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Review

Effects of Biostimulants in Horticulture, with Emphasis on Ornamental Plant Production

Szilvia Kisvarga, Dóra Farkas *, Gábor Boronkay, András Neményi and László Orlóci

Research Group of Ornamental Horticulture and Green System, Institute of Landscape Architecture Urban Planning and Garden Art, Hungarian University of Agricultural and Life Sciences (MATE), 1223 Budapest, Hungary; kisvarga.szilvia@uni-mate.hu (S.K.); boronkay.gabor@uni-mate.hu (G.B.); nemenyi.andras.bela@uni-mate.hu (A.N.); orloci.laszlo@uni-mate.hu (L.O.)

* Correspondence: Farkas.Dora@uni-mate.hu

Abstract: The biostimulant segment is becoming increasingly important worldwide. One of the reasons for this is that fewer plant protection products are placed on the market in the European Union, and environmental sustainability also plays an important role in their use. Biostimulants are often used in several horticultural sectors, including ornamentals, to strengthen plants, achieve commercial standards, produce quality goods, increase plant vitality, and aid harvesting. This paper presents the latest results of the use of biostimulants in horticulture, with special emphasis on ornamental plant production. The legal regulation of biostimulants and their regulatory mechanisms are described in detail in the review. The main groups of biostimulants are also discussed. The response of plants to abiotic stress, in particular physiological, anatomical, and genetic changes, with regard to the application of biostimulants is also detailed. Focus is given to the areas of ornamental crop production, such as sexual and asexual propagation, cultivation, and harvesting, where biostimulants are used.

Keywords: biostimulant; humic and fulvic acids; abiotic stress tolerance; seaweed extracts; ornamental; horticulture

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1. Introduction

Biostimulants can be defined as small amounts of organic or inorganic matter that promote the growth and development of plants in a way that they would not be able to perform without the addition of these compounds. They can also be referred to as 'positive growth regulators' or 'metabolic enhancers' [1]. The term 'plant biostimulant' was first used by Zhang and Schmidt [2], and the industry based on it began to evolve, as did the materials and technologies used. Calvo defined in 2014 [3] that all substances and microorganisms that are beneficial to the plant are considered biostimulants. A year later, in 2015, Du Jardin [4] mentions that the definition of biostimulants is based on what is not a biostimulant rather than what is. For example, fertilizers and pesticides increase plant yields but are not biostimulants.

In the United States, the Coalition of Biostimulants defines biostimulants as substances, including microorganisms, which, when applied to a plant, seeds, soil, or growing media, enhance the nutrient uptake capacity of plants and are beneficial to plant development. Biostimulants are also defined as non-plant nutrients and, therefore, cannot be characterized by nutrient claims [5]. Although they affect growth and development, they also increase resistance to abiotic stress [4]. In 2016, the European Commission classified biostimulants in the CE category, according to which they are fertilizer products that help the growth and development of the plant regardless of the amount applied [6]. In 2018, as defined by the Council of the European Union as an amendment to the definition, they should have one of the effects on the plant rhizosphere, in addition to those described above as follows:

(i) more efficient nutrient use, (ii) tolerance to abiotic stress, or (iii) effect on crop quality and (iv) availability of confined nutrients in soil or rhizosphere [7].

Recently, the agricultural sector has faced the challenge of increasing productivity by feeding a growing global population, mainly by increasing resource efficiency while reducing adverse impacts on ecosystems and the human body [8]. One way to reduce fertilizer use without compromising plant nutrition is to increase nutrient uptake by plants using biostimulants [9]. Their use has become common in agricultural and horticultural practices [10]. Their effects are still largely unknown today, but they usually have a positive effect on plants [11]. In its broader definition, substances categorized as biofertilizers or biopesticides also fall into the category [12]. The term 'biostimulants' often includes natural stimulants, including phenols, salicylic acid, humic and fulvic acids, or protein hydrolases [4]. Their positive effects on horticultural production are mainly due to bioactive compounds that stimulate plant growth, such as phytohormones, amino acids, and nutrients [9]. Biostimulant compositions may be mono- or multicomponent, but synergistic effects of several different components have been observed. Several groups of biostimulants have been distinguished according to their mode of application (soil, foliage), the material of their production (plant, animal), or the process of their formation (hydrolysis, fermentation, extraction) [13]. These compounds help plants grow and develop in a number of ways [14]. Based on the work of Abbott et al. [15], biological modifiers can be divided into the following three main types: groups of biostimulants, organic substances, and microbial inoculants. Within this grouping system, biostimulants include amino acids, chitosan, seaweed extracts, and humic substances.

If the mechanism of action of biostimulants is largely unknown, biostimulants can only be regulated by demonstrating their safety and efficacy and determining a broad mechanism of action (Table 1) [16]. The development of new molecular biotechnology methods will soon help to understand the mechanisms and even possible modes of action of biostimulants [17]. Some studies have shown that biostimulants have no negative effects on the environment or human health due to the low biological toxicity of their components, their rapid degradation in the environment, their low mobility in food, and their low application rate. Their use can be very important in improving agricultural sustainability as they can promote increased production with lower environmental impact [18].

Twenty years ago, in 2002, relatively little research was conducted to document the effects of most biostimulants on crop production or to demonstrate their potential effects on soil processes [19]. Today, all this has changed, and the research and application of biostimulants are evolving at a rapid pace. The demand for sustainable agricultural practices continues to grow with the exclusion of synthetic fertilizers and pesticides [20]. Currently, the legislation also restricts the use of mineral fertilizers and pesticides in the European Union. Thus, the reduced use of chemicals is forced, either by parallel application or by partial replacement with formulations that can increase the effectiveness of conventional treatment [21,22]. New EU rules have forced Member States to amend or withdraw authorizations for products used in plant protection that contain active substances such as auxin (indole-3-butyric acid, IBA) [23]. Due to an increased environmental awareness, the use of synthetic chemicals in agriculture and horticulture to ensure optimal yields is less favorable. The European Union has an EU directive to limit the use of nitrates (91/676/EEC) and a directive banning all persistent, bioaccumulative, or toxic plant protection products (2009/128/EC) [24]. Based on EU regulation 2019/1009, biostimulants and other bio-based yield enhancers are also playing an increasingly important role in EU regulation [25]. In the future, a solution must be developed to reduce the use of chemicals and provide an alternative for farmers [26]. Unlike conventional fertilizers or pesticides, biostimulants are unique in that a single substance can affect crop growth and development in multiple ways based on both timing and location of application [27]. Their physiological effects occur after entry into plant tissues and cells, where they are involved in plant metabolism, signal transduction, and hormonal regulation of growth and development [28]. Biostimulants can be used to improve the environmental and economic sustainability of the horticultural sector with environmentally friendly biostimulants. They provide assistance in crop production, increasing cultivation potential and tolerance to abiotic stress [1]. Plant biostimulants are generally applied to high-value plants, mainly greenhouse plants, fruit trees, outdoor vegetables, flowers, and other ornamentals, to increase yield and product quality in a sustainable manner [29]. Many horticultural companies are investing in the development of new biostimulant products and the development of the most effective bioactive molecules capable of eliciting specific plant responses to abiotic stresses [30]. Modern agriculture is paying increasing attention to more sustainable, organic farming systems. Their positive effects on horticultural cultivation are mainly due to bioactive compounds that promote plant growth, such as phytohormones, amino acids, and nutrients [9,31,32]. Reducing the demand for and/or increasing the efficiency of chemicals used in agriculture is crucial due to climate change [33]. Biostimulants of natural origin can play an important role in this respect, as they increase yields in a sustainable way and at a relatively low cost. When placing EU-marked biostimulant products on the market, manufacturers must ensure that they have been manufactured in accordance with the following requirements set out in the European Commission Regulation (2016) [6]: they must draw up the technical documentation and carry out the appropriate conformity assessment procedure.

Table 1. Proposed biostimulant categories [16].

	Filatov, 1951b	**Ikrina and Kolbin, 2004**	**Kauffman et al., 2007**	**Du Jardin, 2012**	**Calvo et al., 2014**	**Halpern et al., 2015**	**Du Jardin, 2015**	**Torre et al., 2016**
1	Carboxylic fatty acids (oxalic acid and succiric acid)	Microorganisms (bacteria, fungi)	Humic substances	Humic substances	Microbial inoculants	Humic substances	Humic and fulvic acids	Humic substances
2	Carboxylic fatty hydroxyl acids (malic and tartaric acids)	Plant materials (land, freshwater, and marine)	Hormone containing products (seaweed extracts)	Complex organic materials	Humic acids	Protein hydrolysate and amino acid formulations	Protein hydrolysates and other N-containing compounds	Seaweed extracts
3	Unsaturated fatty acids, aromatic and phenolic acids (cinnamic and hydroxycinnamic acids, coumarin)	Sea shellfish, animals, bees	Amino acid containing products	Beneficial chemical elements	Fulvic acids	Seaweed extract	Seaweed extracts and botanicals	Hydrolyzed proteins and amino acids
4	Phenolic aromatic acids containing several benzene rings linked via carbon atoms (humic acids)	Humate- and humus-containing substances	-	Inorganic salts (such as phosphite)	Protein hydrolysates and amino acids	Plant-growth-promoting microorganism (including mycorrhizal fungi)	Chitosan and other biopolymers	Inorganic salts
5	-	Vegetable oils	-	Seaweed extracts	Seaweed extracts	-	Inorganic compounds	Microorganisms
6	-	Natural minerals	-	Chitin and chitosan derivatives	-	-	Beneficial fungi	-
7	-	Water (activated, degassed, thermal)	-	Free amino acids and other N-containing substances	-	-	Beneficial bacteria	-
8	-	Resins	-		-	-	-	-
9	-	Other raw materials (oil and petroleum fraction, shale substance	-	-	-	-	-	-

Plant biostimulants are currently considered a full-fledged class of agricultural inputs and are considered an extremely attractive business opportunity for major players in the agro-industry [34]. Recent decades have seen tremendous growth in the use of biostimulants in agriculture. It was estimated in 2014 that revenue from biostimulants could increase to USD 2 billion [3], with revenue already projected at GBP 2.66 billion in 2022 [35], and other projections suggest it could reach USD 3.68 billion in 2022 [36]. Plant biostimulants also play an important role in improving world nutrition. The development of biostimulants from by-products paves the way for the recycling of waste, bringing benefits to producers, the food industry, traders, as well as consumers [33]. According to the Marketsandmarkets.com (2017) [36] database, Europe is the largest LPG market with 34% of the world market share, followed by the North American and Asia-Pacific biostimulant markets, which account for roughly 23% of the global market, respectively. The main factors driving the rapid growth of the biostimulant market are related to the following: (i) the increasing availability of new biostimulant products that meet specific agronomic needs; (ii) the need to promote more efficient and effective use of synthetic chemicals and mineral fertilizers; (iii) the increasing frequency of adverse environmental conditions in terms of yield growth and productivity [29]. As the regulatory system for the use of biostimulants in the European Union and non-EU countries is not uniform, there is a disproportionate share of small-scale production between producers in each country. It would be necessary to standardize this in the future in order to create a level playing field [17].

2. Groups of Biostimulants

2.1. Industrial By-Products: Protein Hydrolysates and Chitosans

Several types of raw organic materials containing biostimulants or biostimulant components from industrial waste have been shown to be effective in both agriculture and horticulture. These include vermicompost, composted municipal waste, sewage sludge, protein hydrolyzate, and chitin/chitosan derivatives [33]. The use of environmentally friendly and sustainable ornamental horticultural technologies with renewable resources has attracted worldwide interest. One such renewable resource is vermicompost [37]. Vermicompost is an organic matter processed by earthworms. Its production technologies have been widely used to reduce the amount of plant organic waste, manure, paper, food, and sewage sludge [38]. In the case of plants of *Amaranthus hybridus* L., a significant increase in protein, carbohydrate, and chlorophyll content was observed with carcininolide, vermicompost leachate, and eckol [39]. Seaweed extracts and leachate from vermicompost stimulate growth and protect plants from adverse stress conditions [40]. Amino acids and peptide mixtures can be prepared by chemical and enzymatic protein hydrolysis from agro-industrial by-products, plant sources, and materials of animal origin (e.g., collagen, epithelial tissues) [12]. Plant hydrolysates containing amino acids and peptides have several positive effects on the yield of various horticultural plants [41]. This effect is related to the upregulation of metabolites involved in plant growth processes and the induction of hormone-like activities. These, in turn, affect plant growth and development [42].

Chitosans can also be prepared by extracting the cell walls of molds. Chitin and chitosan are natural compounds that are biodegradable and non-toxic. They are extremely remarkable for enhancing crop yield [43], preserving crop quality [44], and contributing to the efficiency of agri-environmental sustainability [45]. Chitosan is a deacetylated form of chitin biopolymer that is produced naturally and industrially. Poly- and oligomers of varying, regulated sizes are used in the food, cosmetics, medical, and agricultural sectors [46]. Chitosan treatment stimulates the rate of photosynthesis, closure of the stoma through ABA synthesis, enhances antioxidant enzymes through nitric oxide and hydrogen peroxide signaling pathways, and stimulates the production of organic acids, sugars, amino acids, and other metabolites required for osmosis to facilitate adaptation under stress [47]. Chitosan has been studied several times as a plant growth regulator and a stress tolerance inducer [48,49]. Synthetic cytokinin could also be replaced by it [50], which could contribute to the development of sustainable agriculture [51].

2.2. Humic and Fulvic Acids

Fulvic acids (FAs) improve the structure and fertility of soils with heterogeneous textures and play a crucial role in increasing crop production [52]. Humic substances are naturally occurring end-products resulting from the decomposition of microorganisms such as bacteria and fungi, and the chemical decomposition of animal and plant residues in the soil. Humic acid and fulvic acids combine to convert minerals into organic compounds that can be digested very easily by plants [53]. The main effects of humic substances are usually the improvement of root growth and morphological properties, the increase in nutrient uptake and utilization efficiency, and the better yield [54]. The use of fulvic acid (FA) on foliage increased the iron uptake and growth of lettuce plants (*Lactuca sativa* L.) under cadmium stress [55]. Soaking of onion plants (*Allium cepa* L.) in fulvic acid increased vegetative development and yield, among others [56]. The use of fulvic acids is an effective solution for crops produced in contaminated industrial areas, such as wheat [57]. In plants of *Lepidium sativum*, the use of high concentrations of humic and fulvic acids reduced chlorine and cadmium uptake [58]. Humic acid is the most common natural polymeric substance worldwide [59], which improves nutrient uptake [60]. Humic substances can also be prepared from leonardites [61]. For example, humic substances (HLSs) obtained from lignin-rich agro-industrial residues isolated by alkaline oxidative hydrolysis have been shown to act as biostimulants for the germination and early development of maize (*Zea mays* L.) [62]. Humic acid is also involved in photosynthesis, amino acids, carbohydrates, protein content, nucleic acid synthesis, and enzyme activities [63] and enhances endogenous auxin signaling in root development [64], but used at higher concentrations causes rooting problems [65].

2.3. Algae Extracts

Anthropogenic climate change, namely, climate change caused by human activities, is causing problems in agricultural systems [66]. Seaweed extracts are derived from the extraction of several macroalgal species, leading to the production of complex mixtures of biologically active compounds depending on the extraction method [34]. Various methods are currently used for this purpose. New extraction technologies are available, such as ultrasonic-assisted extraction (UAE), enzyme-assisted extraction (EAE), supercritical fluid extraction (SFU), microwave-assisted extraction (MAE), and pressure fluid extraction (PLE). Biological compounds offer the advantage of extraction without influencing their activities [67]. The use of marine algae extracts from marine macroalgae due to their beneficial properties began in the mid-2000s [68]. The algae extracts are widely known as substances used to reduce abiotic stress and increase plant productivity. The marine algae extracts are derived from the extraction of several macroalgal species, leading to the production of complex mixtures of biologically active compounds depending on the extraction method [34]. Macroalgae are also effective biostimulants on plants grown under stress conditions [41].

Using VOSView bibliographic analysis software, Rodrigues et al. [69] examined the titles and abstracts of professional articles (Figure 1). The figure shows the most common words related to the topic of biostimulants. The colors indicate the year numbers. Although the fruit and vegetable sectors were examined, the result was that one of the most researched areas was 'algae extract' [69].

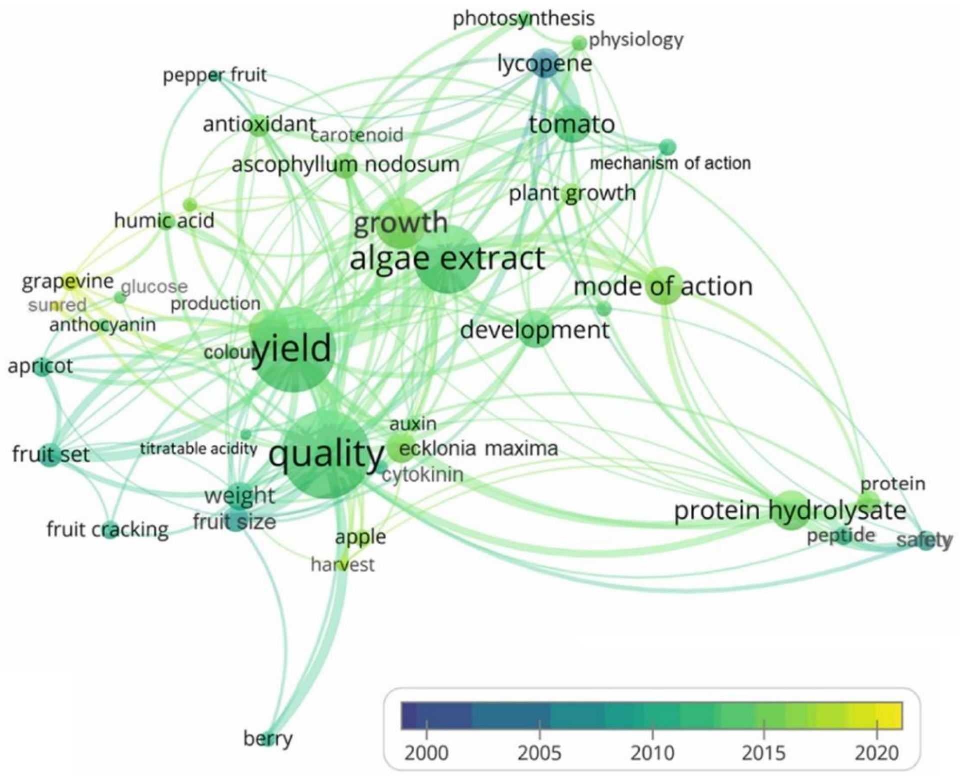

Figure 1. A network of the most commonly used terms in the field of biostimulants [69].

They are largely made from brown seaweeds such as *Ascophyllum nodosum*, *Ecklonia maxima*, and *Macrocystis pyrifera* and contain promoter hormones or trace elements such as Fe, Cu, Zn, and Mn [70]. In addition to *Ascophyllum nodosum*, other brown algae such as *Fucus spp.*, *Laminaria spp.*, *Sargassum spp.*, and *Turbinaria spp.* are used as biofertilizers in agriculture [71], as are the species *Macrocystis pyrifera* and *Durvillea potatorum* [72]. Microalgae biostimulants elicit signaling pathways that provide systemic resistance [73]. Recently, aqueous and alkaline extracts from a variety of commercially available algae have been used in agriculture and horticultural systems for foliar spraying, soil tillage, or often a combination of both [74]. In 2017, nearly 47 companies worldwide are currently involved in the production of extracts from *Ascophytum nodosum* for agricultural and horticultural applications [10]. *Ascophyllum nodosum* is a temperate seaweed found in the Atlantic and Arctic that has been extensively studied for its properties, including promoting plant growth [75]. The possible triggering and disease-suppressing effects of *Ascophytum nodosum* extract were investigated. Spraying *Ascophyllum* extract on greenhouse-grown carrots significantly reduced the incidence of *Alternaria* and *Botrytis* [76]. It also plays a role in the control of powdery mildew (*Podosphaera aphanis)* in strawberry (*Fragaria* ssp.) cultivation [77]. The anthocyanin content in the peel of apples treated with seaweed extract was significantly higher than that of the control, highlighting the potential effect of these substances on the synthesis of secondary metabolites in apples [78]. In the case of container-grown citrus fruits, *Ascophyllum nodosum* increases the drought stress resistance of the plant [79]. The extract also increased phosphorus uptake and salt stress tolerance in *Arabidopsis thaliana* L. [80] and decreased oxidative stress [81]. In the cultivation of *Glycine max* (L.), Merill also increases macronutrient uptake in plants [82], and this enhances drought tolerance by altering physiological properties and gene expression [83]. After the use of an agent containing *Ascophyllum nodosum*, the accumulation of transcripts from plant protection genes was rapidly increased, and transcript levels remained high for 96 h after treatment [84]. The algae extracts also affect morphological properties. The *Ascophyllum* seaweed extract used in *Chrysanthemum* ssp. cultivation had a significant effect on stem height and diameter as well as root dry matter content [85]. *Ascophyllum nodosum* and

Ecklonia maxima in seaweed extracts in potatoes (*Solanum tuberosum* L.) had only a small effect on the quality of potato tubers [86]. The effects of algae extract are particularly pronounced on plant species that have difficulty germinating, rooting, and flowering, or on plants whose growth rate is slower or more difficult to grow in greenhouses and under climatic conditions other than their origin [87]. It can also be used effectively in viticulture [88]. During the propagation of *Robinia pseudoacacia* L. by cuttings, also used as an ornamental tree, the microalgae extract increased the number of shoots and roots formed on the cuttings [89].

The microalgae biostimulants and biofertilizers can be used in crop production to increase the sustainability of agriculture [90]. They can be considered a rich source of metabolites in agricultural production [73,91], providing several macro- and microelements for plants [92]. However, the results are not uniform in all cases. Rouphael et al. [93] effectively used algal containing biostimulants on spinach plants and found that all agents had a positive effect on yield and chlorophyll content. The treated plants also showed higher photosynthetic activity. The use of biostimulants may also be beneficial for tomato plants when the plants are grown under stressful conditions, as they have been shown to be effective in alleviating drought and nitrogen deprivation stress [94].

2.4. PGPR and PGPB

Plant growth-promoting *Rhizobacteria* (PGPR) is a community of soil bacteria, one group of which is plant growth-promoting bacteria (PGPB) [95]. All PGPR/PGPB inoculants are cultured bacteria. One of the most important features of inoculant production is proper fermentation to produce a large population of bacteria that are later formed into a product [96]. In the past, a specific species or strain was used in PGPR/PGPB research, and this is still true in many experimental and commercial applications of *Azospirillum* spp. and *Bacillus* spp.-based products. In laboratory use, analytical ingredients are used for small-scale fermentation studies, and industrial manufacturers of products use fewer purified ingredients to save costs [97]. Plant growth-promoting bacteria (PGPB) affect plant cell processes in various ways [98]. Previous analyses of PGPBs combined with the restoration of heavy metal contamination in the soil have been performed on a few agricultural and horticultural crops [99]. Popular bacteria used as biostimulants include species such as *Arthrobacter* spp., *Acinetobacter* spp., *Enterobacter* spp., *Ochrobactrum* spp., *Pseudomonas* spp., *Rhodococcus* spp., and *Bacillus* spp. [100]. PGPB relieves salinity stress in plants by providing nutrients, maintaining high potassium and sodium ratios, increasing osmolite accumulation, enhancing photosynthesis and antioxidant enzyme activity [101]. In the case of maize, the application of PGPB through the soil increased the yield and the dry matter content of the seed by 92%. The results suggest that the use of PGPB as a new cultivation practice may contribute to the sustainable growth, productivity, and quality of cereals [100] and processed tomatoes [102]. In ornamental plant cultivation (*Handroanthus impetiginosus* (Mart. ex DC.)), *Rummelibacillus* strains function as PGPBs, which also have good salt tolerance [103]. PGPBs also increase the efficiency of the cultivation of orchids such as *Cattleya guttata* and *Zygpopetalum Mackayi* [104]. It can also play a significant role in the cultivation of the annual ornamental *Petunia* × *hybrida* [105] because it promotes plant development and flowering parameters [106]. PGPRs are also very common in ornamental plant production, such as in the cultivation of *Ranunculus asiaticus* L. [107]. In the case of *Ocimum basilicum* L., also used as an annual ornamental PGPRs, also affect morphological parameters and essential oil content [108] and may also play a role in the cultivation of annual ornamental *Osteospermum hybrida* [109]. These rhizobacteria also improve the morphological properties of spring bulbous ornamental plants [110]. They also increase the tolerance of *Camellia japonica* to salt stress, which is also used as an ornamental evergreen shrub, thus greatly reducing cultivation costs [111]. They increase the tendency of root formation in individuals of the ornamental foliage plant *Ficus benjamina* L. [112]. They may also play a role in the reproduction of rare and endangered species such as *Chlorophytum borivilianum* [113]. PGPRs also enhance the color intensity of the upper leaves of ornamental flowering pot plants like *Euphorbia pulcherrima* Willd., which is its main decorative value [114].

2.5. Fungal Inoculants

Selected microbial strains used as active ingredients in biopesticides in agricultural management practices (e.g., IPM, Integrated Pest Management) are known for their ability to defend against phytopathogens, promote plant growth, and/or induce disease resistance [115]. *Trichoderma* has become important as a microbial plant biostimulant in horticulture [116]. The species of the genus *Trichoderma* are also used in various industries, mainly in the production of enzymes, antibiotics, and other metabolites, but also in the production of biofuels. Currently, *Trichoderma* has entered the genomic era, and some of the genomic sequences are publicly available, meaning they can be used for human use to an even greater extent than before. However, further studies are needed to increase the efficiency and safety of the use of these fungi [117]. The *Trichoderma* biostimulants enhance plant nutrition, growth, and stress response. Moreover, *Trichoderma*-induced changes in gene expression are an integral part of phytostimulation. Recent proteomic and genetic data suggest that *Trichoderma* activates mitogen-activated protein kinase 6, transcription factors, and DNA processing proteins, which are promising targets for more efficient products [118]. *Trichoderma*-based biostimulants used in *Lactuca sativa* L. and *Eruca sativa* L. increased yields [119]. *Passiflora caerulea* L., which is also used as an ornamental plant, developed larger leaves as a result of treatment, and the chlorophyll content of the leaves was also higher [120]. In the cultivation of annual ornamentals such as *Callistephus chinensis* (L.) Nees, *Salvia splendens* Sellow ex Roemer and JA Schultes, *Zinnia elegans* Jacq., and *Tagetes patula,* it was also successful [121]. In woody evergreen ornamental plants, it is also a suitable biostimulant, such as for *Olea europea* L., also used as an ornamental tree, as it enhances abiotic stress tolerance [122].

3. Abiotic and Biotic Stress and the Response of Ornamental Plants to Biostimulant Treatment

Global climate change and the associated unfavorable abiotic stress conditions such as drought, salinity, heavy metals, and extreme temperatures greatly affect plant growth and development. This also indirectly influences crop yield and crop quality as well as the sustainability of agriculture [123]. Plants have to cope with various environmental pressures throughout their lives [124]. Under the current scenario of rapidly changing climate change, crops are more often exposed to the stress of abiotic and biotic origins. They are more affected by unpredictable and extreme climatic events that cause and exacerbate changes in the growing season, plant physiology, and plant health hazards [125]. Global climate change may lead to complex combinations of different stressors, of which the interaction between the pathogens and drought stress can have a significant impact on growth and yield [126]. Biostimulants have also been proposed as an agronomic tool to counteract abiotic stress [30]. Plants are unable to move and must endure abiotic stressors such as drought, salinity, and extreme temperatures [127,128]. Plants have developed mechanisms that sense these environmental challenges, transmit stress signals within cells and between cells and tissues, and make appropriate modifications to their developmental mechanisms for survival and proliferation [129]. Various phytohormones are known to play a protective role in plants exposed to environmental stress, and their synthesis and accumulation are increasingly regulated under environmental stress [127]. One of the main goals of horticultural cultivation is to reduce these stress effects.

Recent studies have shown that plants respond to abiotic stresses within seconds, engaging in a number of different metabolic and molecular networks, and altering their stoma opening in a short period of time [130]. Abiotic stress leads to altered biosynthetic capacity and nutrient uptake, which can inhibit plant growth. This phenomenon is also documented in a number of studies on model plants. Consequently, research to understand responses to abiotic stress has come to the fore in the last decade and has led to the discovery of a number of signaling pathways that contain large numbers of genes, proteins, and post-translational modifications [131]. Abiotic stress affects the phytohormonal balance of plants, which has a direct effect on stress adaptation mechanisms such as stoma closure and carbon distribution [40]. As a result of their research, Nemhauser et al. [132] explain that the crosstalk between different hormonal signaling processes is significant. The effects of abscisic acid, gibberellin, auxin, ethylene, cytokinin, brassinosteroid, and jasmine on *Arabidopsis* seedlings were studied. Hepler [133] concluded that Ca^{2+} is a crucial regulator for the growth and development in plants, with research on the subject since the 1960s. To this day, new experiments are being initiated to suggest that Ca^{2+} is a secondary messenger in plant cell development. One of the more modern ways to do this is to use natural plant biostimulants to improve the resistance of plants to an abiotic environmental stress [66]. Many active compounds found in biostimulants that support plant stress tolerance and productivity under adverse growth conditions are metabolites or intermediates that can affect nutritional quality [124].

The use of biostimulants may be a promising strategy to reduce the adverse effects of osmotic stress [134]. The accumulation of reactive oxygen species is toxic to cells and leads to cell damage, resulting in a reduced germination and seedling growth [135]. Biostimulants are known to induce the ROS detoxifying enzyme system and induce/contain non-enzymatic antioxidant compounds that promote ROS detoxification and prevent their accumulation in germinating seeds at the cellular and subcellular levels [136]. Biostimulants of microbial origin also have a role to play in overcoming biotic stress [137]. Microbial biostimulants can promote the growth of ornamental plants (e.g., *Zinnia elegans* and *Petunia* $\times$ *hybrida* [138,139] during production [140] and improve yield performance under abiotic stress [141]. Water stress can also have a negative impact on photosynthetic parameters and plant health in the long run [142]. Plants that are unable to maintain their health and quality under stressful conditions become unmarketable at retail [143]. The use of stimulatory bacteria in ornamental production may be suitable to increase plant stress tolerance in water-scarce conditions. Recent research has shown that the use of plant growth-promoting bacteria increases the size and flowering of plants during greenhouse cultivation under abiotic stress [144] also hybrids [143].

The beneficial effect of PGPB in reducing the susceptibility of plants to pathogenic infections occurs not only through microbial antagonism but also through a mechanism that enhances the defenses of plants, the so-called "induced systemic resistance" (ISR) [145].

The use of biostimulants also induces a number of plant responses, including increased tolerance to abiotic stress, nutrient utilization efficiency, and organ growth and morphogenesis [146]. Experiments on the biotic and abiotic stress have shown the beneficial effects of biostimulants. One of the first responses observed in plants exposed to salt stress is a decrease in shoot length, shoot and root weight, and chlorophyll content. The accumulation of proline was affected by the concentration of NaCl, while polyphenols were not affected by the increase in salinity. However, with the use of microalgae, no harmful increase in these parameters was observed with NaCl [147,148]. In *Arabidopsis thaliana* plants, the use of seaweed extract was also effective in cold stress. The treated plants regenerated more rapidly, showed greater membrane integrity, and suffered 70% less chlorophyll damage after freezing [149]. *Ascophyllum nodosum*, as a seaweed extract, increased the fresh and dry weight of spinach (*Spinacia oleracea* L.) in plants under drought stress, with some detrimental effects on nutritional value [150]. The seaweed extract applied to lettuce (*Lactuca sativa* L.) seedlings increased cotyledon growth [151]. Although some commercial *Ascophyllum nodosum* extracts have been effective in enhancing plant growth under abiotic stress conditions, they may be less effective under biotic or stress-free conditions, and vice versa. The salt stress can be manipulated using panchagavya and positively regulates the physiological, biochemical, and gene expression responses in salt-sensitive and tolerant rice cultivars. Autophagy and programmed cell death, along with salinity, were regulated and helped to adapt to tolerance to stressful situations [152]. Another important abiotic stress factor is drought. The accumulation of osmotic compounds such as proline is one of the most common plant responses to drought stress [153]. The drought-tolerant plants show different adaptation mechanisms to overcome drought stress, including morphological, physiological, and biochemical modifications. These responses include increasing the root/shoot ratio, reducing growth, changing leaf anatomy, and reducing leaf size and total leaf area to limit water loss and guarantee photosynthesis [154]. Another example of the beneficial effect of a biostimulant was observed in *Petunia* spp., *Viola tricolor,* and *Cosmos* spp., which had better performance when grown under water-scarce conditions using extracts of *Ascophyllum nodosum* [155]. Hydrolysates soluble in bio-waste also increased the rate of *Hibiscus* spp. photosynthetic activity and gas exchange when exposed to water scarcity [156]. According to some authors, the positive effects of different biostimulants include the following: greater biomass accumulation, increased flowering, and finally, the production of growth-stimulating hormones such as gibberellins and cytokines [3]. Fluctuating water availability is also an abiotic stress for plants. The application of some bacteria increased the plant size in both *Petunia hybrida* and *Pelargonium* × *hortorum* cultivars and increased the flower numbers after recovery from water stress compared to control water-stressed plants. In addition, the use of bacteria increased the fluorescence parameters of chlorophyll, including the quantum yield and efficiency of photosystem II (PSII) and the rate of electron transport (ETR), while reducing the rate of electrolyte leakage during water application and regeneration [157]. The use of biostimulants is a novel and eco-sustainable agricultural practice that can not only improve the water use efficiency of sensitive and tolerant ornamentals but also provide high yields with inadequate irrigation [158].

The effect of biostimulants on physiological, anatomical, and genetic changes in plants is closely related to the role of biostimulants in the regulation of stress response.

Metabolomics, a multidisciplinary 'omics' science, offers unique opportunities to predictively decode the mode of action of biostimulants on crops and to identify markers that transcribe the effects of biostimulants [32].

Significant progress has been made in recent years on many fronts of stress signaling research, particularly in understanding downstream signaling events. These have culminated in the activation of genes responsive to stress and nutrient restriction, cell homeostasis, and growth adaptation [129]. The recent advances in understanding the molecular mechanisms underlying plant responses to abiotic stress emphasize the multilevel nature of plants; several processes are involved, including sensing, signaling, transcription, transcript processing, translation, and post-translational protein modifications [128]. Recent studies have shown that many epigenetic factors are involved in abiotic stress responses and various modifications of chromatin change when plants are exposed to a stressful environment [159]. Regulating bioactive compounds and metabolites (by modifying gene expression, signaling, and synthetic pathways) in plants and/or symbionts may promote plant–symbion association and performance [160]. Among the upregulated genes, the expression of Bv_PHT2; 1 and Bv_GLN1 induced a twofold change in Leonardite-based biostimulants [161]. The protein hydrolyzate biostimulant treatment has altered the expression and amounts of several genes and proteins involved in redox homeostasis, stress response, glycolysis, the tricarboxylic acid cycle, the pentose phosphate pathway, and the metabolic pathways of carbohydrates, amino acids, and lipids. Furthermore, the metabolic processes of phytohormones and secondary metabolites, especially phenylpropanoids, flavonoids, and terpenoids, as well as mechanisms involved in transport and cytoskeletal rearrangement, have been stimulated. The treatment of rice plants with a seaweed biostimulant induces resistance to *Magnaporthe oryzae* infection, possibly by inducing defense-related genes and enzymes, as transcript levels of various defense genes such as OsPR-1 and PAL-6 are altered [162]. In the plants of *Solanum lycopersicum* L., tannin-based biostimulants upregulated 285 genes, most of which were correlated with root development and salt stress tolerance. The 171 downregulated genes were mainly involved in nutrient uptake [163]. For example, the use of peptone can have a positive effect on the hormonal balance and antioxidant system of water-stressed plants in an economically important species [164]. Investigation of gene expression may provide evidence for regulatory mechanisms of seed germination and biochemical processes regulated by biostimulants. The biostimulant seed treatments can induce changes in gene expression and modulate metabolic fluxes, allowing better seed germination and dynamic seedling growth. The application of biostimulants to seeds has been reported to regulate hormone biosynthetic genes, improving seed germination and seedling growth. Some studies have shown that the biostimulant seed treatment may regulate metabolic or stress-responsive genes [134] and may also affect leaf tissue structure [165].

Biostimulants have, in many cases and cultures, also promoted the efficiency of photosynthesis and increased the amount of chlorophyll. In *Chrysanthemum* sp., in addition to morphological parameters (stem diameter, fresh weight of shoots and roots, dry weight of shoots and roots, leaf area, flower diameter), net photosynthesis rate, chlorophyll fluorescence, and chrysanthemum chloroplast structure were affected by humic acid compared to nitrogen-phosphorus-potassium fertilizer [166]. The translocation of assimilates was also intensified under the effect of auxin-containing microalgae-derived biostimulants in *Pelargonium peltatum* [167]. Humic acids can also positively influence oxidative stress-related processes as well as increase the intensity of gas exchange [23], mediate metabolic processes in the plant [168], and also improve the morphological characteristics of root growth [169]. In *Azalea* × *kurume* plants, humic acid affected the induction of roots during in vitro culture [65]. In the case of *Anthirrinum majus* L., the use of a biostimulant of animal origin also had a positive effect on leaf gas exchange parameters. The biostimulant significantly affected photosynthesis, the rate of evaporation, the conduction of the stoma, and the use of arbuscular mycorrhizal fungi increased the water stress tolerance in the plant [170].

The anatomical structure of the rooting of *Rosa* 'Hurdal' cuttings was influenced by plant-derived biostimulants. As a result of the microalgae extract, the xylem cells thickened, which promoted stem strength, and the plants treated with the microalgae extract reached the highest rooting value [171]. Under the influence of plant-derived biostimulants, the phloem tissues of roses also thicken [172].

4. (Effects and) Application of Biostimulants in Ornamental Horticulture

Ornamental plant production is one of the fastest-growing areas in the horticultural sector. It is one of the most dynamic agricultural sectors, especially in the cultivation of potted ornamental plants, which is showing an increasing trend on the international market worldwide [173]. It is characterized by constant renewal, new species, colors and uses, technologies and varieties that appear and disappear in quick succession. Following the 2008 global economic crisis, ornamental crop production has become a sector with difficulties in the recovery. Today, however, it is playing an increasingly important role. Ornamental plants are also having an increasing role in urban environments, such as in the purification of airborne pollutants [174]. In recent years, however, the world is going through far-reaching processes. World ornamental plant exports already reached USD 9.4 billion in 2014 [175]. The ornamental plant trade has become a leading sector in previously uncharacteristic countries such as Brazil [176] and Thailand [175]. The development of the sector goes hand in hand with the economic development of developing countries [177].

4.1. The Role of Biostimulants in Ornamental Plant Production

There is a growing interest in plant biostimulants, driven by the growing interest of growers in natural materials and beneficial microorganisms that can sustainably increase the productivity of vegetables and ornamentals. The protein hydrolysates and arbuscular mycorrhizal fungi are widely used in greenhouse plant cultivation, mainly due to their improving effects on plant nutrient uptake, growth, yield, and fruit quality, as well as the tolerance of plants to abiotic stressors [178]. Disease treatment with biostimulants has received attention for their natural origin, efficacy, and low or non-existent toxicity [179]. The excellent aesthetic quality of the product and the timing of the harvest are essential for ornamental market competitiveness. Therefore, ornamental horticultural products require a high level of investment in agrochemicals and energy use without a holistic approach and sustainability [1]. By using biostimulants alone or in combination, a significant growth rate and yield can be achieved in ornamentals in solid media. However, biostimulants should be used with caution as an overdose may have adverse effects [180]. This is especially true for humic acids [181]. Wild species such as *Hypericum* sp. can also be successfully produced using biostimulants [182], as can endangered species such as *Comanthera mucugensis* native to Brazil [183]. Not only is the biostimulant of great importance to wild plant species, but it is also becoming increasingly important to cultivated varieties. The ornamental plants sown from seed are particularly important [184–188], such as *Gladiolus grandiflorus* L. [37,189–191]. The cultivation of orchids produced by micropropagation was also greatly facilitated by the use of biostimulants [192].

Biostimulants can also play a major role in breeding. It has been shown that the use of biostimulants in plant breeding can alter the activity of enzymes and affect their antioxidant properties. The lycopene, ascorbic acid, and phenolic compounds have antioxidant properties. Reactive oxygen molecules such as OH^-, O_2, and H_2O_2 are inactivated by antioxidant compounds (e.g., phenols, ascorbic acid) and enzymes (e.g., catalase, peroxidase, superoxide dismutase) [193]. H_2O_2 generated by chloroplasts acts as a retrograde signal that enters the nucleus directly from the chloroplast, avoiding the cytosol and eliciting a transcriptional response [194]. The biosynthetic pathway of phenylpropanoid is activated under abiotic stress conditions (drought, heavy metals, salinity, high/low temperature, and ultraviolet radiation), resulting in the accumulation of various phenolic compounds capable of binding harmful reactive oxygen species, among others [195]. Nutrient restriction or exposure to abiotic stress can limit growth and lead to excessive excitation of the photosynthetic electron transport chain and the formation of potentially harmful oxygen forms. The timely detection of stress leads to modulation of plant growth and activation of defense and acclimatization pathways. They act either on certain plant organs or the whole plant [131]. The effects of stress are usually associated with certain physiological mechanisms of stressed growth, such as the synthesis of protective plant biochemicals in response to stress. Many of these, which are generated during plant primary or secondary metabolism, function as functional compounds not only in plants but also in other organisms [124].

4.2. The Role of Biostimulants in the Propagation of Ornamental Plants

Vegetative propagation is still an important propagation method in horticulture [196,197], and this propagation method makes horticulture even more efficient [198]. However, biostimulants are effective tools for optimizing the propagation efficiency of vegetative cuttings; however, their optimal application rates are often species-specific [199] and also depend on the location of cuttings on the shoot [200]. While many significant advances have been made in vegetative propagation, the economic loss due to the insufficient rooting efficiency remains a burden for the propagation industry, and further work is needed to identify biostimulants that promote rooting [201]. There are species, such as *Abies gracilis* Kom., whose vegetative propagation does not occur without biostimulants [202]. Willow bark extract reduces the time required for additional root and shoot formation in chrysanthemum and lavender [199], so it is recommended for semi-woody and woody plants, as a similar effect can be achieved with hormone-containing *Aloe vera* extract in plant groups [199,203]. In the case of *Cornus alba* L., biostimulants also increased the rooting rate in cuttings [197]. In the case of *Rosa gallica* 'Tuscany Superb', it has been shown that biostimulants can replace indole-3-butyric acid hormone preparations during the rooting of cuttings [204]. The humic acids can enhance the rooting of cuttings [23]. The reduction of the chlorophyll content in leaves was not inhibited by microalgae preparations [205].

Biostimulants are also important in sexual propagation. Relieving environmental stress on seed germination and early seedling growth is also an important goal for seed biologists. Some biostimulants may also protect seeds by enhancing the antioxidant compounds such as vitamin C and thiol, both of which are involved in stress tolerance instead of regulating enzymatic antioxidants [134]. Biostimulants show biotic stress tolerance, so the potential and precise mechanism of action of biostimulants in seed germination and plant growth in relieving biotic stress must be recognized [206]. *Ascophyllum nodosum* algae extract promotes the growth and development of seedlings of *Helianthus annuus* L., also used as an annual ornamental bedding plant, and reduces seedling production costs [207]. Certain seaweed extracts, humic substances, and microbial inoculants play a role in the hormonal metabolism stage, increasing the germination rate [208]. *Ascophyllum nodosum* brown seaweed and seaweed-derived products are widely used as nutrient supplements, biofertilizers, and biostimulants in horticultural plant systems, thus also increasing germination capacity in plants of *Tagetes erecta* L. [186]. In the case of *Lavandula angustifolia* Mill., seed germination is lengthy and difficult, but the use of biostimulants can also increase the germination percentage and germination vigor [209]. Biostimulants for rooting are also effective in *Bellis perennis* L. and *Viola* × *wittrockiana* Gams, but the use of biostimulants with fungicides for germination would further increase the efficiency [210]. In *Inula viscosa* individuals, algae preparations reduced *Sphaerotheca pannosa* var. *rosae* infection [110]. In *Tagetes erecta* L., the germination capacity of the seeds was increased by the applied biostimulant [184] and the height of the seedlings was also increased [28]. For *Tagetes patula* L. and *Callistephus chinensis* L., several biostimulants reduced germination and increased it for *Viola* × *wittrockiana* [210]. The use of *Ascophyllum nodosum* also makes germination and seedling cultivation more efficient [207], especially in the case of ornamental peppers (*Capsicum annuum* L.).

Biostimulants also play an important role in the production and propagation of bulbous plants. Soaking *Eucomis bicolor* Baker bulbs in the chitosan solution before planting stimulated the growth, flowering, and yield of the bulbs. The use of chitosan in appropriate concentrations had a positive effect on the number of leaves per plant, the relative chlorophyll content of the leaves, and the number of bulbs per plant. Chitosan is multidirectional, positively affects plant growth, and can be used as a potential biostimulant [211]. In addition to chitosan, phenolic compounds isolated from seaweed *Ecklonia maxima* also increased bulb size and active surface area in individuals of the species [212]. Chitosan is also a very effective group of biostimulants in micropropagated orchid cultivation, as it has promising biocompatibility and biodegradability characteristics and offers a holistic biostimulating alternative in the commercial propagation of orchids [192]. In the orchid *Cattleya maxima* Lindl., it also has a positive effect on development when used in combination with coconut water [213]. Microbial substances are also effective in *Cymbidium* sp. Sw. orchid micropropagation [214]. Significant results have also been obtained in the flower, seed, and bulb propagation of *Crocus sativus* L. using biostimulants [215].

4.3. Effect of Biostimulants on Plant Growth and Development

In the case of early-grown annual ornamental plants (*Begonia semperflorens* Link. Et Otto), biostimulants promote plant growth at the initial low temperature of cultivation. In woody plants, such as *Rosa* sp., in the case of micro-propagation and cuttings, the rooting of plants can also be promoted [185]; thus, using biostimulants to make rose cuttings environmentally friendly [216]. In the case of annual ornamental seedlings, the weight of the above-ground parts can also be increased by using biostimulants [184,217], so when planting seedlings of *Tagetes patula* L. outdoors, regarding growth and development [187], Dudaš and Šestan [188] did not observe a significant change in the seedlings compared to the untreated groups, but with microalgae preparations, the leaves of the plants did not fall off [218]. In the case of *Portulaca grandiflora* L., the germination percentage was also significantly improved due to the use of microalgae biostimulants [219]. The fermented protein-free alfalfa biostimulant also increases the vegetative weight of plants and influences tissue structure and chlorophyll content in the cultivation of annual ornamental plants [220–222]. Humic acids also promote faster seedling growth in *Salvia splendens* L. [223]. Supplementation of humic acids with organic and fertilizer increased plant height and flower yield of

Polianthes tuberosa L. [224] and *Dendrobium nobile* Lindl. [225]. Spraying and watering with biostimulants has intensified vegetative growth [226]. Chitosan increased the average number of roots and induced random root induction; however, root elongation was reduced in the presence of chitosan during in vitro propagation of *Ipomoea purpurea* (L.) Roth. The root elongation inhibitory effect of chitosan becomes clearer in the presence of an oligomeric mixture. The use of chitosan oligomers instead of polymers may be an environmentally friendly and efficient alternative to synthetic cytokinins in horticultural cultivation [50]. In ornamental plant cultivation, the flower is one of the main ornamental values [227]. In the case of *Gerbera jamesonii* L., seaweed extract increased the number of inflorescences and also had a beneficial effect on growth [228]. The depolymerized gellan also increased flowering and brought earlier flowering in greenhouse cultivation for *Rudbeckia hirta* L. and *Salvia splendens* L. and can therefore be considered an innovative biostimulant [229]. The use of protein hydrolysates as biostimulants as a leaf spray has helped to achieve extra quality plants and this practice can be used to grow petunias commercially under sustainable greenhouse conditions [230], as well as in *Anthirrinum majus* L. [231], which is a major cut flower in the ornamental plant trade [170]. Ornamental grasses have created a dynamic sector of floriculture where a wide range of new varieties is introduced each year. Market competition forces producers to follow procedures from the outset that guarantee the acquisition of the best quality product [232]. One of the unique directions of ornamental plant testing is green area management. Thanks to the success of biostimulants in fruit and vegetable production, the industry also places great emphasis on turfgrass varieties. There are significant business opportunities in this sector due to the area and pesticide reduction regulations. In ornamental grasses (*Lolium perenne* L.), biostimulants have been shown to displace the effects of fertilizers [233]. Most biostimulants increase the content of photosynthetic pigments (chlorophyll and carotenoids) and decrease the content of polyphenols and antioxidant radicals [234].

Due to the growing role of biostimulants in the horticultural sector, their effect when combined with fertilizers is also of interest. In *Salvia hispanica* L., the application of biostimulants and the recommended fertilizer doses also resulted in significantly higher essential oil content and vegetative yield than the application of fertilizer alone [235]. These results may be of interest to growers who want to improve the quality of their ornamental plants by using products that are easy to handle and environmentally friendly [219].

4.4. Post-Harvest Treatment of Ornamental Plants with the Use of Biostimulants

The marketability of ornamental plants is based on their important visual properties such as growth, habit, longevity, and quality, the latter being influenced by parameters such as the number of flowers and buds, flower size and color, leaf color and shape, and absence of pests and pathogens [236]. In ornamental crop production, harvesting can be very diverse, and most operations are variety-specific. *Gladiolus* sp. L. is still one of the most popular ornamental cut bulbs worldwide. However, in the case of cultivation as a cut flower, the length of vase life after harvest is a big problem [237]. In the case of *Gladiolus grandiflorus* L. bulb cultivation, the bulb yield from the humic acid-treated stock was the highest [189] and the number of flowers harvested per unit area was also, so humic acid is a suitable biostimulant in gladiolus production [190,191]. *Moringa* leaf extract is also very beneficial as its use has increased physiological properties and vase life [238]. In *Chrysanthemum* cv. Ratlam Selection, the vase life of plants was also significantly increased by banana extracts used as biostimulants, and humic acid preparations increased the number of inflorescences [239], as described for *Polianthes tuberosa* cv. Prajwal [240] and *Gerbera jamesonii* Hook [241] as well as *Lilium orientale* [60]. In addition to the cultivation of cut flowers, the production of plants is also of great importance, where the role of biostimulants is also increasing. In Hemerocallis spp. and Hosta spp., the number of vegetative propagules has also been increased during cultivation with seaweed abstracts compared to retardants [242]. In the cultivation of Calathea insignis, humic acid can be used in combination with biochar to replace peat [60]. In addition to Calathea, in Gladiolus grandifloras, another very popular species, it is very effective in improving morphological properties (flower number, flower size, flower diameter), but it is worth combining it with PGPB [37]. Biostimulants are also used in many crops in the cultivation of annual and biennial ornamental plants. By adding rhizobacteria that stimulate plant growth to the medium of *Petunia* × *hybrida*, *Impatiens walleriana*, and *Viola* × *wittrockiana*, the plant size increased and thus they became more commercially suitable. In addition, nutrient uptake and tissue nutrient concentrations also increased [243]. In the case of *Tagetes erecta* L., biostimulants of microbial origin (*Azotobacter, Azospirillum,* PSB) also increased the plant height, number of branches per plant, average flower weight, number of flowers per plant, flower yield per plant (g), and flower yield per hectare (t).

5. Conclusions and New Possibilities in the Use of Biostimulants

As a result of abiotic stress and global climate change, agricultural production is suffering severe losses worldwide. Currently, the most promising approach is to breed stress-tolerant plants for abiotic stress tolerance of better quality and yield. One of the preconditions for the development of stress-resistant plant varieties is the elucidation of molecular mechanisms and the research of stress-associated genes that regulate the responses of plants to abiotic stresses. The transcription factors play a crucial role in regulating the expression of stress-responsive genes [244]. In the future, many new biostimulants could also hold promise in crop production and help humanity live a sustainable life. The diluted honey extract increases the activity of antioxidant defense systems in plants and has the potential to counteract the harmful effects of soil salt stress [245]. Many plant extracts can also be effective in enhancing plant vital functions and gene expression. Licorice extract pretreatment increases the levels of CAT, SOD, APX, GR, DHAR, and PrxQ transcription in salt-stressed seedlings [246] enriched with silmarine [247]. Corn extract has beneficial effects on wheat plant performance, hormones, and polyamine gene expression, and is effective in combination with silmarine [248]. *Hermetia illucens* (L.) is also suitable for hydroponic cultivation of vegetable plants and acts as a biostimulant [249]. Sustainable crop production also considers the replacement of peat-based media. Thus, biostimulants can not only act on the plant or the medium but can also act as a growth medium itself, such as *Posidonia*-based compost [250]. Humic substances extracted from peat, in turn, increased the mass of vegetative parts of grasses [251].

Nanoparticles and nanomaterials can be considered biostimulants because they enhance plant growth over certain concentration ranges, usually in small amounts. Nanoparticles and nanomaterials have high-density surface charges that can interact non-specifically with the surface charges of the cell wall and membrane of plant cells. Likewise, functionalized nanoparticles and nanomaterials and crowned nanoparticles and nanomaterials. The latter, formed after exposure to natural fluids, such as water, soil solution, or the interior of living organisms, show a high-density surface charge that interacts with a specific charge. The extent of the interaction depends on the materials adhering to the crown, but the high-density charges located in small volumes elicit intense interactions that can disrupt the density of surface charges on cell walls and membranes [252]. The exploration of these new possibilities, the further development of existing biostimulants, and the research of their mechanisms of action are still ongoing, but in any case, it can be said that the research of biostimulants has undergone tremendous development in the last decade. Their use could trigger a few chemicals, including fertilizers, which would go a long way towards creating a sustainable agricultural system.

In summary, the role of biostimulants is growing within the horticultural sector, especially in ornamental crop production. It has also become important in biotic and abiotic stress tolerance, sexual and asexual reproduction, seedling cultivation, and harvesting. Biostimulants can increase germination vigor and can be used to grow stronger seedlings and thus more stress-resistant plants. During the harvest, they play a particularly important role in the cultivation of cut flowers. Climate change is having an increasing impact, exacerbating the following several abiotic stresses that are also being felt in ornamentals:

plants need to adapt to the stress of heat, drought, and changing water supply through the consistent use of biostimulants. However, with the use of these commercially available products, it is often possible to use old varieties that have been cultivated for a long time (for example, outdoor roses), and it is not necessary to use varieties that are more tolerant of climate change. The use of biostimulants will make horticulture, including ornamentals, more resilient to climate change and create more livable, environmentally friendly, and sustainable agricultural production.

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