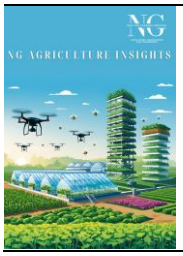

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Role of Biostimulants in Advancing Sustainable Vegetable Cultivation

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A B S T R A C T

The pressure to produce more vegetables due to growing needs across the world is also indicative of the need to use sustainable production methods that can result in improved production with limited effects on the environment. The answer lies in the use of biostimulants, substances which stimulate growth and development of plants. They cause a positive effect on crop yields through promoting root growth and nutrient uptake, crop quality through enhancing levels of nutrients and antioxidants, decreasing dependency on chemical fertiliser and pesticide usage, and increasing the resistance of crops to adverse external conditions. In this review, the authors examine the different forms of biostimulants, i.e., plant growth-promoting rhizobacteria (PGPR), seaweed extracts, amino acids, and humic acids, and application strategies, i.e., foliar spray, soil-application, and seed treatment. It also points out a future of biostimulants in promoting sustainable vegetable production. With sustainable agriculture being eminent, the use of biostimulants is expected to keep growing as more research is carried out and the use of technology is enhanced. Biostimulants combined with other potential technological advancements in agriculture possess great potential of realising sustainable and effective vegetable agriculture. More studies are needed and its large-scale use is vital in capturing the potential of biostimulants in sustaining vegetable farming.

Keywords: Biostimulants, Crop Quality, Environmental Sustainability, Vegetable Production, Yield Enhancement

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1. INTRODUCTION

The world as a whole has experienced a massive desire in the consumption of vegetables as such wants have been fueled by the growth in population, changes in diet to healthy food along with the heightened enlightenment of the nutrition value of a plant-based diet (FAO, 2021). These increased demands have exerted a huge pressure on the agricultural systems to ensure they increase their yields of vegetables on a sustainable manner. A sustainable vegetable production is important not only as a means to satisfy the nutritional requirements of an increasing population, but also as a requirement to sustain the environmental balance and the sustainability of agriculture. Sustainable agriculture targets the production of food consumption with minimum impact on the environment and expenditure of natural resources that support biodiversity. It entails crop rotation, integrated pests management, organic fertilisers (Pretty, 2008). Nonetheless, vegetable production is difficult to attain sustainably owing to numerous aspects which include climate change, soil erosion, water insecurity as well as rising cases of pests and disease (Singh et al., 2020). Such problems require new solutions that will not only increase the productivity of crops but also will decrease the use of chemical additional to crops, as well as lessen ecological damage.

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Biostimulants are very innovative measures of meeting the challenges of sustainable production of vegetables. Biostimulants are said to be substances or microorganisms that when provided on the plants or soils result into plant growth and development, enhancement of nutrient uptake and efficiency and the ability of plants to withstand abiotic stress (Yakhin et al., 2017). As opposed to conventional fertilisers and pesticides, biostimulants do not provide nutrients directly to the plant because they trigger the natural cycle of the plant, thus boosting the natural ability of the plant to grow and survive. Agricultural application of biostimulants has in recent years attracted a lot of interest as a potential solution to the production of crops to a higher yield, quality and sustainability. They may also come in the form of biostimulants generated through plants, seaweed, microorganisms and organic wastes. Their numerous advantages would be higher crop yields, higher crop quality, lower chemical consumption, and better stress resistance. These properties contribute to the fact that biostimulants are one of the promising solutions to sustainable vegetable farming.

2. BENEFITS OF BIOSTIMULANTS IN VEGETABLE PRODUCTION

Increased plant growth and plant development by various mechanisms results in increased crop yields accomplished by biostimulants. These materials have the ability to promote root growth, increase nutrient availabilities, and promote photosynthesis efficiency other than contributing to greater yields. An example here is the plant growth-promoting rhizobacteria (PGPR) that colonise the roots of the plants and promote the absorption of the essential nutrients e.g. nitrogen, phosphorus, and potassium. Research has revealed that using PGPR can enhance tomatoes yield by as much as 20 percent because it improves the roots and nutrients availability to the tomatoes.

Biostimulants actually go further by improving the nutritional value and sensory quality of vegetables in addition to the increased crop yields. They are in a position to enhance the composition of nutritional worth that of the necessary nutrients, nutrients and antioxidants, making the produce more health-compelling and valuable to the consumers (Rouphael & Colla, 2020). As an illustration, it has been demonstrated that seaweed extracts can enhance antioxidant nature and content of lettuce thereby making it more favourable to the health of a human being. The resulting higher level of antioxidants may help prevent the damage of oxidative stress and ensure against chronic disease.

Among the most important advantages of biostimulants, one should note their potential to minimise dependency on chemical fertilisers and pesticides. The uses of chemical inputs result in negative environmental effects such as soil degradation, water pollution and loss of biodiversity. A more sustainable alternative to biostimulants can be seen as increasing the natural plant growth processes avoiding the use of artificial chemical products. Environment costs of a lesser use of chemicals are massive (Sahoo et al., 2021). The use of synthetic fertilisers and pesticides should be diminished to preserve the health of soil, to decrease the number of water contaminants, and to increase biodiversity. This may also result in cost savings by farmers and help produce more sustainably grown crops.

3. TYPES OF BIOSTIMULANTS USED IN VEGETABLE PRODUCTION

3.1. Plant growth-promoting Rhizobacteria (PGPR)

PGPR are root-colonising bacteria that stimulate plant growth via many mechanisms. These bacteria have the abilities to fix atmospheric nitrogen, solubilise phosphates and produce auxins, cytokinins and gibberellins plant hormones. These hormones increase growth of roots, increase nutrient absorption and growth of the whole plant (Bhattacharyya & Jha, 2012). PGPR also synthesises siderophores which sequester iron making it unavailable to phytopathogens to a certain extent indirectly benefitting plants. PGPR are also being extensively applied in the production of vegetable crops to increase the output and thereby improving the health of the plant. An example can be the use of tomato plants that have been inoculated with PGPR, used to increase the yield by up to 20 percent through a healthy root development and availability of nutrients. The commercial products are in different forms such as granules, liquid suspension and wettable powders therefore readily applicable in the various farming conditions.

3.2. Seaweed Extracts

The nutrients and bioactive compounds found in seaweed extracts comprise complex polysaccharides, minerals, vitamins, plant hormones (auxins, cytokinins and gibberellins). These nutrients stimulate the growth of plants by facilitating movement of nutrients, stimulating root growth and making plants tolerant to stressful conditions. Seaweed formula also enhances soil arrangement and fecundity to maintain the general growth of the plants (Craigie, 2011). There is successful positive use of seaweed extracts in most vegetable crops to improve the farming yield and growth.

3.3. Amino Acids

Plants possess essential amino acids which are the building blocks of proteins and are very vital in the growth and development of plants. They accelerate the capture of nutrients, lead to the growth of roots, and increase resistance to stress . Antioxidant and amino acids include proline and can help a plant against oxidative stress. Amino acids are applied in foliar sprays, soil treatments etc to enhance growth of plants and quality of crop.

3.4. Humic Acids

Organic matter differs into humic acids, which have the tendency of enhancing soil fertility. They improve soil texture, they add water holding and they help to grow beneficial microorganisms. The humic acids also enhance the availability of nutrients through the process of mineral chelation making them easily available to the plants. Humic acids have also been found to grow roots, improve nutrient absorption and subsequently total plant growth (Halpern et al., 2015).

Table 1. Types of biostimulants and their effects

Type of Biostimulant	Source	Key Benefits
PGPR	Rhizobacteria	Nitrogen fixation, hormone production, root growth
Seaweed Extracts	Marine Algae	Improves stress tolerance, enhances growth, improves soil structure
Amino Acids	Protein Hydrolysates	Enhances nutrient uptake, stress resistance, root development
Humic Acids	Decomposed Organic Matter	Improves soil texture, increases water retention, boosts root growth

4. APPLICATION METHODS OF BIOSTIMULANTS

The commonest way to apply biostimulants is by foliar spraying as it has direct effect on plant growth and development. This is the spray application of biostimulant solutions on leaf and other aerial plant parts. The benefits of foliar spraying are a quick uptake, specific application and efficiency. By applying the nutrient and the active compounds to the foliage, the rapid uptake of the nutrients and active compounds by the plant can result in an immediate effect on growing and stress adaptation. This approach will enable a direct delivery of the biostimulant to the plant tissues without the need to go through the soil or a chance of losing the nutrients to leaching or a chance of getting destroyed by microbe activities (Satapathy et al., 2021). A lower concentration of foliar sprays can be used than the soil application hence it is also economical and effective. Before utilizing the foliar sprays, the solution containing the biostimulant should be well blended and devoid of any particulate supervision as recommended by the manufacturer. Use the spray in the morning early or at night so that there will be no leaf burn and maximum absorption (Moharana et al., 2020). Cover the leaves as evenly as possible with particular attention to the undersides which have more stomata. Apply according to the advised program, perhaps scrape once a week or once in 2, relying on the type of biostimulant and the necessities of the crop.

Soil application: In this case, the biostimulants are added to the soil where they could increase soil fertility and improve root growth. Some of the soil application advantages are that the soil becomes fertile, increases plant root growth and long term effect. Biostimulants are capable of improving soil structure, improve water retention, and stimulate growth of positive microorganism. There are also certain things which can promote root growth and hence enhance the nutrient uptake and the general health of the plants (Calvo et al., 2014). It is common that soil applied bio stimulants can provide prolonged effects to the crops due to sustained effects over the season rather than a one off event supplied in foliar sprays. Soil biostimulants are used through soil drenching methods, soil incorporation and irrigation systems application. The biostimulant solution should be applied on the soil around the plant but at the bottom where it will cover the entire root zone of the plant through a process referred to as soil drenching. Soil incorporation Sludge incorporation directly into the soil is the act of incorporating the biostimulant into the soil prior to plantation or when transplanting the seedling to guarantee a balanced distribution of the bio stimulant through soil profile. There is consistency and uniformity of application because of the use of drip irrigation or any other irrigation to target delivery to the root zone.

Immediately before planting biostimulants can be applied to seeds: this is seed treatment. The

technique may have a high influence on the rate of germination and initial seedlings. Seed treatment is beneficial because it increases germination, causes an upsurge in seedling vigor, and early provision of nutrients. They have the capability of enhancing seed germination rates through supply of the necessary nutrients and hormones, which stimulates early growth. They may also improve seedling vigour that gives rise to healthier and stronger plants that are much more tolerant to stress. Biostimulants provide important nutrients directly into the seed thus making sure that the seedling has access to the resources that the seedling needs to grow in its most optimum state instead of carrying out a nutrient uptake phase that will only delay the growth of the seedling. Some of the methods that are applied to treat seeds are soaking, coating and the use of seed priming. By placing seeds in a biostimulant solution and soaking them during a certain time span (which varies, but is not very long, certainly not longer than a night), the seeds can be made absorb the biostimulant. Coating consists in a thin film of biostimulant applied to the surface of the seed, and it can be applied in a liquid solution or as a dry powder form of the biostimulant. Certain biostimulants exist as primed seed: the seed is applied to the biostimulant prior to packaging. This will make sure that the seeds are germinated and can be planted immediately and receive the biostimulant as early as possible.

5. CONCLUSION

The biostimulants come in various advantages that render it to be an irreplaceable tool in sustainable vegetable production. They boost the production of crops by enabling growth and development of crops, enhance the quality of crops in terms of nutrient and antioxidant contents, minimise the use of chemicals in the form of fertilisers and pesticides, and make the plants untoward to the environmental stress conditions. All these advantages result in a healthier and more efficient agricultural production. There is promising future of biostimulants in vegetable production. The need of sustainable agriculture will continue to rise and therefore, it is probable that the use of biostimulants will also rise. Newer products developed with more efficacy and convenience of use due to continuous research and development are emerging in the form of biostimulants currently. The combination of biostimulants with other technologies that are also considered as advanced ones in the agricultural domain, like precision agriculture and vertical farming, are the factors with the potential to further improve the effect that biostimulants rave on sustainable vegetable production.

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