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A REVIEW ON BIO-STIMULANTS IN HORTICULTURE: ENHANCING GROWTH AND STRESS TOLERANCE

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ABSTRACT

In horticulture, biostimulants have shown great promise as a means of improving plant growth, yield and stress tolerance. By promoting physiological and biochemical processes in plants, these artificial or natural compounds enhance nutrient absorption, stress tolerance, and total production. The categorization of biostimulants—which include inorganic chemicals, protein hydrolysates, seaweed extracts, humic substances, and helpful microorganisms—is examined in this study. There is discussion of the function of micronutrients in plant health as well as how they work in concert with biostimulants. Furthermore, the capacity of plant growth-promoting rhizobacteria (PGPR) to improve root development, nutrient uptake and stress tolerance is highlighted. The function of biostimulants in reducing abiotic stressors such salt, drought and temperature extremes is given significant attention. Additionally, the several uses of biostimulants in horticulture are explored, including their application in organic farming and sustainable agriculture. Lastly, future directions for biostimulant research are explored, including developments in formulation, regulatory structures, and incorporation into contemporary farming methods. The promise of biostimulants as a sustainable way to increase horticulture output while lowering dependency on chemical inputs is highlighted in this research.

Key words : Biostimulants, Stress Tolerance, PGPR, Classification, Opportunities, Micronutrients.

Introduction

A variety of chemicals and microbes that promote plant growth are referred to as plant biostimulants or agricultural biostimulants. Seeds, plants and soil can all benefit from the use of biostimulants, which can be either natural or artificial. In order to promote plant growth through increased resistance to abiotic stressors and boost seed and/or grain production and quality, these chemicals alter essential and structural processes. Furthermore, biostimulants lessen the requirement for fertilizers (Du Jardin, 2015). Regardless of its nutritional composition, these compounds are effective at tiny concentrations, improving crop quality characteristics, abiotic stress tolerance, and/or nutrition efficiency. When administered exogenously, these compounds function similarly to the classes of recognized plant hormones, the primary ones being cytokinins, auxins, and gibberellins (Yaronskaya *et al.*, 2016).

Non-microbial biostimulants are made from various organic matrices that have undergone various extraction techniques that enable the concentration of bioactive substances that boost crop growth or resistance to unfavorable environmental conditions (Ben *et al.*, 2021; Michalak *et al.*, 2015). It is quite challenging to determine which compounds are the most active and in charge of the biological activity due to the complexity of the raw organic material and consequently, the composition of the final product. Non-nutritional minerals (such as silicon and selenium), vitamins, amino acids, chitin, chitosan, poly- and oligosaccharides, and trace amounts of naturally occurring plant hormones (found in the initial matrix) can all be the substances causing the biostimulant activity (du Jardin, 2015; Xu *et al.*, 2018). The most well-known ingredients are minerals, vitamins, amino acids, poly and oligosaccharides, and trace amounts of naturally occurring plant hormones. It is crucial to emphasize, nonetheless, that the biostimulant activity must not be reliant on the nutrients or naturally occurring plant hormones included in the product. The processes that biostimulants trigger are sometimes difficult to pinpoint and are still being studied (Paul *et al*., 2019).

Major participants in the agro-industry find plant biostimulants to be a very alluring economic prospect and a fully recognized class of agricultural inputs (Boukhari *et al.*, 2020). The application of biostimulants in agriculture has grown significantly in the last several decades. Additionally, plant biostimulants are crucial for enhancing global nutrition. Producers, the food business, merchants, and consumers all gain from the creation of biostimulants from by-products, which opens the door for waste recycling (Xu *et al*., 2018). The following are the primary drivers of the biostimulant market's explosive growth: (i) the growing number of novel biostimulant products that address certain agronomic requirements; (ii) the necessity of encouraging the more economical and efficient use of mineral fertilizers and synthetic chemicals; (iii) the rising incidence of unfavorable environmental circumstances concerning productivity and yield growth (Colla *el al*., 2015).

Plant Biostimulants : In agriculture, plant biostimulants have generated a lot of attention as a sustainable means of boosting crop yield and plant development. It has been shown that biostimulants made of organic materials and bacteria can increase nutrient intake, promote growing crops, and improve stress tolerance (Paraðikoviæ *et al*., 2019). Algal extracts, protein hydrolysates, humic and fulvic acids, and nonpathogenic microbes are some of the several sources of biostimulants. Higher yield, better nutrient absorption and utilization, enhanced photosynthetic activity and resistance to biotic and abiotic stressors are just a few of the ways that these biostimulants have been demonstrated to enhance plant development (Calvo *et al*., 2014). Understanding the processes underlying biostimulants' effects on agricultural plants is crucial for their optimal usage in horticulture.

Classification of Biostimulants

Microbial inoculants, such plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF), are beneficial microorganisms that can improve nutrient absorption and increase plant resistance to stress (Calvo *et al*., 2014; GonzálezGonzález *et al*., 2020). By forming symbiotic relationships with plants, these biostimulants improve soil structure, nutrient availability, and plant defense mechanisms, among other advantages. These biostimulants promote photosynthetic activity, boost plant vitality, and facilitate root growth.

Seaweed extracts are widely used as biostimulants in agriculture, particularly those derived from species such as Ascophyllum nodosum (Calvo *et al*., 2014; De Saeger *et al*., 2019). Seaweed extracts have been shown to include bioactive substances such as hormones, polysaccharides, betaines and phenolic compounds that help plants develop, better absorb nutrients and endure stress (De Saeger *et al.,* 2019; Boukhari *et al.,* 2020).

Fulvic acids and humic substances : The biodegradation of organic matter yields a combination of acids with carboxyl and phenolate groups, which are then converted into fulvic and humic acids. Humic acids with a lower molecular weight and a greater oxygen concentration are called fulvic acids (Bulgari *et al*., 2015). The breakdown of plants, animals, and microbial leftovers, as well as the metabolic activity of soil microorganisms, produce humic compounds, which are naturally occurring components of soil organic matter (Rouphael *et al*., 2018). Treatments with humic compounds have been shown to promote the growth and development of plant roots (Canellas *et al*., 2002; Trevisan *et al*., 2020). This is demonstrated by improved water and nutrient absorption as well as increased resilience to environmental stressors (Canellas *et al*., 2015; Nardi *et al.*, 2016). Field crop monocots likely to gain advantages from humic acid extracts as well. When vermicompost extracts were applied to rice (*Oryza sativa* L.), they enhanced ROS scavenging enzymes and activated anti-oxidative enzymatic performance. Toxic free oxygen radicals generated in plants under salt and drought stress must be inactivated by these enzymes (García *et al*., 2012).The differential control of proton ATPases found in the vacuolar and plasma membranes might be one way that vermicompost works.

Hydrolysed proteins, amino acids, carbohydrates and lipids : Proteins from plant and animal sources can be hydrolyzed chemically, enzymatically, or thermally (or by combining these various hydrolysis types) to produce hydrolyzed proteins, which are a mixture of amino acids, peptides, polypeptides, and denatured proteins (Nardi *et al*., 2019). By chemically and enzymatically hydrolyzing proteins from plant sources, animal-derived materials (such as collagen and epithelial tissues), and agro-industrial by-products, amino acids and peptide combinations can be produced (Halpern *et al*., 2019). Amino acid and peptide-containing plant hydrolysates have a number of beneficial impacts on the production of different horticultural plants (Petropoulos, 2020). This action is linked to the stimulation of hormone-like activities and the upregulation of metabolites involved in plant development processes. Plant growth and development are subsequently impacted by these (Colla *et al*., 2017).

Amino acid-rich extracts could contribute to improved resistance to cold. When lettuce plants (*Lactuca sativa*) were exposed to cold and treated with Terra-Sorb, an amino acid combination made from the enzymatic hydrolysis of proteins, the treated plants showed enhanced stomatal conductance and greater fresh weights (Botta *et al*., 2013). Melatonin, which is produced from l-tryptophan through the shikimate pathway, has been shown in recent studies to prepare seeds to withstand unfavorable climatic circumstances throughout the imbibition and germination stages (Posmyk *et al*., 2016). Upon germination, corn seeds that have been pre-treated with melatonin exhibit heightened resistance to chilling stress, suggesting that melatonin has a priming effect (Kołodziejczyk *et al*., 2016). Melatonin could work well as a biostimulant to increase seedlings' ability to withstand stress.

Algal/Seaweed extracts : Seaweed extracts (SWE) are becoming commercially available as biostimulants that may be used to increase plant growth and increase resistance to heat, drought, and salinity. Algal extracts improve stress tolerance by focusing on many mechanisms. Although numerous species have shown growth-promoting benefits from seaweed extracts (Battacharyya *et al*., 2015; Verkleij, 1992), little is truly understood about the processes behind these effects. Because these compounds are complex and varied, it might be challenging to pinpoint the precise components that are essential. When used as a foliar spray, they can improve photosynthetic activity, abiotic stress tolerance, plant development, and resistance to bacteria, viruses, and fungus, increasing agricultural output and productivity (Norrie *et al*., 2006; Sharma *et al*., 2014). Cytokinins, auxins, and other hormone-like compounds are found in seaweeds used to produce biostimulants. Complex polysaccharides including laminarin, fucoidan, alginates, and plant hormones that support plant development are among the numerous active mineral and chemical substances they contain (Battacharyya *et al*., 2015). Now, the connection between cold tolerance and SWEs is becoming clear. SWEs and their capacity to increase resistance to cold stress have been the subject of very recent research. Only extracts high in zinc and magnesium were able to increase tolerance through improved ROS responses when many extracts were examined for their capacity to improve cold tolerance in maize. In this instance, giving plants micronutrients that function as co-factors in anti-oxidative enzymes is probably what causes the protective benefits (Rayirath *et al.,* 2009).

Now, the connection between cold tolerance and SWEs is becoming clear. SWEs and their capacity to increase resistance to cold stress have been the subject of very recent research. Only extracts high in zinc and magnesium were able to increase tolerance through improved reactive oxygen species responses when many extracts were examined for their capacity to improve cold tolerance in maize. In this instance, giving plants micronutrients that function as co-factors in anti-oxidative enzymes is probably what causes the protective benefits (Bradáèová *et al*., 2016). These findings suggest that by providing Sea Weed Extracts high in micronutrients to enhance oxidative stress tolerance, nutritional deficiency stress produced on by cold can be avoided. The effectiveness of nutritional seed priming was shown in earlier research using maize seedlings under root freezing stress supplemented with micronutrients (Imran *et al*., 2013).

Microorganisms : Micro-algae, filamentous fungus, yeast, and bacteria are all members of this category. They are kept apart from organic materials such as composted manures, plants, soil, and water. Through metabolic processes, they are added to the soil to boost crop yield. Through nitrogen fixation and nutrient solubilization, they improve nutrient uptake; they alter hormonal status by promoting the biosynthesis of plant hormones like auxins and cytokinins; they increase resistance to abiotic stressors; and they generate volatile organic compounds (VOCs), which may also directly affect plants. Arbuscular mycorrhizal fungi (AMF), bacteria, and fungi that can be isolated from soils, plants, and organic materials make up the majority of microorganism-based biostimulants (Baltazar *et al*., 2021; Del Buono, 2021). Direct application of these biostimulants to seeds or soils is possible (Franzoni *et al*., 2021). These biostimulants can work directly with the plants to create a symbiotic relationship or indirectly by increasing the plants' access to nutrients (Franzoni *et al*., 2021).

Plant growth-promoting Rhizobacteria (PGPR): Plant growth-promoting bacteria (PGPB) have various kinds of effects on plant cell functions (Brock *et al*., 2013). A few horticultural and agricultural crops have previously undergone PGPB tests in conjunction with soil restoration of heavy metal pollution (Ren *et al*., 2019). *Arthrobacter* species, *Acinetobacter* species, *Enterobacter* species, *Ochrobactrum* species, *Pseudomonas* species, *Rhodococcus* species and *Bacillus* species are among the common bacteria utilized as biostimulants (Efthimiadou *et al*., 2020). By supplying nutrients, preserving high potassium and sodium ratios, boosting osmolite buildup, improving photosynthesis, and boosting antioxidant enzyme activity, PGPB helps plants cope with salinity stress (Bhise *et al*., 2019). The morphological characteristics of spring bulbous ornamental plants are also enhanced by these rhizobacteria (Prisa *et al*., 2021). Additionally, they make Camellia japonica, an attractive evergreen plant, more resistant to salt stress, which significantly lowers cultivation expenses (Park *et al*., 2017). In individuals of the decorative foliage plant *Ficus benjamina* L., they enhance the propensity for root development (Sezen *et al*., 2014). The protective properties of *Rhizobium* against abiotic stress in plants have been well discussed in a number of recent articles (Gopalakrishnan *et al.,* 2015).These bacteria's most well-documented growth boost is linked to high levels of IAA, which has been shown to reduce salt stress (Egamberdiyeva *et al*., 2009).These microorganisms have different levels of tolerance to salt stress, and their ability to withstand stress can benefit the host-microbe connection. Two distinct strains of *Rhizobium leguminosarum* were inoculated into two legumes, pea (*Pisum sativum*) and fava bean (*Vicia faba*). The plants infected with the salt-tolerant strain (GRA19) outperformed the salt-sensitive strain (GRL19) under mild salt stress (Pilar *et al*., 1999).

Fungal Inoculating agents : In horticulture, *Trichoderma* has emerged as a significant microbial plant biostimulant (Harman, 2000). *Trichoderma* species are also employed in a number of industries, mostly in the synthesis of biofuels but also in the synthesis of enzymes, antibiotics, and other metabolites. Now that *Trichoderma* has reached the genomic age, some of its genome sequences are accessible to the general public, increasing its potential for use in human applications. To improve the effectiveness and safety of using these fungi, more research is necessary (Blaszczyk *et al*., 2014). The application of biostimulants based on *Trichoderma* in *Lactuca sativa* L. and *Eruca sativa* L. enhanced yields. As a result of treatment, the ornamental plant *Passiflora caerulea* L. grew bigger leaves with a greater chlorophyll content (Sesan *et al*., 2020). It is also a good biostimulant for woody evergreen ornamental plants, including *Olea europea* L., which is also utilized as an ornamental tree, since it increases resistance to abiotic stress (Vaio *et al*., 2021).

Biostimulants and Abiotic Stress tolerance in crops

A number of variables, including the biostimulants' method of action and administration timing, affect how well they work to combat stressful conditions. Biostimulants can be applied at various times, such as before the stress impacts the crop, during the stress, or even after. Depending on the intended outcome, they might be applied to seeds, early-stage plants, or fully-grown crops (Kunicki *et al*., 2010).The most crucial stages for crop yield determine when applications should be made, and this varies from species to species. Therefore, in order to prevent product loss and excessive production expenses, determining the ideal timing to apply biostimulants is just as crucial as figuring out the precise dosage. Following the administration of several exogenous treatments, more recent data of interest regarding vegetable crop tolerance have been acquired. According to (Cao *et al*., 2018), a decreased red to far-red ratio enhanced tomato seedling resistance to salt stress via influencing phytochrome activity. After applying exogenous melatonin to tomato plants cultivated under a mix of heat and salt, (Mertinez *et al*., 2018) demonstrated favorable outcomes. Another intriguing method for promoting abiotic stress resistance is to immerse plant seeds in various natural or synthetic chemicals. This tactic, which is commonly referred to as seed priming, has been thoroughly examined by Asharaf *et al.* (2018).

Heat Stress : High temperatures can harm plant cells in a number of ways, primarily by degrading membranes, inactivating enzymes and interfering with the production and action of proteins. The ideal temperature range for enzymatic activity and structural integrity is between 30 and 45 degree Celsius, since temperatures beyond 60 degree Celcius permanently denature them. Physiological processes including respiration and photosynthesis are impacted as a result. One of the most common throwbacks is an excess of harmful substances, such as reactive oxygen species, which results in oxidative stress (Hasanuzzaman *et al*., 2013). A temperature higher than ideal prevents seeds from germinating and slows the development of plants. Heat stress may hinder flower development and differentiation, interfere with the reproductive phase, decrease pollen viability and germination, and impair fruit set, all of which can limit growth and yield. Heat stress frequently causes extended style lengths and a reduced fruit set in tomatoes, which are among the species most susceptible to suboptimal temperatures (Camejo *et al*., 2005). Nahar *et al*. (2015) investigated into the way exogenous glutathione application protected against heat stress. Before being exposed to high temperatures, mung bean seedlings had lower levels of oxidative stress and methylglyoxal, a reactive substance that harms cells. This results the antioxidant defense mechanism to become more effective.

Salinity Stress : One of the most detrimental elements affecting plant development and metabolism is salinity, which results from osmotic stress brought on by salt. Higher amounts of sodium chloride (NaCl), the salt that is more prevalent in salty conditions, are hazardous (Viégas, 2006). Because saline water is commonly used to irrigate crops near the shore, it occurs particularly there (Colla, 2010). Because of the restricted absorption of minerals from the soil, salt stress results in a nutrient imbalance that jeopardizes the nutritional quality of horticultural crops. Salinity impairs nutrient availability and leads to a number of illnesses, including lower water potential, mobility issues within the plant and competitive absorption with other ions such Ca_2^+, P and K (Blaylock *et al*., 1994). The pH of the soil solution also affects the solubility of micronutrients like Cu, Fe, Mn, Mo and Zn, and under saline conditions, their availability is very low. When compared to the non-inoculated plants, the inoculation increased the development of the roots and shoots in chickpeas and faba beans by alleviating the stress brought on by salt. Since sweet peppers are a crop that is sensitive to salt, the inoculation had a good effect in reducing the negative effects of NaCl. In fact, at a variety of salt concentrations, dry weight was higher than that of non-inoculated plants. Additionally, the injection accelerated the rate of CO_2 assimilation. By using two distinct Rhizobium strains on faba bean and pea plants (Cordovilla *et al*.). Pilar *et al.* (1999) achieved a similar outcome. In comparison to the control plants, there was a reduction in electrolyte leakage and lipid peroxidation and an increase in antioxidant system activity. When applied as a foliar spray or as a seed soaking solution, Moringa oleifera leaf extract, either by individually or in conjunction with salicylic acid, enhanced a number of physiochemical parameters, including the concentration of carotenoids and chlorophyll, the amount of total soluble sugars, and the amount of ascorbic acid. A recent study shown how a biostimulant derived from bee honey might increase onion plant resilience to salt stress. In fact, treated plants displayed increased photosynthetic pigments, biomass and bulb production. Additionally, the membrane stability index, enzymatic and non-enzymatic antioxidant activity, and the osmoprotectans concentration as proline, soluble sugars, and total free amino acids were all improved (Semida *et al*., 2019).

Cold or Chilling Stress : Reduced metabolism brought on by cold stress causes photoinhibition, which is the suppression of photosystem II activity. Cell membranes are damaged by cold, which causes the phospholipid layers to become unstable. Psychrotolerant soil microorganisms have been used to improve tomato cold resistance.

In winter settings, a number of strains have been isolated from soil and employed as a cold protector. When exposed to cold temperatures, tomatoes treated with these psychro tolerant bacteria demonstrated increased seed germination, decreased membrane damage and antioxidant system activation (Subramanian *et al*., 2016, 2015). It is possible to speculate about those soil bacteria as potential biostimulants that shield plants from cold stress. Fresh weight and stomatal conductance increased when lettuce plants growing in various cold conditions were externally treated with an amino acid biostimulant (Terra-Sorb® Foliar) (Botta, 2012). The buildup of suitable osmolytes, including amino acids, which provide tolerance, is a common plant response to stress. Asahi SL or Goemar Gateo (Arysta Life Science) treatments have been shown to have positive benefits on coriander plants growing in cold vegetative chambers (Pokluda *et al*., 2016). The application of biostimulants had a positive impact on various metabolic pathways, causing stressed plants to go through a phase of acclimation to low temperatures, according to the results of the study of stress indicators such as antioxidant activity, photosynthetic pigment concentration and activity, hydrogen peroxide and malondialdehyde amount.

Drought Stress : Farmers are regularly compelled to operate in less than ideal conditions, and abiotic stressors are strongly related to the issue of resource availability. Another important rising component in a more sustainable use of resources is the availability of water. The risk of soil salinization increases with increased irrigation. The idea that certain areas may become drier as a result of the adverse effects of global climate change on water supplies is widely accepted by scientists (Elliott *et al*., 2014). Drought stress has a significant impact on plant gas exchange, altering transpiration and photosynthetic rates, both of which are directly related to yield. Using Ascophyllum nodosum on spinach (Xu *et al*., 2015) and broccoli (Kałuzewicz *et al*., 2017) improved gas exchange by decreasing stomatal closure, which made the plants more resilient to water stress. Another prominent sign of drought stress is leaf yellowing, which is caused by the breakdown of chlorophyll during leaf senescence and serves as a consistent signaling of an energy and metabolic imbalance in stressed plants. Tomato leaves treated with biostimulants including *A. nodosum* had higher levels of total chlorophyll (Goñi *et al*., 2018). Bacterial infections that block xylem channels and stop water flow can occasionally cause water stress in plants. Romero *et al.* (2014) showed that tomato plant withering was postponed by treatments with *Azospirillum brasilense*, a strain obtained in dry settings. In fact, treated plants had a larger area of xylem vessels, which led to a more effective transfer of water from the soil to the leaves. Two plants that support rhizobacteria were examined by Arshad *et al.* (2008) in relation to the pea (Pisum sativum) crop cultivated under drought stress conditions in various phenological stages. Additionally, they found that PGPR containing ACC-deaminase, an ethylene precursor, dramatically reduced the impacts of stress on yield and growth. Under water stress circumstances, Pseudomonas sp.-treated basil plants have shown positive effects in terms of antioxidant and photosynthetic pigment activity (Heidari *et al*., 2012).

Nutrient Deficiency : Increasing nutrient absorption by various means is one of the functions attributed to biostimulant compounds. For example, they can alter the nutrient solubility or soil structure, directly alter the architecture of roots, or improve plant nutrient transport (Halpern *et al*., 2015). Low input horticultural cultivation techniques and poor soil conditions may benefit greatly from their utilization (Toscano *et al*., 2019). Numerous tests have been conducted to see if using biostimulants permits a decrease in fertilizer use without compromising crop quality and output. Anju Metal conducted an experiment on garlic plants that were given half the required amount of nutrients (Anjum *et al*., 2014). Applying a biostimulant together with a little amount of macronutrients had a good impact on garlic growth and production. Okra seedlings cultivated with various nutritional shortages have been used to evaluate a seaweed-based product (Kelpak®) (Papenfus *et al*., 2013). The treatments were administered three times a week and contrasted with a therapy using a polyamine solution. Under phosphorus and potassium deprivation, plants treated with the biostimulant exhibited an increase in growth metrics, including shoot length, stem thickness, number of leaves and roots, and fresh weight. Although the polysaccharide content of seaweed extracts is typically credited with improving soil structure, (Vernieri *et al*., 2006) achieved beneficial outcomes by using Actiwave in a hydroponic system with varying nutrient solution concentrations. The majority of biostimulants consist of a blend of short peptides known as protein hydrolysates and various amino acids. They improve plant development and provide defense against a variety of stressors. An imbalance in nutrients may be the root cause of a number of problems that arise during the growth and development of plants. Young pepper fruits that have a local calcium deficit are typically the source of blossom-end rot. These studies showed that while biostimulant products cannot completely replace fertilizers, they may be very helpful in reducing mineral nutrition intake or in circumstances involving nutrient deficiencies and imbalances. For instance, the nutrient solution can be lowered by 75% of Hoagland's solution while growing baby leaves like rockets in a floating system (Vernieri *et al*., 2005). By boosting root biomass, nutrient transport/translocation, and enzyme activities involved in nutrient digestion, biostimulants that aid in reducing nutritional deficits often enhance crops' nutrient intake.

Plant Biostimulants effects on growth and development

Rose cuttings may be made more ecologically friendly by employing biostimulants to encourage roots in woody plants, like *Rosa* sp., in the case of micro-propagation and cuttings (Para *et al*., 2017). It is also possible to use biostimulants to raise the weight of the above-ground sections of annual ornamental seedlings (Florijan *et al*., 2009). In addition to increasing the vegetative weight of plants, the fermented protein-free alfalfa biostimulant significantly affects tissue structure and chlorophyll content in the production of annual decorative plants (Bákonyi *et al*., 2020). Additionally, humic acids accelerate the development of *Salvia splendens* L. seedlings (Jela¡ci´c *et al*., 2007).

Improved fruit quality and nutritional value : It has been demonstrated that biostimulants improve the nutritional content and quality of fruits and vegetables. They can boost crops' nutritional value and health-promoting qualities by increasing the quantity of bioactive ingredients including vitamins, phenolic compounds and antioxidants (Francesca *et al*., 2020; Godlewska *et al*., 2021). Additionally, biostimulants can enhance the fruits' taste, color and shelf life, among other sensory attributes.

Improvements in production and growth : According to Kocira *et al.* (2020), biostimulants have the ability to promote all aspects of plant growth, including root development, shoot growth, and overall vigor. The use of biostimulants has been demonstrated to improve plant growth (germination rate, leaf area, nitrogen content, chlorophyll and protein content, root and stem development, root and stem weight biomass, yield, and drought tolerance). It has been demonstrated that biostimulants enhance plant growth and increase agricultural output. Fruit production, biomass accumulation, and increased plant height are a few examples (Ertani *et al*., 2014; Francesca *et al*., 2020). Biostimulants also lower pollutant toxicity, boost agricultural yields, improve natural soil fertility, and aid in seed germination.

Enhanced nutritional value and fruit quality : It has been demonstrated that biostimulants improve the nutritional content and quality of fruits and vegetables. They can boost crops nutritional value and health-promoting qualities by increasing the quantity of bioactive ingredients including vitamins, phenolic compounds and antioxidants (Francesca *et al*., 2020; Godlewska *et al*., 2021). Additionally, biostimulants can enhance the fruits' taste, color, and shelf life, among other sensory attributes. A plant's ability to grow, develop and withstand stress is enhanced by plant biostimulants. They can support metabolic activity, stress tolerance, nutrient intake, crop nutritional content and quality and other processes (Calvo *et al*., 2014). Biostimulants are useful instruments in sustainable agriculture for boosting crop resilience and production as a result of these impacts.

Conclusions and Emerging opportunities for the use of Biostimulants

In order to improve the development and stress tolerance of horticulture plants, plant biostimulants have shown great potential. According to the reviewed studies, biostimulants can improve the performance, production, nutrient absorption, and stress tolerance of horticultural crops. Breeding plants that can withstand abiotic stress to improve quality and production is now the most promising strategy. The identification of stress-associated genes and the clarification of molecular processes governing plants responses to abiotic stressors are prerequisites for the creation of stress-resistant plant types. The transcription factors are essential for controlling how stress-responsive genes are expressed. Many novel biostimulants may potentially show promise in agricultural production in the future, enabling people to live sustainably. Using biostimulants significantly improves a plant's capacity to perform better under stress and generate higher-quality plants overall. To optimize the use of biostimulants in the growth of ornamental plants, more research and development are needed. This involves analyzing the precise effects of different biostimulant types and formulations on different ornamental plant species. More study is also needed to determine the optimal biostimulant administration techniques, dosages, and timing for different development stages and environmental conditions. To ensure product efficacy, quality and consumer confidence, certain definitions and restrictions are needed.

It is especially important to highlight the beneficial effects of plant hydrolysates and microbial consortia on agricultural plant development and yield. Enhancing the antioxidant capacity of plants treated with algae-based biostimulants is also crucial. The primary benefits of biostimulants are improved soil qualities, enhanced biodiversity of helpful microbes, improved crop quality and performance and no adverse or damaging effects on humans, animals, or the environment. Their methods of action are, in certain situations, still difficult to understand and must be acknowledged since the nature of their beneficial impact is not entirely known. Because of this, biostimulants are one of the hottest subjects in agriculture and still need in-depth study.

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