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Review Article

Use of Biostimulants in Fruit Crop Enhancement

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Abstract

Biostimulants have emerged as a vital component in modern agricultural practices, offering significant benefits for fruit crop production. These substances, whether of natural or synthetic origin, exert beneficial effects on plant growth by enhancing metabolic processes and improving stress tolerance, thereby augmenting both crop yield and quality. Moreover, they contribute positively to soil health, further bolstering their impact on agricultural productivity. Principal categories of biostimulants encompass humic substances, seaweed extracts, amino acids and protein hydrolysates, microbial inoculants and silicon-based products. Each category functions through a different mechanism, such as increasing the absorption of nutrients, promoting the growth of roots, controlling hormone levels and increasing the water-use efficiency. In order to ensure crop resilience, support sustainable agriculture and satisfy the increasing demand for premium fruit crops worldwide, biostimulants are well-positioned to play a significant role. This article examines how biostimulants can boost fruit crop yield while maintaining the safety and quality of the food supply.

Keywords: Biostimulants, Humic substances, Stress tolerance, Sustainable agriculture

Introduction

The population of the world is forecast to grow quickly; in the next 30 years, it is predicted to reach 9.1 billion, a 34% rise from today's numbers. This unprecedented growth presents a significant challenge to global food security, demanding a substantial increase in agricultural productivity. Although chemical fertilizers have historically contributed to increased food production, their widespread application has resulted in diminished food quality and soil health, presenting significant long-term sustainability challenges. The development of sustainable and environmentally friendly agricultural systems has become a crucial concern as we work to both protect the environment and meet the world's growing food demand. This is especially challenging given the decreasing availability of arable land and the approaching genetic yield limits of staple crops. It is crucial to increase crop yields while preserving the quality and nutritional value of the produce, particularly under unfavourable growing conditions. Fruit crops are especially vulnerable to biotic and abiotic stresses, which can have a big effect on their production and quality. Traditional methods of addressing these issues often heavily rely on chemical inputs, which have harmful effects on human health and as well as on the environment. The visual appeal and nutritional value of fruits are crucial for consumer acceptance, highlighting the need for innovative agricultural practices that can enhance these attributes. Farmers are increasingly seeking sustainable methods to increase productivity while ensuring food security and quality, which can, in turn, lead to better economic returns. In recent years, a variety of new strategies have emerged to improve sustainable production in horticultural crops. Plant biostimulants have gained significant attention as substances or microorganisms that, when administered to plants, amplify their growth and productivity by enhancing nutrient utilization efficiency, stress resilience and crop quality (Colla *et al.*, 2017). Unlike traditional fertilizers and pesticides, biostimulants work through natural processes, making them an environmentally friendly alternative.

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Overall, biostimulants enhance plant performance and productivity by fostering interactions among various stress response processes. These activities lead to a higher accumulation of antioxidant compounds, thereby mitigating plant sensitivity to stress (Tara *et al.*, 2024). In conclusion, plant biostimulants represent a promising approach to address the pressing challenges of modern agriculture and offer a viable path toward sustainable food production that can support the growing global population while preserving environmental health.

Definition and Classification of Biostimulants

Plant biostimulants are products derived from diverse organic or inorganic substances and microorganisms, aimed at enhancing plant growth, increasing productivity and mitigating the detrimental effects of abiotic stresses (du Jardin, 2015). Biostimulants encompass a diverse array of substances that exert advantageous effects on plants, promoting their growth, development and resilience to environmental stresses. These biostimulants can be categorized into several groups based on their origin and mechanisms of action (Yakhin *et al.*, 2017). Plant-based biostimulants include extracts derived from seaweeds, as well as compounds sourced from plants such as amino acids, proteins and carbohydrates. Microbial biostimulants consist of beneficial microorganisms like mycorrhizal fungi, rhizobacteria and other biocontrol agents that promote nutrient uptake, disease resistance and overall plant health. Other categories encompass humic and fulvic acids derived from organic matter, which enhance soil structure, water retention and nutrient availability, as well as inorganic substances like silicon.

Humic and Fulvic Acids

Humic and fulvic acids are organic compounds formed through the decomposition of plant and animal matter, collectively termed as humic substances. They play a crucial role in promoting plant growth and improving soil health through various mechanisms. Their ability to chelate nutrients prevents nutrient leaching and ensures that essential elements remain available for plant uptake (Jindo *et al.*, 2012). Moreover, by improving soil structure, these acids enhance soil aeration, water retention and root penetration. Additionally, they stimulate microbial activity, promoting nutrient cycling and the decomposition of organic matter. They also help plants tolerate environmental stresses by improving metabolic processes and nutrient uptake. Their natural origin and multifaceted roles make them excellent alternatives to synthetic chemicals, enhancing crop growth and resilience in a sustainable manner.

Seaweed Extracts

Seaweed extracts, derived from various marine algae species, have gained significant attention in agriculture due to their extensive benefits for plant growth and soil health. These extracts are rich in natural plant hormones, minerals, vitamins and other bioactive compounds, making them valuable inputs for sustainable and organic farming practices. The primary sources of seaweed extracts include brown, red and green seaweeds, with commonly used species such as *Ecklonia maxima*, *Sargassum* spp., *Ascophyllum nodosum* and *Macrocystis pyrifera*. These extracts consist of various beneficial substances, including plant hormones (like auxins, cytokinins and gibberellins), essential minerals, vitamins (including B-vitamins, vitamin C and vitamin E), polysaccharides (such as alginates, laminarins and fucoidans), amino acids, proteins and antioxidants. One of the significant benefits of seaweed extracts is their ability to promote plant growth. The natural plant hormones found in these extracts, such as auxins and cytokinin, promote cell division, elongation and differentiation, leading to increased growth of roots and shoots. This leads to more vigorous plants and improved seed germination rates and early seedling development. Furthermore, seaweed extracts improve stress tolerance in plants. Additionally, seaweed extracts boost the plant's immune system by stimulating the production of natural defense compounds, thereby increasing resistance to pests and diseases (Rouphael and Colla, 2020).

Amino Acids and Protein Hydrolysates

Amino acids and protein hydrolysates are increasingly recognized as significant biostimulants, offering a multitude of benefits that enhance plant growth, nutrient uptake and stress tolerance. Derived from the hydrolysis of proteins, these compounds come from a variety of sources including animal by-products (such as collagen and keratin), plant materials (like soy and corn) and microbial fermentation processes (Schaafsma, 2009). A key advantage of amino acids and protein hydrolysates is their role in stimulating plant growth. Amino acids act as fundamental components for protein synthesis and play a crucial role in various metabolic processes. They support overall plant growth by enhancing metabolism and improving photosynthesis. In addition to promoting growth, amino acids and protein hydrolysates significantly improve plants' stress tolerance (Halpern *et al.*, 2015). They assist plants in coping with abiotic stresses such as drought and salinity by stabilizing cellular structures and regulating osmotic balance. Proline, an amino acid, is particularly notable for its role in stress responses, as it accumulates in plants under stress conditions, protecting cellular functions. Furthermore, these compounds enhance biotic stress resistance by boosting the plant's immune responses. They stimulate the production of defence-related compounds and enzymes, providing a protective effect against pathogens and pests.

Microbial Inoculants

Microbial inoculants, commonly referred to as biofertilizers, are increasingly being adopted in agriculture due to their capacity to enhance plant growth, enhance soil fertility and provide a sustainable alternative to chemical fertilizers. These inoculants consist of beneficial microorganisms, including bacteria, fungi and other microbes, which form symbiotic relationships with plants, thereby promoting nutrient uptake and overall plant health. Notable examples include Rhizobium bacteria, which fix atmospheric nitrogen in symbiosis with leguminous plants and mycorrhizal fungi, which enhance phosphorus uptake and improve soil structure (Begum *et al.*, 2019). Applying these microbial

Table 1: Impact of different biostimulants on fruit crops growth and quality

Fruit crop	Biostimulants name	Mode of application	Positive effects on the fruit trees	References
1. Humic substances (Humic acid & Fulvic acid)				
Kiwifruit	Humic acid	Both foliar and Drenching	• ↑↑ Yield and physico-chemical characteristics [total soluble solids and titratable acidity; amount of vitamin C (Ascorbic acid)].	Mahmoodi *et al.* (2018)
Strawberry	Nitrogen and humic acid	Soil application and foliar	• Highest values for the leaf area, fruit yield.	Rostami *et al.* (2022)
2. Phosphites				
Grapes	Potassium phosphite	Foliar spray	• ↑↑ Productivity, total soluble phenolic compounds. • ↑↑ Total soluble solids and pH. • ↓↓ Total titratable acidity of the berries.	Pereira *et al.* (2012)
Strawberry	Phosphorous acid	Nutrient solution applied to the roots	• ↑↑ Acidity, sugars, ions concentration and anthocyanin concentration in fruits.	Estrada-Ortiz *et al.* (2013)
3. Seaweed extracts				
Mango seedling	Seaweed extract	Foliar Spray	• ↑↑ Leaf nitrogen content, leaf potassium, leaf iron and leaf zinc content.	Al-Marsoumi and Al-Hadethi (2020)
Grapes	Seaweed extract	Foliar spray	• ↑↑ Yield and berry attributes. • ↑↑ Amino acid content and Vitamins improved vine C/N ratio.	El-Sese *et al.* (2020)
4. Protein hydrolysates (PHs)				
Date palm	Coconut milk + Casein hydrolysate	Foliar spray	• ↑↑ Chlorophyll content, total carbohydrate, protein, amino acid, phenol and indole.	Hosny *et al.* (2016)
Grapevine	Protein hydrolysates (PHs)	Foliar spray	• ↑↑ Yield per vines. • ↑↑ Qualitative parameter like anthocyanin content colour shape, phenolic content, TSS.	Boselli *et al.* (2019)
5. Chitosan				
Washington Navel Orange	Chitosan	Foliar spray	• ↑↑ Leafy inflorescence. • ↑↑ Fruit set % and Canopy yield as weight (kg m^{-3}). • ↑↑ Chlorophyll contents. • ↑↑ Physico-chemical properties of fruit.	Mohamed and Ahmed (2019)
Pomegranate	Chitosan	Foliar spray	• ↑↑ Yield and the fruit quality. • ↓↓ The fruit cracking.	Badawy *et al.* (2019)
7. Arbuscular mycorrhizal fungi (AM Fungi)				
Newhall navel orange	*Diversispora spurca* and *D. versiformis*	Soil application	• ↑↑ Root fungal colonization. • ↑↑ Soil phosphatases and aggregate stability. • ↑↑ Fruit quality and mineral element contents.	Cheng *et al.* (2022)
8. Beneficial bacteria				
Strawberry	*Bacillus licheniformis* CKA1 + Root dip method + Foliar application	Root + foliar application	• ↑↑ Growth and yield. • ↑↑ Fruit quality	Seema *et al.* (2018)

NB: ↓↓ Decreased; = Maintained; ↑↑ Increased inoculants enriches soil nutrients naturally, reducing reliance on synthetic fertilizers and mitigating their associated environmental impacts. Moreover, microbial inoculants contribute to disease suppression and stress tolerance. Certain microbes, such as *Trichoderma* spp. and *Bacillus* spp. produce natural antibiotics and enzymes that inhibit the growth of plant pathogens, thereby protecting crops from diseases.

Chitosan and Other Biopolymers

Chitosan and other biopolymers have emerged as promising biostimulants in agriculture, offering a natural and environmentally friendly approach to enhancing plant growth, stress tolerance and overall crop productivity. Chitosan, derived from chitin present in the exoskeletons of crustaceans and other biopolymers (such as alginate, carrageenan and cellulose) are characterized by their biodegradability, biocompatibility and low environmental impact, making them ideal candidates for sustainable farming practices. These biopolymers exert their biostimulant effects through various mechanisms. Chitosan, for example, acts as an elicitor, triggering plant defence responses against pathogens and pests (Katiyar *et al.*, 2015). It stimulates the production of phytoalexins, enzymes and other defence compounds, thereby enhancing plant resistance to diseases. Additionally, chitosan enhances nutrient uptake by forming complexes with ions in the soil, thereby increasing the availability of essential nutrients to plants. It also promotes root development and increases the activity of beneficial soil microorganisms, contributing to overall soil health and fertility.

Silicon

Silicon, an essential mineral element for plant growth, has gained recognition as a biostimulant in agriculture due to its ability to enhance plant vigour, stress tolerance and overall crop productivity. While silicon is classified as an inorganic compound, its beneficial effects on plants are well-documented, making it a valuable addition to sustainable farming practices. One of the primary roles of silicon in plant biology is its contribution to structural strength and rigidity. When absorbed by plants, silicon accumulates in the cell walls, forming a strengthening matrix known as the silicon cuticle (Ma, 2004). This reinforced structure not only provides mechanical support to the plant, reducing lodging and improving standability, but also enhances resistance to biotic stresses such as pest and pathogen attacks.

Table 2: Effects of various biostimulants on fruit crops under different types of abiotic stress

Types of abiotic stress	Name of crop	Biostimulants agent	Effects	References
Cold stress	Blueberry	AMF (*Glomus mosseae*)	• ↑↑ Superoxide dismutase, ascorbate peroxidase. • ↑↑ Improves peroxidase activities, soluble. • ↑↑ Sugar, proline ascorbate and glutathione accumulation.	Liu *et al*. (2017)
Heat stress	Pomegranate	Kaolin	• ↓↓ Sunburn. • ↓↓ Fruit cracking and incidence of fruit borer and bacterial blight. • ↑↑ Physico-chemical properties of the fruit.	Sharma *et al.* (2018)
Drought stress	Mango	Potassium silicate	• ↑↑ Vegetative and productive growth. • ↑↑ Tolerance to water stressed conditions. • ↓↓ Harmful effects of ROS.	Helaly *et al.* (2017)
Salinity stress	Strawberry	Potassium silicate	• ↑↑ Peroxidase and superoxide dismutase enzyme activity. • ↓↓ Ion of proline content. • ↑↑ Fruit yield.	Yaghubi *et al.* (2016)
Nutritional	Almond	Seaweed extract: Mixture of commercial plant based biostimulants (Mega Fol, Brexil-Zn and MC-Extra) (GroZyme)	• ↑↑ Shoot leaf area, shoot length. • ↑↑ Biomass.	Saa *et al*. (2015)

NB: ↓↓ Decreased; = Maintained; ↑↑ Increased

Effects of Biostimulants on Growth, Yield and Quality of Fruit Crops

Biostimulants, applied to fruit crops, offer a range of benefits. They stimulate root growth, boost nutrient and water uptake, which translates to increased shoot growth and overall biomass. Fruit yield sees a boost through improved flower and fruit set, leading to larger and more numerous fruits. Quality parameters like flavor, color and nutritional content are enhanced, while biostimulants also help plants withstand environmental stresses and combat diseases (Colla *et al.*, 2017). Additionally, they extend the post-harvest shelf life of fruits. Derived from natural sources, biostimulants promote sustainable agricultural practices, reducing reliance on synthetic chemicals and fostering soil health. Despite variations in effectiveness due to factors like crop type and environmental conditions, ongoing research aims to optimize biostimulant use for fruit growers, promising continued improvements in productivity, quality and sustainability. The findings concerning the application of biostimulants to enhance the growth, yield and quality of fruit crops have been reviewed and summarized in table 1.

Effect of Biostimulants to Abiotic Stresses Tolerance in Fruit Crops

The primary constraint on fruit crop cultivation lies in its susceptibility to climatic factors. Adverse environmental conditions and soil health issues such as salinity, drought, thermal stress, unfavorable soil pH and nutrient deficiencies, can hinder plant growth and development significantly (Rouphael and Colla, 2018). Research indicates that abiotic stresses can lead to a reduction in production by up to 50% (Ladan and Soleimani, 2010). Biostimulants emerge as a promising solution to mitigate such abiotic stresses, presenting a unique tool to bolster crop resilience and productivity (Table 2).

Conclusion and Future Thrusts

The uses of biostimulants have significantly improved the ability of fruit crops to withstand abiotic stresses. By enhancing antioxidant activities, improving water use efficiency, stimulating root growth, regulating hormone levels and altering gene expression, biostimulants help plants maintain growth and productivity under adverse conditions. These innovations contribute to sustainable agricultural practices, offering farmers effective tools to ensure crop resilience and improve yield and quality.

The future of biostimulants in enhancing fruit crop production is marked by several promising advancements and areas of focus. Integration with precision agriculture technologies, such as smart formulations and sensor technology will enable more precise and effective application of biostimulants tailored to specific crops and conditions. Advances in microbial inoculants, including microbiome engineering and genetically enhanced microbes, aim to optimize plant-microbe interactions for better nutrient uptake and stress resilience.

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