Plant Archives Vol. 25, Supplement 2, 2025 pp.1725-1732 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.218

IMPACT OF BIOSTIMULANTS ON VEGETATIVE GROWTH, REPRODUCTIVE TRAITS AND POST HARVEST LIFE OF *GERBERA JAMESONII*: A COMPREHENSIVE REVIEW

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(Date of Receiving : 07-05-2025; Date of Acceptance : 13-07-2025)

ABSTRACT

The growing demand for sustainable horticultural practices has intensified interest in plant biostimulants as eco-friendly alternatives to synthetic agrochemicals. Biostimulants comprising humic substances, protein hydrolysates, seaweed extracts, amino acids, microbial inoculants, chitosan, and triacontanol enhance plant vigor, nutrient efficiency, and resilience to abiotic stress. This review critically evaluates the roles of biostimulants in improving vegetative growth, reproductive traits, and post-harvest life of *Gerbera jamesonii*, a high-value floricultural crop. Seaweed extracts stimulate nutrient uptake and hormonal activity, resulting in improved shoot development and flower yield. Humic and fulvic acids contribute to root development, nutrient assimilation, and vase life extension by enhancing membrane permeability and antioxidant activity. Protein hydrolysates and amino acids provide energy-saving building blocks that promote growth during stress-sensitive stages. Microbial inoculants, particularly plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF), enhance nutrient solubilization and hormone modulation. Triacontanol, a long-chain alcohol, and chitosan, a biopolymer, have demonstrated significant regulatory effects on flowering, stem strength, and post-harvest quality by modulating metabolic and defense-related pathways.

The integrated use of these biostimulants has shown synergistic effects under protected cultivation, enhancing flower size, pigmentation, and vase life while reducing chemical inputs. However, variations in response due to cultivar sensitivity, environmental conditions, and formulation complexity remain key challenges. This review highlights the scope for standardizing dosage, delivery methods, and combinations tailored to specific crop needs. Biostimulants represent a promising frontier for sustainable floriculture, contributing to productivity, quality enhancement, and environmental conservation.
***Keywords*:** Biostimulants; Gerbera jamesonii; Humic acid, Sea weed extracts, Post harvest physiology, Sustainable floriculture

Introduction

Horticultural production must be sustainable in order to satisfy consumer expectations. Increasing the effective use of resources to produce and supply healthy products is the greatest way to do this. A number of technical and technological advancements have been put forth recently with the goal of significantly reducing the use of agrochemicals while increasing the sustainability of production systems. The use of chemicals and/or microorganisms that promote plant development, boost resistance to adverse soil and environmental conditions, and increase resource usage efficiency would be a potential approach. The term "biostimulants" was proposed for these compounds and microbes (Zhang and Schmidt 1997). A plant biostimulants is any agent or microorganism administered to plants in order to improve nutrition efficiency, abiotic stress tolerance, and/or crop quality attributes, regardless of nutrient content. Plant biostimulants refer to commercial products that contain a combination of these chemicals and microorganisms (du Jardin 2015). Jena *et al.*, 2025 stated that bio enzymes are promising environmental production strategy for ornamental crops including foliage crops in shade net. Initially, biostimulants application yielded unsatisfactory results due to the lack of a scientific basis for development and quality control, with a focus solely on marketing. The European Biostimulants Industry Council (EBIC) defines plant biostimulants as substances or microorganisms that stimulate natural processes in plants or the rhizosphere, improving nutrient uptake, efficiency, tolerance to abiotic stress, and crop quality, regardless of nutrient content. Various biostimulants include peptides, amino acids, polysaccharides, humic acids, and phytohormones. According to du Jardin (2015), biostimulants are combinations of chemicals that affect plant physiological responses. These products aim to accelerate plant metabolism, reduce stress, and improve overall plant health rather than providing nourishment. According to Parrado *et al.* (2008), they can improve crop development and production through many methods, such as activating soil microbial activity and promoting the activity of plant growth hormones.

Biostimulants: Bridging Nutritional and Hormonal Gaps

Biostimulants are substances or microorganisms that improve nutrient efficiency, abiotic stress tolerance, and crop quality through mechanisms not attributable to nutrient content alone. They include:

a. Protein hydrolysates and amino acids
b. Seaweed extracts
c. Humic acid
d. Fulvic acid
e. Chitin and chitosan derivates
f. Inorganic Compounds
g. Microbial inoculants
h. Triacontanol

Protein Hydrosylates and N-Containing Compounds

Biostimulants can be produced by chemically synthesizing amino acids from plant proteins (e.g. algae, corn, and soybean) or enzymatically hydrolyzing animal proteins. Protein hydrolysate biostimulants are a combination of soluble peptides and amino acids. Formula of Protein Hydrosylates is $C_2H_5NO_2$. Protein hydrolysates contain amino acids like glycine, proline, lysine, etc. Plants rely on amino acids for structural, metabolic, and transport functions. They are the fundamental building blocks of proteins. Plants have the ability to synthesize amino acids, although this process requires significant energy. Using ready-to-uptake amino acids can help plants save energy and accelerate development, particularly during vital stages. In the agricultural industry, amino acids are used as metal ion chelates.

Sea Weed Extracts

It is derived from marine algae; these marine bioactive compounds are utilized in horticultural and agricultural crops and have numerous positive effects on quality and yield (Blunden *et al.*, 1997). The red, green, and brown macroalgae known as seaweeds account for 10% of marine production. Since the eleventh century, seaweeds, especially brown algae (*Ascophyllum nodosum*), have been successfully employed in agriculture (Temple and Bomke 1988). They were either dried, ground, and then added to the soil as seaweed meal, or they were added straight to the soil as seaweed compost. Seaweed extracts have become more and more popular in recent years because of their potential use in organic and sustainable agriculture (Russo and Beryln, 1991), particularly in rainfed crops as a way to enhance mineral absorption and prevent excessive fertilization. Traversari (2022) conducted an experiment in which he said, today's challenges in horticulture include achieving an effective, environmentally friendly, and sustainable plant production. In fact, it would be ideal to replace the chemical products used to encourage the germination of cuttings in plant vegetative propagation of woody ornamentals with natural extracts.

Representative Monomer of Sea weed extract chemically is β-D-mannuronic acid or α-L-guluronic acid with Formula $(C_6H_8O_6)n$. Seaweed extracts are rich in polysaccharides (alginates, laminarin), Mannitol ($C_6H_{14}O_6$) and Betaines and phytohormones (e.g., cytokinins)

Plants gain disease resistance through seaweed extracts (SWE). It has been reported to eliminate "black spot" in roses, and spraying turnip and melons with seaweed extract reduced mildew on the leaves (Booth, 1966). Poincelot (1994) found that using ROOTPLUS (*Ascophyllum nodosum*) at 1% increased the height of Celosia cultivars 'Fire Drallon' and 'Sweet Oregano' by 30.4 and 25.9 percent, respectively. Similarly, he demonstrated 20% more flowers after 35 days of transplanting and seven days earlier flowering in Cosmos cv. 'Sunny Red' as compared to the control. Matraszek *et al.* (2015) discovered a considerable rise in the number of heads in umbels (7–20%), a larger diameter of heads (23–41%) and an increase in the main stem height (14–10%) after applying Hemozyme (sea weed extract) @ 0.05 percent to *Ageratum houstonianium.*

Fulvic Acid

Ali (2022) said over the past few decades, plant biostimulants (BIOs) have been acknowledged as one of the best agricultural practices. Hajizadeh (2020) by application of fulvic acid and iron nano-chelate has a favorable impact on the majority of flowering and biochemical indices, according to the research's findings. Early flowering was brought on by the application of fulvic acid at low concentrations (50 mg L^{-1}) combined with iron nano chelate. General Formula of Fulvic acid (FA) is $C_{14}H_{12}O_8$ (varies based on source and extraction) with Functional groups as –COOH (carboxyl), –OH (hydroxyl), phenolic and aromatic rings. Fulvic acid is a complex mixture, so the formula is approximate and not fixed.

Humic Acid

Humic compounds are the byproducts of microbial decomposition and chemical breakdown of dead biota in soils (Asli and Neumann 2010). Approximate Formula Range: $C_{135}H_{181}O_{95}N_5S$ (widely varies). It is structurally composed of heterogenous mix of large organic acids with Aromatic + aliphatic backbone and having functional groups as –COOH, –OH, =C=O. Humic matter is created by the chemical and biological humification of plant and animal matter, as well as microbes. Humins are large, dark, and insoluble compounds that cannot be extracted from soil. Humic acids are medium-sized and soluble in alkaline solutions. Fulvic acid is smaller and soluble in both acidic and alkaline solutions. Humic acids are primarily found in the sedimentation layers of soft brown coal, known as leonardite. Humic acid concentrations are high here. Leonardite is biological matter that has not reached the stage of coal and is distinguished from soft brown coal by its high oxidation degree. It enhances soil structure, mineral content, compaction, and loosening, leading to increased aeration and workability. It also boosts soil's water retention capacity, which aids in drought resistance. Ali (2008) in his study found that Humic acid (HA) may promote plant development by enhancing hormone and nutritional absorption. The impact of HA on gerbera (*Gerbera jamesonii* L.) cv. 'Malibu' growth, macro- and micronutrient contents, and postharvest life was investigated. Yazdani (2014) observed that in the cultivation of gerberas, flower quality loss, particularly short postharvest life, is a significant issue. It appears that one way to enhance the quality of gerbera flowers is by utilizing modest amounts of Fulvic acid.

Humic compounds are formed by the chemical and biological breakdown of plant and animal wastes, as well as through the synthetic activity of microbes. When coal degrades, it also produces humus matter. Humic acid levels were found to be greater in peat and lignite (Schnitzer, 1991). Humic acid has been shown to increase plant membrane permeability, resulting in increased metabolic activity. It supports healthy soil structure as a factor in improving physical qualities of soil, resulting in enhanced tilth, aeration and moisture retention. Humic compounds, which make up a substantial amount of the dark matter in humus, are heterogeneous mixes of altered biomolecules with supramolecular structures that can be separated into their small molecular components through progressive chemical fractionation (Piccolo, 1993).

Humic acid promoted plant growth by altering plant physiology and increasing soil's physical, chemical and biological qualities. Its increased cation exchange capability demonstrates its chemical function. Humic acid serves as an energy source for nitrogen-fixing bacteria, demonstrating its biological activity (Stevenson, 1994). Humic acid has a comparatively high concentration of oxygen-containing functional groups (Schnitzer, 1999). Humic acids are complex organic molecules that are generated through the biogeochemical breakdown of plant detritus and animal residues, as well as the condensation of the degraded segments (Li *et al.*, 2003).

Inorganic Compounds

Beneficial elements are chemical components that support plant growth; while they may be necessary for certain species, not all plants need them. Al, Co, Na, Se, and Si are the five primary advantageous elements. According to reports, these components support plant development, plant product quality, and abiotic stress tolerance. The mechanism of action involves cell wall rigidification, osmoregulation, reduced transpiration by crystal deposits, enzyme activity by co-factors, plant nutrition through uptake and mobility, antioxidant protection, interactions with symbionts, pathogen and herbivore response, heavy metal toxicity protection, and plant hormone synthesis and signaling. Fungicides include inorganic salts of important elements such chlorides, phosphates, phosphites, silicates, and carbonates.

Microbial Inoculants

Over the last two decades, the use of microbial inoculants in agriculture has grown significantly (Hayat *et al.*, 2010). This is due to efforts by both public and private sector agricultural research and development communities to address modern agricultural challenges. Microbial inoculants are classed as either biocontrol agents (also known as biopesticides) or biofertilizers (Bashan, 1998). Xavier and Boyetchko (2002) describe microorganism-based formulations as biostimulants. Inoculants often consist of free-living bacteria, fungus, and arbuscular mycorrhizal fungi (AMF). Microbial inoculants can stimulate plant growth and nutrient uptake through various mechanisms, including symbiotic nitrogen fixation, nutrient solubilization, hormone modification, and the application of bacteria like Rhizobium and Azospirillum. They also increase plant tolerance to salinity conditions. Nitrogen-fixing bacteria, such as *Azotobacter chroococcum* and *Azospirillum lipoferum*, can fix nitrogen and produce phytohormones like Gibberellic acid and Indole acetic acid, which can promote plant growth, nutrient absorption, and photosynthesis. These mixes may include microbes, yeast, seaweed extracts, PGPR, trace elements, enzymes, and plant hormones. Fungi, including mycorrhizal fungi, arbuscular mycorrhizal fungi (AMF), Rhizobacter, fungus-based products, and fungal endophytes like Trichoderma spp., interact with plant roots in a variety of ways, ranging from mutualistic symbioses to parasitism. In a similar vein, microbes and plants can interact in any way. Two primary categories of biostimulants should be regarded as significant in relation to agricultural applications: mutualistic PGPRs and rhizospheric and Rhizobium endosymbionts. Rhizobium and related taxa are marketed as biofertilizers, or microbial inoculants, which help plants absorb nutrients. Other bacteria include *Rhodococcus coprophilus*, *Pseudomonas fluorescens*, *Streptomyces spp.*, *Bacillus safensis*, and *Microbacterium sp.*

Chitosan

Chitosan is a copolymer of N-acetyl-d-glucosamine and d-glucosamine, created by removing over 80% of the acetyl groups from N-acetyl-d-glucosamine residues (chitin). Chitosan (monomer unit) with chemical formula: 2-Amino-2-deoxy-β-D-glucopyranose i.e, $C_6H_{11}NO_4$, mostly Derived from chitin by deacetylation; consists of glucosamine units. Chitosan-based products have unique qualities that make them useful in many industries, including agriculture as plant biostimulants. It is a deacetylated version of chitin, a biopolymer generated both naturally and industrially. It activates defense genes in plants, including pathogenesis-related genes like glucanase and chitinase. It activates enzymes in the reactive oxygen species scavenging system, including superoxide dismutase, catalase, and peroxidase.

Triacontanol

Ries *et al.* (1977) discovered the plant growth regulatory activity of triacontanol (TRIA) in Alfalfa (*Medicago sativa* L.). It is a secondary plant growth substance and not considered as phytohormone.

Mechanism of Action of Bio-stimulants

Researchers propose that the impact of biostimulants on plants is a result of their influence on plant metabolism in a broad sense, although it is hard to propose a single mode of action for all biostimulants. They promote the production of natural hormones, which can occasionally increase their activity, aid in the uptake of nutrients from the substrate, encourage root development, and increase yield while frequently enhancing quality. Biostimulants help plants withstand harsh conditions like drought, frost, and heavy metal pollution. This could be connected to changes in enzymatic activity or antioxidant production. They may improve water retention, increase antioxidants, and stimulate metabolism. They postpone senescence, reduce transpiration, and improve stomatal conductivity. They have also been shown to activate mechanisms that strengthen cell walls and increase plant sensitivity to water scarcity, as well as to promote basic metabolic processes in plants and soil, hence improving plant growth and development and increasing stress resistance. Bioenzymes functions as an anti-stress promoting, growth-stimulating, nutrient absorption, crop productivity improvement, dormancy-breaking, boosting foliage quality, pigment content improvement, enhancing root formation, enhancing photosynthetic as well as vegetative tissue processes, enhancing plant resilience and coherence, and regulates effect on foliage crop growth, quality parameter and development. (Jena *et al*., 2025)

Biostimulants are a broad group of substances and microorganisms that enhance plant vigor, yield, and quality by stimulating physiological and biochemical processes independently of their direct nutrient content. Unlike fertilizers, which supply essential elements, biostimulants enhance the plant's ability to assimilate and use available nutrients more efficiently. Their application in floriculture, especially in high-value crops like *Gerbera jamesonii*, has emerged as a sustainable and potent alternative for boosting plant performance and marketability.

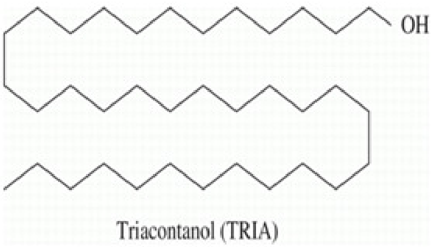

Fig. 1: Structural Formula of Triacontanol: $C_{30}H_{60}O$

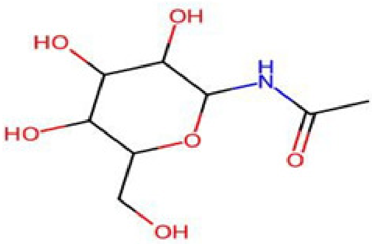

Fig. 2: Chitosan

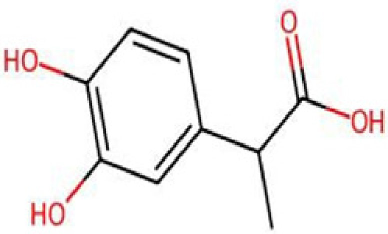

Fig. 3: Fulvic acid

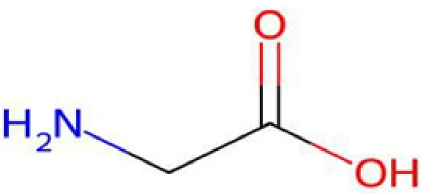

Fig. 4: Protein Hydrosylate

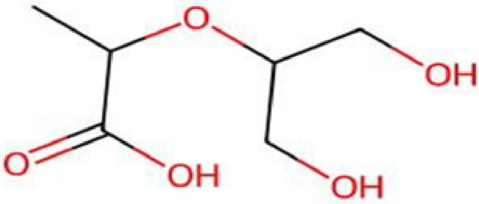

Fig. 5: Sea Weed Extract

Plant Bio-stimulants Formulations and Applications

The formulation needs to be simple to use and maintain an efficient capacity for biocontrol or plant growth promotion. There are several ways to formulate PGPR inoculants, ranging from the formulation procedure to the selection of carriers (peat, coir dust, charcoal, sawdust, clay, perlite, vermiculite, and polymer-like alginate). Additionally, there are a number of useful methods for applying inoculants and achieving production. These are Biostimulants with trade names like JIVRAS (Humic acid + Fulvic acid & their derivatives), SAMRAS (Protein Hydrosylates + Amino acids), Dhanzyme Gold (Sea weed extract formulations), Biozyme vegetable plus (Sea weed fermented biomass-22% & Amino acids-4%), Vipul Booster (Triacontanol 0.1% w/w) with abiotic and biotic stress tolerance.

Bio-stimulant vs Biofertilizers vs Biocontrol Agents

Regardless of its nutrient content, a plant biostimulants is any material or microorganism that is administered to plants in order to improve crop quality attributes, abiotic stress tolerance, and/or nutrient efficiency. Consequently, plant biostimulants are also classified as commercial goods that contain combinations of these compounds and/or microbes.

Regardless of the inoculant's nutrient composition, a biofertilizer is any bacterial or fungal inoculant that is administered to plants with the intention of increasing nutrient availability and plant consumption. Another way to describe biofertilizers is as a subclass of microbial biostimulants that increase the effectiveness of plant nourishment.

In Biocontrol agent case, one organism is under the power of another. Living creatures known as biocontrol agents are employed in plant production to defend plants from their adversaries, such as by bringing pest or disease populations down to manageable levels. Parasitism and competition antibiosis are two possible modes of action.

Benefits of Using Bio-stimulants

According to Nardi *et al*. (2009), biostimulants can either directly affect plant physiology or enhance soil conditions. They increase plant tolerance to and recovery from abiotic stresses, improve crop quality and yield by improving the efficiency of the plant's metabolism; facilitate the assimilation, translocation, and use of nutrients; improve the quality attributes of produce, such as sugar content, color, and fruit seeding; make water use more efficient; and improve soil fertility, especially by encouraging the growth of complementary soil microorganisms. Biostimulants improve plant performance by stimulating enzyme activity, chlorophyll biosynthesis, and root architecture. Their use in gerbera has shown to increase flower size, stem thickness, petal pigmentation, and vase life (Nikbakht *et al*., 2008; Tavakoli and Asadi-Gharneh, 2020). It has been found that Seaweed extract-treated gerbera exhibited enhanced shoot length, stem diameter, number of suckers, and increased flower yield (Das *et al*., 2022). Humic substances improved root volume, nutrient uptake, and delayed senescence, thereby extending vase life (Kumari *et al*., 2023).

- **Impact on Vegetative Growth**

Biostimulants improve vegetative growth by enhancing root development, increasing photosynthetic efficiency, and improving nutrient mobility. Humic and fulvic acids act as natural chelators, aiding in micronutrient uptake, while amino acids serve as precursors for protein synthesis and stress resistance. In a study by Nikbakht *et al*. (2008), humic acid-treated gerbera plants showed increased plant height and leaf area. Similarly, Mahgoub (2010) reported that foliar application of amino acid-based biostimulants significantly improved shoot biomass and root development in gerbera.

- **Effect on Flowering and Reproductive Traits**

Biostimulants influence flowering by modulating hormonal pathways, increasing the translocation of nutrients to floral organs, and enhancing enzymatic activities.

According to Sivasankari *et al*. (2013), seaweed extract application improved flower number and diameter in gerbera. Amino acids and protein hydrolysates act as precursors for polyamines and secondary metabolites, contributing to improved floral differentiation and pigmentation.

- **Influence on Post-Harvest Life and Quality**

Post-harvest vase life of gerbera is greatly influenced by pre-harvest treatments that determine stem strength, vascular integrity, and water uptake efficiency. Biostimulants like seaweed extract and humic acid improve water retention and reduce oxidative stress, leading to longer vase life. Rathore *et al*. (2020) observed that humic acid application extended vase life by 2–4 days in gerbera by maintaining stem firmness and delaying petal senescence. Tricontanol has also been reported to reduce transpiration loss and microbial colonization, thus enhancing post-harvest longevity.

Postharvest Life-A Key Determinant of Marketability

In commercial floriculture, vase life is a critical quality parameter. It is influenced by nutrient status, environmental conditions, and pre- and post-harvest treatments. Studies reveal that preharvest biostimulants application significantly improves vase life by delaying senescence, maintaining turgor, and reducing microbial blockage in xylem tissues (Nair and Prasad, 2003; Gantayet *et al*., 2020).

Application of Bio-stimulants on Flower & Foliage Crops

The quality of the most floriculture crops such as bedding plants is defined by the visual appearance, plant biomass, flower number and turnover. It is well known that plants during transplantation undergo several abiotic stresses causing environmental conditions to deviate from the optimum (Kijne, 2006). The application of biostimulants reduces the stress in the case of adverse temperatures and increases yield and the consequences are fewer cases of drought, freezing, mechanical and chemical damages as well as less viral plant infection (Maini, 2006). With the use of biostimulants at the stage of plantlet growth and development it is possible to create better conditions by adding active substances such as polysaccharides, proteins, amino acids and glycosides. The growth and development of *Begonia semperflorens* plants were positively impacted by the application of the biostimulants Radifarm to the soil (Zeljkovic *et al*., 2010). This commercial product is a member of a class of biostimulants that include amino acids (arginine and asparagine) and glucosides (energy growth factors). Jena *et al*., 2025 evaluated that [Humic acid (15%) + Amino acids (2%) + Fulvic acid (6%)] @ 1.5 ml/l, [Seaweed fermented biomass (22%) + Amino acids (4%)] @ 1.5 ml/l and [Triacontanol (a.i.) 0.1% w/w (1000 ppm), emulsifier (ethoxylated esters of fatty acids) 0.5% w/w, and preservatives (esters of benzoic acid) 0.1% w/w in demineralized aqua QS with total 100% w/w] @ 1.0 ml/l was found effective in improving growth traits, pigment quality and vase life of *Cordyline terminalis* highlighting potential of bioenzymes as biostimulants, offering an organic alternative to chemical fertilizers by improving overall plant health of Cordyline in Foliage crop industry through sustainable and eco-friendly approaches by enhancing vegetative growth, developmental stages and qualitative traits. Effect of integrated nutrient management on growth and flowering of gerbera (*Gerbera jamessonii*) cv. Rosalin under naturally-ventilated polyhouse condition was studied by Bellubi (2014). The experiment was conducted with six kinds of organic substrates along with inorganic fertilizers. The results proved that 75 per cent RDF + *Glomus fasciculatum* + *Trichoderma harzianum* + Panchagavya + Amrit Pani + dry mulch + Agnihothra ash improved the growth and flowering attributes in gerbera. Zaghloul *et al.* (2009) stated that treating Thuja orientalis L. seedlings with potassium humate significantly increased plant height, stem diameter, root length, fresh and dry weights of shoots and roots. El-Bably (2017) in tuberose (*Polianthes tuberosa* L.), indicated that humic acid treatment significantly increased all growth parameters (leaf length, number of leaves and fresh weight).

Conclusion

The over use of pesticides in agriculture has negatively impacted the environment, causing soil, water, and food quality issues. Organic farming is becoming increasingly popular as a solution to the issues associated with modern chemical agriculture. Developing a viable organic nutrient management package for different crops requires careful consideration of scientific facts, local conditions, and economic feasibility. These products attempt to enhance plant metabolism rather than providing nourishment. Biostimulants solutions provide a sustainable and environmentally friendly way to increase agricultural output in both broad acre and specialty crops globally. Numerous studies show that biostimulants can enhance crop output and reduce abiotic challenges including drought and soil salt. Using biostimulants in floriculture crop production improves sustainability by reducing fertilizer use and environmental contamination, while also increasing plant tolerance to abiotic and biotic challenges, resulting in improved internal and external quality. To properly characterize a biostimulants, it's important to include plant responses, including physiological targets and metabolic networks. Furthermore, the action of biostimulants varies by plant species. This could be due to varying sensitivity thresholds for bioactive chemicals in treated plants, preventing synergistic effects from occurring. Future biostimulants research could focus on combining several categories. Combining microbial inoculants with seaweed extracts or humic compounds may provide more consistent benefits for crop productivity. The application of biostimulants in *Gerbera jamesonii* cultivation presents a promising eco-friendly alternative to conventional chemical inputs. Biostimulants including humic acids, seaweed extracts, amino acids, and Tricontanol positively influence physiological functions, nutrient efficiency, and post-harvest longevity. Treatments combining microbial and organic components, especially when applied under protected cultivation, have shown synergistic benefits across all key parameters. However, variability in response due to cultivar differences, environmental conditions, and lack of dosage standardization remains a challenge. Future research should focus on multi-location trials, molecular interaction studies, and development of crop-specific bio-formulations.

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