

# **Biostimulants in Ornamental Horticulture: A Review on Growth Promotion, Quality Enhancement, and Eco-friendly Practices**

## **ABSTRACT**

The significant rise in demand for flowers in recent years due to population growth, improved living standards, and tourism, stimulate the demand for fresh floral arrangements. Conversely, to increase the yield and quality of flowers, the application of synthetic chemicals results in harmful effects on humans and on the environment. Hence, sustainable agricultural practices such as the application of biostimulants are gaining momentum and being adopted. Biostimulants are materials which comprises any substances or microorganisms that, when applied to plants or the rhizosphere, enhance natural processes to improve nutrient uptake, nutrient use efficiency, tolerance to abiotic stress, and crop quality. Biostimulants are highly beneficial for plants due to their application in various fields of horticulture, which are regarded as eco-friendly and cost-effective commodities. It provides benefits such as increased crop yield, quality and fostering growth and development, tolerance to biotic and abiotic stresses, enhancement of the storage life of flowers and foliage and phytoremediation of various elements. Biostimulants are environmentally safe inputs that lower cultivation costs, particularly in horticultural crops. Their use supports sustainable agriculture in relation with global initiatives promoting eco-friendly and resource-efficient farming practices

**Keywords:** *Biostimulants, floriculture, growth promotion, quality enhancement, stress tolerance, sustainable horticulture.*

## **1. INTRODUCTION**

The demand for flowers and floral products has been increasing over the past few years due to the rapid population growth, improvement in living standards, gifting culture, and the growth of establishments, such as hotels and resorts. In addition, the tourism sector has been playing an important role in promoting the demand for fresh flowers, thus generating the need to increase the production of flowers and foliages. On the other side, the utilization of synthetic chemicals in farming has led to the hazardous effects on humans and the environment. In case of human health, agricultural workers are at a greater risk of cancer and neurological disorders due to exposure to synthetic chemicals (Curl *et al.*, 2020; Rani *et al.*, 2020). These chemicals can also cause reproductive disorders and disrupt thyroid function, posing significant risks to endocrine health (Curl *et al.*, 2020; Rani *et al.*, 2020). Synthetic fertilizers degrade soil health by retarding microbial diversity and function, harming beneficial microorganisms that are essential for recycling of

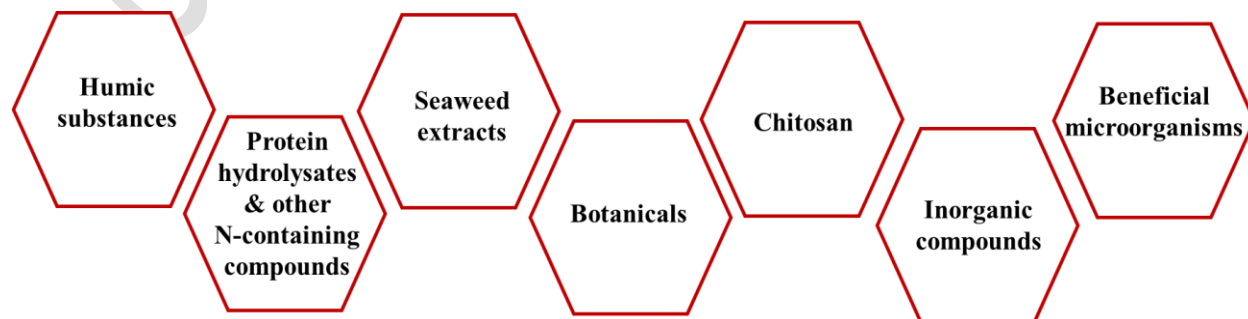
nutrients and soil fertility (Shahid & Khan, 2022; Tripathi *et al.*, 2020). This leads to reduced soil fertility and altered soil processes (Tripathi *et al.*, 2020; Syed *et al.*, 2021). The accumulation of chemical residues in the soil results in prolonged pollution, affecting both soil and water quality, and poses risks to the food chain (Bhaskar *et al.*, 2023; Ankit *et al.*, 2020). Moreover, synthetic chemicals add a considerable cost to cultivation practices, with estimates reaching approximately \$130 billion annually (Martin, 2024). This expenditure is particularly challenging for small scale farmers who are largely sustained by their production (Mashamaite *et al.*, 2024). Considering these situations, it is essential to explore and adopt different sustainable agricultural practices. An essential strategy in this context is the incorporation of biostimulants into cultivation practices (Rouphael and Colla, 2020).

Biostimulants have gained considerable interest over the past few years with their extensive range of advantages in all aspects of development and growth in plants. These are organic or inorganic substances, which are useful in a different ways, ranging from seed treatment to soil and foliar applications, fertigation, and postharvest treatment. Biostimulants are material that contains substance(s) and/or microorganisms whose function, when applied to plants or the rhizosphere, stimulates natural processes to benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and/ or crop quality, independently of its nutrient content (EBIC, 2015). The mode of action results in enhanced plant health and performance. Through the regulation of physiological activities like nutrient uptake, photosynthesis, and defense mechanisms. Biostimulants enable plants to grow under different environmental conditions, thus being a valuable resource in sustainable floriculture. Recent research has shown the significant role biostimulants play in floriculture by enhancing plant growth, propagation, flower quality, and yield. Biostimulants have proved to positively influence a variety of flower crops, such as anthurium, orchids, chrysanthemum, marigold, tuberose, and lilies (Thomas & Cr, 2024; Suvagiya *et al.*, 2024; Bhargavi *et al.*, 2018; Zeljkovic *et al.*, 2023; Saravani *et al.*, 2025; Sari, 2024). Apart from the promotion of flower quality and yield, biostimulants also play a part in promoting tolerance to stresses and prolonging postharvest shelf life of flowers. This review aims to summarize the classification, mode of action, results of current research, and prospects for biostimulants in floriculture.

## 2. CATEGORIES OF BIOSTIMULANTS BASED ON COMPOSITION AND MECHANISM OF ACTION

The categories of biostimulants are commonly recognized by a range of scientists, as confirmed through the research studies performed by Filatov (1951), Ikrina and Kolbin (2004), Kauffman *et al.* (2007), Du Jardin (2012), Calvo *et al.* (2014), and Halpern *et al.* (2015). In this regard particularly, Du Jardin (2012) has classified a broad category of biostimulants based on the sources and mechanism of action, which include humic substances, protein hydrolysates, several nitrogen-containing compounds, seaweed extracts, botanicals, chitosan, inorganic substances, beneficial microorganisms, *i.e.*, bacteria and fungi, etc.

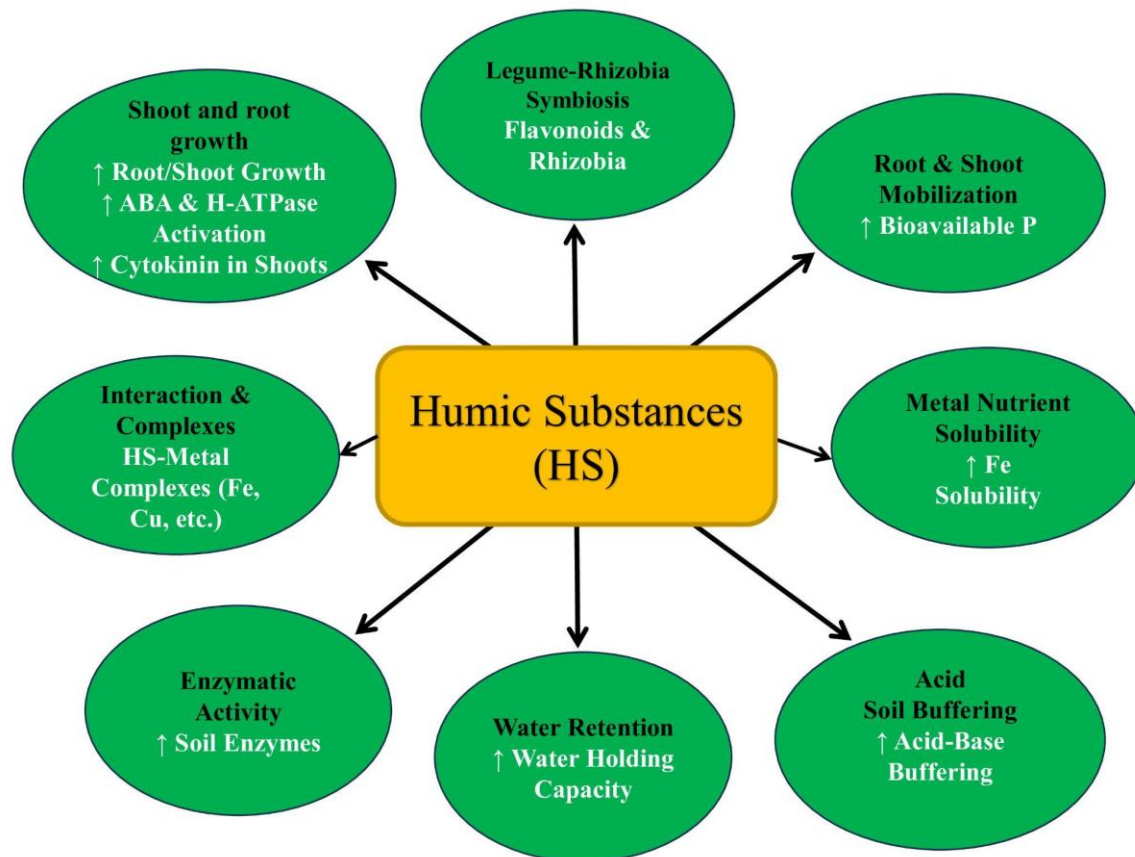
**Fig. 1. Classification of biostimulants (Du jardin, 2012)**



## 2.1 HUMIC SUBSTANCES

Humic substances (HS) are generally derived from soft coals, peats, compost, and sapropels and result from the humification of dead vegetation residues in soils and composts (Nardi *et al.*, 2007). They are complex associations of biologically altered organic residues with non-humic materials such as long-chain hydrocarbons, acids, esters, and polar entities such as polysaccharides and glomalin (Hayes & Clapp, 2001). These compounds consist of humic and fulvic acids, kerogen precursors, and are produced during early diagenesis and sedimentation (Khokha *et al.*, 2023). Humic acids are compounds of undefined composition and depend on the origin, functional groups in their structures, including phenols, quinones, and carboxylic acids (De Melo *et al.*, 2016). These compounds are essential in soil chemistry and fertility (Nardi *et al.*, 2007). HS are grouped according to molecular weight and solubility. Humins are of the highest molecular mass, fulvic acids are of the lowest, and humic acids are of intermediate molecular mass. Humic acid exhibits solubility in alkaline pH, fulvic acid in acidic pH, and humins are insoluble (Rodriguez & Nunez, 2011). Humic substance facilitates the transformation of phosphorus into bioavailable forms, contributes to soil mobilization and plant uptake (Yuan *et al.*, 2023), and increases enzymatic activities and nutrient availability in calcareous soils (Qian *et al.*, 2020). It influences the solubility of nutrients such as phosphorus, iron, and copper (Gerke, 2022). These compounds are essential in the formation of acid-base buffering and metal complexes and in regulating the effect of urea on soil based ammonia oxidizers (Csubak, 2006; Dong, 2009). In addition, it can hold large amounts of water and promote microbial activity (Wright & Lenssen, 2013; Qiao *et al.*, 2019), stimulate root and shoot growth by stimulating root ABA and H<sup>+</sup>-ATPase, thereby increasing cytokinin concentration in the shoot (Olaetxea *et al.*, 2019). Fulvic acid supports legume-rhizobia symbiosis by enhancing rhizosphere synthesis of endogenous flavonoids and rhizobia populations (Qiu *et al.*, 2024).

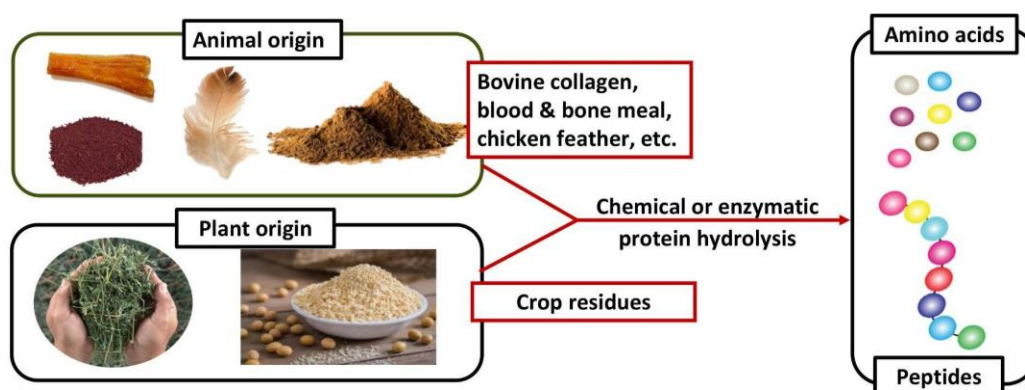
**Fig. 2. Multifunctional roles of Humic Substances in soil-plant systems**



## 2.2 Protein hydrolysates and other N-containing compounds

The source of protein hydrolysates (PHs) includes animal-based sources, bovine collagen, blood meal, chicken feathers, and bone meal, or plant-based sources, such as alfalfa and the residual by-products of soybean meal. Through either chemical, enzymatic, or ultrasound hydrolysis, these materials undergo a transformation that releases amino acids and peptides, collectively called as protein hydrolysates (Colla *et al.*, 2015).

**Fig. 3. Derivation of amino acids and peptides from agricultural and livestock residues**



Other nitrogen-containing compounds include homoserine, an intermediate product in the biosynthesis of some amino acids. Ornithine and canavanine are found either from plant or animal sources (Wink, 1997).

Amino acids mediate nutrient uptake by selective transport systems, e.g., root uptake, source-sink segregation, and absorption into the floral tissues and seeds (Tegeeder & Rentsch, 2010). It modulates plant nitrogen metabolism by regulating nitrate and ammonium uptake, their reduction, and subsequent incorporation into essential biomolecules for growth and development (Causin, 1996). Amino acids are involved in nitrogen-metabolic pathways and carbon-nitrogen balance regulation and function as signal molecules (Lai-ua, 2012). Amino acid metabolism contributes a role in the adaptation of plants to stress through alterations in oxidation pathways such as Glutathione-ascorbate cycle, Reactive oxygen species scavenging mechanisms and signalling molecules that contain target of rapamycin and, sucrose non-fermenting 1-related protein kinase (Heinemann & Hildebrandt, 2021). Functional amino acids, including threonine, serine, arginine, and  $\beta$ -aminobutyric acid, play a role in metabolic pathways involved in growth and development, such as glycolysis, tricarboxylic acid cycle, and phosphorylated glycerate and glycolate pathways (Kawade, 2023). These are essential in signal transduction, restoration of energy homeostasis, stomatal opening regulation, detoxification of heavy metals, osmolyte and ion transport regulation (Yuxiao, 2023, Rai, 2002).

### 2.3 Seaweed extracts (SWEs)

Seaweed extracts represent a complex derivation from various algal species that multiply in marine environments. Among those, brown and red algae have gained commercial popularity and utility as biostimulants. Various brown algae include *Ascophyllum*, *Sargassum*, *Macrocystis*, and *Kappaphycus* species. These diverse SWEs are comprised of a rich bioactive components, which include both macro and micronutrients such as nitrogen, phosphorus, potassium, magnesium, and zinc, as well as complex polysaccharides include alginate, laminarin, and fucoidans. In addition, these extracts also include a range of sterols, fatty acids, essential vitamins, and phytohormones (Siegel & Siegel, 1973). The complex nature of these bioactive compounds shows the potential of these SWEs in agri-horticultural use and their importance in enhancing plant growth and resilience.

Fermented seaweed (*Eucheuma cottonii*) decreases soil bioavailability of fluoride and improves fertility (Moirana *et al.*, 2022). The seaweed fertilizers nurture the mean crop yield by 15.17% and soil properties (Pei *et al.*, 2024). Moreover, *Gracilaria tenuistipitata* var. *liui* extracts have been reported to increase soybean yield and drought tolerance under water stress (Mannan *et al.*, 2023). SWEs can enhance drought resistance in *Hydrangea paniculata* and optimize water consumption (Clercq *et al.*, 2023). Additionally, advance the growth and resilience of Salam turfgrass under drought and saline conditions (Elansary *et al.*, 2017). Seaweed fertilization increases the density of ammonia-oxidizing archaea, thus enhancing soil fertility (Prasedya *et al.*, 2023), and it controls root-knot nematode activity (Williams *et al.*, 2021).

### 2.4 Botanicals

Botanicals refer to a range of substances derived from different plant parts (root, stem, leaf, flower). They are involved in improving seed germination, enhancing nutrient absorption, extending the postharvest longevity of flowers, promoting plant resistance, and mitigating various stresses in plants. (Carvalho *et al.*, 2021). Additionally, these substances have extensive applications in various industries, including the pharmaceutical and cosmetic sectors, where they serve as essential ingredients. Notable examples of botanicals include alfalfa (*Medicago sativa*), which is prominent for its nutritional benefits; moringa (*Moringa oleifera*), referred to as a superfood due to its rich nutrient profile; and borage (*Borago officinalis*), which is recognized for its potential health-related properties and uses.

### 2.5 Chitosan

Chitosan is the deacetylated derivative of the naturally occurring biopolymer chitin, which is synthesized from natural biological pathways and several industrial processes. The primary sources are the exoskeletons of crustacean organisms, such as shrimps and lobsters, and the cuticles of insects include damselflies and cockroaches. Deacetylation of these organic materials is a process through which they get converted to form chitosan. This compound has significant attention for its industrial uses, especially as a biostimulant in agriculture and horticulture (Mathur & Narang, 1990).

Chitosan promotes plant growth by enhancing photosynthetic activity, photosynthetic element induction, regulation of major photochemical processes, carbohydrate production (Ahmed *et al.*, 2020), and stomatal closure induction in plants (Bittelli *et al.*, 2001). Chitosan enhances physiological processes such as nutrient uptake, protein synthesis, and cell division (Chakraborty *et al.*, 2020). Chitosan triggers the expression of defense genes, boosts abiotic stress resilience, and strengthens pathogen resistance by engaging signaling pathways mediated by hydrogen peroxide and nitric oxide (Pichyangkura & Chadchawan, 2015). It regulates the expression of 56 miRNAs linked to photosynthesis, carbon and nitrogen metabolisms, defence, and transcription regulators (Zhang *et al.*, 2018). Chitosan-based nanomaterials have antimicrobial properties (Kumaraswamy *et al.*, 2018) and control postharvest rot in fruits and vegetables by inducing host defenses through the development of a protective edible coating (Romanazzi *et al.*, 2018). As a key inducer of plant defense against fungal pathogens, chitosan exhibits cytotoxicity of around 100  $\mu\text{M/mL}$  at the plasma membrane (Amborabe *et al.*, 2008). Furthermore, chitosan and oligosaccharides of chitosan stimulate various signalling pathways such as G protein-coupled receptor, phospholipase C/protein kinase C, mitogen-activated protein kinase, and innate antiviral defences (Ahmed *et al.*, 2020; Iriti & Varoni, 2015; Xing *et al.*, 2014).

## 2.6 Inorganic compounds

Inorganic compounds can be grouped into two broad categories: the beneficial elements and inorganic salts formed from the beneficial elements. The beneficial elements include aluminium, selenium, sodium, silicon, cobalt, etc. however, inorganic salts, symbolized by salts namely phosphates, chlorides, silicates, carbonates and phosphites, are essential in plant development and growth (Van Tuil, 1965). Furthermore, it is essential to understand their role in enhancing the level of available nutrients to plants, these inorganic salts play a role in being an essential requirement to specific taxa, thus indicating their function in the attainment of nutrients and plant well-being (Smits *et al.*, 2009). Therefore, the interaction between these functional components and inorganic salts offers insight into their synergistic action on plant physiology.

Aluminium enhances phosphorus availability and neutralizes toxicity in acidic soils by attracting beneficial rhizobacteria (Muhammad *et al.*, 2019). Selenium increases the chemo-preventive phytochemicals in plants, increasing their antitumoral activity in human carcinoma cell lines, particularly in cruciferous vegetables (Gaspar *et al.*, 2015). It enhances nutritional quality and modulates plant ecosystems by inhibiting herbivore consumption and increasing tolerance to pathogenic bacteria (Chao *et al.*, 2022). Sodium negatively affects plant growth by suppressing enzyme activities, requiring an ideal  $\text{K}^+ : \text{Na}^+$  ratio for proper development and yield (Wakeel, 2013). Menadione sodium bisulfite in chitosan/tripolyphosphate nanoparticles enhances water deficit tolerance and accelerates recovery after rehydration (Jimenez-Arias *et al.*, 2023). It is advantageous to plants when potassium is lacking, and plants might need mechanisms to track sodium concentration to control gene expression and transport processes (Maathuis, 2014). Silicone stimulates plant growth under different stresses and guards against biotic and abiotic stresses (Savvas & Ntatsi, 2015; Coskun *et al.*, 2018). Cobalt plays an important role in biological nitrogen fixation, stress tolerance, and activation of enzymes for growth and resistance to various stresses (Banerjee & Bhattacharya, 2021; Pilon-Smits *et al.*, 2009).

## 2.7 Beneficial microorganisms

In the beneficial fungi, the arbuscular mycorrhizal fungi (AMF) have peculiar capacity to establish specialized structures that are referred to as arbuscules; these fungi constitute the phylum, *Glomeromycota* and these fungi are characterized by their hyphae that grow directly into the cortical cells of the roots of host plants, which in turn develop into branching structures that enhance the host plant's capacity to assimilate nutrients (Croll *et al.*, 2009). AMF facilitates nutrient absorption, and protects the plant against environmental stresses in the form of drought, soil salinization, and sub optimal thermal conditions (Sun & Shahrajabian, 2023), absorption and translocation of mineral elements, modification of the secondary metabolism, disruption in the phytohormone balance thereby affecting the development and resistance of the plant to environmental stresses (Rouphael *et al.*, 2015). AMF has synergistic activities with microbial



communities, such as nitrogen fixation, phosphorus solubilization, synthesis of siderophores, phytohormones, and antibiotics (Giovannini *et al.*, 2020).

Another example is *Piriformospora indica*, a fungal endophyte species isolated from orchids of the Thar desert; this fungus has resulted in nutrient uptake process of its host plants (Jisha *et al.*, 2019). It enhances plant growth by developing symbiotic relationships with plant roots and alters phytohormone signalling pathways to control stress tolerance (Aslam *et al.*, 2019). It mobilizes phosphates and moves phosphorus into the host through an energy-dependent mechanism (Singh *et al.*, 2000). Additionally, the *Trichoderma* genus, which contains many species, has emerged as a potential biocontrol agent, which is highly capable of tackling several plant pathogens threatening crop harvests. *Trichoderma* encourages nutrient-absorbing capability and dichotomous root branching (Lopez-Bucio *et al.*, 2015).

Concurrently, bacterial biostimulants promote plant growth and yield **via** nutrient uptake, antimicrobial metabolites, growth regulators, and stress-sensitive phytohormones. (Hamid *et al.*, 2021). However, beneficial bacteria are associated in plant health promotion and growth, e.g., *Rhizobium* species are renowned mutualistic endosymbionts that are involved in symbiotic relationships with leguminous plants, where nitrogen fixation occurs within root nodules. The plant growth-promoting bacteria namely *Pseudomonas*, *Azotobacter*, and *Azospirillum*, among others, which have been well-studied and known for their role in improving plant growth and resistance (Kloepper *et al.*, 1989). Rhizobia and legume hosts secrete phytohormones, siderophores, and enzymes such as ACC (1-Aminocyclopropane 1-carboxylic acid deaminase that directly or indirectly induces plant growth (Jaiswal *et al.*, 2021).

Plant growth-promoting rhizobacteria (PGPR) exert their functions by stimulating growth and triggering systemic resistance, decreasing disease susceptibility and severity (Loon *et al.*, 2007). *Pseudomonas* species induce the synthesis of phytohormones, enhance the accessibility of nutrients, and inhibit soil-borne plant pathogens **via** siderophores, antibiotics, and systemic resistance (N *et al.*, 2021). It enhances fruit size, quality, fruit number, plant and root mass, and photosynthetic activity under stressful conditions (Trueba & Adaro, 2017). *Azospirillum* covers various mechanisms such as phosphate solubilization, nitrogen fixation, and increased membrane activity (Cassan *et al.*, 2020). It increases phytohormone production, primarily auxins and indole-3-acetic acid, through additive and selective action (Coniglio *et al.*, 2019). *Azospirillum brasilense* Az19 enhances UV tolerance and incompleteness of the denitrification pathway, which could be a part of its stress-adaptation mechanisms (Garcia *et al.*, 2020).

Table 1. Applications of Biostimulants In Floriculture

Plant Species	Planting Material Used for the Study	Biostimulant Concentration	Method of Application	Plant Response	Reference
<b>Plant Propagation</b>					
French rose ( <i>Rosa gallica</i> var. Tuscany Superb)	Root cuttings	Root Juice™ 0.01% and Tytanit 0.04%	Immersion of cuttings	Increased rooting percentage	Monder <i>et al.</i> , 2019
Ground cover roses ( <i>Rosa</i> sp. var. Elfrid and Weisse Immensee)	Stem cuttings	Goteo® 0.2% - <i>Ascophyllum nodosum</i> extract	Immersion of cuttings	Stimulated the development of fresh shoots in cuttings	Pacholczak <i>et al.</i> , 2020
Chrysanthemum ( <i>Dendranthema grandiflora</i> ) and lavender ( <i>Lavendula officinalis</i> )	Semi-hardwood and softwood stem cuttings	1 mL L <sup>-1</sup> of Root Nectar® and 1.06 µL L <sup>-1</sup> of willow bark extract	Immersion of cuttings	Enhanced the root branching and adventitious root formation	Wise <i>et al.</i> , 2020
Jade plant ( <i>Crassula ovata</i> )	Stem cuttings	Sangral®	Immersion of cuttings	Increased number of roots of the stem cuttings	Toța <i>et al.</i> , 2022
Hybrid tea roses 'Michelangelo' and 'Cosmos'	Stem cuttings	Kelpak®	Immersion of cuttings	Increased rooting percentage	Traversari <i>et al.</i> , 2022



<i>Ecklonia maxima</i> extract					
<b>Growth and Development</b>					
Marigold ( <i>Tagetes erecta</i> )	Seeds	Acadian Seaplants™ 15 mL L <sup>-1</sup>	Seed treatment	Enhanced seed germination rate, seedling growth, and fresh and dry mass of shoots	Tavares <i>et al.</i> , 2020
Pansy ( <i>Viola tricolor var. hortensis</i> )	Whole plant	Radifarm® 0.30%	Foliar application	Greater fresh and dry mass of root	Zeljko <i>et al.</i> , 2021
Petunia ( <i>Petunia hybrida</i> 'Picobella Blue')	Whole plant	<i>Caballeronia</i> <i>zhejiangensis</i> C7B12, microbial biostimulant	Foliar application	Increased flower bud, shoot dry weight, crop canopy percentage	South <i>et al.</i> , 2021
Narcissus ( <i>Narcissus pseudonarcissus</i> ), Iris ( <i>Iris germanica</i> ), Tulip ( <i>Tulipa gesneriana</i> ) and Freesia ( <i>Freesia corymbosa</i> )	Bulbs	1 litre of EM inoculum is diluted 1:100 for every 10 liters of peat	Bulb treatment	Enhanced plant height, increased root and vegetative biomass, bulb mass and diameter, prolonged flowering duration	Prisa and Benati, 2021
Chrysanthemum ( <i>Chrysanthemum morifolium</i> var. Pina Colada and Radost)	Whole plant	Trainer®	Foliar application	Increased elongation and the apical flower diameter, reduced flower stem senescence	Carillo <i>et al.</i> , 2022

Sea lily ( <i>Pancratium maritimum</i> )	Seeds	Chitosan 1 mg mL <sup>-1</sup>	Seed treatment	Enhanced germination, overall plant growth, synthesis of secondary metabolites	Allam <i>et al.</i> , 2024
Money plant ( <i>Epipremnum aureum</i> )	Whole plant	0.1% amino acid complex	Foliar application	Increased leaf petiole length, chlorophyll content, total superoxide dismutase activity, dry mass	Cheng <i>et al.</i> , 2024
Primrose ( <i>Primula acaulis</i> )	Whole plant	0.15% PHs	Drenching	Improved dry weight and leaf area	Tutuncu, 2024
<b>Stress Management</b>					
Petunia ( <i>Petunia hybrida</i> )	Whole plant	<i>Moringa oleifera</i> leaf extract	Foliar application	Enhanced drought resistance, altered growth parameters, and changes in proline, MDA, and enzyme activity	Toscano <i>et al.</i> , 2023
Pansy ( <i>Viola tricolor</i> var. <i>hortensis</i> )	Whole plant	1% HGG	Foliar application	Alleviated the salt stress	Salachna <i>et al.</i> , 2024
Celosia ( <i>Celosia</i> sp.) and periwinkle ( <i>Catharanthus roseus</i> )	Whole plant	400 mg L <sup>-1</sup> of <i>Ascophyllum nodosum</i>	Foliar application	Partially mitigated the effects of salt stress on biomass accumulation and leaf gas exchange	Sales <i>et al.</i> , 2024

Postharvest Interventions					
Bird of paradise ( <i>Strelitzia reginae</i> )	Flower spikes	GO + SNPs 1 $\mu\text{L L}^{-1}$	As vase solution	Prolonged the postharvest life of flower spikes	Thakur <i>et al.</i> , 2022
Tuberose ( <i>Agave amica</i> L.)	Whole plant	MT (100 mM) + arsenic (50 mM)	Preharvest foliar application	Boosted growth, photosynthetic rate, photosynthetic pigments, proline and protein content, which leads to extended vase life under Arsenic stress	Zulfiqar <i>et al.</i> , 2023
<i>Brunnera macrophylla</i> , <i>Echinacea purpurea</i> , <i>Heuchera</i> $\times$ <i>hybrida</i> , <i>Persicaria amplexicaulis</i> , and <i>Rudbeckia</i> $\times$ <i>hybrida</i>	Whole plant	0.4% Guard <sup>®</sup>	Foliar application	Improved shoot length, leaf characteristics, and root characters	Miler <i>et al.</i> , 2024
Peony ( <i>Paeonia lactiflora</i> Pall.)	Cut flowers	50 $\mu\text{mol L}^{-1}$ MT	As vase solution	Increased flower diameter, reduced relative electrical conductivity and MDA content	Wang <i>et al.</i> , 2024
Gladiolus ( <i>Gladiolus grandiflorus</i> )	Flower spikes	3% borage leaf extract	As vase solution	Prolonged vase life, attributed to elevated levels of total soluble	Zulfiqar <i>et al.</i> , 2024

				proteins, sugars, and phenols in the florets	
<b>Phytoremediation</b>					
Duckweed ( <i>Lemna minor</i> )	Whole plant	Valagro Megafol®	Direct application to the roots	Enhanced the plant's ability to purify water contaminated with the herbicide terbutylazine	Panfili <i>et al.</i> , 2019
Halacsy ( <i>Noccaea goesingensis</i> )	Whole plant	Kelpak® With an endophytic fungus, <i>Phomopsis columnaris</i>	Foliar application	Improved Ni phytoextraction efficiency of the plants	Wazny <i>et al.</i> , 2021
Welden Plantain ( <i>Plantago weldenii</i> ) and Sow thistle ( <i>Sonchus oleraceus</i> )	Whole plant	Humic and fulvic acid-derived biostimulant	Root targeted application	Reduced bioavailability of Cd in the soil	Grammenou <i>et al.</i> , 2024

### 3. APPLICATIONS OF BIOSTIMULANTS IN FLORICULTURE

#### 3.1 Utilization of Biostimulants in Plant Propagation

Monder *et al.*, (2019) found that *Rosa gallica* root cuttings showed improved propagation, with higher rooting success in thicker cuttings (76.8%) than medium (67.9%); Rhizopon AA 020XX and Chryzotop Green yielded 90.0% and 87.5% success in thick and medium cuttings, respectively. Pacholczak *et al.* (2020) reported that Goteo enhanced chlorophyll and soluble sugar levels in ground cover rose cuttings, while reducing free amino acids and polyphenolic acids, compared to IBA and Algaminoplant. The application of Root Nectar® (1 mL L<sup>-1</sup>) and willow bark extract (1.06 µL L<sup>-1</sup>) significantly improved adventitious root formation and branching in lavender and chrysanthemum cuttings (Wise *et al.*, 2020). The biostimulant Sangral significantly enhanced vegetative propagation of jade tree (*Crassula ovata*) through stem cuttings, promoting greater root number (11.3) and improved rooting length (Tota *et al.*, 2022). Kelpak®, a seaweed-derived biostimulant, promoted root induction and increased survival and rooting percentage (77%) in rose cuttings, suggesting its potential as a sustainable alternative to synthetic rooting agents (Traversari *et al.*, 2022).

#### 3.2 Application of Biostimulants in Enhancing Plant Growth and Development

The *Ascophyllum nodosum* extract (15 mL L<sup>-1</sup>) doubled germination rate and increased seedling height by 84% in *Tagetes erecta*, significantly improving seed germination and early growth (Tavares *et al.*, 2020). Radifarm® (0.30%) significantly improved pansy seedling quality by increasing leaf and flower numbers by 13%, root fresh mass by 51%, and above-ground fresh mass by 40%, while also enhancing tolerance to temperature stress (Zeljkovic *et al.*, 2021). *Caballeronia zhejiangensis* C7B12 treatment enhanced greenhouse ornamental crop growth, quality, and flowering, achieving performance comparable to plants with higher fertilizer inputs (South *et al.*, 2021). Effective Microorganisms (EM) treatments improved ornamental bulbous plant growth, increasing height, bulb weight and diameter, extending flowering duration, and enhancing resistance to *Botrytis cinerea* compared to controls (Prisa and Benati, 2021). Plant-based protein hydrolysates enhanced stem elongation, apical flower diameter, and increased nitrate and phosphorus in leaves, along with higher calcium content in flowers of *Chrysanthemum morifolium* varieties (Carillo *et al.*, 2022). Soaking of *Pancratium maritimum* bulbs for 8 hours in chitosan nanoparticles (1 mg mL<sup>-1</sup>) enhanced growth, yield, and increased levels of pancratistatin, lycorine, and antioxidants (Allam *et al.*, 2024). Amino acid biostimulants at 0.08% and 0.10% concentrations significantly enhanced peroxidase and catalase activities, chlorophyll content, dry mass, and total antioxidant capacity in *Epipremnum aureum*, indicating improved physiological and growth responses (Cheng *et al.*, 2024). PH application at 1.5 g L<sup>-1</sup> significantly increased dry mass (4.85 g) and leaf area (39.87 cm<sup>2</sup>) in pot-grown primrose (*Primula acaulis*), while 1.0 g L<sup>-1</sup> treatment yielded the highest chlorophyll content (SPAD 34.35) and improved root length and surface area (Tutuncu, 2024).

#### 3.3 Application of Biostimulants in Managing Plant Stress

Toscano *et al.* (2023) studied petunia responses to *Moringa oleifera* extract under water stress. The biostimulant enhanced flower number and photosynthesis, especially during severe drought. Drought affected evapotranspiration, sugar, phenol, salicylic acid, chlorophyll, and carotenoid levels, while PSII quantum efficiency declined with increasing stress. Salachna *et al.* (2024) explored the use of partially hydrolyzed gellan gum (HGG) as a natural biostimulant to promote growth and enhance stress resilience in pansy plants. The findings revealed that HGG improved vegetative growth and flowering at a concentration of 100 mg dm<sup>-3</sup>, effectively alleviating the detrimental impacts of salt stress. Biostimulant (*Ascophyllum nodosum*) application under brackish water irrigation improved stress tolerance in *Catharanthus roseus* and *Celosia argentea*. While salinity negatively impacted growth, especially in *C. roseus*, moderate levels enhanced the visual appeal of *C. argentea*, increasing consumer preference (Sales *et al.*, 2024).

### 3.4 Role of Biostimulants in Postharvest Intervention

Thakur *et al.* (2022) experimented on enhancing the postharvest life of the bird of paradise flower (*Strelitzia reginae* L.) using silver nanoparticles (SNPs) and graphene oxide (GO). Results indicated that the combination of GO and SNPs significantly prolongs the flower's vase life by six days compared to flowers treated with deionized water. Melatonin (MT) application improved the performance of tuberose plants under arsenic stress by enhancing photosynthesis (191%), postharvest flower life (15%), and increasing carotenoid and proline contents (31% and 28%). It also reduced oxidative stress indicators like MDA, hydrogen peroxide, and electrolyte leakage (Zulfiqar *et al.*, 2023). Microbiological biostimulants improved physiological and morphological traits in in vitro ornamental plants during storage. *Brunnera macrophylla* showed enhanced shoot elongation, while *Echinacea purpurea* exhibited improved root and leaf traits, especially with the biostimulant Guard (Miler *et al.*, 2024). MT (50  $\mu\text{mol L}^{-1}$ ) delayed senescence in peony cultivars 'Qi Hua Lu Shuang' and 'Da Fu Gui', extending vase life by 1.6 and 1.2 days, respectively. It also improved flower diameter, water balance, and reduced MDA content and electrolyte leakage (Wang *et al.*, 2024). *Borago officinalis* leaf extract (1–4%) extended gladiolus vase life from 6.2 to 13 days, with 3% being most effective. It increased floret diameter, relative fresh weight, chlorophyll, carotenoids, proline (up to 41%), and phenolics, while reducing oxidative stress and bacterial growth (Zulfiqar *et al.*, 2024).

### 3.5 Utilization of Biostimulants in Phytoremediation

Panfili *et al.* (2019) found that *Lemna minor* effectively remediates terbutylazine-contaminated water. Treatments enhanced antioxidant enzyme activity, improving phytofiltration efficiency. *P. columnaris* increased biomass yield of *Noccaea goesingensis* by 85% in Ni-enriched soil, while its combination with an IAA-based biostimulant enhanced Ni accumulation by 48%, indicating strong potential for improved nickel phytoextraction (Wazny *et al.*, 2021). A humic–fulvic acid biostimulant reduced Cd bioavailability in *Plantago weldenii* from 17.57 to 13.12  $\text{mg kg}^{-1}$ , indicating immobilization, while increasing it in *Sonchus oleraceus* from 10.13 to 13.03  $\text{mg kg}^{-1}$ , highlighting its potential as a Cd hyperaccumulator (Grammenou *et al.*, 2024).

## 4. TECHNIQUES FOR THE APPLICATION OF BIOSTIMULANTS

Biostimulants can be applied to the growth medium and other plant structures since they do not have residual effects. Application techniques are foliar sprays, media incorporation, fertigation, seed treatment, seedling immersion prior to transplanting, and postharvest applications, which include spraying on the flowers and foliages, immersion of flower spikes in biostimulants, etc., The strength of biostimulants depends on the particular category used and the desired aim of their application. Additionally, biostimulants can be administered via foliar sprays, including PHs, SWEs, botanicals, humic substances, and inorganic compounds. Humic and fulvic acids, protein hydrolysates, and microbial components are applied using fertigation, soil application, and seed treatment. Inorganic compounds, botanicals, and chitosan are used in postharvest treatments.

## 5. CONCLUSION & FUTURE PROSPECTS

Biostimulants such as humic substances, SWEs, chitosan, PHs, inorganic compounds, beneficial fungi, and plant growth-promoting bacteria which promote plant growth, nutrient uptake, stress tolerance, and disease resistance. These effects are mediated through mechanisms including nutrient transformation, symbiotic relationships, hormone regulation, and antimicrobial properties. Biostimulants comprise one of the most innovative approach in the field of agriculture and horticulture, not just with regards to increasing production and productivity but also in plant propagation, growth and development and prolonging postharvest shelf life of produce as well as mitigating biotic and abiotic stresses. In addition, these substances have a high impact on the phytoremediation processes of heavy metals in the soil. Notably, biostimulants are generally safe for both people and the environment, especially when compared to conventional synthetic agricultural inputs. The use of biostimulants reduces the costs of cultivation,

especially in horticultural crops. It also represents a sustainable agricultural approach in accordance with global initiatives promoting environmentally friendly and resource conserving farming practices. Regulatory problems, excessive prices, low availability, supply chain disruptions, and inadequate local availability or knowledge limits the biostimulant access. The cellular processes of biostimulants are still not well studied, which limits their effective use in horticultural operations. Lack of regulation of biostimulant production makes things more complicated. Multiple factors affect biostimulants' performance, generating inconsistency and lack of reliability in farming practice. The scientific community needs to explore biostimulants' genetic, molecular, efficacy duration and physiological mechanisms. Determining the longevity of biostimulants under different conditions is crucial for agricultural optimization. Examining the interactions between biostimulants, micro-organisms, and chemical inputs is essential for developing sustainable production systems.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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