Application of Biostimulants in Ornamental Horticulture

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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.

Keywords: Biostimulants ; Ornamental Horticulture ; Disease

1. Introduction

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 [1]. 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 [2]. In recent years, however, the world is going through far-reaching processes. World ornamental plant exports already reached USD 9.4 billion in 2014 [3]. The ornamental plant trade has become a leading sector in previously uncharacteristic countries such as Brazil [4] and Thailand [3]. The development of the sector goes hand in hand with the economic development of developing countries [5].

2. 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 [6]. Disease treatment with biostimulants has received attention for their natural origin, efficacy, and low or non-existent toxicity [7]. 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 [8]. 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 [9]. This is especially true for humic acids [10]. Wild species such as *Hypericum* sp. can also be successfully produced using biostimulants [11], as can endangered species such as *Comanthera mucugensis* native to Brazil [12]. 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 [13][14][15][16][17], such as *Gladiolus grandiflorus* L. [18][19][20][21]. The cultivation of orchids produced by micropropagation was also greatly facilitated by the use of biostimulants [22].

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) [23]. 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 [24]. 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 [25]. 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 [26]. 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 [27].

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

Vegetative propagation is still an important propagation method in horticulture [28][29], and this propagation method makes horticulture even more efficient [30]. However, biostimulants are effective tools for optimizing the propagation efficiency of vegetative cuttings; however, their optimal application rates are often species-specific [31] and also depend on the location of cuttings on the shoot [32]. 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 [33]. There are species, such as *Abies gracilis* Kom., whose vegetative propagation does not occur without biostimulants [34]. Willow bark extract reduces the time required for additional root and shoot formation in chrysanthemum and lavender [31], 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 [31][35]. In the case of *Cornus alba* L., biostimulants also increased the rooting rate in cuttings [29]. 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 [36]. The humic acids can enhance the rooting of cuttings [37]. The reduction of the chlorophyll content in leaves was not inhibited by microalgae preparations [38].

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 [39]. 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 [40]. *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 [41]. Certain seaweed extracts, humic substances, and microbial inoculants play a role in the hormonal metabolism stage, increasing the germination rate [42]. *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. [15]. 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 [43]. 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 [44]. In *Inula viscosa* individuals, algae preparations reduced *Sphaerotheca pannosa* var. *rosae* infection [45]. In *Tagetes erecta* L., the germination capacity of the seeds was increased by the applied biostimulant [13] and the height of the seedlings was also increased [46]. For *Tagetes patula* L. and *Callistephus chinensis* L., several biostimulants reduced germination and increased it for *Viola* × *wittrockiana* [44]. The use of *Ascophyllum nodosum* also makes germination and seedling cultivation more efficient [41], 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 [47]. In addition to chitosan, phenolic compounds isolated from seaweed *Ecklonia maxima* also increased bulb size and active surface area in individuals of the species [48]. 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 [22]. In the orchid *Cattleya maxima* Lindl., it also has a positive effect on development when used in combination with coconut water [49]. Microbial substances are also effective in *Cymbidium* sp. Sw. orchid micropropagation [50]. Significant results have also been obtained in the flower, seed, and bulb propagation of *Crocus sativus* L. using biostimulants [51].

4. 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 [14]; thus, using biostimulants to make rose cuttings environmentally friendly [52]. In the case of annual ornamental seedlings, the weight of the above-ground parts can also be increased by using biostimulants [13][53], so when planting seedlings of *Tagetes patula* L. outdoors, regarding growth and development [16], Dudaš and Šestan [17] 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 [54]. In the case of *Portulaca grandiflora* L., the germination percentage was also significantly improved due to the use of microalgae biostimulants [55]. 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 [56][57][58]. Humic acids also promote faster seedling growth in *Salvia splendens* L. [59]. Supplementation of humic acids with organic and fertilizer increased plant height and flower yield of *Polianthes tuberosa* L. [60] and *Dendrobium nobile* Lindl. [61]. Spraying and watering with biostimulants has intensified vegetative growth [62]. 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 [63]. In ornamental plant cultivation, the flower is one of the main ornamental values [64]. In the case of *Gerbera jamesonii* L., seaweed extract increased the number of inflorescences and also had a beneficial effect on growth [65]. 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 [66]. 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 [67], as well as in *Anthirrinum majus* L. [68], which is a major cut flower in the ornamental plant trade [69]. 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 [70]. 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 [71]. Most biostimulants increase the content of photosynthetic pigments (chlorophyll and carotenoids) and decrease the content of polyphenols and antioxidant radicals [72].

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 [73]. 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 [55].

5. 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 [74]. 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 [75]. In the case of *Gladiolus grandiflorus* L. bulb cultivation, the bulb yield from the humic acid-treated stock was the highest [19] and the number of flowers harvested per unit area was also, so humic acid is a suitable biostimulant in gladiolus production [20][21]. *Moringa* leaf extract is also very beneficial as its use has increased physiological properties and vase life [76]. 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 [77], as described for *Polianthes tuberosa* cv. Prajwal [78] and *Gerbera jamesonii* Hook [79] as well as *Lilium orientale* [80]. 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 [81]. In the cultivation of Calathea insignis, humic acid can be used in combination with biochar to replace peat [80]. 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 [18]. 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 [82]. 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).

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