Natural Boosters in Farming: Exploring Biostimulants for Future Agriculture

Shagun Thakur[1]*, Vinod Sharma[1], Sandeep Manuja[1], GD Sharma[1], Barsha Mansingh[1] and Aakriti[2]*

Department of Agronomy, College of Agriculture, CSK HPKV, Palampur, HP
Department of Vegetable Science and Floriculture, College of Agriculture, CSK HPKV, Palampur, HP

Corresponding Author
Shagun Thakur
Email: shagunthakur213@gmail.com
Aakriti
Email: aakriti1599@gmail.com

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ABSTRACT

In the era of climate change and rising food demand, sustainable agricultural practices are crucial for ensuring long-term productivity and environmental safety. Biostimulants have emerged as eco-friendly inputs that enhance plant growth, improve nutrient use efficiency, and increase tolerance to environmental stresses. Derived from natural sources such as seaweed extracts, beneficial microorganisms, and organic compounds, they support soil health and reduce dependence on chemical fertilizers. However, their adoption is limited by inconsistent field performance, lack of standardization, and low farmer awareness. Advancements in formulation technologies, improved understanding of plant–microbe interactions, and integration with precision farming offer promising solutions to these challenges. With adequate research, regulatory support, and farmer education, biostimulants can play a vital role in sustainable and climate-resilient agriculture.

INTRODUCTION

Agriculture is currently facing unprecedented challenges due to climate change, increasing population pressure, and degradation of natural resources. Conventional agricultural practices rely heavily on chemical fertilizers and pesticides,

which often lead to environmental pollution, reduced soil fertility, and potential health risks. Therefore, there is a growing need to adopt sustainable and eco-friendly agricultural approaches. Biostimulants have gained attention as a promising alternative that enhances crop productivity without adversely affecting the environment (Rouphael and Colla 2020). These substances work by stimulating natural plant processes, improving nutrient uptake, and enhancing stress tolerance. Their integration into modern farming systems offers a pathway toward sustainable and resilient agriculture.

Concept and Types of Biostimulants

Biostimulants are substances or microorganisms that enhance plant growth by stimulating physiological and biochemical processes rather than directly supplying nutrients. Derived from natural sources, they include seaweed extracts, humic substances, protein hydrolysates, amino acids, and microbial inoculants such as plant growth-promoting rhizobacteria (PGPR) and fungi (Sharma *et al*. 2014). Seaweed extracts contain plant hormones and bioactive compounds that promote growth and stress tolerance, while humic substances improve soil fertility and nutrient availability. Protein hydrolysates support plant metabolism, and microbial biostimulants enhance nutrient solubilization and hormone production, thereby improving plant health and productivity.

Mode of Action of Biostimulants

Biostimulants act through coordinated molecular, cellular, and physiological processes that enhance plant performance. At the molecular level, they upregulate stress-responsive genes and antioxidant enzymes (SOD, CAT, APX) and improve nutrient transport. At the cellular level, they enhance photosynthesis, increase chlorophyll content, and stimulate metabolic activity. These effects translate to improved root and shoot growth, better nutrient uptake, enhanced water-use efficiency, and increased tolerance to abiotic stresses such as drought and salinity, ultimately leading to higher productivity and improved crop quality.

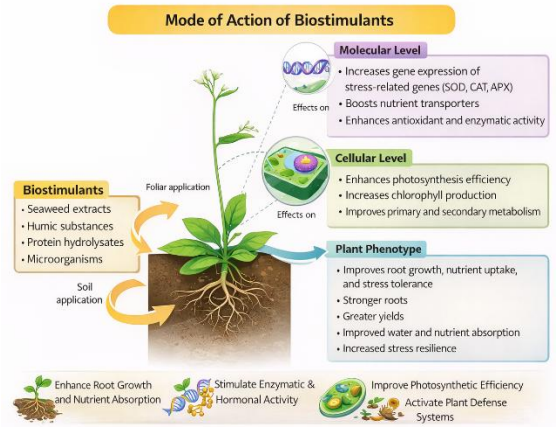

Figure 1: Mechanistic overview of biostimulant action

Role of Biostimulants in Sustainable Agriculture

Biostimulants play a significant role in enhancing agricultural sustainability. One of their key functions is improving nutrient use efficiency by promoting better absorption and utilization of essential nutrients. This reduces the need for excessive fertilizer application and minimizes environmental pollution. They also enhance plant tolerance to abiotic stresses such as drought, salinity, and extreme temperatures by activating physiological and biochemical defense mechanisms. This helps maintain crop productivity under adverse environmental conditions. In addition, biostimulants promote soil health by stimulating beneficial microbial activity, improving soil structure, and enhancing nutrient cycling. These effects contribute to long-term soil fertility and sustainability. Furthermore, the use of biostimulants has been associated with improved crop yield and quality, particularly in horticultural crops.

Table 1: Types of Biostimulants and Their Functions

Type of Biostimulant	Source	Key Functions	Examples
Seaweed Extracts	Marine algae	Enhance growth, improve stress tolerance	*Ascophyllum nodosum*
Humic Substances	Organic matter decomposition	Improve soil structure, nutrient availability	Humic acid, Fulvic acid
Protein Hydrolysates	Plant/animal proteins	Stimulate metabolism, enzyme activity	Amino acid formulations
Microbial Biostimulants	Bacteria & fungi	Nutrient solubilization, hormone production	PGPR, Mycorrhiza
Organic Compounds	Natural biomolecules	Enhance physiological processes	Vitamins, polysaccharides

Role of Biostimulants Across Crop Growth Stages

Biostimulants play a dynamic and stage-specific role throughout the crop life cycle, ensuring optimal growth, resilience, and productivity. At the initial seed stage, treatments such as microbial inoculants and humic substances enhance germination, root initiation, and early seedling vigour.

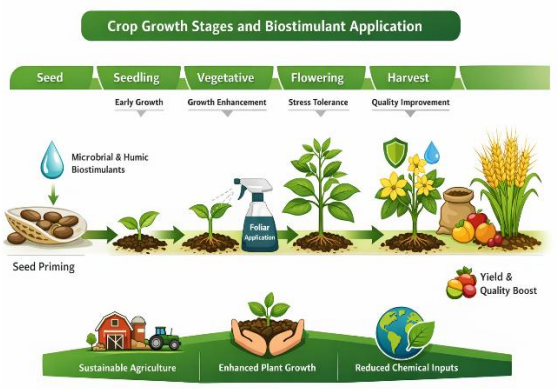

Figure 2: Stage-wise application of biostimulants across crop growth stages

As the crop progresses to the vegetative stage, foliar application of biostimulants promotes rapid biomass accumulation, improves nutrient uptake efficiency, and enhances photosynthetic activity. During the flowering phase, plants become more sensitive to environmental stresses; here, biostimulants help in strengthening physiological and biochemical defense mechanisms, thereby improving tolerance to drought, salinity, and temperature fluctuations. In the final stages leading to harvest, their application contributes to better yield formation, improved quality traits, and enhanced nutrient composition.

Challenges in the Application of Biostimulants

Despite their advantages, biostimulants face challenges such as inconsistent field performance due to environmental, crop, and soil variability. Lack of standardization in formulations and limited understanding of their mechanisms restrict reliability and scientific validation. Regulatory uncertainties and the gap between laboratory results and field performance further limit their widespread adoption.

Opportunities and Future Prospects

Biostimulants offer strong potential for sustainable agriculture. Advances in plant science and microbiology are improving their effectiveness, while better formulations enhance consistency. Integration with precision agriculture enables targeted use, and their role in climate resilience supports crop performance under stress. Increased awareness, farmer education, and supportive policies will further drive adoption.

CONCLUSION

Biostimulants are promising tools for sustainable agriculture, improving plant growth, nutrient efficiency, and soil health while reducing chemical dependence. Addressing challenges through research, technological innovation, and policy support will enable their wider adoption and strengthen climate-resilient farming systems.

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