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Plant biostimulants as a tool for hydroponic vegetable production

The agriculture sector is faced with increasing productivity to fulfill the food requirements of an ever-growing population, all while limiting the environmental impacts of increased production. Biostimulants are a class of materials that may have the potential to increase crop performance and stress resistance while reducing fertilizer and pesticide use. However, biostimulants are a relatively new broad class of materials that have not been well studied for greenhouse crops. Most commercially available materials do not have labeled application rates for greenhouse crops. This article serves to provide a background to biostimulants, a description of their categories, and provide an example of effects of biostimulants in hydroponic lettuce production.

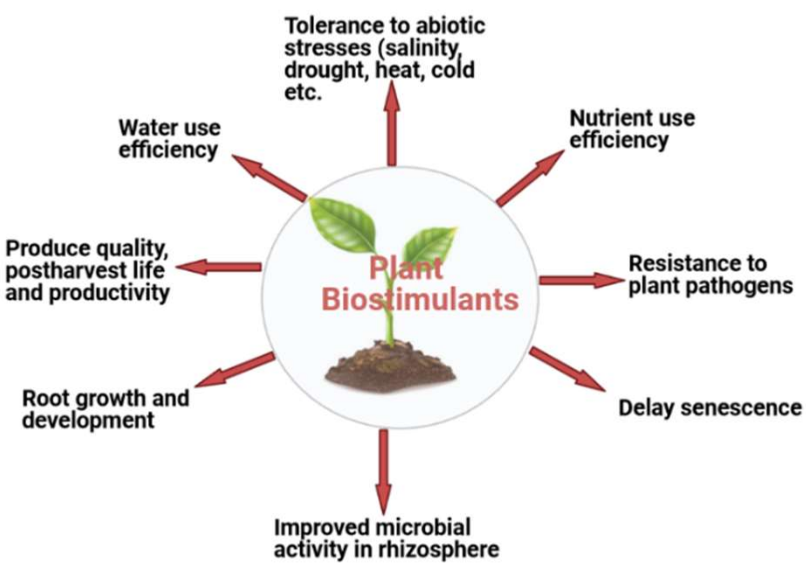

Figure 1. Beneficial effects of plant biostimulants. Image: Muhammad Shahid, University of New Hampshire

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Introduction

Biostimulants have been known by different names such as plant strengtheners, agricultural biostimulants, organic biostimulants, biofertilizers, plant growth promoters, plant health stimulators, probiotics for plants, and metabolic enhancers.

The definition of a "plant biostimulant" has been thoroughly debated over the last decade, and various definitions differentiating between plant biostimulants and fertilizers have been introduced over the years. The first statutory wording for plant biostimulants appeared in December of 2018, in the Farm Bill or the "Agriculture Improvement Act of 2018." According to the 2018 Farm Bill, a plant biostimulant is "a substance or microorganism that, when applied to seeds, plants, or the rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stresses, or crop quality and yield." This legal description of plant biostimulants codified in the 2018 Farm Bill is the first step towards developing a regulatory statute for approval and developing the labeling process of these substances that are presently labelled as plant nutrients, soil amendments or soil inoculants.

Categories of plant biostimulants

Plant biostimulants are available in different forms such as humic substances, seaweed extracts, plant beneficial microbes (fungi and bacteria), chitosan, protein hydrolytes and some inorganic compounds such as silicon. Plant biostimulants improve the plant growth and development and strengthen the plant's defensive system to plant pathogens and various environmental stresses (Figure 1).

Below we provide more background information into the different categories of biostimulants. It is important to note that not every type of biostimulant will have a positive effect but should be tested for specific crops in specific production settings.

Humic substances

Humic substances are produced through the natural microbial degradation of animals and plant materials, which are enriched with high organic carbon. There are three main groups of humic substances: fulvic acid, humic acid, and humin. Most of the humic substances available are produced through extraction of non-renewable resources, such as humates, which are mined from humate ore deposits of oxidized lignite and soft coal. However, humic substances can also be obtained from renewable sources like compost and vermicompost. Fulvic acid has the highest cation exchange capacity (CEC), followed by humic acid, and then humins with lowest CEC. Humic substances induce an auxin-like effect, improving cell differentiation. They improve seed germination and chlorophyll contents in leaves. Humic substances improve root growth and development, which results in improved water and nutrient uptake. They also improve CEC and soil buffering potential. They also increase the activity of plant beneficial microbes by providing them with carbon.

Seaweed extracts

Seaweed extracts (SWEs) are marketed in powder and liquid form. Their extracts contain different types of phytohormones, polyphenols, alginates, laminarins, polyamines, and free amino acids, as well as various macro and micronutrients, all of which make SWEs plant growth-promoting agents (Stirk et al., 2014).

The growth promoting effects of SWEs have been observed in various growth stages of different horticultural crops: seed germination, seedling growth, and plant establishment, as well as benefitting plant overall health (Abd El-Samad et al., 2019). SWEs stimulate green pigments in leaves, which consequently results in greater and more efficient photosynthetic activities (Kulkarni et al., 2019). SWEs of Laminaria spp. and Ascophyllum nodosum were found to be very effective in improving nutrient uptake, resulting in greater nutrient use efficiencies. Use of SWEs also had mitigating effects on plant tolerance to abiotic stresses (salinity, heat, drought) and enhanced plants' resistance to pathogens (Zhang and Ervin, 2008).

Plant beneficial microbes

Plant beneficial microbes (PBM) are a class of biostimulants that improve plant growth, development, and productivity by increasing green pigments, photosynthetic activity, and the solubility and bioavailability of nutrients in rhizosphere (area around plant roots) (Naik et al. 2019). They are also known as plant growth promoting microbes (PGPMs). PBM can also generate bioactive substances like vitamins, phytohormones and enzymes, which enhance plant growth and increases tolerance to various abiotic stresses such salinity, drought, and heavy metal toxicity. Most of the plant beneficial bacteria belong to genus: *Bacillus, Rhizobium, Pseudomonas, Azospirillium, Azotobacter* etc. and genus: *Glomus and Trichoderma* in the case of fungi. PBM can improve the nitrogen status of plants by enhancing nitrogen fixation and improving availability of other nutrients such phosphorus, iron, potassium to plants. They also provide frontline defense for roots against root damaging pathogens through their antibiotic action. Plant growth promoting bacteria such as *Psuedomonas spp* enhanced resistance to *Botrytis cinerea* (South et al 2020), and improved plant quality and drought tolerance in greenhouse ornamentals (Nordstedt and Jones, 2021).

Protein hydrolysates

Protein hydrolysates (PHs) are blends of polypeptides, oligopeptides and amino acids formed by hydrolysis of various protein sources such as animal (leather and fish byproducts, blood, chicken feathers) and plant (legume seeds, alfalfa hay, corn residues and vegetable waste) (du Jardin, 2015). Plant based PHs can have significant auxin like activity. They are found to be effective in improving seed germination, root development, number of flower buds, leaf area, plant biomass and productivity in various horticultural and agronomic crops. They also help plants in improving nutrient and water use efficiency under low nutrient and water deficient conditions.

Chitosans

Chitosan is a natural polysaccharide formed by deacetylation of the exoskeleton of nematode eggs, cray fish, lobsters, prawns, crab, and shrimp. It can also be extracted from microbes such as fungi and bacteria. Chitosan works as a biofungicide, biobactericide, and biovirucide, which improves the immune system of various plant species including fruits and vegetables (Liang et al. 2014). It can also have a positive effect on microbes in the rhizosphere and establishes a symbiotic association with growth promoting microbes, thus accelerating seed germination and nutrient uptake. Supplementing nutrients with chitosan has improved physiological and biochemical processes related to biotic and abiotic stress tolerance.

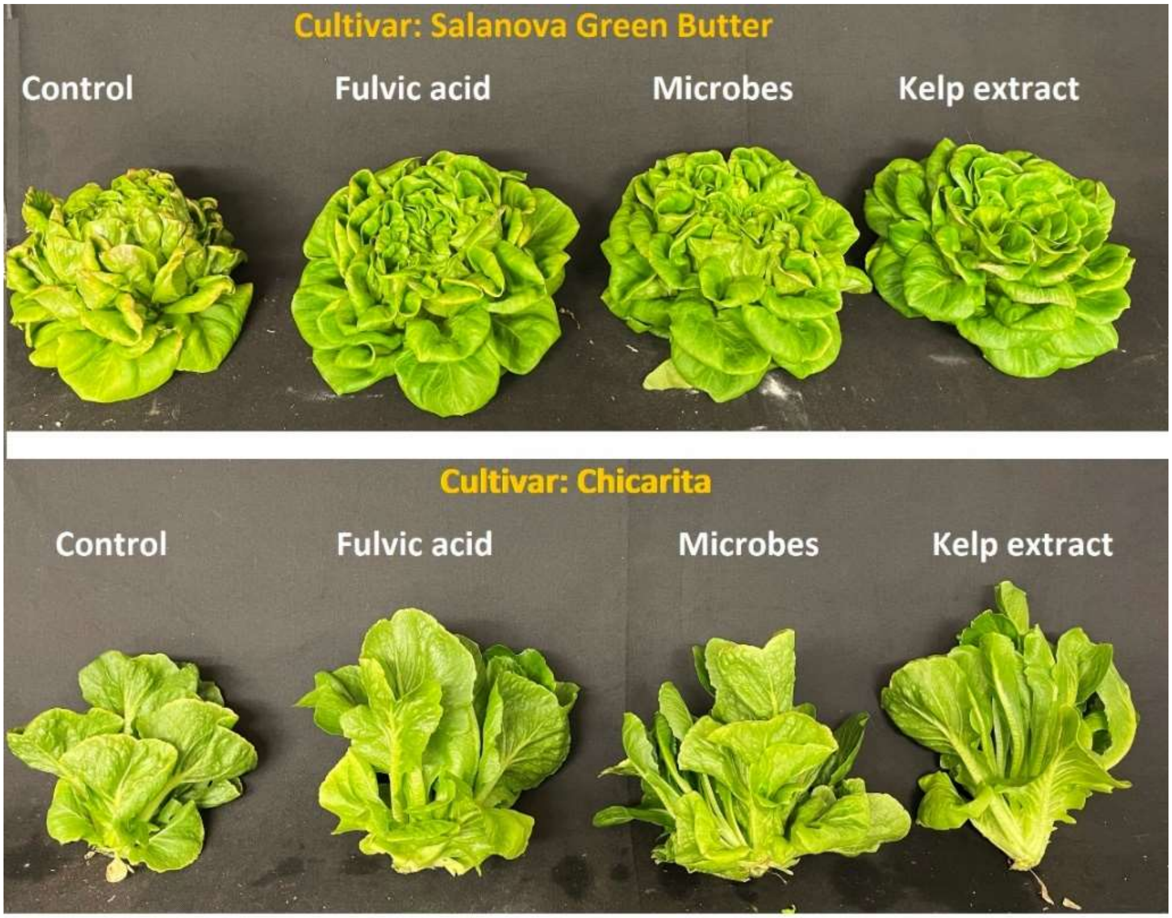

Figure 2A. Effect of three different biostimulants on head size in four different lettuce cultivars. Image: Muhammad Shahid, University of New Hampshire

Biosimulants could be an ecofriendly approach in hydroponic vegetable production to reduce dependence on synthetic fertilizers and improving the productivity, produce quality and postharvest life. There is a need to establish best-management-practices (BMPs) for biostimulant application in hydroponic vegetable production. There is not a lot of research-based recommendations on their use, plant impacts, and economics. This is the main hurdle to biostimulant application in hydroponic vegetable production.

University New Hampshire experiment with hydroponic lettuce production

The main objective of this study is to study the impact of commercially available biostimulants on hydroponic lettuce, including the potential to reduce the use of chemical fertilizers. The base nutrient program we used was made up of Jack's water soluble 5-26-12 and calcium nitrate (15-0-0) formulated at 100% strength (150 ppm N) for the control (no biostimulants) and 80% strength (120 ppm N) for the biostimulant treatments. The treatments were three different commercially available biostimulant 1) fulvic acid (Mr. Fulvic [Tallahassee, Florida] @ 2.5mL/gal), 2)kelp extract (GS kelp [Maitland, Florida] @ 30mL/gal) and 3) microbes (RAW Microbes-Grow Stage [Chico, Canada] at 5 grams/gal). The fulvic acid and Kelp extract were added directly into the nutrient solution and were applied once, two weeks after transplants. The microbes were applied through a foliar spray once per week. The control was 100% nutrient solution (150 ppm N), and the experimental treatments were 80% Nutrient Solution + fulvic acid, 80% Nutrient Solution + microbes, and 80% Nutrient Solution + Kelp extract. These biostimulant were tested in four different lettuce cultivars ('Chicarita', 'Red Batavia', 'Green Butter', and 'Green Sweet Crisp') provided by Johnny's Selected

Figure 2B. Effect of three different biostimulants on head size in four different lettuce cultivars. Image: Muhammad Shahid, University of New Hampshire

Seeds, ME. The lettuce was grown in NFT hydroponic systems in a greenhouse with a daily light integral target (sunlight + HPS supplemental light) of 17 $mol \cdot m^{-2} \cdot day^{-1}$ and a temperature of 68-70 °F.

The addition of biostimulants improved leaf greenness, photosynthetic activity, head diameter, head height, dry weight and yield compared to the control (100% nutrient solution). The head diameter of lettuce was increased by 20-45%, 15-35%, and 10-20% for fulvic acid, kelp extract and microbes, respectively, as compared to the control. Biostimulants had a positive effect on harvestable yield. Overall fulvic acid was found to be very effective with maximum increase in yield (35-50%) followed by kelp extract (20-30%) and microbes (10-15%) compared to the control plants (Figure 3). Visually, biostimulants (especially the microbe application) were found to alleviate tipburn, a physiological disorder caused by lack of calcium supply to the growing tip (Figure 4). And biostimulants (particularly fulvic acid) appeared to reduce symptoms of marginal necrosis of lower leaves which may be due to a nutritional deficiency (such as magnesium) (Figure 5).

Overall, our results demonstrate that using biostimulants could lead to improved plant growth and quality while using less fertilizer. Further research is needed to understand the mechanisms that led to biostimulant benefits as well as on the applicate rate and timing to lead to optimum responses. As well, the work needs to be validated at a larger scale in commercial greenhouse systems. The effects of biostimulants are highly dependent on the species and cultivar of the plant grown and environmental

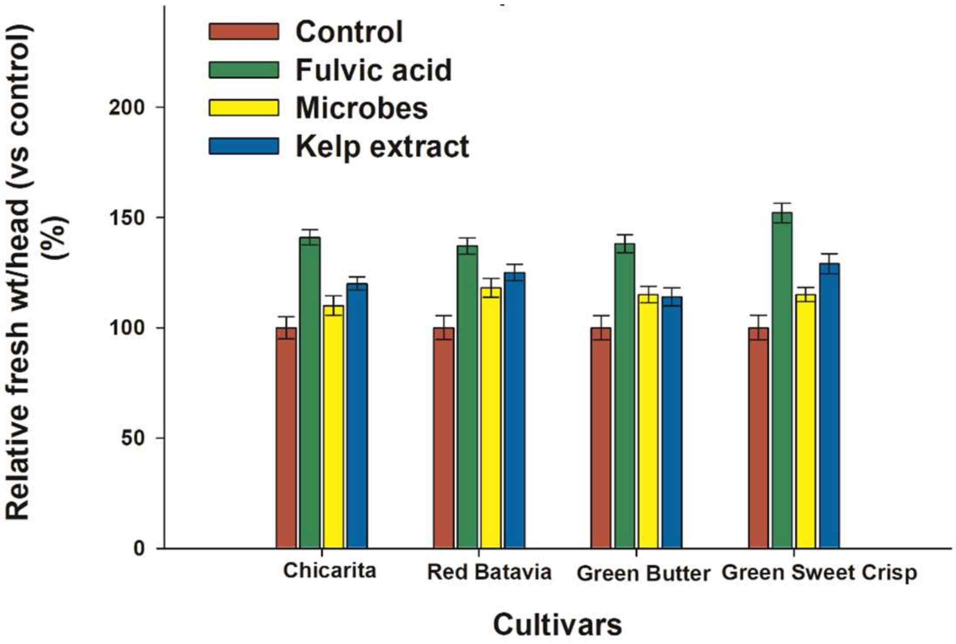

Figure 3. Relative head fresh weight in response to biostimulants. Image: Muhammad Shahid, University of New Hampshire

conditions. Therefore, it is very important that growers interested in using biostimulants in their nutrition programs understand that biostimulant effects varies with the application method (foliar or supplemented in nutrient solution), concentration applied, crop type, and growing environment. Growers should always get complete information from the manufacturer on the biostimulant composition, the recommended application rate, the nutrient profile, and the application method (and any PPE or applicator requirements that must be followed). It is advised to always run a small-scale test before application to the entire crop.

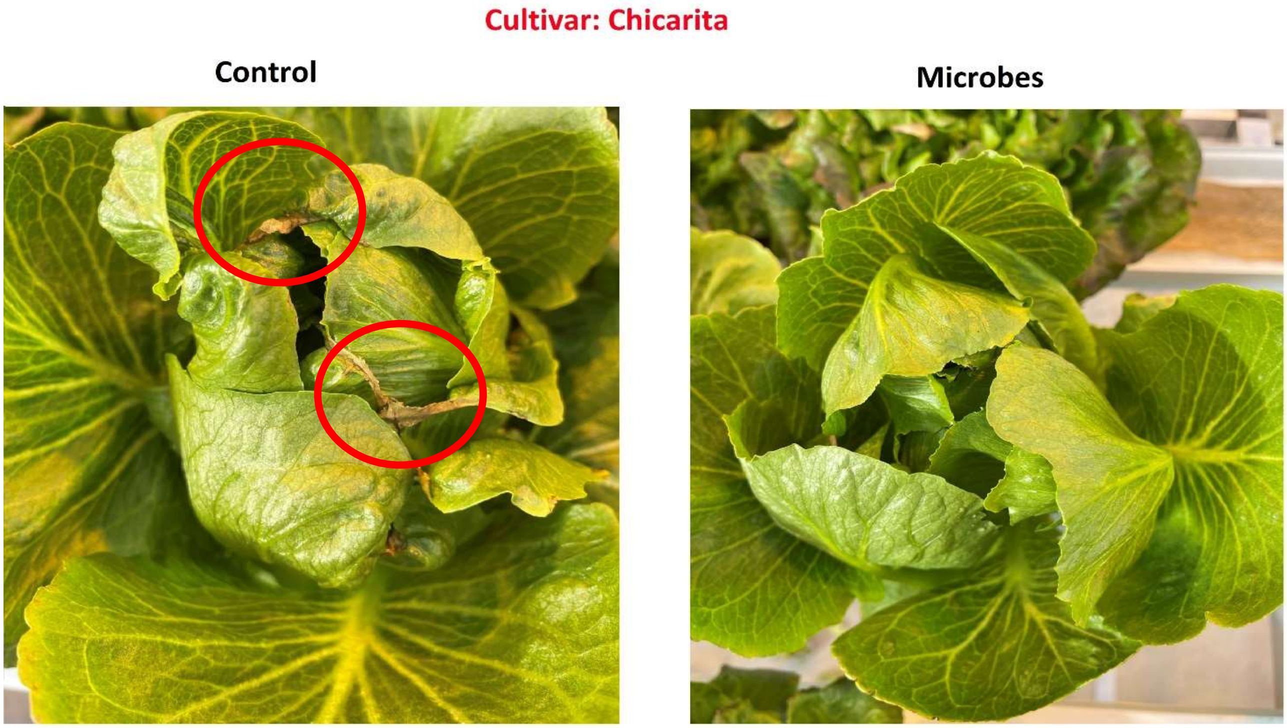

Figure 4. Biostimulants (ex: microbes) mitigated symptoms of tipburn. Image: Muhammad Shahid, University of New Hampshire

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Cultivar: Salanova Green Butter

Control | **Fulvic acid**

Figure 5. Biostimulants (ex: fulvic acid) reduced symptoms of lower leaf edge necrosis. Image: Muhammad Shahid, University of New Hampshire

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