Chapter 5

Biofertilizers: A review on advancing sustainable agriculture and enhancing soil health

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Abstract: Global population growth and rising food consumption pose significant challenges for agriculture which led to greater usage of inorganic fertilizers without considering soil health, which is crucial for achieving sustainable high yields. According to FAO (Food and Agriculture Organization) agricultural product consumption will increase by 60% by 2030. However, the increased usage of chemical fertilizers had a negative impact on the environment and living organisms. Moreover, the negative impacts of using inorganic fertilizers can be seen on the ecosystem, subsurface water sources, and soil microorganisms. Biofertilizers play a key role in replenishing the lost biological activity in soil due to the overuse of chemical fertilizers, as they consist of beneficial microorganisms that foster healthy interactions with plants in the rhizosphere. These interactions ultimately contribute to enhancing plant health, soil fertility, and long-term sustainability. They create growth-promoting chemicals and vitamins, maintaining soil fertility and suppressing pathogens and illnesses, leading to improved production and yield components. Biofertilizers are micro-organisms that improve productivity by fixing nitrogen, solubilizing phosphate and creating growth stimulants for plants. Biofertilizers are a cost-effective alternative to chemical fertilizers, reducing the significant investment required for fertilizer use. Biofertilizers provide a possible alternative to toxic chemicals, hence promoting agricultural sustainability.

Keywords: Agricultural sustainability, Biofertilizers, Soil health

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1. Introduction

Biofertilizers are natural mixes of beneficial microorganisms such asmycorrhizal fungi, phosphorus-solubilizing bacteria and nitrogen-fixing bacteria. These microbes increase nutrient availability and soil fertility by forming symbiotic partnerships with plants. Biofertilizers, as opposed to chemical fertilizers, promote long-term soil health, improve physical, chemical and biological qualities and reduce negative environmental impacts (Pahalvi et al. 2021). Furthermore, they improve plant tolerance and serve as an effective pest deterrent. To reduce resistance and increase long-term benefits, biofertilizers use sustainable, inexpensive and popular insect pest control strategies in the community (Ghimirey et al. 2024).

Biofertilizers have been shown to increase crop yields by 10-40% and boost the content of essential nutrients such as proteins, amino acids, vitamins, and facilitate nitrogen fixation (Shahwar et al., 2023). They harness the capabilities of nitrogen-fixing microorganisms like *Azotobacter*, *Azospirillum, Rhizobium, as well as fungi like Aspergillus niger and A. tubingensis* (Heba et al., 2021). This natural approach also involves beneficial soil bacteria and fungi, which act as organic fertilizers (Ammar et al., 2022; Aioub et al., 2022). Cyanobacteria, such as *Nostoc sp., Anabaena sp., and Oscillatoria angustissima*, are also promising sources of biofertilizers.

This overview highlights the environmentally friendly nature of biofertilizers and underscores their advantages over synthetic fertilizers. Biofertilizers, being biodegradable, possess high eco-economic value, reduce the risk of plant diseases, pose fewer threats to human health compared to synthetic alternatives, help mitigate pollution, and improve soil fertility without the accumulation of heavy metals and residues over time.

2. Types Biofertilizers

A biofertilizer is applied to plant surfaces, seeds or soil, it can colonize the rhizosphere and promote plant growth by increasing nutrient availability and uptake. Biofertilizers, unlike chemical fertilizers are more affordable for marginal and small farmers. Microbial biofertilizer is mostly composed of bacteria, algae, fungus and cyanobacteria, which have symbiotic relationships with plants. Microbial fertilizers mostly provide nitrogen and phosphate to the plant for growth.

Bacteria as Biofertilizers

Bacterial biofertilizers play a crucial role in enhancing plant growth and development through various mechanisms (Kumar et al., 2022). These include synthesizing plant nutrients and phytohormones that are easily absorbed by plants, mobilizing soil chemicals for better plant nutrition, and providing protection to plants under stressful conditions. Such systems help reduce the negative impacts of stress factors and defend plants against pathogens, ultimately decreasing plant diseases and death. Plant growth-promoting rhizobacteria (PGPR) have been widely utilized as biofertilizers globally, contributing to enhanced agricultural yields and soil fertility for more sustainable agriculture and forestry practices.

For instance, *Azotobacter*, a well-studied biofertilizer, has been utilized for over a century due to its ability to fix nitrogen in the rhizosphere and roots of rice, promoting plant growth and development. Research indicates that *Azotobacter* not only fixes atmospheric nitrogen as an endophyte in rice but also produces phytohormones and growth stimulants. Apart from nitrogen fixation, these bacteria also aid in phosphate breakdown and promote plant growth (Daniel et al., 2022).

On the other hand, cyanobacteria, known as the oldest and most productive prokaryotic group, possess a wide range of organisms. The biomass or extracts of cyanobacteria can notably enhance the physical and chemical properties of soil. Additionally, cyanobacteria are recognized for producing biologically active compounds that are effective against plant diseases and are beneficial in the phytoremediation of industrial effluents.

Rhizobium is utilized as a biofertilizer in agriculture to aid plant growth alongside chemical fertilizers. These soil bacteria, known as rhizobia, are nitrogen-fixing bacteria (diazotrophs) that establish themselves inside nodules on the roots of leguminous plants. They possess the unique ability to infect legume root hairs and induce the formation of effective nitrogen-fixing nodules. Rhizobia, which include various genera such as *Rhizobium, Mesorhizobium, Bradyrhizobium, Azorhizobium, Allorhizobium, and Sinorhizobium*, develop close symbiotic relationships with legumes by responding to flavonoid molecules released by the legume host as signaling agents. The survival of rhizobacteria in the soil is influenced by a wide array of abiotic and biotic factors. To enhance their survival rates, viability, and effectiveness in the soil, these bacteria are often mixed with a carrier (Negash and Wondimu 2022). Inoculation with Azospirillum has been demonstrated to be beneficial for plants primarily through nitrogen fixation from the atmosphere, but it also has the capability to produce phytohormones, especially indole-3-acetic acid.

Phosphorus (P) is a macronutrient required by plants to operate properly. Because P is essential for all aspects of plant growth and development, shortages can have a negative impact. Though soil contains total P in the form of organic and inorganic molecules, the majority of them are inactive and so unavailable to plants. Phosphate solubilizing microbes (PSMs) are helpful bacteria that can hydrolyze organic and inorganic insoluble phosphorus compounds into soluble P that plants may easily absorb. PSM provides an environmentally and economically sound strategy to overcome the P scarcity and subsequent uptake by plants (Girmay Kalayu 2019).

Algae as Biofertilizers

Biofertilizers are considered to be highly effective substitutes for synthetic fertilizers, with algae species showing significant potential in biofertilizer technology in terms of cost-effectiveness and eco-friendliness (Chatterjee et al., 2017). Algae offer various benefits, including the production of valuable byproducts, enhancement of soil health, and their effectiveness as biofertilizers due to their physicochemical properties. The utilization of algae in biofertilizer production is seen as advantageous for the environment, technology, and business sectors, positioning algae as a valuable and sought-after bioresource in the twenty-first century (Mahapatra et al., 2018).

Fungi as Biofertilizer

Fungi comprise a diverse taxonomic group of eukaryotic and heterotrophic organisms on Earth, including mildew, mold, mushrooms, yeast, and puffballs. They play a significant role in enhancing crop protection, growth, and yield. Fungi contribute to plant health by producing siderophores, gluconase antagonists, antibiotics, and enzymes such as cellulases and glycosidases that break down cell walls. They also play a role in solubilizing micronutrients such as phosphorus, potassium, and zinc, while generating plant growth regulators like auxin, gibberellins, cytokinin, and ethylene (Berg et al., 2007).

The association between arbuscular mycorrhizal (AM) fungi and plants involves competition with plant pathogens for nutrients and space through the production of antibiotics or by enhancing resistance in host plants. These microorganisms have been utilized for biocontrol of pathogens. It has been suggested that AM fungi can enhance host plant tolerance to pathogen attacks by compensating for the loss of root biomass or function caused by diseases such as nematodes and fungi (Cordier et al., 1998).

Vermicompost as Biofertilizer

Organic waste dumps on barren ground are a common sight on the outskirts of our city. According to a CIPS-ASCI waste management research, India's top eight cities generate an average of 4,500 tons of solid garbage every day, for a total of 36,500 tons. This amount does not include the uncollected waste and sewage water that travels down our waterways. These pose environmental risks. However, recycling techniques may convert these waste materials into usable things that benefit both the environment and society. Vermicomposting is the most environmentally beneficial way to minimize organic waste. This recycling process not only turns organic garbage into high-quality compost, but the chemical changes in the debris make nutrients readily available to plants. Vermicomposting can also help to reduce heavy metals and pollutants in sewage sludge. It has also been discovered that vermicomposting can greatly lower the presence of pathogens in organic debris. Vermicomposting is a key biotechnological composting technique that involves using specific species of earthworms to improve waste conversion and produce a higher-quality final product. The Red Wiggler or manure worm (*Eisenia foetida*) and the Red Worm (*Lumbricus rebellus*) are two commonly recommended earthworm species for vermicomposting. These earthworms are cultivated in agricultural settings to consume various types of organic waste, effectively processing biodegradable materials. sThey subsequently distribute the excreta, known as'vermi-cast'. These vermi-castings are high in nitrate and contain minerals such as phosphorus, potassium, calcium and magnesium, all of which are great fertilizers and soil conditioning agents (Tanweer and Abrar 2020).

3. Biofertilizers and Their significance for Soil Health and Plant Growth

Employing biological fertilizers as a supplement or alternative to chemical fertilizers is vital, as numerous studies have demonstrated that their use enhances plant root development through increased root hair formation. Improved rooting and expansion of the root system boost the plant's capacity to absorb water and nutrients, leading to enhanced vegetative growth, faster plant development, and higher crop quality. Compared to chemical fertilizers, biological fertilizers are less commonly associated with plant toxicity, thus providing healthier food options. Consequently, soil properties-physical, chemical, and biological—improve significantly, especially in regions where organic matter is depleted. Enzyme production is stimulated, facilitating the breakdown of complex organic materials into simpler, plant-accessible mineral elements. The rapid breakdown of readily soluble nitrogenous compounds plays a crucial role in compensating for the swift depletion of nitrogen, thereby preserving soil fertility (Koele et al., 2014). Introducing beneficial microorganisms into the soil helps in outcompeting pathogenic microbes, preventing their activity and infestation on plants. Additionally, these microorganisms secrete antibiotics that protect plants from soil-borne pathogens by inhibiting the growth of harmful microbes. Fertilizers contribute to enhancing soil structure by promoting the aggregation of soil particles and binding them with organic matter (Mir et al., 2014).

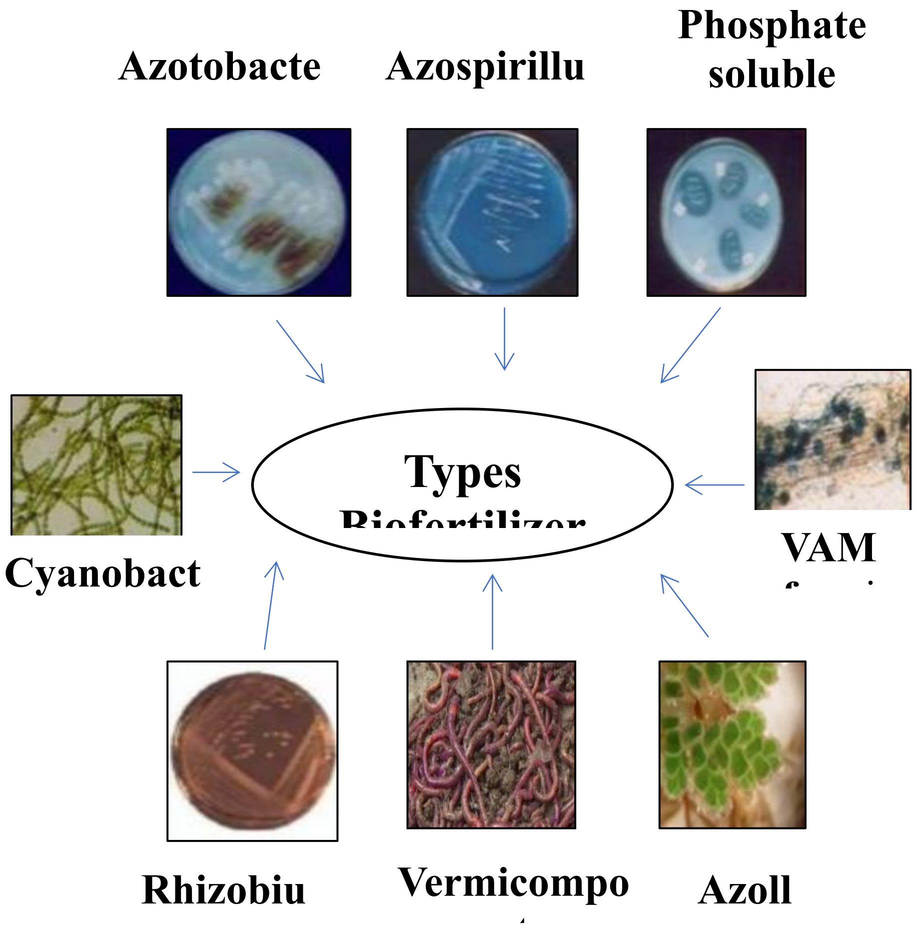

Fig.1. Microorganisms used as biofertilizers in crop growth

Mechanisms for Enhancing Plant Growth

This paper aims to elucidate the importance of microbial inoculants employed as biofertilizers and their mechanisms for enhancing crop productivity. The review underscores the direct and indirect mechanisms through which bioinoculants operate, including biological nitrogen fixation (both symbiotic and non-symbiotic), production of phytohormones, nutrient solubilization (phosphate and potassium), siderophore production, and the biocontrol of phytopathogens. Additional properties such as chitinases, hydrogen cyanide (HCN), and other antifungal capabilities are highlighted as tools of biofertilizers that contribute to increasing crop yields.

Conclusion

While chemical fertilizers and pesticides have traditionally been effective in promoting plant growth and preventing diseases, their continuous use poses risks to plants, humans, and the soil environment. Therefore, utilizing beneficial bacteria as biofertilizers and biocontrol agents offers an affordable and environmentally friendly solution to address these concerns and promote sustainable agriculture. Encouraging the use of biofertilizers in agriculture is crucial, as they have the potential to serve as alternatives to synthetic pesticides while enhancing crop yields. It is important for farmers to be informed about the benefits of plant growth-promoting rhizobacteria as biofertilizers, and there should be a priority on promoting the commercial use of biofertilizers in agricultural practices. Utilizing biofertilizer holds significant promise for improving resource efficiency, lowering pollution levels in the environment and yielding better agricultural goods. Therefore, we came to the broad conclusion that plant biofertilizers are extremely beneficial to agriculture. As a result, studies and research are still being conducted to learn more about biofertilizers and how they might be used in sustainable agriculture.

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