirulina) and has been used for the production of biofuels, animal feed and agricultural fertilizers (14).

It is possible to combine algae extracts with inorganic (2,15,16) and organic (2,15,17,18) fertilizers and that could allow for sustainable agricultural productivity. They can be applied in different ways: foliar applications (2), soil amendments (4,19) and on seeds (2,3,20), showing a wide range of positive responses that include increased germination, system development radicular, improved crop yield, higher chlorophyll content and leaf area, increased fruit quality and vigor, high resistance to biotic and abiotic stress and increased shelf life of postharvest products (2,3,6,8,9,15,16,19,20-26). It is suggested that obtaining these beneficial effects could be due to active compounds, such as growth hormones that occur naturally in algae, such as auxins, cytokinins, betaines, gibberellins or other low-weight components [4,6,8,9,12,27-29]. Algae can also serve as an important source of plant defense inducers since they contain a series of substances that allow this activity to be carried out [3,4,6].

Algae extracts have been used with significant results in plants grown in greenhouse and field conditions such as, bulbs (potato, carrot, beet, sweet potato), fruit trees (lemon, banana, peach, pear), vegetables (tomato, pepper, brine), grains (rice, corn), legumes (pea, black grains, green beans, common beans) and flowers (orchid, rose, sunflower) or *in vitro* cultivation conditions (*Arabidopsis*, tomato, eggplant, millet) [8]. For these reasons, the objective of this review is to investigate the potential role of macro and microalgae in the yield and protection of different crops.

1. Increase in crop yield with the use of microalgae

Numerous studies indicate that microalgae contain some substances that promote plant growth, such as auxins, cytokinins, betaines, amino acids, vitamins, and polyamines [27,28]. They provide promising resources such as fatty acids, steroids, carotenoids, polysaccharides, lectins, mycosporin-type amino acids, halogenated compounds, polyketides, toxins, agar agar, alginic acid and carrageenan [2]. Furthermore, they may contain significant amounts of gibberellins and brassinosteroids [2]. The amino acids contained in the microalgae are a biostimulant with positive effects on plant growth and crop performance. These amino acids can contribute to mitigate the injuries caused by abiotic stress [2].

The microalgae can also be composed of micro and macronutrients, especially nitrogen (N), phosphorus (P) and potassium (K), so it could be considered a slow-release organic fertilizer [15]. When the dry biomass *Arthrospira* spp. showed it contains 6.70; 2.47 and 1.14 % N, P and K, respectively, while the calcium (Ca) content is relatively lower than that of other minerals [2]. Some of the cyanobacterial species can fix atmospheric nitrogen within their cells [30]. Most of the studies focused on the use of these cyanobacteria in rice fields to make atmospheric nitrogen available to the plant [31,32].

1.1 Microalgae in seed germination

To achieve healthy postures, careful work must be done in the germination stage in order to have the expected growth and yield of the crops. Microalgae extracts were shown to increase seed germination [3], root development [24] and sprouts [2]. The application of *Chlorella* sp. The germination rate of wheat, barley and corn seeds improved [33.34]. Lettuce seeds germinated in soils containing different concentrations of biofertilizer based on *Chlorella vulgaris* Beijerinck [2]. Extracts from the biomass of spirulina had beneficial effects on the germination of watercress and winter wheat seeds [35,36]. The application of the biomass and aqueous extract of *Acutodesmus dimorphus* (Turpin) P.M.Tsarenko on seeds allowed the germination of the same two days faster than in the control experiment. The seeds treated with *A. dimorphus* had larger lateral roots, which could improve the absorption of water and nutrients by the plants and increase their growth [37]. Hydrolysates of *Dunaliella salina* (Dunal) Teodoresco stimulated the germination of wheat seeds and the growth of positions in saline soils [38]. Intracellular polysaccharides from two microalgae (*Dunaliella salina* and *Phaeodactylum tricornutum* Bohlin) were reported to increase the germination rate of pepper seeds under saline conditions [23].

1.2 Improvement of soil characteristics for crops

Microalgae can be inoculated into the soil, this could be an important source of organic carbon and improve its quality [3,39,40]. Under specific growth conditions, some microalgae and cyanobacteria produce and secrete extracellular polymeric substances (EPS) [41-43]. When growth conditions are not favorable, algae produce these compounds to protect their cells from stress conditions [43]. The deposition of EPS in the soil is one of the mechanisms to increase its organic content [3] and was identified as a main component for its stabilization [44]. Furthermore, it was shown that EPS could strengthen soil porosity and increase resistance to penetration, by reducing the damaging impact of adding water [40]. In the field, it was observed that inoculating green microalgae (*Botryococcus*, *Chlamydomonas*, *Chlorella*, etc.), the stability of the soil was improved by increasing the EPS content in the upper strata [39].

The inoculation of blue-green algae in the soil could be an alternative source of N to increase the productivity of the rice crop [22]. A mixture of inocula from different blue-green algae (*Nostoc* spp., *Anabaena* spp., *Westiellopsis* spp., *Aulosira* spp. and *Scytonema* spp.) With different levels of synthetic N (between 0 and 80 kg of N ha^{-1}) was used) in a field trial and it was observed that the plants inoculated with the microalgae mixture increased the grain yield up to 20.9 % and the straw yield up to 18.1 %, respectively [22].

Microalgae are also used in bioremediation of wastewater due to their ability to concentrate heavy metals. The extracellular and intracellular mechanisms linked to the absorption of metals are complex and influenced by the species of microalgae, metal ions (Pb> N)> Cd> Zn) and the conditions of the growth system such as pH (2.45)

1.3 Increased growth and quality of crops

Microalgae and cyanobacteria-based bioproducts can improve plant performance and the quality of certain vegetable and food crops [(3)]. The nutrients available in the microalgae extracts are easily absorbed by the leaf through the stomata and pores of the cuticle and it is shown to be more effective if applied in the morning, when the stoma pores are fully open [(46)]. Some studies found a positive effect of microalgae fertilizers, especially when applied to the leaves of horticultural crops such as eggplant, garlic, pepper, tomato and ornamentals such as petunia [(24, 37, 47-49)].

The co-production of microalgae (*Scenedesmus quadricauda* Chodat or *Chlorella vulgaris* Beyerinck) with tomato plants was to provide satisfactory results shown since *S. quadricauda* increased the growth of tomato sprouts together with the increase in the biomass of the microalgae [(2)]. When using *Aulosira fertilissima* S.L.Ghose in rice cultivation, there was an increase in the growth of the postures due to the presence of hormones (auxins, cytokinins and gibberellic acid) [(2)]. Another study in leafy vegetables (*Eruca sativa* Mill., *Ameranthus gangeticus* L. and *Brassica rapa* ssp. *Chinensis* L.) showed that using spirulina-based fertilizers can improve plant growth [(10)]. Biostimulants based on *Nannochloris* spp. used in tomato plants determined a better development of root length, a greater number of leaves and leaf area compared to the control [(24)]. When applying microalgae biofertilizers (dry biomass of *Nannochloropsis* spp., *Ulothrix* spp., *Klebsormidium* spp.) in the tomato crop, increases in the concentrations of sugars and carotenoids in the fruit were recorded, showing the ability of these biofertilizers to increase the quality and economic value of the fruit [(15)].

The *Acutodesmus dimorphus* extract used as a foliar application at 3.75 g L^{-1} showed a greater growth of tomato plants. In particular, a higher plant height and number of flowers and branches per plant were recorded [(37)]. Field experiments were carried out to evaluate the influence of foliar applications of the extract of *Arthrospira fusiformis* (Voronichin) Komárek & JWGLund at the rate of 1 ml L^{-1} on the growth. Yield and its components and the useful life of the plants of garlic and the results indicated that only the height of the plant increased compared to the control [47].

When dry powder of *Chlorella vulgaris* was applied to soil planted with lettuce, there was an increase in crop yield, while some biomass compounds protected the plant against pathogens [3]. The foliar applications of *Spirulina platensis* (Gomont) Geitler in beet and pepper crops increased the yields that when compared with those obtained with commercial fertilizers (NPK), were on par [48]. Spirulina-based biofertilizers have been found to increase the post-harvest quality of eggplant, and the firmness of the pulp was improved over a longer period even under higher temperature conditions, allowing for a longer shelf life after the harvest [48]. A foliar mixture containing *Chlorella* sp. and *Spirulina* sp., enriched with nitrogen, phosphorous, magnesium, zinc and potassium, increased the yield and quality of potatoes, peas and wheat [2]. When *Spirulina* sp. was applied directly to the soil sown with sunflower, chili, soybeans, green grains and peanuts, there were positive effects on the growth of the plants and their yield [36]. Several tomato and organic fruit growers spray a suspension of *Chlorella* sp. live that allows the supply of complex polysaccharide compounds and microelements directly through the stoma of the plant, which leads to a better aromatic and natural smell [2]. In the corn crop, extracts of blue-green algae (*S. platensis*) were applied foliarly in different concentrations and with 6 g L^{-1} and it allowed highest percentages of the length and cob diameter, cob weight per plant, number of rows per cob, number of kernels per row, number of kernels per cob. Besides, weight of kernels per cob, weight of 100 kernels as well as plant height, cob length, stem diameter, cob leaf area, yield grain, straw yield, protein, oil and carbohydrate percentage in grains [16] were achieved. When *S. platensis* extracts at different concentrations were with nitrogen fertilization at different levels combined. In addition, it increases in growth and yield parameters were shown as doses increased, but it was recommended to use 100 kg of N together with foliar applications of 4.5 g L^{-1} of blue-green algae extracts to increase the yield of corn kernels and their quality in addition. All this in order to reduce production costs and environmental contamination by nitrogen under ecological studies at the experiment site [16].

In ornamental plants, the use of microalgae biofertilizers can improve the quality of the flower, for example, in roses increased carotenoids that typically stimulate the yellow and orange color of the petals [2]. Foliar applications of extracts of *Scenedesmus almeriensis* at the concentration of 10 g L^{-1} in petunia plants improved the development of the plant where higher growth rates of roots, leaves, shoots and the earliness of flowering were observed compared to the control. While, with the same concentration of *Arthrospira* spp. extract, in the same crop and the same type of application the dry matter of the root, the number of flowers per plant and the water content of the plant were improved [(2)].

1.4 Improvement of tolerance to abiotic stress with the use of microalgae

The application of microalgae extracts can provide protection against abiotic stress in plants [(21)]. Saline stress was mitigated during the pepper seed germination process with extracts of *Dunaliella* spp. and *Phaeodactylum* spp., due to a significant reduction in the production of radicals without peroxide and a low lipid peroxidation [(23)]. Salinity tolerance of wheat plants irrigated with seawater can be improved by applying microalgae extracts to them [(21)]. The use of aqueous extracts of *Spirulina* spp. and *Chlorella* spp. improved wheat tolerance to salinity, antioxidant capacity and protein content of the whole grains produced [(21)]. Applying a biostimulant product based on *Nannochloris* spp. in tomato plants alleviated the effects of water stress and increased plant height [(24)].

2. Increase in crop yield with the use of macroalgae

Marine macroalgae are considered valuable resources for plant improvement due to their high content of polysaccharides, glycerol and growth regulators. Its chemical composition includes auxins, cytokinins and gibberellins, which have a wide range of biological activities [(4)]. The efficiency of fertilization with liquid algae extracts is due to the presence of micro and macro nutrients and growth hormones at preferential levels [(6,19)].

2.1 Macroalgae in seed germination

Macroalgae extracts can be used to improve seed germination and posture growth [(20)]. Neutral alkaline extracts of *Ulva lactuca* L and *Padina gymnospora* (Kützing) Sonder to 0.2 % increased the germination percentage of tomato seeds, reduced the average germination time and increased the vigor index of the postures. However, neutral and alkaline extracts of *Caulerpa sertularioides* (Gmelin) had an inhibitory effect on the germination of the seed of this culture [20]. The presence of various bioactive compounds in the algae extracts can stimulate and inhibit seed germination, which may help explain this difference [20]

2.2 Improvement of soil characteristics for crops

Macroalgae have a great ability to improve the physical and chemical properties of the soil [4]. They are used as biofertilizers, which allows increasing the yield of various crops [4,6,19]. The use of *U. lactuca*, *Cystoseira* spp., *G. crinale* as soil amendment increased the yields of canola plants [19]. By adding *Ascophyllum* spp. to soils at 100 % of field capacity, it developed microbial activity and improved soil stability, increased root biomass, water use efficiency and onion crop yield. Algae were added to two types of soils and the clays developed well the microbial activity, the stability of the aggregates and the efficiency of the use of the water in comparison with the sandy soil. Whereas, the sandy soil had largely developed the biomass of the roots and the yield of the onion [29].

2.3 Increased growth and quality of crops

The application of seaweed extract (10 g L) in onion plants increased the plant biomass, the leaf area, the dry matter content and the efficiency in the use of water [29,50]. When some vegetable crops such as eggplant, tomato and chili were treated with liquid red algae fertilizer (*Gracilaria verrucosa* (Hudson) Papenfuss) they increased the growth rate in all parameters [51]. In many plants such as tomato, chili [51], corn [52] and eggplant [53], high productivity was indicated in response to treatment with seaweed.

Alkaline extracts of *U. lactuca* and *Padina gymnospora* (Kützing) Sonder at 0.2 % showed an increase in the length of the shoots and roots of tomato positions; however, neutral and alkaline extracts of *Caulerpa sertularioides* (Gmelin) had an effect inhibitor in radicle length [20]. The highest dry weight of tomato positions was recorded from seeds embedded with both extracts (neutral and alkaline) of *P. gymnospora* at 1.0 % [20]. When the liquid fertilizer of *Ulva lactuca* was applied at 8 %, the root length, shoot length, seed resistance index, length and the vigor of the posture vigor of crops such as *Trigonella foenum-graecum* L. (fenugreek) were increased and *Spinacia oleracea* L. (spinach), while at concentrations of 6 % the same occurred for *Corinderum sativum* L. (coriander) [25].

The use of algae allows the increase of photosynthetic pigments (chlorophyll a, chlorophyll b, chlorophyll a+b, carotenoids, total photosynthetic pigments) both under normal conditions

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and under stress conditions (19). An example of this is *Ulva lactuca, Cystoseira* spp., *Gelidium crinale* (Hare ex Turner) Gaillon that under conditions of salt stress increased pigments in canola plants. They can also increase the concentration of different phytohormones (Indolacetic Acid (IAA), Indolebutyric Acid (IBA), Gibberellic Acid (GA3), Jasmonic Acid (JA), Abscisic Acid (ABA), and Cytokinins (CKs; Zeatin (Z) and Benzyl adenine (BA)) under stress conditions (19). *Cystoseira* spp. increased GA3 and JA, *G. crinale* IBA and ABA and *U. lactuca* IAA and cytokinins (Z and BA) (19). When soybean plants were treated with Liquid algae fertilizer increased the amounts of chlorophyll a and b with respect to the untreated control (29,54). It was shown that treating the *Corinderum sativum* culture with liquid biofertilizer of *U. latuca* at 6 % increased the levels of chlorophyll a, b. The total of chlorophylls, carotenoids compared to that observed in *Trigonella foenum graecum* and *Spinacia oleracea* when treated with 8 % concentration of this same fertilizer, while the protein and carbohydrate content increased in *T. foenum* graecum and *S. oleracea* (25).

It was demonstrated that aqueous extracts of *Sargassum wightii* Greville ex J.Agardh applied foliarly in the culture of *Ziziphus mauritiana* Lam. (Indian plum) increased the yield and the quality of the fruit (55). *Hypnea musciformis* (Wulfen) J.V.Lamouroux, *Spatoglossum asperum* J.Agardh, *Stoechospermum marginatum* (C.Agardh) Kützing and Sargassum spp. were also reported to induce the growth of green chili, turnip and pineapple plants (56). Numerous previous studies showed that 15 species of macroalgae could stimulate the growth of melon and sesame seeds (57). When evaluating solid fertilizers of *Sargassum crassifolium* J.Agardh in rice, an increase in the height of the plant was observed, as well as the number of shoots and the number of leaves, this last parameter also increased with solid fertilizers from other algae (*Sargassum cristaefolium* C.Agardh and *Sargassum aquifolium* (Turner) C.Agardh). Solid fertilizers from S. crassifolium and *S. aquifolium* promoted vegetative growth, however, liquid fertilizers proved to be more effective in promoting rice yield (26).

2.4 Improvement of abiotic stress tolerance with the use of macroalgae

Algae mitigate the harmful effect of salinity in plants when used as biofertilizers in the soil (4,19). This is the case of *Ulva lactuca* L, *Cystoseira* spp., *Gelidium crinale* (Hare ex Turner) Gaillon) that when used in canola plants under saline stress conditions, an inhibitory effect proportional to the applied NaCl concentrations was observed (0.75, 159 mM NaCl) (19). The applied amendments of these algae allowed a significant stimulatory effect of all growth parameters (root length, shoot length, number of pods per plant, average leaf area, fresh and dry weight of the sprout, fresh and dry weight root) of canola plants (19). They also allowed for the increase of primary metabolites like carbohydrates and an additional accumulation of proline in plants under these conditions. Furthermore, a significant increase in secondary metabolites such as phenols, flavonoids and anthocyanins was seen in response to 150 mM NaCl (19). The use of *U. lactuca*, *Cystoseira* spp., *G. crinale* allowed a significant increase in the average yield parameters (shoot length, root and stem, number of siliqua per plant, number of seeds per siliqua and weight of 1000 seeds) of canola under saline stress conditions (19). Incorporation of *Ascophyllum* spp. Extract limited the negative effects of water stress on sandy soils and increased onion yield (29).

The methanolic extracts of *A. nodosum* and to a lesser extent *Laminaria digitata* (Hudson) J.V.Lamouroux, *Laminaria hyperborea* (Gunnerus) Foslie and *Fucus serratus* Thunberg have been applied for large-scale production of biofertilizers due to their high content of betaines; osmolytic compounds organics that can play a crucial role in effective protection against salt, water and extreme temperature stress (4).

3. Biocidal action of algae

The application of chemicals to control insects, pests, fungi and bacteria in the field is associated with adverse environmental effects and risks to human health; therefore, there is a growing demand for alternative bio-based products (3,4). Algae and cyanobacteria were proposed as promising and safe biocidal agents (58,59). These can serve as an important source of plant defense inducers since they contain a series of substances that allow this activity to be carried out (4,6,24). An example is laminarin, a linear β- (1.3) glucan and the sulfated fucans of brown algae that provoke multiple defense responses in alfalfa and tobacco (6). Foliar applications of *Ascophyllum nodosum* extract reduced infection by *Phytophthora capsici* (Leonian) in *Capsicum* (chili) and *Plasmopara vitícola* (Berk. Et Curtis ex De Bary) in grapes. The application in the soil of liquid extracts of algae in cabbage stimulated the growth and activity of microbes that were antagonistic to *Pythium ultimum* Trow, a serious fungal pathogen that causes damping-off disease in postures (6).

Some macro and microalgae species have the ability to produce certain compounds that show antifungal, insecticidal, nematocidal, herbicidal, and cytotoxic properties (3,4). These bioactive compounds inhibit physiological and metabolic activities in specific pathogens. For example, studies indicate that the extracts of *Chlorococcum humicolum* FEFritsch & RPJohn have inhibited the growth of pathogens such as *Botrytis cinerea* (De Bary) in strawberry and *Erysiphe polygoni* DC., Fl. *Agenaise* in tomato, turnip and saprophyte [3]. Certain cyanobacterial formulations were effective in preventing rot disease in cotton root and improving the rhizosphere [60]. Algae inoculation and application of dried algae powder were reported to effectively reduce gall formation and nematode infestation [61]. Many studies have shown the fungicidal effect of extracts from microalgae because they have a beneficial effect in inhibiting the growth of fungi (mold, botrytis, and mildew) and at the same time improve plant growth [62,63].

The applications of *Padina* sp. extracts showed a significant mortality of insect nymphs, in turn they were able to control the mating period and fertility. Therefore, the use of this bioinsecticidal algae could be an alternative for pest management in economically important crops [5,64]. It was demonstrated *in vitro* that the *Anabaena* sp. and of *Ecklonia* sp. inhibited the growth of the colonies, the colony forming units (CFU) and the growth of the CFUs of *Botrytis cinerea* in the strawberry crop, while the polysaccharides of *Jania* sp. they only reduced spore germination of the fungus. All concentrations of Anabaena sp., *Ecklonia* sp. and *Jania* sp. decreased both the infected area of strawberry fruits and the sporulation of the pathogen in the pre-harvest treatment [59]. Other studies reported that extracts from *Laminaria digitata*, *Undaria pinnatifida* (Harvey) Suringar, and *Porphyra umbilicalis* Kützing inhibited both mycelial growth and spore germination of *B. cinerea* [65]. Furthermore, the extract of *Lessonia trabeculata* Villouta & Santelices showed a protective effect against *B. cinerea* in tomato leaves [59,66]. The combination of *A. nodosum* extract and humic acid in *Agrostis stolonifera* L. increased SOD activity and significantly decreased dollar spot disease caused by *Sclerotinia homoeocarpa* F.T. Benn [6]. Hydrolyzed algae extracts sprayed on apple trees reduced red mite populations [6]. The use of Maxicrop (commercial algae-based product) in strawberry plants was observed to greatly reduce the population of red spider mite (*Tetranychus urticae*) [6].

The methanolic extract of *Sargassum swartzii* was shown to show increased bactericidal activity against *Pseudomonas syringae* Van Hall causing leaf spot disease in *Gymnema sylvestre* R.Br. [67] and inhibited the growth of *Xanthomonas oryzaep* v. oryzae, which causes rice blight [4]. Acetone extracts from *Sargassum polyceratium* Montagne showed remarkable activity against different types of bacteria such as *Erwinia carotovora* (Smith). The application of aqueous extracts of *Cystoseira myriophylloides* Sauvageau and *Fucus spiralis* L. in the greenhouse significantly reduced crown gall disease caused by the bacterial pathogen *Agrobacterium tumefaciens* (Smith & Townsend) in tomato [68]. Furthermore, the methanolic extract of *Padina gymnospora* (Kützing) Sonder characterized by a high proportion of palmitic acid showed high antibacterial activity against *Ralstonia solanacearum* (Smith) and *P. carotovora* [69]. By using algae such as *Spatoglossum variabile* Figari & De Notaris *in vivo*, *Polycladia indica* (Thivy & Doshi) and *Melanothamnus afaqhusainii* M.Shameel had significant suppressive effects against root rot fungi, *Fusarium solania* and *Macrophomina phaseolina* in eggplant and watermelon [70]. It was recently revealed that *in vivo* application of powder from *Padina gymnospora*, *Sargassum latifolium* (Turner) C.Agardh and *Hydroclathrus clathratus* (C.Agardh) M.Howe, as soil amendments, decreases the percentage of disease caused by *Fusarium solani* (Mart.) in eggplant [69].

Also in the greenhouse, a significant resistance to the disease caused by *Verticillium dahliae* (Kleb.) In tomato was evaluated using aqueous extracts of the brown algae *Cystoseira myriophylloides*, *Laminaria digitata* and *Fucus spiralis* by application to the whole plant or by imbibition of seeds [68]. By mixing the soil with *Spatoglossum variabile* powders, *Polycladia indica* and *Melanothamnus afaqhusainii* were shown to significantly suppress infection with the nematode *Meloidogyne incognita* (Kofoid and White) in watermelon and eggplant [70]. Commercial algae-based extracts such as *Ascophyllum nodosum* and *Ecklonia maxima* were found to have the potential to adversely affect egg hatching and sensory perceptions when applied *in vivo* against nematodes *Meloidogyne chitwoodi* Golden, O'Bannon, Santo & Finley and *Meloidogyne hapla* Chitwood [71].

CONCLUSIONS

- Macro and microalgae have shown enormous potential as biostimulants, biofertilizers, promoters of plant growth and performance, abiotic stress relievers and biocides.
- The effects caused by the algae extracts in the germination of the seeds, the quality of the fruits and the defense of the plants against pests and pathogens are satisfactory.

For these reasons, the application of these bioproducts in agriculture can be recommended.

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