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Plant Biostimulants: Definition and Overview of Categories and Effects[1]

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Introduction

Recent years have seen an explosion of non-chemical crop production materials termed "plant biostimulants" promoted as environment-friendly alternatives to chemical-based products. Although the major driving force for these materials is the organic farming industry, consumer demands for more sustainable crop production along with a growing number of reports regarding their beneficial properties have resulted in increasing popularity among conventional farmers. The global market for biostimulants was valued at $2.19 billion in 2018 and is projected to reach a compound annual growth rate of 12.5% from 2019 to 2024. Although the largest market for biostimulants is in Europe (approximately 40% of the market share), the North American market is estimated to reach $605.1 million in 2019. This article provides an overview of the definition and regulatory status of plant biostimulants and the most popular materials used in agriculture.

Definition

Confusion exists regarding the meaning of the term biostimulant, and various definitions have been proposed in the past. Most of these definitions attempted to differentiate between biostimulants and fertilizers and between pesticides and biocontrol agents and were intended to promote the acceptance of biostimulants by future regulations (Du Jardin, 2015). This is complicated by the fact that some biostimulants can have a dual function of biostimulant and biocontrol agent and/or are offered in different combinations that may include fertilizers.

In December 2018, the first statutory language regarding plant biostimulants was provided in the Farm Bill (https://www.congress.gov/115/bills/hr2/BILLS-115hr2enr.pdf). It describes a plant biostimulant as "a substance or micro-organism that, when applied to seeds, plants, or the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield." This legal definition of plant biostimulants provides a first step in the process to develop a regulatory framework, appropriate review, approval, and uniform national labelling of these materials that are currently regulated as fertilizers, soil inoculants, or soil amendments at the state level. The definition provided in the 2018 Farm Bill is consistent with the definition currently proposed by the European Union (http://www.biostimulants.eu/).

Effects and Categories

Biostimulants are available in many formulations and with varying ingredients. The most popular ingredients include humic substances (humic and fulvic acids), seaweed extracts, beneficial bacteria, and beneficial fungi. Other products may contain chitosans (a soluble version of chitin), protein hydrolysates, and inorganic compounds such as silicon. Acid-based materials account for the largest

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segment in the biostimulant market, followed by seaweed-based materials.

For many years biostimulant-type materials were considered to be “snake oils,” and skepticism regarding their positive effects on plant growth persists. However, a large number of scientific studies have shown that many crop systems, particularly row crops and cereals, respond to these materials with higher productivity and improved tolerance to diseases and other biotic and abiotic stresses (Calvo et al., 2014). Other positive effects include improvement of water and nutrient uptake, improvement of water and nutrient use efficiency, improvement of root architecture and lateral root growth, and induction of systemic resistance (Figure 1). Although the scientific basis of biostimulant effects is well documented, the exact mechanisms of action are not always understood.

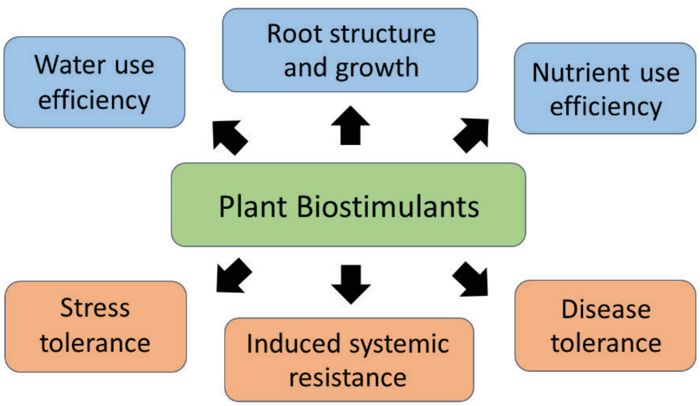

Figure 1. Biostimulant effects on plants.

Humic substances are collections of natural components of the soil organic matter with relatively low molecular mass that result from the decomposition of plant, animal and microbial residues, and from the metabolic activities of soil microbes. Compared with fulvic acids, humic acids are darker in color, have a higher molecular weight and carbon content, and have a higher degree of polymerization. Most sources of humic substances used in agriculture are non-renewable and include natural humified organic matter, such as peat and organic soils, and mineral deposits, such as leonardite and soft coal. More sustainable, renewable sources are humic substances derived from compost and vermicompost. Plant physiological responses are often better with humic substances isolated from peat, compost, or vermicompost compared with those isolated from brown coal. Most reported positive effects of humic substances on plants are improvement of soil physicochemical properties, root nutrient uptake, and lateral root development. These effects are associated with the polyanionic nature of humic substances, resulting in an increased cationic exchange capacity (CEC) of the soil, and their ability to interact with root membrane transporters (Canellas et al., 2015).

Seaweeds have long been known for their beneficial effects on plant growth. The most commonly used seaweeds in agriculture are the brown seaweeds, including species of the genera *Ascophyllum*, *Fucus*, and *Laminaria*. Most seaweed products are soluble powders or liquid formulations derived from different extraction procedures. The biological activity of these extracts strongly depends on the raw material and the extraction process, which could be alkali extraction, acid extraction, or other technology (Battacharyya et al., 2015). One of the major components of seaweed extracts are polysaccharides, which may account for 30%–40% of the dry weight and include alginates and laminarins. These polysaccharides possess plant-growth-promoting activities and are known to elicit plant defense responses against fungal and bacterial pathogens. In addition, seaweed extracts are rich in phenolic compounds and may contain phytohormones, which can directly influence plant growth and development. Besides facilitating the uptake and use of nutrients, seaweeds also possess soil-conditioning and metal-chelating properties. Because of their ability to form gel-like networks or hydrogels, seaweeds are also known to positively influence the water retention capacity of plants.

Beneficial bacteria that promote plant growth, also known as PGPBs (plant-growth-promoting bacteria), include free-living bacteria that inhabit the zone around the root (ectorhizosphere), bacteria that colonize the root surface (rhizoplane), and bacteria that live within the roots (endorhizosphere). Their mode of action is currently well understood (Ruzzi and Aroca, 2015). Bacteria with plant-growth-promoting activity are found in the genera *Bacillus*, *Rhizobium*, *Pseudomonas*, *Azospirillum*, *Azotobacter*, and many others. One of the best-understood effects of PGPBs on plants is their ability to fix nitrogen. This ability is specifically associated with root-nodule-forming rhizobacteria, which live in a symbiotic relationship with leguminous plants. Another effect of PGPBs is their ability to produce siderophores, small iron-chelating compounds that reduce the growth of deleterious soilborne pathogens. PGPBs can also influence plant growth directly by producing plant hormones such as auxins, cytokinins, and gibberellic acid, and indirectly by inducing hormonal changes in the plant host. Several PGPBs emit volatile organic compounds (VOCs), such as 2,3-butanediol (2,3-BD), which are known to increase plant resistance to insects and bacterial pathogens.

Beneficial fungi with plant biostimulant activity are found in the group of symbiotic fungi, particularly arbuscular mycorrhizal fungi (AMF) within the genus *Glomus*, which penetrate plant roots and form a highly branched tree-like network of roots and hyphae. This network enables the plants to extend their root system beyond the depletion zone, allowing for enhanced uptake of nutrients and water and rendering them more tolerant to drought stress. Besides improving nutrient uptake, the best-known effect of AMF is their improvement of phosphorous uptake, particularly in phosphorous-deficient soils. One of the difficulties associated with the use of AMF is their susceptibility to different crop management practices, such as soil tillage, bare fallow periods, and the use of high levels of fertilizers and fungicides. Other plant-beneficial fungi are found within the genus *Trichoderma*, a group of hyphae-forming fungi found in the soil or on dead wood and bark. *Trichoderma* form close symbiotic associations with plants and are known to release active metabolites into the rhizosphere, promoting root-branching and nutrient uptake (López-Bucio et al., 2015). Due to their ability to parasitize other fungi, they are often used as biocontrol agents for control against fungal diseases of plants.

Chitosans are deacetylated forms of chitin, a naturally occurring component of fungal cell walls, nematode egg shells, and the exoskeleton of insects and crustaceans. Chitosans are best known for their ability to induce plant-defense responses, particularly the accumulation of phytoalexins, pathogenesis-related proteins, reactive oxygen species, and other defense-related compounds, rendering the plants more tolerant to stress and diseases. In addition, they possess antibacterial, antifungal, and antiviral properties. The exact mechanisms of chitosan effects are not yet fully understood but seem to be associated with direct toxicity or chelation of nutrients and minerals necessary for pathogen growth and survival (El Hadrami et al., 2010). Because of these antimicrobial properties, chitosans are often applied as seed-coating agents, foliar treatments, and postharvest coatings of fruits and vegetables to prevent postharvest decay and increase produce shelf life. In addition, chitosans are used as soil amendments to control *Fusarium* wilts or other soilborne diseases. As with other biostimulant materials, plant effects vary depending not only on the time and rate of application, but also on the molecular weight of the chitosan product, the percentage of deacetylation, and other characteristics resulting from the manufacturing process.

Protein hydrolysates are mixtures of peptides and amino acids that are produced by enzymatic or chemical hydrolysis of proteins from animal- or plant-derived raw materials (Colla et al., 2015). Source materials can include crop residues or by-products, dedicated crop biomass such as from legumes, and animal wastes and industrial by-products such as leather, collagen and epithelial tissues. Other N-containing compounds such as polyamines, glycine betaine, and non-protein amino acids are also included in this group of plant biostimulant materials. Glycine betaine and polyamines are well characterized in regards to their function as compatible solutes and their other roles in plant stress protection. Protein hydrolysates can increase soil fertility and soil microbial activities, thereby indirectly affecting plant growth and productivity. Direct effects of these materials include hormonal activities and modulation of primary and secondary metabolism through regulation of genes and enzymes involved in N assimilation and the TCA (tricarboxylic acid) cycle. Some amino acids have chelating properties and can serve as protectants against heavy-metal-induced stress, while others contribute to micronutrient acquisition and mobility. Plant effects are variable and depend on the composition of protein hydrolysate materials as well as timing and dose of application.

Silicon is a biostimulant in the group of inorganic products. It is the second-most abundant element in the Earth's crust but is not considered essential for plant nutrition except in some monocotyledons, especially *Poaceae* species such as rice or sugarcane. The beneficial properties of silicon are best documented regarding its positive effects on abiotic stress tolerance and resistance to pathogens and diseases. In the soil, silicon usually exists as insoluble quartz or silicates that are chemically bound to metals. In the soil solution, silicon occurs as non-ionic silicic acid, which is easily taken up by plant roots and moved throughout the plant. It is mainly deposited at the end points of the transpiration stream in cell walls, cell lumens, and intercellular spaces in the form of hydrated amorphous silica (Savvas and Ntatsi, 2015). Highest concentrations are usually found around the stomata. These silica depositions or phytoliths increase leaf mechanical strength and erectness, thereby increasing light interception and photosynthesis. They also modulate nutrient and water mobility and increase plant resistance to abiotic stresses, diseases, and pathogens, although the exact mechanisms are not fully understood. Improvement of water relations is presumably due to silica gel formation in the cell walls, which thereby reduce transpiration. Other stress-alleviating effects of silicon include its ability to immobilize toxic metals in plant tissues and the soil and to delay plant senescence processes.

Concluding Remarks

It is important to recognize that many crop systems respond differently to plant biostimulants and that positive effects are mostly reported under controlled laboratory or greenhouse conditions and in specific crop species. Within commercial agricultural production systems, the crops that have been studied most widely and demonstrated to respond positively to biostimulant materials are row crops and cereals. Different product formulations (often containing multiple types of biostimulants or additions of macro- or micronutrients), different agricultural practices, and varying environmental conditions further complicate their use. Close attention should therefore be directed at product ingredients and compatibility with management practices before using these materials, and careful optimization prior to use on a larger scale is recommended.

References

Battacharyya D, Babgohari MZ, Rathor P, Prithiviraj. (2015). Seaweed extracts as biostimulants in horticulture. *Sc. Horticulturae* 196:39–48.

Calvo P, Nelson L, Kloepper JW. (2014). Agricultural uses of plant biostimulants. *Plant Soil* 383:3–41.

Canellas LP, Olivares FL, Aguiar NO, Jones DL, Nebbioso A, Mazzei P, Piccolo A. (2015). Humic and fulvic acids as biostimulants in horticulture. *Sc. Horticulturae* 196:15–27.

Colla G, Nardi S, Cardarelli M, Ertani A, Lucini L, Canaguier R, Rouphael Y. (2015). Protein hydrolysates as biostimulants in horticulture. *Sc. Horticulturae* 196:28–38.

Du Jardin P. (2015). Plant biostimulants: Definitions, concept, main categories and regulations. *Sc. Horticulturae* 196:3–14.

El Hadrami A, Adam LR, El Hadrami I, Daayf F. (2010). Chitosan in plant protection. *Mar. Drugs* 8:968–987.

López-Bucio J, Pelagio-Flores R, Herrera-Estrella A. (2015). *Trichoderma* as biostimulant: exploiting the multilevel properties of a plant beneficial fungus. *Sc. Horticulturae* 196:109–123.

Ruzzi M, Aroca R. (2015). Plant growth-promoting rhizobacteria act as biostimulants in horticulture. *Sc. Horticulturae* 196:124–134.

Savvas D, Ntatsi G. (2015). Biostimulant activity of silicon in horticulture. *Sc. Horticulturae* 196:66–81.