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Review

An Overview of Biostimulants' Effects in Saline Soils

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Abstract: The unsustainable use of natural resources and their overexploitation continue to be major threats to global agriculture development. This practice increases the abiotic stresses, resulting both in crop yield losses and soil degradation. Low productivity is often associated with salinized soil, which is caused by the toxic and osmotic effects of soluble salt accumulation and, consequently, lack of organic matter. Conversely, there is a need to improve the current crop productivity to meet the increasing food demands. Among the current methodologies proposed to increase plant resistance to abiotic stress, the utilization in crop production of plant biostimulants has been recently proposed. These are organic products mainly based on algae, microorganisms, fulvic and humic acids, proteins, and amino acids that improve physiological plant performance, leading to increased crop productivity. Among their positive benefits, the application of plant biostimulants can also reduce the usage of conventional chemical fertilizers. The aim of this work was to present the effects of different biostimulants on saline conditions. In particular, in this review, we report and critically discuss the most recent research dealing with the effects of the application of plant biostimulants both on crop growth and on plant salinity resistance.

Keywords: biostimulants; salinity stress; plant growth promoter; Arbuscular mycorrhizal fungi; seaweeds; humic substances; higher plant extract

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1. Introduction

Climate change and the growing population are two of the main factors challenging future agriculture worldwide. The Department of Economic and Social Affairs, related to the UN [1], estimated that the global population is expected to reach 9.6 billion in 2050. In the last decades, high temperatures and severe droughts on the one hand, and extremely powerful rainstorms and devastating floods on the other hand, have become the new "normal" weather regime [2,3]. These authors also indicated that these climatic patterns affect large parts of the world, and they are the most important factors in several dry land regions. In addition, agriculture development has often been driven by the more intensive use of chemical fertilizers and synthetic pesticides, which has eroded the quality of land for cultivation [4]. These inadequate practices of land management have induced continuous soil salinization and the loss of organic matter and fertility. Additionally, deforestation, overgrazing by livestock, and overexploitation of the vegetative cover for domestic and (bio)industrial activities worsen the general situation.

Soil salinization is one of the items that most negatively impact plant development and induce land degradation. It is estimated that in the Mediterranean region, about 25% of irrigated agricultural land is affected by salinization, leading to soil degradation and, consequently, lowering potential net primary productivity and accelerating desertification [3]. The increase in soil salt amounts adversely affects both their physical and chemical properties as well as microbiological processes. Saline soil, measured by electrical conductivity (EC), is characterized by the high accumulation of Na^+, Mg^{2+}, Ca^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, and B ions and has negative effects on plant growth [5]. In fact, the accumulation of these ions causes both osmotic stress and toxicity by increasing the assimilation of Na+ ions and decreasing the Na^+/K^+ ratio. A study [6] pointed out that these problems can be due to lower osmotic potential within the plant roots, which affects almost all aspects of plant growth including germination, vegetative growth, and reproduction. Salinity modifies different morphological, biochemical, and molecular features [7]. Toxic ions often increase reactive oxygen species (ROS) accumulation in plant tissues. The generated ROS caused protein denaturation, DNA damage, lipid peroxidation, and carbohydrate oxidation, which impair enzyme function and pigment degradation in plants [7]. Photosynthesis parameters, such as leaf chlorophyll in the form of the light energy conservation rate (Fv/Fm) and coefficients of photochemical quenching (qP and qL), are significantly affected by increases in salinity levels [8]. Accordingly, salinity stress may affect the electron transport rate (ETR), induce the closure of stomata, cause photoinhibition stimulated by excessive light intensity, and thus damage the photosynthetic machinery [9,10]. Other issues are also linked to salinity, e.g., protein synthesis and lipid metabolism are affected [11]. Furthermore, NaCl accumulation affects the integrity of plant cellular membranes [12], increases the electrolyte leakage value, and damages the chloroplast [13] and other cellular components [14]. Plants have developed complex defense mechanisms involving both enzymatic (superoxide dismutase (E.C.1.15.1.1) SOD, ascorbate peroxidase (E.C. 1.11.1.11) (APX), glutathione reductase (E.C. 1.8.1.7) (GR), and catalase (E.C. 1.11.1.6) (CAT)) and non-enzymatic (ascorbate, carotenoids, flavonoids, and other phenolics) antioxidant mechanisms to mitigate the deleterious effects of oxidative damage [15].

A wide range of adaptations and mitigation strategies are required to cope with such an environmental impact. Based on future scenarios, adaptation and mitigation are essential to increase the resilience capacity of agricultural systems in Mediterranean areas and to ensure crop yield and quality stability. However, since the environmental conditions cannot be controlled, except in long-term periods, several strategies on different levels are required such as agronomical procedures and, within them, the techniques that include biostimulant application. The biostimulants are a set of organic materials and/or microorganisms that can enhance water assimilation, nutrient uptake, and resilience to abiotic stresses. They represent an innovative and ecofriendly option for sustainable agriculture goals. Different authors [16,17] have reported that plant biostimulants constitute an emerging class of agricultural inputs that help to improve crop yield and quality since their application also protects from biotic and abiotic stresses [18]. Large categories of biostimulants are used as plant growth promoters (PGPs), plant growth promoter rhizobia (PGPR), Mycorrhiza, seaweeds, composted materials, humic substances, protein hydrolysate, chitosan, and plant extracts. Each category contains a different type and number of microorganisms, which positively affect the plant growth stages. They also contain a wide spectrum of bioactive compounds and molecules, as well macro- and micronutrients, inducing several direct and indirect benefits for cultivated plants. Moreover, their application changes and may impact different agricultural production stages including seed treatments, foliar sprays during growth, and harvested products [19]. A study on this matter [20] reported that since plant biostimulants are characterized by a high complex and different chemical nature, they employ a wide range of biochemical pathways and regulatory networks, which induce their effects in plants. Several biostimulants have been reported to stimulate plant growth by increasing plant metabolism, stimulating germination, enhancing photosynthesis, and increasing the absorption of nutrients from the soil, thereby increasing plant productivity [19].

The present work constitutes an overview on the updates on biostimulants' beneficial effects with a special emphasis on saline soil. The novelty of the present concise review lies in pointing out the recent available data on biostimulants (PGPs, mycorrhiza, seaweeds, composted and humic substances, and plant extracts) with regards to growth traits, physiological properties, biochemical parameters, and molecular features within plants subjected to abiotic stresses, particularly salinity. In fact, the impact of these biostimulants, especially in their combined applications, on plants under abiotic stresses has rarely been highlighted through a review. Therefore, this review summarizes the diverse applications of biostimulants, and it would allow one to design the preparation of a second generation of biostimulants in which synergistic and compatible processes may be practically developed and implemented in future studies.

2. Types of Biostimulants

2.1. Bacterial PGPs

High salt concentration adversely affects important soil processes such as respiration, residue decomposition, nitrification, denitrification, soil biodiversity, and microbial activity [21,22]. Different authors [23,24] pointed out that some main soil biological activities as arylsulphatase (E.C. 3.1.6.1), phosphatase (E.C. 3.1.3.2), dehydrogenase (E.C.1.1), β-glucosidase (E.C. 3.2.1.21), urease (E.C. 3.5.1.5), and CAT were negatively affected by soil salinity. Recent attention has been given to the application of beneficial microorganisms that increase salinity and drought tolerance and consequently improve plant growth [25,26].

The incorporation of PGPs constitutes an ecofriendly biostimulant to promote productivity in degraded soil. In a study on this matter [22], it was indicated that various genera of salt-tolerant plant-growth-promoting rhizobacteria have been isolated from extreme alkaline, saline, and sodic soils. The same authors suggested that many of them are also known to mitigate several biotic and abiotic stresses in plants. The application of PGPR *Arthrobacter endophyticus*, *Zobellella denitrificans*, and *Staphylococcus sciuri* significantly enhanced shoot and root dry weight, leaf area, leaf number, shoot and root K^+ concentration, and relative water content (RWC) in pistachio seedlings [27].

2.1.1. Actions of PGPs in Saline Stress

Microbial biostimulants can be successfully applied to increase both the seedling growth and vigor, and can also affect metabolism, thus helping plants to better adapt in the presence of salt stress [28,29]. PGPs are rhizosphere/endophytic bacteria that colonize the root interior or exterior and provide tolerance to host plants during abiotic stresses. The main actions of PGPs can be summarized as follows.

Antioxidant System

In Figure 1, the general effects of salinity on plants are reported. Salinity can be a stress factor causing physiological disorders, which restricts plant vigor and affects both plant growth and development. Different authors [30,31] pointed out that these disorders cause increases in the volumes of reactive oxygen species (ROS), which change the redox state, cause DNA damage, denature membrane-bounded proteins, reduce membrane fluidity, change the protein formation process, and damage both the enzymatic actions and homeostasis of cells. Therefore, the inoculation of PGPs promotes and increase the efficiency of the detoxification mechanisms since they remove the radicals produced under stress conditions.

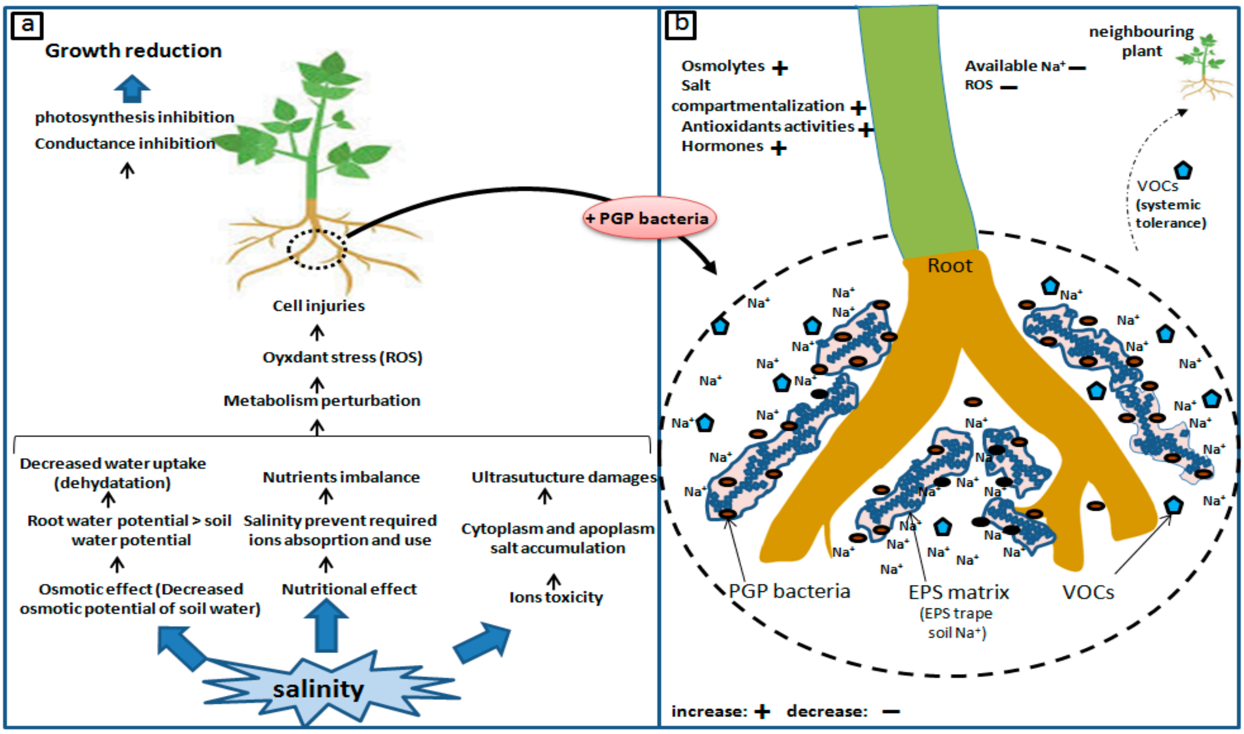

Figure 1. (**a**) General effects of salinity on plants: osmotic, nutritional, and toxic effects. (**b**) PGP bacteria's biostimulant effect in presence of salt stress. Na^+: sodium ions. EPS matrix: exopolysaccharides secreted by PGP bacteria. VOCs: Volatile organic compounds secreted by PGP bacteria. (+): increase; (−): decrease.

Exopolysaccharide Production

Some PGPR are able to secrete exopolysaccharides (EPSs) to protect themselves and, consequently, their plant hosts against environmental fluctuations and other abiotic stresses such as salinity, drought, or heavy metal pollution [32] (Figure 1). EPSs are biological polymers secreted by microorganisms to cope with harsh environmental conditions [33]. They are some of the main components involved in the formation of extracellular biofilm matrices to protect microorganisms from adverse factors such as temperature, pH, antibiotics, and host immune defenses [34]. EPSs consist of repeated units of sugar monomers and some non-carbohydrate substituents, i.e., phosphates, acetyls, succinate, glycerol, or pyruvate, in different ratios, and they have multiple protecting functions. These units are arranged in linear or branched configurations determining their rheological properties. EPSs are classified according to their composition; they are homopolysaccharides when they include the monosaccharides of a single structural unit, heteropolysaccharides when the mosaic is composed of two or more repeating structural units, and polysaccharides when the mosaic is characterized by an irregular structure [35].

According to Morcillo and Manzanera [32], salt tolerance in plants depends on the ability to select ion uptake and homeostasis, discriminating between toxic ions, such as Na^+ and Cl^-, and essential elements, such as K^+ and NO_3^-. The production of EPS polymers by NaCl-tolerant isolates can decrease plants' Na^+ uptake by trapping and thus decrease the amount of available ions [36]. In the same way, the same authors [32] suggested that EPSs have the potential to bind cations including Na^+ and, therefore, limit their uptake by root plants, maintaining a K^+/Na^+ balance. In this sense, another study [37] has demonstrated the beneficial effect of EPSs in alleviating salt stress via sodium chelation in the soil, which makes Na^+ inaccessible to plant roots. Moreover, an EPS polymer prevents nutrient imbalance and osmotic stress and can hence promote the survival of microorganisms and benefit plants.

Volatile Organic Compounds

The Volatile Organic Compounds (VOCs) are lipophilic compounds derived from microbial metabolic pathways characterized by low molecular weight (<300 $gmol^{-1}$), low boiling point, and high pressure. Their releases have a specific profile that includes compounds derived from different metabolic pathways belonging to the alkane, alcohol, ester, ketone, terpenoid, and sulfur families. Different authors [38,39] indicated that these pathways depend on specific environments. These characteristics allow the VOCs to act as signal molecules over short and long distances [40]. Therefore, these volatile gas productions confer systemic tolerance to abiotic stresses by regulating the production of proline, antioxidants, and hormones and reduce the accumulation of sodium ions in plants [41,42] (Figure 1). Subsequently, one of the first papers on this topic [43] pointed out that the volatiles released *Bacillus subtilis,* enhancing growth in the shoot–root biomass of *Ocimum basilicum* L., which increased 2-fold. A further study [44] reported that the 13-tetradecadien-1-ol, 2-butanone, and 2-methyl-n-1-tridecene produced by *Pseudomonas fluorescens* enhanced the growth of *Nicotiana tabacum* L. Other authors [45] reported the key role of the emitted VOCs from the *Pseudomonas simiae* strain in inducing systemic salt tolerance in soybean. The authors specified that this behavior can be a direct consequence of the reduction in the concentration of Na^+ ions in roots and shoots and the induction of proline content in roots. It is also an indirect consequence of the expression of vegetative storage proteins, gamma-glutamyl hydrolase, and RubisCO large-chain proteins.

Osmotic Adjustment

Salinity damages plant growth by causing both osmotic imbalance and ion toxicity (Figure 1). The first osmotic phase occurs immediately when salt concentration increases above a threshold level around the roots [46]. The inoculation of crop plants with beneficial PGP microbes is gaining agronomic importance since these microbes facilitate cultivation under such conditions by improving salt tolerance and hence restoring yield and enhancing resilience during crop cultivation. To overcome osmotic stress, PGPR contribute to osmotic adjustment regulation and ion homeostasis through the modulation of phytohormone status, gene expression, protein function, and metabolite synthesis in plants [46] (Figure 1). Accordingly, other authors [47] reported that PGPR were involved in the accumulation of osmolytes; low-molecular-weight organic compounds such as amino acids, tertiary sulfonium, and quaternary ammonium compounds; sugars; and polyhydric alcohols. These compounds are highly soluble and do not interfere with normal metabolic reactions because they are non-toxic, even at high cellular concentrations. PGPR also improve antioxidant activity, proton transport machinery, salt compartmentalization, and nutrient status and thus reduce both osmotic stress and ion toxicity [46].

2.2. Mycorrhiza

The Arbuscular mycorrhizal fungi (AMF) are some of the most beneficial microorganisms used as biostimulants in agriculture [48]. They are classified as members of the subkingdom *Mucoromyceta* and the phylum *Glomeromycota*, and according to the definition by [49], they include three classes (*Glomeromycetes*, *Archaeosporomycetes*, and *Paraglomeromycetes*). A subsequent study [50] reported that the AMF are beneficial soil microorganisms establishing mutualistic symbioses with the roots of the most important food crops. The authors also indicated that they play key roles in the maintenance of long-term soil fertility and care. The reasons for the widespread use of AMF compared to that of the other beneficial symbionts are that they can establish symbioses with almost all higher plants and are able to grow in a wide range of climatic conditions. In particular, these microorganisms establish symbiotic relations with the roots of all major plant taxa including the most relevant species such as cereals, sunflower, cotton, sugarcane, tobacco, coffee, tea, cocoa, fruit trees, medicinal plants, and, further, economically important vegetables [51]. Several studies, investigating the role of AMF in protection against salt stress, have demonstrated that symbiosis often results in increased growth and nutrient uptake, enhancing the photosynthetic rate, accumulation of osmoregulators, and water use efficiency [28,52,53] (Figure 2). This suggests that salt stress alleviation by AMF results from a combination of nutritional, biochemical, and physiological effects. These effects are summarized in these following subparagraphs.

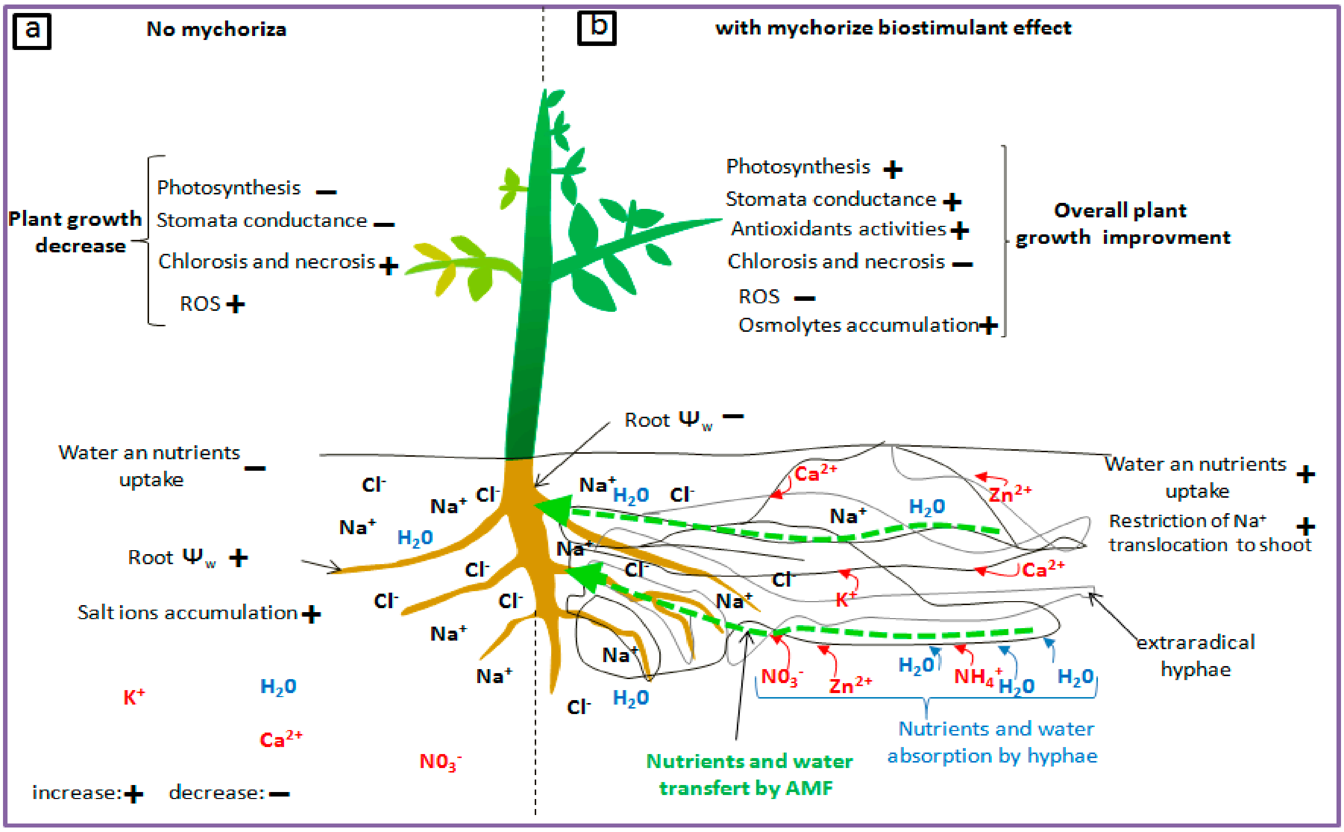

Figure 2. Comparison between (**a**) no-mycorrhiza effect on saline soil and (**b**) mycorrhiza biostimulant effect in mitigating salinity. (+): increase; (−): decrease.

2.2.1. The Effect of Mycorrhiza on Growth and Biomass

The efficiency of different mycorrhiza is generally estimated and interpreted as their ability to increase plant growth and nutrient uptake. Actually, mycorrhization was found to increase the fitness of a host plant by enhancing its growth and biomass [54]. Different studies reported that mycorrhizal fungal symbioses can improve plant growth and yield and enhance tolerance under salt stress in many host plants [29], as pointed out in Figure 2. The authors also highlighted that mycorrhiza-inoculated plants grow better than non-inoculated ones under salt stress. However, the benefit of the fungi-based inoculum to the plant biomass depended on different plant species at varying salinity levels of the growing medium. Accordingly, a study on this subject [55] reported that AMF symbiosis could be a good tool to enhance physiological traits and biomass production under combined low-phosphorus and salt stress conditions during the early developmental stages in *Arundo donax* L. Moreover, it was also determined that under saline growth conditions, AM-inoculated plants have similar biomass compared to non-AM ones in non-saline conditions. Vascular-arbuscular mycorrhiza maintained the plant length and increased the fresh weight of the stem and roots in tomato under salinity stress, but could not influence the dry weight of the stem and roots [56]. Favorable modifications in the morphological parameters of the vegetable crops tomato, aubergine, chili, and okra were observed following the inoculation of plants with AM fungi [57]. Additionally, the root and shoot length, dry weight, fresh weight, number of leaves, and leaf area for each plant were increased, as clearly indicated in Figure 2. Accordingly, inoculation with AMF enhanced the stand establishment rate in cucumber seedlings, especially in salt-stressed grafted plants, by extending their root systems and enhancing the photosynthetic rate [58].

2.2.2. Mycorrhiza's Effects on Plant Water and Nutrient Homeostasis

Salinity increases the electrical conductivity (EC) of a soil solution and thus enhances its osmotic potential, which limits water availability to plants and determines both the reduction water uptake and partial dehydration of the cell cytoplasm [29]. Different authors [59,60] pointed out that elevated Na^+ in soil solution inhibits the uptake of other nutrients by disrupting the uptake of nutrients directly by interfering with various transporters in the root plasma membrane such as K^+-selective ion channels. It also inhibits root growth via the osmotic effects of Na^+ on soil structure. In the same way, the saline–alkaline stress has an effect on the decrease in P uptake because of the possible competition between P and Cl^- absorption [61]. Another study on this topic [62] found a decrease in the K^+/Na^+ ratio with an increasing Na^+ concentration, both in plant shoots and roots, indicating that the saline–alkaline stress interfered with the selective absorption of K^+ and Na^+ in plant tissues and then led to the imbalance of the intracellular K^+-Na^+. On the other hand, salinity affects not only the AMF but also the host plant by hampering the colonization capacity, spore germination, and growth of the hyphae of the fungus [54].

Figure 2 shows how the AMF enhance both the water and nutritional status. The inoculation with *Glomus mosseae* of tomato plants irrigated with saline water significantly increased plant biomass, fruit fresh yield, and shoot contents of P, K, Cu, Fe, and Zn [63]. The plant growth improvements due to AMF inoculation were probably due to the enhanced uptake of nutrients. The increased nutrient uptake observed may be explained by the extraradical hyphae of AMF, which are able to explore several meters away from the nutrient depletion zone, increasing the root surface area and facilitating nutrient absorption by the plants, as reported previously [62,64]. The findings of a study on this topic [29] pointed out the improvement of water use efficiency in salt-stressed inoculated tomato compared to the control seedlings. Different authors [52,65] also indicated an accumulation of osmoregulators improving osmotic adjustment and increasing both hydraulic conductivity and leaf conductance in response to rhizosphere salinity. AMF inoculation can increase the uptake of nutrients in the host plant (*Cucumis sativus* L.) and the K^+/Na^+ ratios in plant tissues and, thus, improve water osmotic homeostasis, even in saline environments [66,67]. It seems that higher K^+ accumulation by mycorrhizal plants under salt stress conditions may help in maintaining a high K^+/Na^+ ratio, thus preventing the disruption of various enzymatic processes and inhibition of protein synthesis [60]. In accordance, a recent study [68] found a restricted translocation of Na^+ from root to shoot in *Leymus chinensis* seedlings colonized by AMF. They reported this restriction to the compartmentalization of this toxic ion thus: (i) First, AMF-inoculated plants could retain Na^+ inside intraradicals in both the fungal hyphae and root cell vacuoles to restrict the transfer of this toxic ion from root to shoot. (ii) Second, AMF symbiosis might trigger the expression of Na^+/H^+ transporters that allow plants to sequester Na^+ in vacuoles and limit its uptake into plant root systems.

2.2.3. Mycorrhiza's Effects on Plant Photosynthetic Attributes

The reduction in plant growth under salt stress could be attributed to the reduction of photosynthesis capacity caused by excessive salt ions [69,70]. The osmotic and toxic effects of salinity significantly damage photosynthetic machinery by reducing stomatal conductance, gas exchange, and enzymatic reactions such as RubisCO activity. Different authors [53,71] found higher intercellular CO_2 concentration values in salt-stressed plants than in those under unstressed conditions. They also indicated that enzymes in the photosynthesis apparatus were destroyed, resulting in a decrease in CO_2 assimilation and its accumulation in intercellular areas. In the same way, salinity damaged photosynthetic pigments, related most likely to a decrease in synthesis and/or both an increase in the degradation of chlorophyll and chlorophyllase activity stimulation [69].

Previous studies have indicated that AMF can give (or induce) salt tolerance to host plants by stimulating enzyme activity protection systems, both increasing photosynthesis capacity and enhancing nutrient uptake [53,72]. Several authors [52,73] indicated that mycorrhizal plants had higher net photosynthetic rates, stomatal conductance, and chlorophyll content compared to non-mycorrhizal plants under saline–alkaline stress. This is reported in Figure 2. The AMF can enhance chlorophyll synthesis in host plants under stress, thereby promoting the potential capacity of carbon fixation [74]. Furthermore, another paper [54] found an improvement in the gas exchange capacity, most likely by maintaining the stomatal opening, reducing stomatal resistances, and increasing the transpiration fluxes of *Leymus chinensis* seedlings inoculated by the AMF *Funneliformis mosseae* and *Rhizophagus intraradices*. Finally, other authors [62] reported improvements in leaf gas processes with increasing nutrient uptake, chlorophyll content, and water use efficiency (WUE) induced by AMF inoculation.

On the other hand, mycorrhizal seedlings (*Salvia fruticosa*) suffered less disorder in the electron transport chain than non-mycorrhizal ones [75]. Thus, the actual quantum yields of photosystem II (PSII) of mycorrhizal seedlings were significantly higher than those of non-mycorrhizal ones under salt stress at 100 and 150 mM NaCl conditions [53]. The authors reported that this efficiency increased the tolerance to moderate stress.

2.2.4. Mycorrhiza's Effects on Plant Antioxidant and Enzyme Activities

To mitigate the detrimental effects of salinity, plants physiologically and biochemically adapt via ion homeostasis-compatible solute biosynthesis, antioxidant enzyme activation, and antioxidant compound synthesis [67] (Figure 2). Salinity operates as a stressor causing physiological disorders, which both restrict a plant's vigor and affect its growth and development. These adverse effects are frequently associated with changes in biochemical activities such as the stimulation of reactive oxygen species (ROS), including non-radicals such as $^1O_2$ and H_2O_2 and free radicals such as $OH^\bullet$ and $O^{\bullet-}{}_2$ [76]. They also affect mostly lipids, proteins, carbohydrates, nucleic acids, and cellular metabolism. A plant copes with salt stress by increasing the production of some osmolytes and antioxidant enzymes, which protect the plant cells from oxidative damage [77,78]. The plant acclimatizes to oxidative damage by deploying different defense mechanisms such as using enzymatic and non-enzymatic pathways to scavenge ROS [79,80]. The importance of antioxidant enzymes is associated with their ability to scavenge ROS, and therefore, they prevent oxidative damage. The antioxidant system includes several enzymes such as SOD, APX, GR, and CAT. The superoxide radicals generated are converted to H_2O_2 by the action of SOD, and the accumulation of H_2O_2 is avoided due to the activities of both APX and CAT [81].

The AMF have the potential to cope with salinity and have a biostimulant effect on plants grown under salt-affected soil. An increase in the activity of antioxidant enzymes and gene expressions of SOD, CAT, APX, GR, monodehydroascorbate reductase (EC 1.6.5.4) (MDHAR), and dehydroascorbate reductase (EC 1.8.5.1) (DHAR) was found in plants inoculated with AMF under salinity–alkalinity conditions, suggesting that AMF induced an effect on ROS. A study on this matter [82] reported that these mechanisms protect watermelon seedlings from extensive oxidative damage while another study [83] pointed out higher activity of SOD, CAT, and APX in plants inoculated with AMF compared to non-AMF ones during salt stress conditions. These results show that AMF symbiosis can help plants protect themselves from the oxidative effects of ROS. SOD, CAT, and APX are metalloenzymes whose activities depend on the availability of micronutrients [54].

2.3. Seaweed Algae

Algae were defined as the autotrophic photosynthetic organisms that are able to colonize both complex and not-complex habitats [84]. There are two main groups of algae. The first one is macroalgae (commonly named seaweed), which are multicellular, marine, or fresh-water organisms, frequently separated into three divisions: brown (*Phylum ochrophyta*, class Phaeophyceae), red (*Phylum rhodophyta*), and green (*Phylum charophyta* and *Phylum* *chlorophyta*) algae [84,85]. The second group is represented by microalgae, which include both blue and green algae present in any aquatic eco-system and in topsoil. Among them, the *Spirulina* spp., *Chlorella* spp., *Dunaliella* spp., and *Haemotococcus pluvialis* have a large economic value [84]. Among the biostimulants, special attention is given to seaweed extracts [86,87]. They are derived through the extraction of several macroalgal species, leading to the production of complex mixtures of biologically active compounds depending on the extraction method [88,89].

2.3.1. Seaweed Composition

The quantity and quality of bioactive metabolites in microalgal extracts largely depend both on the extraction technique and on the microalgal species used [90]. Several studies have shown significant intra-species variation in biomass composition depending on abiotic factors such as light, temperature, minerals, or season production [91,92]. Furthermore, the authors indicated that one of the highest variations occurs due to geographical item and, in particular, where the seaweed has been growing. The main compositions of seaweeds are described below.

Mineral Elements

Seaweeds are an excellent nutrient source, containing high amounts of macro- and micronutrients. In particular, they contain high levels of cations, i.e., macroelements (Na, P, K, and Ca) and microelements (Fe, B, Mn, Ca, Mo, Zn, and Co), that play critical roles in plant development and growth [93]. Furthermore, important minerals are accumulated in seaweeds at levels much higher than in many well-known land sources. The proportions of mineral element content in seaweeds may be dependent on different environmental factors. Several authors [94,95] indicated that these factors are associated with the concentrations of elements in water, interactions between elements, salinity, pH, light intensity, and metabolic factors, such as the dilution of element contents, as a consequence of seaweed growth.

Carbohydrates

Seaweeds also contain large amounts of polysaccharides (as alginate, laminarin, and fucoidan) with important functions for the macroalgal cells including structural functions and energy storage [96]. The total polysaccharide concentrations in macroalgae range from 4 to 76% of dry weight (DW), with the highest contents described in *Ascophyllum*, *Porphyra*, and *Palmaria*. However, other green species, such as *Ulva*, showed contents of up to 65% on a DW basis [97]. In any case, the composition of seaweeds depends not only on the species being studied but also on the time of collection and habitat and on external conditions such as temperature, light intensity, and nutrient concentration in water [98].

Protein

Protein concentration ranges from 5 to 47% of DW (basic). Its value depends particularly on both the species and the environmental conditions. Seaweed protein is a source of all amino acids, especially glycine, alanine, arginine, proline, glutamic, and aspartic acids [99]. In a recent study [100], it was highlighted that seaweeds are rich in protein, with an excellent amino acid profile comparable to those of the other conventional protein sources. These authors also reported that protein contains bioactive components such as free amino acids, peptides, lectins, and phycobiliproteins including phycoerythrin and phycocyanin. In the most seaweeds, the aspartic and glutamic acids constitute, together, a large part of the amino acid fraction (between 25 and 30% of total amino acids) [101].

Lipids

Despite the low total lipid concentration that seaweeds contain, these lipids have substantial importance due to the presence of essential unsaturated fatty acids [102,103]. Generally, the lipid profiles of seaweeds differ across species [102], and therefore, there is a need to evaluate different seaweed species to understand their potential for industrial application, exploitation, and production [103]. On average, seaweeds have a lipid amount that is between 0.61 and 4.15% of their DW. However, other authors [104] have indicated that some seaweed species can present higher values, being considered good sources of unsaturated fatty acids. The fatty acid content depends on the seaweed's habitat, harvest season, and genetics [105].

Phytohormones and Vitamins

In a study [106], it was indicated that seaweeds contain phytohormones. Their chemical entities, biosynthetic pathways, signal transduction mechanisms, and physiological roles were sufficiently unraveled in this study. Other researchers [107,108] reported that a liquid macroalgae extract contained plant hormones and that the solid extract contained essential elements allowing yield increases in several species of plants. The active concentrations of growth regulators in plants are very low and generally have a range of 10^{-10} to 10^{-6} mol kg^{-1} [109]. According to these authors, the brown algae have been identified as the main sources of plant growth regulators because of their high content of active compounds and high availability throughout the year. Other authors [110] reported two red seaweeds, i.e., *Pyropia yezoensis* and *Bangia fuscopurpurea*, that contain indol acetic acid (IAA) comprising 101.7 and 11.5 ng g^{-1} dry weight (DW) and abscisic acid (ABA) comprising 1.2 and 1.3 ng g^{-1} DW, respectively.

On the other hand, seaweeds are a good source of some water- (B1, B2, B12, and C) and fat-soluble (β-carotene with vitamin A activity, and vitamin E) vitamins [111]. Another study [112] pointed out that when a cucumber plant was treated with an extract of *Macrocystis pyrifera*, it showed significant increases in total phenols, antioxidant capacity, and vitamin C in the fruits. More specifically, the highest content was found in brown and green algae [111,113], with concentrations of 0.5 and 3.0 mg g^{-1} dry weight (DW) and red algae containing between 0.1 and 0.8 mg g^{-1} DW [114].

Antioxidant Compounds

Seaweeds are valuable sources of bioactive compounds, antioxidants, and vitamins that could be used as functional ingredients [115]. Antioxidant compounds play an important role in deterring harmful factors, and therefore, they are potential biostimulants for industrial application, exploitation, and production. The antioxidant activity of seaweeds is due to the presence of pigments including chlorophylls, xanthophylls (fucoxanthin), carotenoids, vitamins (vitamins B1, B3, C, and E), vitamin precursors (α-tocopherol, β-carotene, lutein, and zeaxanthin), phenolics such as polyphenols (gentisic acid, phloroglucinol, gallic acid, and protocatechuic acid), flavonoids (rutin, quercetin, myricetin, flavones, flavonols, flavanones, chalcones, hesperidin, flavan-3-ols, isoflavones, and methylated flavones), lignins, tocopherols, tannins, phenolic acids, hydroquinones, phospholipids (particularly phosphatidylcholine), terpenoids, peptides, and other antioxidative substances, which directly or indirectly contribute to the inhibition or suppression of oxidation processes [115–118]. However, the variation in the composition of biologically active compounds in seaweeds depends on the environmental growth factors. This variation induces the variability of the composition of seaweeds within the same species across the world.

2.3.2. Seaweeds' Effects

Algae extracts are widely known as substances used both to reduce abiotic stress and to increase plant productivity. Algae extracts are biostimulants rather than fertilizers since they stimulate defense and growth response when applied to plants [119]. Seaweed extract reduced the effects of abiotic stress at early stages and increased potassium (K) and calcium (Ca) concentrations in leaves [120] (Table 1). Seaweeds reduce the uptake of Na^+ and induce the accumulation of stress-related compounds, such as glucosinolates, terpenoid phytoalexins, and jasmonates, as reported in a study [121]. *Padina gymnospora* seaweed increased the length, area, and fresh weights of tomato, and the proline osmolyte and flavonoid contents [122]. Additionally, this seaweed stimulated the photosynthesis apparatus via an enhancement of the photochemical quantum efficiency of PSII (Fv/Fm) and a photosynthetic pigment. In the same way, a recent study [123] pointed out that *Sargassum* improved photosynthetic pigments, non-enzymatic antioxidants, proline osmolyte content, the activity of antioxidant enzymes, and the expression of defense genes. *Kappaphycus alvarezii* (red algae) seaweed increased osmoprotectant content and inversely reduced electrolyte leakage, malondialdehyde (MDA) content, the volume of reactive oxygen species, superoxide, and peroxide contents [124]. These authors reported significant phytohormone (abscisic acid, cytokinin, and auxin) regulation by *Kappaphycus alvarezii* application and an increase in antioxidant activity. Similarly, an enhancement of the enzymatic activities of CAT, APX, and guaiacol peroxidase (EC 1.11.1.7) was observed in an okra plant when it was subjected to *Sargassum wightii* application [125]. According to a study [119], seaweeds have also phytoelicitor activity as their components cause defense responses in plants that contribute to resistance against several pests, diseases, and abiotic stresses including drought, salinity, and cold. This is certainly a promising and sustainable approach that farmers can incorporate into their farming systems, even in integrated crop management, since efforts can be made to minimize chemical pesticide utilization by replacing synthetic inputs with seaweed extracts/products.

Table 1. Seaweed biostimulant effects.

Biostimulant	Plant	Effects	Reference
Ascophyllum nodosum	Avocado (*Persea americana Mill.*)	-improved nutrient uptake of Ca^{2+} and K^+	[120]
seaweed extracts	Lettuce (*Lactuca sativa* L.)	-reduced Na^+ uptake -accumulation of stress-related compounds such as glucosinolates, terpenoid phytoalexins, and jasmonates	[121]
Padina gymnospora	Tomato (*Solanum lycopersicum* L.)	-increase in the length, area, and fresh weights of shoots and roots -increase in ETR_{MAX}, the photochemical quantum efficiency of PSII (Fv/Fm), and a photosynthetic pigment (chlorophyll) -increase in the proline osmolyte and flavonoid contents -early flowering and an increase in yield	[122]
Sargassum spp.	Tomato (*Solanum lycopersicum* L.)	-increase in photosynthetic pigments, nonenzymatic antioxidants, and proline and the activity of antioxidant enzymes -increase in expression of defense genes	[123]
Kappaphycus alvarezii	Wheat (*Triticum durum*)	-increased root length, enhanced chlorophyll content and carotenoids, and greater tissue water content -increase in osmoprotectants such as total proteins, proline, amino acids, and soluble sugars -regulation of phytohormones abscisic acid, cytokinin and auxin	[124]
Sargassum wightii	Orka (*Abelmoschus esculentus*)	-overaccumulation of glycine betaine -growth-promoting metabolites and hormones -Modulation of ionic contents (Na^+, K^+, Ca^{2+}, and Mg^{2+}) and ratios (K^+/Na^+, Mg^{2+}/Na^+, and Ca^{2+}/Na^+) -increased levels of carbohydrates, proteins, lipids, carotenoids, and proline -enhancement of enzymatic activities of catalase, ascorbate peroxidase, and guaiacol peroxidase	[125]

Table 1. *Cont.*

Biostimulant	Plant	Effects	Reference
Lessonia nigrescens	Wheat (*Triticum durum*)	-decreased membrane lipid peroxidation and increased chlorophyll content -improved antioxidant activities -coordination of efflux and compartmentation of intracellular ions	[126]
Grateloupia filicina	Rice (*Oryza sativa* L.)	Enhanced synthesis of soluble sugars and polysaccharides	[127]
Sargassum horneri extract	Tomato (*Solanum lycopersicum* L.)	-improved photosynthetic capacity -increased plant yield -shortened fruit-ripening time	[128]
Ascophyllum nodosum	Tomato (*Solanum lycopersicum* L.)	-fruit yield improvement	[129]
Ascophyllum nodosum	*Arabidopsis thaliana*	-modulation of a range of processes at the transcriptomic, metabolic, and lipid levels allowing tolerance to oxidative stress	[130]
Ascophyllum nodosum	Tomato (*Solanum lycopersicum* L.) and sweet pepper (*Capsicum annuum*)	-improved germination percentage and growth parameters including the root and shoot lengths of a seedling	[131]
Ascophyllum nodosum	Asparagus (*Asparagus aethiopicus*)	-both the transpiration and photosynthetic rates as well as the stomatal conductance were enhanced -increase in expression of several genes responsible for water management -secondary metabolite production and antioxidant accumulation -transcriptional and metabolic regulation of environmental stress	[132]

2.4. Composted Material and Humic Substances

The adverse climate conditions have led to a reduction in the organic matter content in soils, resulting in their productivity being limited. In addition, inadequate agriculture management and practices, such as irrigation with poor quality water, are some of the main factors resulting in salt accumulation and decreasing agricultural productivity. These practices induced the excessive accumulation of salt amounts, which adversely affected both the physical and chemical properties of soil as well as the microbiological processes [23]. The World Bank states that the soil salinization caused by inappropriate irrigation practices affects about 60 million hectares, or 24% of all irrigated land worldwide [133]. The Food and Agricultural Organization of the United Nations (FAO) recognizes the need to preserve soil resources from degradation and to boost healthy soils and has established a program on soil organic carbon mapping to support countries and improve soil governance at the global, regional, and national levels [134,135].

A potential solution involves the implementation of both composted materials and humic substances in agriculture as there is a growing demand for their utilization. These substances may enrich saline soil with organic matter, and most likely play crucial roles in soil characteristic improvement. Consequently, these biostimulants offer substantial benefits to plants under salinity stress.

2.4.1. Composted Wastes

Composting is the natural process of recycling organic matter, such as crop residues, agro-industrial wastes, and food scraps, into a valuable organic material that can be used as fertilizer to sustain the plant production of different crops and maintain or improve soil organic content. Anything that grows at the end could transform into compost. The composting process simply speeds up its natural process by providing an adapted environment for bacteria, fungi, and other decomposing organisms (such as worms, sowbugs, and nematodes). The result is a stable organic material, which can be used as soil conditioner and fertilizer to improve microbial activities [136] and consequently induce growth stimulation. The application of these composted wastes became a common practice in different salt-affected areas in the last few decades, and it represented an important way both for soil regeneration and for fertility enhancement [137,138]. The repeated application of MSW (municipal solid waste compost) consistently increased soil organic matter content, brought the soil C/N ratio to levels greater than those of unamended soil [139], and created a better resilience to extreme weather events [140].

2.4.2. Humic Substances

Humic substances (HSs) are complex natural organic compounds in soils that are derived from plant and animal residues by a process called "humification". They are complex aggregates of brown-to-dark-colored amorphous substances, which have originated during the decomposition of plant and animal residues by microorganisms, under both aerobic and anaerobic conditions, in soils, composts, peat bogs, and water basins. Soil HSs constitute a significant fraction of the soil organic matter (about 65–70%) as reported by several authors [141,142]. Based on their solubility, HSs can be classified into humic acids (insoluble below pH 2 value), fulvic acids (soluble at any pH), and humin (insoluble in water).

HS applications provide many benefits for agricultural soil including an increased ability to retain moisture, a better nutrient-holding capacity, a better soil structure, and a higher level of microbial activity.

2.4.3. Effects of Composted Materials and Humic Substances on Saline Soil

The input of both composts and HSs as plant biostimulants under saline soil improves soil characteristics and consequently has a positive effect on plant growth. Table 2 summarizes some examples of the effects of composted materials and humic substances. These biostimulants have indirect and direct effects on both soil and plants. In particular, the indirect effects refer to the changes in the chemical and physical properties of soil and the rhizosphere while the direct ones indicate the actions on plasma membrane (PM)-bound activities and plant metabolic pathways [143].

Indirect Effect: Improvement of Soil Characteristics

As reported previously [138], one of the most important problems with saline soils is the excess of Na^+ that constitutes a highly dispersive agent, resulting directly in the breakup of aggregates. Consequently, it contributes to repulsive charges that disperse clay particles. Both composts and HSs enrich the soil and rhizosphere with complex organic molecules called 'humus'. The beneficial effects of composts on affected soil properties depend mainly on both soil texture and moisture conditions. HSs increase soil aggregation, water retention, infiltration rate, and water-holding capacity [144,145]. When they are applied to clay soils, humic acids can help break up compacted soils, allowing for the enhancement of water penetration and better root zone growth and development [146]. Moreover, the application of organic matter promotes the flocculation of clay minerals, which is an essential condition for the aggregation of soil particles, allowing an increase in the oxygen diffusion rate for soil microorganisms [23]. On the other hand, when they are applied to sandy soils, the HA add essential organic materials necessary for water retention, thus improving root growth and enhancing sandy soil's ability to retain and not leach out important and essential plant nutrients [146]. Furthermore, in saline–alkali soils, humic acid adsorbs soluble salts from soil, obstructs unfavorable cations, and decreases both salt concentration and soil pH. Such substances have the potential to mitigate the acidity and salinity of the soil and act as a natural chelator for metal ions under alkaline conditions [145]. In this matter, Khaled and Fawy [146] suggested that the HA are also especially important because of their ability to chelate micronutrients, thus increasing their bioavailability. They exchange H^+ ions with Na^+ in the soil, thereby causing a decline in Na^+ content and increasing H^+ levels as pointed out by several studies [142,145,147]. As a consequence, both soil pH and the sodium adsorption ratio (SAR) are reduced. Accordingly, HSs decrease soil Na^+, EC, and pH, probably due to high supplies of Ca, Mg, and K, which hold the cation-exchange sites on soil particles, restrict the Na^+ adsorption, and thus enhance Na^+ leaching losses during precipitation events [138,145].

Direct Effect: Growth Stimulation

The results of a study on growth stimulation [148] highlighted the presence of key functional groups in HSs that might induce positive local and systemic physiological responses. The predominant plant physiologic adaptation triggered by HA involves the stimulation of the plasma membrane proton pump [149]. This modulation influences the cellular electrical environment and ion fluxes [150]. This behavior occurs due to a complex network of hormone-like signaling pathways. In a paper on this matter [151], the authors found an increased root biomass in *Urochondra setulosa*, suggesting the hormone-like nature of HA, which helps in the proper uptake and transport of essential nutrients under saline conditions. In a previous work [152], it was found the hormone-like activity following HA was applicable, and the authors explained this behavior with the presence of the indoleacetic group in its structure. The findings obtained by another study [153] also showed that the HS in the study induced lateral root formation via auxin-like activity, as confirmed both by the activation of the auxin synthetic reporter DR5::GUS and the enhanced transcription of the early auxin responsive gene IAA19. The HA application may induce changes in the ion balance and other physiological adjustments such as the accumulation of osmoprotectant compounds or enzymatic and non-enzymatic scavenge activity [154,155]. The application of humic substance-based biostimulants for plants subjected to saline stress showed a capacity for osmotic adjustment by maintaining both water absorption and cell turgor [156,157]. In the same way, an increase in soluble sugars and proline mediated by HA was reported in a recent study [151], as organic compounds can act like antioxidants and protectants of cellular membranes. Plants treated with HSs have been shown to induce changes in root morphology and modulate plant membrane activities related to nutrient acquisition, pathways of primary and secondary metabolism, and hormonal and reactive oxygen balance [143,152]. HSs can act on plant phenols and secondary metabolism as ways to improve stress protection. The phenylpropanoid biosynthetic pathway is activated under abiotic stress conditions (salinity, drought, heavy metal, . . .) resulting in the accumulation of various phenolic compounds [158]. Previous research [159] pointed out that HA not only promotes phenol content but also stimulates the activity of phenylalanine ammonia-lyase, an enzyme crucially involved in the phenylpropanoid pathway at the gene expression level. Correspondingly, HSs activates the same antioxidative pathway, stimulating the production of vitamin C and E, as a protective action during intense metabolic activities [160]. Additionally, it stimulates the antioxidant defense system, resulting in the reduction in the ROS volume [161].

Furthermore, it has been demonstrated by other authors [162] that leaf application of HA solution increased K, Mn, and Zn contents in the studied plant, thus suggesting that HA enhanced the absorption of these three elements. HA enhanced the soil's N, P, K, Ca, Mg, Fe, Mn, Zn, Cu, and B availability and microbial activity, allowing improvements in lime tree growth, canopy size, leaf chlorophyll, and nutrient contents under stress conditions [163]. In this matter, it was also reported that there was an improvement in both dry weight and the uptake of mineral elements under NaCl treatments following the foliar application of HA at 0.1% [146]. The HA also increased photosynthesis photochemical quenching (qP), evapotranspiration (ETR), and the efficient quantum yield of PSII (YII), as well as led to a decrease in light-regulated non-photochemical energy dissipation Y (NPQ) in concomitance with lower Na^+ content and less leaf damage in *Urochondra setulosa* under salt stress [151].

On the other hand, seed priming using stress-alleviating chemicals has proven to be an efficient approach in triggering salt tolerance mechanisms in treated plants [164]. HSs have emerged as highly promising priming factors, being extensively tested in various crops due to their remarkable capacity to enhance plant development and increase tolerance to abiotic stress [165]. Priming plant seeds with HA exerts a beneficial influence on their hormonal-signaling pathways and enhances the activity of various functional and regulatory stress-responsive genes [166].

Table 2. Composted materials and humic substances: biostimulants effects.

Biostimulant	**Plant**	**Effects**	**Reference**
Humic acid	*Urochondra setulosa*	-improves water/mineral uptake, leaf Na^+ secretion, and selective K+ transport -increase in leaf pigments, helping to alleviate the negative effects of salinity on chlorophyll fluorescence parameters: improvement of maximum quantum yield of photosystem II, photochemical quenching (qP), and electron transport rate (ETR) at high salinity	[151]
Humic acid	Maize (*Zea mays*) and tomato (*Solanum lycopersicum*)	-Changes ion balance -Promotes plasma membrane proton pump activity -Enhances photosynthesis rate and plant growth -High transcription level of salt responsive genes and transcription factors even before salt exposition	[155]
Humic acid	Maize (*Zea mays* L.)	-humic fraction induces changes in phenylpropanoid metabolism -stimulation of the activity of phenylalanine ammonia-lyase at the gene expression level	[159]
Compost	Tomato (*Solanum lycopersicon* L.)	-increase in nutritional status -greater accumulation of osmoprotectants such as soluble sugars and amino acids -accumulation of metabolites involved in modulating salinity	[167]
Compost	Date Palm (*Phoenix dactylifera* L.)	-improvement in K^+ and proline content -decrease in H_2O_2 concentration	[168]
Compost	Alfalfa (*Medicago sativa*)	-increases plant productivity in sandy clayey soils -increase in N and P contents	[169]
Compost and farmyard manure	Barley (*Hordeum vulgare* L.)	-increases soil organic matter, cation exchange capacity, and available P, Ca, Mg, and K -improvemnt of grain yield and nutrients contents	[170]
Compost	Quinoa (*Chenopodium quinoa*)	-improves soil water-holding capacity and nutrient availability -enhances plant antioxidative defense system	[171]
Humic acid	*Bean* (*Phaseolus vulgaris*)	-increases in growth parameters and leaf pigment contents -increase in ascorbic acid content, glutathione (GSH) content, proline content, K content, and volume of antioxidant enzymes -reduction in Na content, H_2O_2, and $O_2{}^{\bullet -}$	[172]
Humic acid	common sage (*Salivia Officinalis* L.)	-improves the yield components and salt resistance index -increase in total chlorophyll content and volatile oil production	[173]

2.5. Higher Plant Extracts

2.5.1. Plant Extract Composition

Plant extracts (PEs) are considered to be some of the most important sources of biomolecules that can be screened from plant parts [174]. Plant extracts are the concentrates of plants and could be prepared using any part of a plant, i.e., seeds, roots, stems, leaves, bark, flowers, etc., as pointed out in different past [175,176] and recent [177] studies.

Conventionally, PEs are prepared through maceration [177]. Then, the extraction is performed in some solvent, either hydrous or organic. For aqueous extraction, the desired plant part is macerated or processed mechanically in deionized H_2O, and this is followed by its purification and centrifugation. In organic solvent extraction, the desired plant part is homogenized in an organic solvent, generally ethanol, and this is followed by fractionated extraction with hexane, ethyl acetate, and/or butanol-like solvents [177]. Plant extract composition changes largely with plant species and growth conditions. It contains a different range of chemicals, such as terpenoids, phenolic compounds, alkaloids, glucosinolates, and various organic acids, as reported by recent research carried out with different plants and environments [177–179]. The extraction of such biomolecules through plants is accomplished by using various solvents and methods of extraction [174].

2.5.2. Plant Extract Effects

The biological activity of these chemicals can improve the growth and development of crops under stress conditions. Plant extracts can affect primary or secondary metabolism and mechanisms involving phytohormones and antioxidants, and can modulate phytohormone metabolism as pointed out by several authors [176,180–183]. These authors also reported the effects of plant extracts on water and nutrient uptake, enzyme function, photosynthesis, gene expression, signal transduction, antioxidant defense system, stomatal conductance, and leaf senescence. Consequently, these natural extracts could be considered as promising ecofriendly strategies to mitigate salinity [177]. Table 3 presents some biostimulant effects of plant extracts. The root and leaf–root application of the biostimulant in one study increased fresh yield, dry biomass, and the root dry weight of lettuce under salinity conditions in concomitance with an improvement of plant nitrogen metabolism and an increase in the Fv/Fm-ratio efficiency in biostimulant-treated plants [184]. The application of *Crataegus oxyacantha* L. extract on tomato plants under salt stress has been shown to neutralize the NaCl effect by increasing the physiological parameters of the plants [185]. A paper on this matter [186] revealed the presence of three hydroxycinnamic acids (p-coumaric, caffeic, and ferulic acids) in addition to two simple phenolic compounds (the p-hydroxybenzoic and syringic acids) in corn treated with spelt husk extract that may lead to a significant increase in both shoot growth and height compared to plants treated with NaCl only.

For example, Silymarin (Sm) has recently been used to support stressed plants. It is extracted from the *Silybum marianum* L. plant as an essential secondary metabolite and used individually or as an additive to enrich a biostimulant [187]. It combines six flavonolignans as ingredients: silybin A and B, isosilybin A and B, and silychristin and silydianin, along with taxifolin [188]. These authors found an important plant improvement following the exogenous application of a Silymarin-and-honey mixture in order to feed and encourage chili pepper growth under NaCl salinity stress. This mixture positively affected the growth parameters, metabolism, components of the antioxidant defense system, and fruit yield under normal and salinity conditions. These effects are probably due to the rise in the plant's resistance to stress.

Accordingly, exogenous Moringa plant extract application exhibited a high stimulator on plant height, spike length, flower numbers, shelf-life corm weight, and size in *Gladiolus grandiflorus* L. [189]. The leaves of this plant are rich sources of vitamin A and C, calcium, β-carotene, riboflavin, iron, phenolics, and antioxidants [190]. The Moringa leaf extract is also a rich source of growth regulators, e.g., zeatin, phenolics, ascorbate, and mineral nutrients [191,192]. The application of Henna *Lawsonia inermis* L. leaf extract at

1.0 g L^{-1} dose using a combination of seed priming and foliar spray can be recommended as a nonpolluting, inexpensive, promising biostimulant; it can effectively enhance wheat growth, biochemical traits, and productivity, as well as improve the quality of the yielded grains [193].

Other authors [194] reported an important biostimulator effect of *Rosmarinus* extract, which induced salt resistance in 30-day-old maize seedlings, with beneficial effects in the maintenance of a higher photosynthetic efficiency and the strengthening of the antioxidant system under salt stress conditions. Finally, in accordance, the plant response to salinity was affected by a biostimulant, involving the processes related to oxidative stress mitigation, osmotic adjustment, and the hormone network, as well as the sterols, terpenes, and the glucosinolate profile, resulting in greater crop performance [184].

Table 3. Plant extracts: biostimulants effects.

Biostimulant	**Plant**	**Effects**	**Reference**
Crataegus oxyacantha extract	Tomato (*Solanum lycopersicum*)	-increase in plant growth, photosynthetic pigment contents, and amounts of soluble sugars and amino acids -improvement in the antioxidant enzyme activities of superoxide dismutase (SOD), glutathione peroxidase (GPx), glutathione S-transferase (GST), and glutathione reductase (GR)	[185]
Lawsonia inermis L. extract	Wheat (*Triticum aestivum* L.)	-both 0.5 and 1.0 g/L doses enhanced the growth of shoot and root systems -enhancement of quality of yielded grains as revealed by increasing the content of soluble sugars (23%), starch (19%), gluten (50%), and soluble proteins (37%), as well as amylase activity (27%) -Increases in amounts of total phenolics, favonoids, and tannins (67, 87, and 23%, respectively) -Increase in the levels of different phytohormones, soluble sugars, and favonoids (quercetin, resveratrol, and catechin).	[193]
Aqueous garlic bulb extract	Eggplant (*Solanum melongena* L.)	-Improved plant growth, morphology, and biomass and enhanced antioxidant enzymes (superoxide dismutase (SOD) and peroxidase (POD)) -Improved photosynthesis and chlorophyll abundance, observed at vegetative, first-flowering, and fruit-setting stages	[195]
Mangosteen (*Garcinia mangostana*) pericarp extract	mungbean (*Vigna radiata* L.)	Improved plant height, leaf area, yield components and yield	[196]
Moringa (*Moringa oleifera* and *Moringa peregrena*)	sweet basil (*Ocimum basilicum* L. cv. cispum)	-Increase in shoot length, dry weight, number of branches, root length, and root dry weight -increase in anthocyanin, total carbohydrate, and superoxide dismutase contents -increased ascorbic acid oxidase content	[197]
Licorice (*Glycyrrhiza glabra*) root extract	Pea (*Pisum sativum*)	-pretreatment enhanced seedling growth and photosynthetic attributes (chlorophylls, carotenoids, Fv/Fm, Pn, Tr, and gs) -increased amounts of ascorbate and glutathione and their redox states, proline, soluble sugars, and α-TOC and increased enzyme activities -upregulated transcript levels of CAT-, SOD-, APX-, GR-, DHAR-, and PrxQ-encoding genes -decreased oxidative stress and Na^+ and Cl^- contents; increased K^+ content and K^+/Na^+ ratio	[198]

Table 3. *Cont.*

Biostimulant	Plant	Effects	Reference
Ocimum basilicum leaves extract	Faba bean (*Vicia faba*)	-increased the activity of antioxidant enzymes -increased levels of osmolytes (soluble sugar and soluble protein) -ion content increase (K^+, Ca^{2+}, and Mg^{2+})	[199]
Yeast and carrot (*Daucus carota*) extracts	Maize (*zea mays*)	-improve protection of the photosynthetic pigments, chlorophylls, and carotenoids -primed plants restricted Na^+ accumulation in both roots and shoots while maintaining a higher K^+ content and lower Na^+/K^+ ratio -production of osmolytes: accumulating of total free amino acids and soluble sugars, especially in the roots -enhanced levels of ascorbic acid and phenolic compounds and activities of reactive oxygen species-detoxifying enzymes superoxide dismutase, catalase, and ascorbate peroxidase, with a concurrent reduction in lipid peroxidation in the leaves	[200]
Licorice (*Glycyrrhiza glabra*) root extract	Bean (*Phaseolus vulgaris* L.)	-decreases in electrolyte leakage (EL) and amounts of malondialdehyde (MDA), Na^+, hydrogen peroxide (H_2O_2), and superoxide radical ($O_2^{\bullet-}$) -increases in growth and yield parameters, photosynthetic pigments, and levels of free proline, total soluble carbohydrates (TSC), total soluble sugars (TSS), nutrients, and selenium (Se); increased ratio of K^+/Na^+, relative water content (RWC), membrane stability index (MSI), and activities of all enzymatic antioxidants	[201]

3. Conclusions and Future Remarks

The utilization of different kinds of biostimulants appears to be growing in both conventional and sustainable agriculture and, as a consequence, more and more research is being carries out on this topic. Research ranging from a variety of different plants demonstrates that biostimulants have the capacity to improve plant growth and development. Furthermore, since there are unavoidable effects of abiotic stress (in particular, salinity) due to soil pollution, the intensity of production, and climate change, the application of biostimulants may provide a possible solution in cropping systems, increasing the resilience of cultivated plants. Therefore, biostimulant products are expected to be regularly used by farmers in the near future, and we also expect that the industry will supply high- quality and reliable inoculants. This is an important future remark that can spread, more and more, this agronomical practice.

In fact, to have a large application and ensure the positive results of biostimulant application, we have to consider a large number of factors (different effects among crop species, different levels of soil salinity, different environments, etc.) that can open an array of possibilities for the fine tuning of these products. As pointed out throughout this review, a lot of research has been carried out to further this understanding; however, this matter still has a long way to go, and other research should be conducted. In particular, it is important to develop a collective collaboration within the scientific community to better understand the potential of these products in order to enhance agricultural sustainability, increase food security, and enhance the resilience of crop production in the presence of climate change.

Finally, this review highlighted that biostimulants can significantly improve sustainable agricultural production, enhancing plant tolerance to abiotic stress, improving nutrient uptake, and increasing crop production. The utilization of biostimulants is not only an environmentally friendly practice, but it is also a promising method that can improve the efficiency of natural resources to reduced agrochemical inputs, both in sustainable and conventional farming.

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