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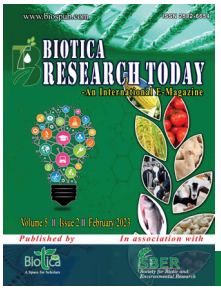

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Biostimulants in Crop Performance and Soil Health Management

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Abstract

Biostimulants are a vital and sustainable solution to address key agriculture challenges *viz.* increased agricultural demand necessitated by a growing population, extreme weather and growing conditions related to climate change and limited natural resources. Due to rapid depletion of agricultural areas, water and soil quality by means of ever-increasing population and an excessive addition of chemical fertilizers, a rehabilitated attention is a need of the hour to maintain sustainable approaches in agricultural crop production. Biostimulants are materials, other than fertilizers, that promote plant growth when applied in low quantities. It aims to enhance nutrient efficiency, abiotic stress (*i.e.*, frost, drought, salinity) tolerance and crop quality traits regardless of its nutrients content. Main objective behind using these products is not to supply nutrition but rather to favor and stimulate the metabolism of the plant, decrease plant stress *etc*. Industry focus is to develop and commercialize biostimulants that are compatible with advanced farming techniques used in integrated crop management (ICM), the cornerstone of sustainable agriculture.

Keywords: Depletion, Efficiency, Nutrient, Sustainable

Introduction

Du Jardin (2015) defined plant biostimulants (PBs) as any substance or microorganisms supplied to plants primarily with the aim of enhancing nutrition uptake efficiency, but also increasing abiotic stress tolerance and/or crop quality traits, regardless of its nutrients content.

European Biostimulant Industry Council (EBIC) defined that plant biostimulants are products of biological origin, including microorganisms, which when applied to plants or soil (roots) stimulate physiological processes promoting better plant performance, with increased growth, production, greater stress tolerance and increased product quality. The most promising PBs are: seaweed extracts, protein hydrolysates, humic and fulvic acids, silicon, chitosan, inorganic compounds and beneficial fungi and bacteria. The enhancement of the nutrient uptake and assimilation is one of the benefits of using biostimulants. It is often attributed to at least one of the following factors: biostimulants can increase the activity of soil both microbiologically and enzymatically, they are able to affect the root structure, and change the solubility and transportability of micronutrients. One of the roles of plant biostimulants is increasing the amount of nutrients available for plants by increasing soil cation exchange *via* providing nitrogen and enhancing solubility of soil nutrients. They can be composed of microorganisms, protein hydrolysates, seaweed extracts and other substances. The aim of these products is not to supply nutrition but rather to favour and stimulate the metabolism of the plant, decrease plant stress *etc*. They are also claimed to enhance crop growth and yield through a series of widely varying mechanisms including activation of soil microbial activity and promotion or augmentation of the activities of critical soil enzymes or plant growth hormones.

Application Methods of Biostimulants

Foliar

Foliar is the largest application for the biostimulant market in terms of revenue and volume. The application of foliar includes seaweed, fish emulsion and compost in the production of organic crops. Biostimulants intensify root growth by fostering healthy microbial development. Moreover, deeper and bigger roots increase the overall volume of nutrient uptake and extract nutrients deeper in the soil profile.

Soil

Drenching of soil is done with the suitable biostimulants

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an organic amendment product which affects the soil microbial population and uptake of nutrients. It is also used as soil conditioner to improve soil texture, structure by enhancing aeration, water holding capacity and cation exchange capacity.

Seed

Seeds can be treated in required concentration with biostimulants prior to the sowing with the aim to improve seed germination, counteract environmental stress and produce healthy crops.

Benefits Associated with using Biostimulants

• Enhance uptake and efficient use of nutrients, both applied and existing.

• Improve soil health by enhancing beneficial soil microorganisms in the rhizosphere.

• Improve tolerance to abiotic stress: drought, extreme temperatures (cold, frost and heat) and salinity.

• Induce systemic resistance to pathogen.

• Enhance crop quality through plant health and vigor.

• Increase harvestable yields.

Biostimulants are compatible with the most advanced farming and the benefits associated with biostimulants are depicted in the Figure 1.

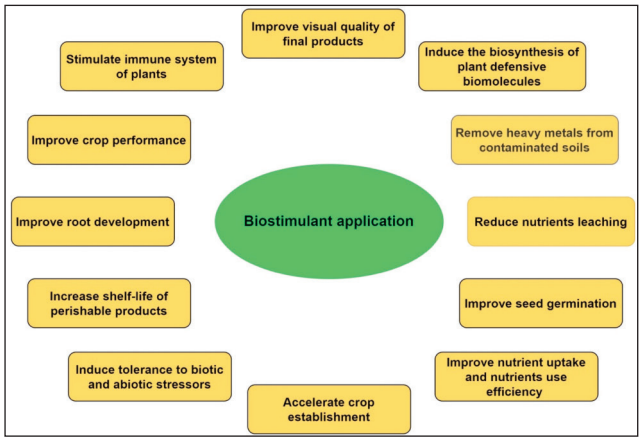

Figure 1: Important effect of biostimulants on crops (Shahrajabian *et al.*, 2021)

Classification of Biostimulants

Biostimulants has been classified into 7 categories on the basis of their mode of action.

- Humic substances
- Chitin and chitosan derivates
- Beneficial chemical elements
- Seaweed extracts and botanicals
- Protein hydrolates
- Inorganic salts including phosphate and free amino acids and
- Other nitrogen containing compounds

Four major groups of biostimulants have been shown to affect root growth and nutrient uptake:

1. Humic substances (HS),
2. Protein hydrolysate and amino acid formulations (AA),
3. Seaweed extract (SWE), and
4. Plant growth-promoting microorganisms (PGPM).

Global Biostimulants Market Share

Biostimulants provide new solutions that increase yields while minimizing inputs and environmental impacts. Biostimulants market includes humic and fulvic acids, seaweed extracts, proteins, amino-acids and microbials. In India, biostimulants market is projected to be of US$ 180.949 million by 2023 increasing from US$ 71.232 million in 2017, witnessing a CAGR of 16.49% while in world, biostimulants market was valued at US$ 2638 million in 2020, and it is projected to reach USD 5040 million by 2026, registering a CAGR OF 11.71%. A data pertaining to global biostimulant product line market share is presented in the Figure 2.

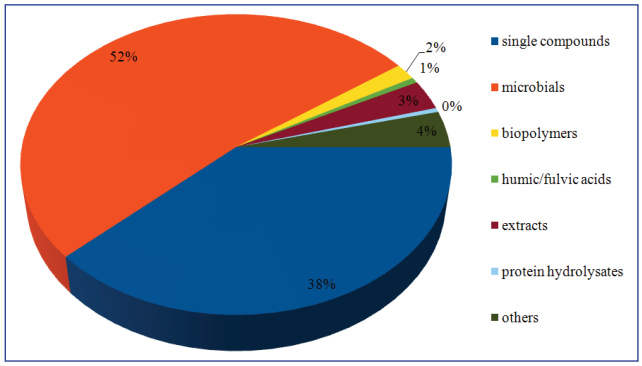

Figure 2: Global biostimulant product line market share (Du Jardin, 2015)

Soil Nutrient Availability and Plant Nutrient Uptake of Different Biostimulants

Humic Substances (HS)

Humic substances are natural substances resulting from the chemical and biological transformations of dead cell materials as well as from microbial metabolism. HS have been recognized as essential contributors on the physico-chemical properties of soils. Moreover, most biostimulant effects of HS refer to stimulation of root growth and improvement of plant nutrition resulting from the increase of soil nutrient availability. HS act on soil nutrient availability by increasing cation exchange capacity and buffering (neutralize) soil pH. Humic substances have also the ability to impact stress reduction and the production of secondary metabolites. Humic and fulvic acids can bind heavy metals, therefore there are less likely to be assimilated by the plant during nutrient uptake.

Protein Hydrolysates (PH) and Amino Acid Formulations (AA)

Protein hydrolysates, are derived from the hydrolysis of proteins from plant, animal and microbial sources, often from industrial and agricultural waste products such as crop residues, animal skin, feathers and blood. Protein hydrolysates are basically available as soluble granular or

powder as well as liquid extracts that can be applied as a foliar spray, soil drench, seed treatment or dosed into the soil near the plant's roots. They not only enhance soil properties like respiration but also act as growth stimulants for soil microbiota due to their ability to use the pH are an easy carbon and nitrogen sources readily available sources for microorganisms. Protein hydrolysates can also complex and chelate soil micro and macronutrients so that these become more accessible to plants. Application of exogenous Amino acid to plant leaves and roots has been shown to increase nutrient uptake and nutrient-use efficiency for both macro- and micronutrients.

Bacteria and Fungi

Another important category of plant biostimulants are bacteria and fungi that have the ability to promote plants growth. They are used to enhance plants growth by increasing the amount of nitrogen, phosphorus and other micronutrients in soil. The usefulness of those bacteria goes beyond fixing the N_2; they also have the ability to recycle organic matter. In general PGPR or plant growth promoting fungi such as arbuscular mycorrhiza fungi (AMF) and *Trichoderma* sp. may induce plant growth promotion by improving the availability of nutrients such as N, P and Fe. A variety of symbionts such as *Azorhizobium*, *Allorhizobium*, *Bradyrhizobium*, *Mezorhizobium*, *Rhizobium*, and *Sinorhizobium* and non-symbiotic nitrogen-fixing bacteria such as *Azospirillum*, *Azotobacter*, *Bacillus* and *Klebsiella* sp. are now being used worldwide aiming to enhance the availability of different nutrients including N, P and micronutrients. These beneficial soil microbes can play an important role in recycling organic nutrients, since soil-nitrifying bacteria are able to mineralize organic nitrogen to nitrite and then to nitrate, which can be easily absorbed by the crops.

Similarly to PGPR, Arbuscular Mycorrhiza Fungi (AMF) are defined as beneficial associations between soil fungi and plant roots can also enhance P availability under nutrient deficiency/ availability. Mycorrhizal fungi can indirectly increase nutrient availability in the soil through the improvement of soil aggregate stability (resulting from the soil particle binding agent 'glomalin' released by AMF) which increases root growth and activity.

Seaweed Extracts (SWE)

Seaweed extracts are amongst the most commonly utilized important sustainable biostimulants. Seaweed extract are a complex mixture of bioactive compounds like polysaccharide, fatty acids, vitamins, phytohormones and mineral nutrients. SWE also contains some plant nutrients, and when applied to plants grown in a nutrient-deficient medium, the simple availability of these nutrients may improve growth and nutrient uptake. Biologically, seaweed extracts are dissimilar from chemical fertilizers. They are characterized by being biodegradable and harmless, making them environmentally friendly substances with no chemical residues and/or hazards. SWE have been shown to contain plant hormones such as auxins, cytokinins, and abscisic acid. SWE improves plant nutrition by affecting soil processes and by affecting the plant's physiology directly. Positive impact of seaweed extract on whole plant-soil system is depicted in the Figure 3. The mechanisms that affect soil processes include: (1) improvement of soil structure, (2) improvement of micronutrient solubility in the soil. The mechanisms that affect the plant's physiology directly include: (3) changes in root morphology and (4) increased root colonization by arbuscular mycorrhizal fungi.

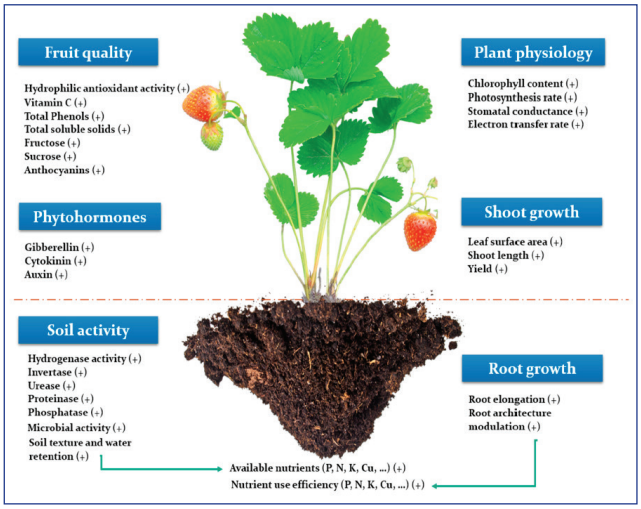

Figure 3: Positive impact of seaweed extract on whole plant-soil system (EL Boukhari *et al.*, 2020)

Biostimulant Formulations

The formulation must maintain an effective plant growth promotion or biocontrol capacity and be easy to use. In case of PGPR inoculants there are various formulation methods from the choice of carriers (peat, coir dust, charcoal, sawdust, clay, perlite, vermiculite and polymer-like alginate) to the formulation process. There are also various practical techniques for inoculant application and production achievement. Seed treatment has attracted attention as a simple and economically viable technique being convenient for both farmers and industry. Examples of some of the formulations are presented in the Table 1.

Mechanism of Action of Plant Biostimulants

It is impossible to suggest one common mode of action for all biostimulants but researchers suggest that the effect of biostimulants on plants is a consequence of their influence on plant metabolism in a wide sense of the word. They stimulate the synthesis of natural hormones sometimes increasing their activity, facilitate the uptake of nutrients from the substrate, stimulate root growth and cause higher yield often improving its quality at the same time. They increase the resistance of plants to unfavorable conditions such as drought, frost, pollution of the environment with heavy metals *etc*. This may be related to changes in enzymatic activity and the synthesis of antioxidants. They may enhance water holding capacity, increase antioxidants and induce metabolism. They delay senescence, reduce transpiration and enhance stomatal conductance. They are also found to activate the mechanisms of strengthening cell walls and sensitivity of the plants to water deficiency, enhance the basic biochemical processes in plants and soil and thereby improve the growth and development of plants and increase their resistance to stress. The activity of different biostimulant is presented in the Table 2.

Table 1: Biostimulant formulations and their field application

Formulation	Major component	Target stress factor	Field application
Rygex	Humic acids, algal extracts	Drought and salt stress	Foliar spray (20 kg/ 300 l of water)
Algavyt	Algal extract	Drought and cold stress	Foliar spray (100-500 g/ 100 l of water)
Ryzoset	Plant extracts and polysaccharides	Enhanced root growth to reduce abiotic and biotic stress	Foliar spray (20 l/ 300 l of water)
Manek	Fatty acid, vegetable oil	Enhanced resistance to biotic stress	Fertigation (15 l/ 300 l of water)
Ecoryg	Plant peptides and amino acids	Drought stress	Foliar spray (70 kg/ 300 l of water)

(Source: Sharma *et al*., 2019)

Table 2: Activity of different type of biostimulants

Source of Biostimulant	Example	Main Activity
Hydrolysis Product	Enzymatic (alfalfa hay, pulses, and vegetable or fruit waste) and chemical (feathers, bone meal, casein, collagen from skins, animal tissue, or fish waste)	• Increase in nitrogen and phosphorus content in leaves and macro- and micronutrients. • Increase in protein content in cereal grains. • Protection against biotic and abiotic stresses. • Increased soil fertility through the development of soil microorganisms.
Anaerobic Digestion Product	Plant, animal, and lignin biomass	• Call of the auxin-like effect. • Improving the availability of nutrients.
Biopreparations from Marine Algae	*Ascophyllum nodosum, Sargassum wightii, Ecklonia maxima, Enteromorpha intestinalis, Gelidium pectinutum*	• Antioxidant potential and ability to capture free radicals. • Chelating effect. • Increase in plant resistance to fungal and bacterial infections. • Extension of the shelf-life of fruit for consumption. • Improve the thermal resistance of plants. • Protection against drought stress.
Consortia of beneficial Fungi	*Rhizophagus intraradices, Rhymbocarpus aggregatus, Glomus viscosum, Glomus etunicatum, Glomus claroideum, Trichoderma* sp., *Heteroconium chaetospira*	• Increase in the growth and yield of plants alone and in symbiosis with bacteria, *e.g*., from *Azotobacter* spp. • Plant protection against oxidative stress.

(Source: Drobek *et al*., 2019)

Conclusion

The application of biostimulants in crop cultivation has allowed the higher levels of sustainability by the reduction of chemical fertilizers and environmental contamination. At the same time, it has been found to increase plant tolerance to abiotic and biotic stresses enhancing internal and external quality. Combinations of microbial inoculants with biostimulants like humic substances or seaweed extracts would deliver more benefits to the crop production in terms of good quality production. The use of biostimulants on a commercial scale would limit the amount of mineral fertilizers used in the environmental pollution, which is vitally important when it comes to global warming.

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