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Application of Biofertilizers in crop production: A review

Aplicación de biofertilizantes en la producción de cultivos: Una revisión

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Abstract

Nutritious foods are needed for the continuously growing population together with the nutrient for plant growth and production. Inorganic chemical-based fertilizers have been base and are used heavily in today's soil management procedures, posing serious health and environmental concern. Biofertilizer has been recognized as a reasonable solution for improving soil fertility and crop output in sustainable farming. The use of beneficial microorganisms as biofertilizers has escalated its importance in the agricultural industry due to its potential significance in food safety and sustainable crop production. Biofertilizers can be a valuable component of a comprehensive nutrient management strategy. Overall, nitrogen fixers (N-fixers), potassium and phosphorus solubilizers, growth-promoting rhizobacteria (PGPR), endo and ectomycorrhizal fungi, cyanobacteria, and other beneficial microscopic organisms are incorporated into biofertilizers. Utilizing bio-fertilizers, enhance nutrient and water uptake, plant development, and plant tolerance to abiotic and biotic impacts. These prospective biological fertilizers would play a essential role in soil production and sustainability and also in environmental protection, being eco-friendly and cost-effective inputs for farmers.

Keywords: *Biofertilizer, crop production, sustainability.*

Resumen

Los alimentos nutritivos son necesarios para la población en continuo crecimiento junto con los nutrientes para el crecimiento y la producción de las plantas. Los fertilizantes químicos inorgánicos han sido la base y se utilizan en gran medida en los procedimientos actuales de gestión del suelo, lo que supone una grave preocupación para la salud y el medio ambiente. Los biofertilizantes han sido reconocidos como una solución razonable para mejorar la fertilidad del suelo y la producción de los cultivos en la agricultura sostenible. El uso de microorganismos beneficiosos como biofertilizantes ha aumentado su importancia en la industria agrícola debido a su potencial importancia en la seguridad alimentaria y la producción de cultivos sostenibles. Los biofertilizantes pueden ser un valioso componente de una estrategia integral de gestión de nutrientes. En general, los biofertilizantes incorporan fijadores de nitrógeno (fijadores de N), solubilizadores de potasio y fósforo, rizobacterias promotoras del crecimiento (PGPR), hongos endo y ectomicorrícicos, cianobacterias y otros organismos microscópicos beneficiosos. La utilización de biofertilizantes mejora la absorción de

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nutrientes y agua, el desarrollo de las plantas y su tolerancia a los impactos abióticos y bióticos. Estos futuros fertilizantes biológicos desempeñarían un papel esencial en la producción y la sostenibilidad del suelo y también en la protección del medio ambiente, siendo insumos ecológicos y rentables para los agricultores.

Palabras clave: *Biofertilizante, producción de cultivos, sostenibilidad.*

Introduction

Biofertilizers are soil microbe cultures that can be employed as microbial or soil inoculants to increase plant and soil fertility and productivity. Biofertilizers are economical and sustainable plant nutrition sources. A biofertilizer is simply a product that contains living microorganisms that colonize the rhizosphere and stimulate development by increasing the supply or availability of nutrients to the host plant when applied to the soil, seed, or plant surface. Some of the most often used biofertilizers include nitrogen-fixing soil bacteria (*Azotobacter, Rhizobium*), nitrogen-fixing cyanobacteria (*Anabaena*), phosphate-solubilizing bacteria (*Pseudomonas* sp.), and Arbuscular Mycorrhiza (AM) fungus. Phytohormone (auxin)-producing bacteria and cellulolytic microorganisms are also included in biofertilizer formulations. By increasing specific microbial processes, these microbial formulations are used to increase the availability of nutrients in a form that can be digested by plants.

A biofertilizer is an organic fertilizer supplemented with beneficial microorganisms. Biofertilizers are all organic resources for plant growth that are transformed into a useable state for plant uptake by microorganisms, plant associations, or interactions. Biofertilizers are carrier or liquid based products constituting living or dormant microbes (i.e., bacteria, fungi, algae, actinomycetes) single or in combination, which assist in fixing atmospheric-N_2 or solubilizers of different soil nutrients together with production of growth promoting substances for promoting crop growth and yield (Dineshkumar et al., 2018). Biofertilizers contain microorganisms with peculiar functions, such as *Azospirillum*, which fixes nitrogen, and P solubilizing bacteria, which solubilizes P from soil and fertilizer to be available to plants (Saraswati & Sumarno, 2008). Biofertilizers are becoming more essential as a means of achieving high-quality harvests while reducing pollution. In agriculture, the application of both nitrogen and phosphate fertilizer is critical for achieving the best seed yield. Azimi et al. (2013) discovered that when applying Super nitro plass biofertilizer with Phosphate bar var2, the Pishtaz cultivar (wheat crop) has the highest seed yield (7.6 t/ha), whereas the non-application of biofertilizers treatment has the lowest seed yield (6.3 t/ha). They claimed that using biofertilizers increased grain yield and biomass yield, which is a substantial benefit, resulting in reduced production inputs due to lower costs of chemical fertilizer and higher yield (Beyranvand, 2013). *Trichoderma viride* and *Pseudomonas fluorescens*, fertilized with a half dose (50 %) of recommended fertilizers (120:60:40 NPK kg/ha) boost growth and yield of maize crop and are demonstrated as prospective biofertilizers (Nepali et al., 2020). Biofertilizers once isolated can be readily propagated economically unlike chemical fertilizers and are fuel independent, lucartive, and easily accessible (Umesha et al., 2018). Combing biofertilizers and chemical can minimize rate of recommended synthetic fertilizers and can conserve soil productivity and sustainable rice production (Ghimire et al., 2021).

Biofertilizers are formulated in an easy-to-use, low-cost carrier substance that can increase plant availability and/or mineral nutrient uptake (Malusa et al., 2012). A biofertilizer, according to Vessey (2003), is a substance which when applied to seed, plant surfaces (leaves), roots, or soil and promote growth through several approaches and that helps to elevate the supply or accessibility of primary nutrients to the host plant containing living microorganisms that colonize the rhizosphere or the interior of the plant. Biofertilizers should not be confused with green manure, manure, intercrop, or organic supplemented chemical fertilizer (Bhattacharyya & Jha, 2012; Halpern et al., 2015, although they are also named as microbial inoculants or bio formulations (Arora et al., 2011)). It was lately suggested that PGPR classification be limited to microbial strains that satisfy minimum two of three standards, combining aggressive colonization, plant growth stimulation, and biocontrol (Bhattacharyya & Jha, 2012).

The objective of this review paper was to gather information on types of biofertilizer and their role in crop production.

Types of biofertilizers

Nitrogen Fixing Biofertilizers

Nitrogen is the nutrient that limits plant growth (Gupta et al., 2012). Even though the atmosphere contains around 80 % nitrogen in its free form, most plants are unable to utilize it. To fix this nitrogen and make it available to the plant, certain group of bacteria are required. Biological nitrogen fixers (BNFs) are microorganisms that fix nitrogen in the environment. They convert inert N_2 into an organic form that plants can utilize (Reed et al., 2011). Nitrogen fixation can yield 300–400 kg nitrogen per hectare per year and accounts for up to 25 % of total nitrogen in plants by increasing agricultural production by 10 % – 50 %.

Nitrogen fixing bacteria are categorized into free-living bacteria (*Azotobacter* and *Azo spirillium*), blue-green algae, and symbionts, such as *Rhizobium*, *Frankia*, and *Azolla*. The N_2-fixing bacteria associated with legumes include *Rhizobium*, *Azorhizobium*, *Mesorhizobium*, *Sinorhizobium*, , *Allorhizobium* and *Bradyrhizobium* and those with non-legumes include *Achromobacter*, *Alcaligene*s, *Arthrobacter*, *Acetobacter*, *Azomonas*, *Beijerinckia*, *Clostridium*, *Bacillus*, *Enterobacter*, *Erwinia*, *Desulfovibrio*, *Derxia*, *Corynebacterium*, *Campylobacter*, *Herbaspirillum*, *Klebsiella*, *Lignobacter*, *Mycobacterium, Rhodospirillum, Rhodopseudomonas, Xanthobacter, Mycobacterium,* and *Methylosinus* (Meena et al., 2017). . They can efficiently replace chemical fertilizers in a variety of ways like reducing the chemical load on the environment. In the rhizosphere, plant roots emit compounds that induce bacterial colonization and nitrogen fixation.Although numerous genera have been identified from the rhizosphere, members of the *Azotobacter* and *Azospirillum* genera have been thorougly studied in the field to enhance legume and cereal yields (Bhat et al., 2015).

Phosphate Solubilizing and Mobilizing Biofertilizers

Phosphorus which accounts about 0.2 percent of the plant's dry weight is an indispensable nutrient for plant growth and development. In contrast to other macronutrients, phosphorus is the lowest transportable macronutrient available to plants in many soil conditions. Insoluble forms of phosphate are transferred into to soluble forms by microorganisms (Kalayu, 2019; Prabhu et al., 2019). Several bacteria and fungus species participate in phosphate solubilizing process (Antoun, 2012). Phosphate-solubilizing bacteria (PSB) make use of a several processes to convert insoluble phosphates like HPO_4 and H_2PO_4 into soluble forms, along with that PSB help in formation of organic acids, chelation, and ion exchange reactions. PSB constitute 1–50% of microbial populations, while fungi account for only 0.1–0.5% of phosphate-solubilizing activity (Sharma et al., 2013). PSB can prepare metabolites when interact with hydroxyl (gluconic) and carboxyl (ketogluconic) groups that chelate the phosphate cation and convert it into a soluble form that plants can take. Plants are able to utilize nutrient when bonded phosphorous was dissolved because acidic soil and soil Ph decreased as a result of acids prepared by PSB (Itelima et al., 2018). Microorganisms use the proton-extrusion mechanism to solubilize phosphate in addition to the organic technique (Park et al., 2009; Patel & Goswami, 2020). Not only Phosphate, but also other trace elements like Fe and Zn, are supplied by the PSB, which facilitate the plant to flourish. They also produce the enzyme that kills the pathogen, ensuring that the plant is disease-free.

Phosphate solubilizers incorporates *Bacillus*, *Rhizobium*, *Pseudomonas* and *Enterobacter* bacteria, as well as *Penicillium* and *Aspergillus* fungi (Anand et al., 2016). In Cameroon's acidic soils, the use of the *Pseudomonas fluorescence* strain considerably raises maize shoot length, plant dry weight, grain yield, and seed phosphorus content (Henri et al., 2008). Similarly, in recent study, it was observed that the phosphorus solubilizer *Aspergillus niger* remarkably elevated plant height, fruit size, leaf length/width, and fruit numbers per plant as compared to control plants. Also, it was noticed that combined use of phosphorus-solubilizing (*Aspergillus niger*) and nitrogen-fixing (*Aspergillus niger*) biofertilizers in plant as an inoculant assisted plant to perform better than those treated with single type biofertilizer (Din et al., 2019).

The immobile forms of phosphorous can be mobilized by phosphorus-mobilizing bacteria (Suthar et al., 2017). They transport and mobilize insoluble phosphate from the soil layers to the root cortex. Phosphate-mobilizing fungi, such as arbuscular mycorrhiza, penetrate the roots and increase their surface area, activate metabolic processes, and absorb nutrients. Phosphate-solubilizing bacteria are said to act as phosphate mobilizers on occasion (Chang & Yang, 2009). They have the capability to solubilize/mobilize roughly 30–50 kg P_2O_5/ha under appropriate conditions, as a result it can increase crop output by10 % – 20 % (Asoegwu et al., 2020).

Potassium Solubilizing and Mobilizing Biofertilizers

Potassium (K) is the ranked as the second most common and important nutrient in plants after nitrogen and phosphorus. 1 % – 2 % of phosphorous is only available to the plants even if it is available in surplus amount in soil and the remainder is present as mineral K, which plants cannot absorb. As a result, soil solution K must be replenished regularly (Park et al., 2009; Meena et al., 2014). A different bacterial and fungal strains have been identified that use variety of process to solubilize insoluble into soluble form, together with acid generation, chelation, acidolysis, complexolysis, and exchange processes (Etesami et al, 2017; Sindhu et al., 2016; Ahmad et al., 2016). A recent investigation discovered that elevation of potassium availability raised K uptake in tea plants in mica waste-treated soil employing the *Bacillus pseudomycoides,* potassium-solubilizing strain (Pramanik et al., 2019). Likewise, another strain *Bacillus cereus* encourage plant height, shoot dry weight, and branch number by 15 %, 26 %, and 27 %, respectively as compared to control (Ali et al., 2021). Few fungi such as, *Aspergillus niger* and *Penicillium niger*, may solubilize and mobilize K including from organic and inorganic sources (Xiafang & Weiyi, 2002). Consequently, K solubilizers has a vital role to ascertain those agricultural plants can receive a regular supply of K. These have a favorable effect on the accessibility of other essential nutrients in the soil and hence play a crucial role in soil sustainability (Bahadur et al., 2016).

Sulfur Oxidizing Biofertilizers

Sulfur (S) is required as a micronutrient by plants as well. Sulfur has been demonstrated to help in the enhancement of biological and physical qualities of soil. The potential of sulfur to buffer soil pH is well-known. Sulfur also improves the efficacy of nitrogen and phosphate fertilizers, as well as the ability of plants to absorb micronutrients, according to previous research (El-Halfawi et al., 2010). Most agricultural soils contain some microorganisms that can oxidize Sulphur. However, the most important microorganisms belong to a group of bacteria of *Thiobacillus* genus named as Sulfur oxidizing bacteria (SoxB). *Thiobacillus* sp. is an example of a sulfur-oxidizing bacterium; *Thiobacillus thioparous* and *Thiobacillus thioxidans* may oxidize sulfur to plant-usable sulfates, which aid in plant nutrition (Riaz et al., 2020; Vidyalakshmi et al., 2009). Inoculating *Thiobacillus* with elemental sulfur improves elemental sulfur oxidation, resulting in increased nutrient availability in soil and, as a result, increased plant development, according to a recent study (Pourbabaee et al., 2020). Sulfur compounds are exceptionally polluting environment when they present in reduced forms. Sulfur oxidizing bacteria by naturally eliminating sulfur pollution provide environment protection (Pokorna & Zabranska, 2015).

Zinc Solubilizing Biofertilizers

Zinc is an essential element that plants require in their tissues in relatively small concentrations (5 mg/kg – 100 mg/kg) for growth and reproduction. Zinc deficiency is common in soil, and it's caused by improper fertilizer application, intensive agriculture, and poor soil health. Zinc insufficiency is anticipated to rise from 42 % to 63 % by 2025 if the underlying issues are neglected. Zinc is necessary for growth hormone synthesis. Zinc deficiency in plants causes stunted shoot growth, compromised membrane integrity, smaller leaves, chlorosis, and increased vulnerability to light, heat, and fungal infections, as well as affecting grain yield, root development, pollen formation, and water intake and transport (Kamran et al., 2017; Tavallali et al., 2010). Zinc deficiency in wheat can cause yellowing of the leaves and limited growth. Zinc insufficiency in humans can be caused by eating zinc-deficient wheat (Kamran et al., 2017). Zinc insufficiency is the sixth biggest cause of death in less developed countries. As a result, among other minor nutrients, addressing the Zn deficiency in agriculture is given top priority (Graham, 2008; Kumar et al., 2019; Hussain et al., 2018).

Microbial inoculants have been found to solubilize the complex form of zinc in soil. (Naz et al., 2016). variety of rhizobacteria taxa, such as *Pseudomonas* sp. and *Bacillus* sp., and both *Mycorrhiza*, Saccharomyces sp. have been reported to increase Zn availability in soil. Inc solubilization of zinc take place when these microorganisms utilize chelated ligands and oxidoreductive systems. (Kamran et al., 2017). These bacteria manufacture antibiotics, phytochromes, antifungal chemicals and vitamins, which assist the plant collectively (Goteti et al., 2013). Inoculation of rice plant with a appropriate combination of Zn solubilizing bacterial strains (*Burkholderia* sp. and *Acinetobacter* sp.) advance growth characteristics and rice yield and were shown to be more efficient in obtaining Zn from the soil than non-inoculated plants, according to a study (Vaid et al., 2014). Maize productivity has been observed to be boosted by biofertilizers containing Zn solubilizing bacteria (Hussain et al., 2020).

Plant Growth Promoting Rhizobacteria

Plant growth-promoting rhizobacteria (PGPR) are bacteria that invade plant roots and stimulate plant growth (Beneduzi et al., 2012). They perform their role as fertilizers by fostering plant growth and development, enabling for biotic and abiotic stress resilient, and facilitating soil mineralization through the breakdown of organic matter. The plant benefits from PGPR inoculation in a variety of ways. They improve plant tolerance to drought (Timmusk et al., 2014; Vurukonda et al., 2016; Niu et al., 2018; Ilya et al., 2020), salinity (Mayak et al., 2004; Bharti et al., 2013), and biotic stress (Timmusk et al., 2014; Vurukonda et al., 2016; de Vasconcellos & Cardoso, 2009; Verma et al., 2016). They improve seed germination (Almaghrabi et al., 2014) and soil fertility (Islam et al., 2016; Jang et al., 2017) as well as increase growth by releasing phytohormones such as auxins, Indol acetic acid, ethylene, gibberellin, and others (Kumar *et al*., 2016; Barnawal et al., 2017; Tahir et al., 2017). Plant secondary metabolites, as well as heavy metal and pollution bioremediation, are all affected by them (Sayyed et al., 2015; Ordookhani et al., 2011).

The two most common types of PGPR are extracellular plant growth-promoting rhizobacteria (ePGPR) and intracellular plant growth-promoting rhizobacteria (iPGPR). ePGPR are present either in the rhizosphere (on the rhizoplane) or in between the cells of the root cortex, while iPGPR are established essentially inside the peculiar nodular structures of root cells. The bacterial genera included as ePGPR are *Azotobacter*, *Serratia*, *Azospirillum*, *Bacillus*, *Caulobacte*, *Chromobacterium*, *Agrobacterium*, *Erwinia*, *Flavobacterium*, *Arthrobacter*, *Micrococcous*, *Pseudomonas* and *Burkholderia*.

Endophytic microorganisms such as *Allorhizobium*, *Bradyrhizobium*, *Mesorhizobium*, and *Rhizobium*, including *Frankia* species, can fix atmospheric nitrogen especially for higher plants (Bhattacharyya & Jha, 2012).

Plant roots and soil microorganism interaction

Plant-associated microorganisms exchange carbon from plants for minerals accumulated in the soil. Mycorrhiza- assisted plant uptake include availability of low diffusion rate nutrient like phosphorus (P) and zinc (Zn), sulfur (S) to plant assisted by bacteria and mycorrhizal fungus, and transfer of atmospheric nitrogen N_2 pool to soil and then to plant (Smith & Smith, 2012; Gahan & Schmalenberger, 2014). Not only increment of limiting nutrient like Nitrogen and phosphorus assisting plant growth, enzymes and hormone engender root development, enhance nutrient use efficiency. The mechanisms involved in the improvement of plant nutrient absorption by several biostimulants were reviewed by Halpern *et al.* (2015). Biostimulants are compounds or materials that, when applied to seeds or plants, can influence physiological processes in plants, potentially improving growth, development, or stress response, however nutrients and herbicides are excluded. This group comprise plant growth promoting rhizobacteria (PGPR), which aid in atmospheric N_2 fixation, P and iron solubilization, and root morphological changes. Plant disease incidence has also been shown to be reduced by microbes acting as root pathogen antagonists or generating systemic resistance in plants (Choudhary et al., 2011). When pathogens or insects attack, plants can recruit defensive microorganisms and increase microbial activity to avoid diseases in the rhizosphere. Yang et al. (2009) found that PGPR can generate “induced systemic tolerance” to abiotic stresses such as salinity and drought, as well as providing protection for plant health. Other mechanisms may be implicated in the PGPR–plant interactions, although they have yet to be discovered. Palacios et al. (2014) recently raised the possibility of vitamins playing a role in plant-PGPR interactions, which would require further investigation. According to Amin and Hamidreaza (2015), various N and P biofertilizers had substantial effects on maize yield and yield components. The capacity of biofertilizers to increase phosphorus and other nutrient availability may be beneficial, especially when the soil is calcareous, which lowers nutrient availability.

The Grouping of Biofertilizers based on their functions is given in Table 1.

Role of biofertilizers in crop production

An ecofriendly way to replace chemical fertilizers

Through nitrogen fixation, phosphate, and potassium solubilization or mineralization, the release of plant growth regulating substances, the production of antibiotics, and the biodegradation of organic matter in the soil, biofertilizers keep the soil environment rich in all kinds of micro- and macronutrients (Bhardwaj et al., 2014). By incorporating artificially multiplied cultures of beneficial microorganisms in the form of biofertilizers, the lost biological activity in the soil due to excessive use of chemical fertilizers can be slowly restored. Biofertilizers minimize the ecological disturbance. The use of biofertilizers replace the application of chemical fertilizers; chemical fertilizers are hazardous to environment. Biofertilizers are getting popular as a viable alternative to hazardous chemical fertilizers in the pursuit of sustainable agriculture (Nosheen et al., 2021). Microbes in biofertilizers deliver atmospheric nitrogen to plants directly. The importance of nitrogen-fixing bacteria in soil nitrogen fixation is demonstrated by their contribution to the nitrogen cycle. NO_2 emissions are increased when nitrogen fertilizer is used. Biofertilizer can lessen global warming as a result of this (Naher et al., 2015).

Enhancement on plant tolerance to environmental stress

The utilization of biofertilizers has shown to exhibit the improve tolerance capacity of plant to environmental problems. Abiotic and biotic variables are the most significant constraints on agricultural productivity. Many modern scientific methodologies for crop development

Table 1. Categorization of biofertilizers according on their functions

Groups	Examples
N2-fixing biofertilizers	
Free-living	*Clostridium, Klebsiella, Anabaena*, *Azotobacter, Beijerinkia,* and *Nostoc*
Symbiotic	*Frankia*, *Rhizobium*and *Anabaena azollae*
Associate symbiotic	*Azospirillum*
P-solubilizing biofertilizers	
Bacteria	*Bacillus subtilis, Bacillus circulans*, and *Pseudomonas striata Bacillus megaterium* var. *phosphaticum,*
Fungi	*Penicillium* sp. and *Aspergillus awamori*
P-mobilizing biofertilizers	
Arbuscular mycorrhiza	*Acaulospora* sp., *Scutellospora* sp., and *Sclerocystis* sp.*Glomus* sp., *Gigaspora* sp.,
Ectomycorrhiza	*Pisolithus* sp., *Laccaria* sp., and *Boletus* sp.
Ericoid mycorrhizae	*Pezizellaericae*
Orchid mycorrhiza	*Rhizoctonia solani*
Biofertilizers for micronutrients	
Silicate and zinc solubilizers	*Bacillus* sp.
Plant-growth-promoting rhizobacteria	
Pseudomonas	*Pseudomonas fluroscence*

Source: Umesha et al., 2018; Singh et al., 2014a; Singh et al., 2014b.

under stress have been widely used, with the role of PGPRs as a bio-protectant becoming increasingly essential. Biofertilizers also helps plants to withstand salinity and drought stress, for example *Pseudomonas aeruginosa* has been shown to be able to resist both biotic and abiotic stress and Pseudomonas *putida* RS-198 enhance germination rate and different growth parameters such as plant height, dry weight, and fresh weight of cotton under alkaline and high salt conditions by accelerating the rate of uptake of K^+, Mg^{2+}, and Ca^{2+} while declining the rate of absorption of Na^+. Moreover, some strains of Pseudomonas used 2, 4-diacetylphloroglucinol to cause plant to resist high temperatures, while salinity stress tolerance are assigned by *Mycobacterium phlei*. Ansari et al. (2013) found that inoculating plants with Arbuscular mycorrhiza fungus promotes plant development under salt stress as well. Ansari *et al.* (2013) also note that the root endophytic fungus *Piriformospora indica* was discovered to protect the host plant from salt stress. A combination of the AM fungus and nitrogen-fixing bacteria benefits drought-resistant legume plants. During water scarcity, *Pseudomonas* sp. increases antioxidant and photosynthetic pigment content of basal plants. Rice plants that were subjected to drought was looked for increased photosynthetic efficiency and anti-oxidative response after inoculation with *arbuscular mycorrhiza* in both drought and saline environments to observe the beneficial effects of mycorrhizae Ruiz-Sanchez *et al.* (2010).

PGPRs have been demonstrated to be a viable biological alternative to chemical agents for conferring disease resistance in a variety of disorders. In addition to functioning as growth promoters, they can offer disease resistance. *Bacillus subtilis* GBO can activate defense mechanisms. *Bacillus subtillis*N11 along with mature compost was observed to control *Fusarium* infestation on banana roots. Also, in general PGPRs have been highly effective to be control useful spotted wilt viruses in cucumber mosaic, tomatoes and pepper virus, and banana bunchy top virus. Mycorrhizae have been proven to provide resistance to fungal infections as well as inhibit the growth of various root diseases such as *R. solani* and *Pythium* sp. in rare cases.

Enhancement on soil fertility

The amount of nutrient fixed in soil by biofertilizers in crops is given in Table 2. The combination of N fertilizer and *A. brasilense* increased grain yield by up to 29 percent when compared to N fertilization alone. Observation made on *Rhizobium* strain give an idea about complexities about plant-microbe interaction and plant development and grain yield that are affected due to many elements. These studies show that mixing rhizobia secondary metabolites with biofertilizers can help grain crops grow and produce more. Inoculating maize plants with a P-solubilizing *Pseudomonas fluorescens* strain, help it to grew faster and had much greater (AMF) infection rates than non-inoculated control plants as maintained by Krey et al. (2013).

Two P-solubilizing bacterial strains that have an essential role in plant growth promotion and soil fertility improvement in various agroclimatic areas was found out by Kaur and Reddy (2014). Owen et al. (2015) examined the terminology, composition, and roles of P solubilizers, as well as the many variables that influence their efficacy in increasing P availability in various soil and plant settings. AMF has long been thought to be advantageous to plant P nutrition. Smith and Smith (2012) emphasized their ability to efficiently absorb P from the soil and make it available to the plant they are linked with. Soil characteristics and environmental conditions such as temperature and soil moisture, as well as the availability of other nutrients like nitrogen, will impact the outcome of this beneficial interaction (Johnson *et al*., 2015). Beneficial dual inoculation (AMF and rhizobia, for example) has been successfully tested in the field to boost woody legume growth (Lesueur et al., 2001; Lesueur & Duponnois, 2005). Despite this, due to production constraints and a lack of applied research, commercial biofertilizers of this sort are rarely available on international markets.

Improvement on nitrogen and phosphorus use efficiency

The efficacy of Arbuscular mycorrhizal fungi (AMF), P solubilizers, and N fixatives was boosted when there were higher amounts of P in the soil. With decreased organic matter concentration and a neutral pH, meta-regression revealed that successful AMF inoculation was more likely.Our comprehensive study serves as the foundation and guidelines for properly selecting and applying biofertilizers. Nitrogen and phosphorus are the most important elements, but they are also the most restrictive minerals for living things. Most agricultural soils include plenty of organic and inorganic P, but most of it is unavailable to plants. As phosphorus is easily immobilized, less soluble, and less accessible to plants, plants may not have enough phosphorus even after applying phosphorus fertilizer to the soil. The world's principal source of phosphorus is phosphate ore, a nonrenewable resource, and

Table 2: Amount of nutrients fixed in soil by biofertilizers in crops

Biofertilizers	Nutrient fixed (kg/ha/year)	Crops
Blue Green Algae	25 kg N /ha	Rice, banana
Azolla	900kg N /ha	Rice
Phosphate solubilizing bacteria and fungi	Solubilize about 50-60%of them fixed phosphorus in the soil	All crops
Rhizobium	50 to 300 kg N/ ha	Green-gram, Black-gram, Lentil, Cowpea, Bengal-gram andFodder legumes
Azotobacter	0.026 to 20 kg N/ha	Cotton, Vegetables, Plantation Crop, Rice, Wheat, Barley, Ragi, Mustard, Safflower, Niger, Sunflower, Tobacco, Fruit, Spices, Condiment, Ornamental Flower
Azospirillum	10-20 kg N /ha	Sugarcane, Vegetables, Maize, Pearl millet,Rice, Wheat, Fodders, Oil

(Source: Sahu et al., 2012)

phosphorus mining and trade contribute to global energy consumption that is both environmentally harmful and wasteful. As cheap and high-quality deposits become increasingly scarce, the quality of rock phosphate is rapidly worsening, notably in terms of cadmium pollution

Evidence on the bio-fertilizers application in crop production

Increments in grain yields of crops by biofertilizers is given in Table 3. The use of microbial inoculants to inoculate legumes with rhizobia is the most well-known success story. It has largely revolutionized legume production methods, reducing their need for nitrogen fertilizer for high yields. Alves et al. (2003) and Melchiorre et al. (2011) found that using BNF and legume inoculants containing both rhizobia and active compounds such as lipo-chito oligosaccharides (LCOs), which signal the symbiosis of rhizobia with legumes and the formation of nitrogen-fixing root nodules, grain yields in Brazil, Argentina, and the USA. For decades, free-living diazotrophs have been utilized to promote endophytic and associative nitrogen fixation in cereals and grasses, most notably *Azotobacter*, *Azospirillum*, and more recently *Herbaspirillum, Gluconaceto bacter*, and *Burkholderia*. *Azospirillum* bacteria promote plant growth predominantly through the production of phytohormones, particularly Indole-3-acetic acid (IAA) (Halpern *et al*., 2015). Inoculants employed in the experiments included liquid and peat-based formulations of several *Azospirillum* species and strains applied to both seeds and soil, and soil and plant development stimulation was generally detected only once inoculum potential and proper formulation were considered. Other field tests (Diaz–Zorita & Fernandez–Canigia, 2009) have shown similar rates of improved yield. Ferreira et al. (2013), under two different soil clay and sandy, observed the reaction of maize to *Azospirillum brasilense* inoculation and nutrient (macronutrients and micronutrients) treatments in the Brazilian Cerrado. The reaction was considerable when maize was infected with *Azospirillum brasilense,* but it differed depending on the soil type. The combination of N fertilizer and *A. brasilense* increased grain yield by up to 29 % when compared to N fertilization alone. All these observations on *Azospirillum* strains inoculation in the field demonstrate the complexities of plant-microbe interactions in the field, as well as the many elements that influence plant development and grain yield. Marks et al. (2013) effectively used rhizobial signaling molecules to inoculate soybean and maize fields with *Bradyrhizobium* sp. and *Azospirillum brasilense*, respectively. These studies show that mixing rhizobia secondary metabolites with biofertilizers can help grain crops grow and produce more. According to Saikia et al. (2010), *Azospirillum* research should focus on a deeper fundamental knowledge of the system's encompassing essential components other than broad field studies to fully exploit the potential. Bacterial biofertilizers may greatly rise the yield of various crops by improving P uptake is indisputable (Hinsinger et al., 2009). However, field results are frequently uneven, despite some recent favorable field inoculation research. For example, maize response with increased growth rate and greater Arbuscular mycorrhizal fungi (AMF) infection rates than non-inoculated control plants when it was inoculated with a P-solubilizing *Pseudomonas fluorescens* strain (Krey et al., 2013). In distinct agroclimatic areas, Kaur and Reddy (2014) identified two P-solubilizing bacterial strains that fulfil a vital role in plant growth increasement and soil fertility amelioration. Owen et al. (2015) looked examined the terminology, composition, and roles of P solubilizers, as well as the many variables that influence their efficacy in increasing P availability in various soil and plant environments. These researchers concluded that weak quality control standards and a lack of understanding of the underlying principles confuse the efficiency of commercial biofertilizers, resulting in inconsistent field performance results. AMF has long been thought to be advantageous to plant Phosphorous nutrition. Smith and Smith (2012) illuminated their capaability to adequately absorb P from the soil and make it accessible to the plant. The outcome of this beneficial interaction between AMF and plant root is impacted by Soil properties, environmental conditions such as temperature and soil moisture and as well as the availability of other nutrients such as nitrogen, (Johnson et al., 2015). Beneficial dual inoculation (AMF and rhizobia, for example) has been successfully tested in the field to increase woody legume growth (Lesueur et al., 2001; Lesueur & Duponnois, 2005; Mortimer et al., 2013). Despite this, due to production constraints and a lack of applied research, commercial biofertilizers of this sort are rarely available on foreign markets.

Challenges in the use of biofertilizers

The main constraints of biofertilizers are the poor availability of carriers; it affected the shelf life. One of the major limitations of biofertilizers is mutation during fermentation (Singh et al., 2016). The main challenges with the usage and development of bio-fertilizers include reliability, inappropriate formulations, high levels of contamination, low quality, and consistency of these inoculants in field conditions. Biofertilizers that perform well in the lab and greenhouse may not work as well in the field, because it is sensitive to biotic and abiotic stress. Crops are grown under a wide range of conditions, including temperature, rainfall, soil type, biodiversity, and crop variety. As a result of these differences, biofertilizer efficacy is inconsistent. Furthermore, because the inoculum must build up its concentration and colonize the root, biofertilizers take longer to act than synthetic fertilizers (Roy, 2021). To prevent these difficulties, suitable isolates should be chosen based on their performance in the field, with a variety of crops, and in a variety of soil types and environmental circumstances (Basu et al., 2021). Biofertilizers should also not be used in place of other fertilizers; rather, they should be used in conjunction with them to reduce the amount of fertilizer used (Roy, 2021). The shelf life of a biofertilizer is another important consideration throughout its development and commercialization. Live microbial cells in biofertilizers have a short shelf life (about 6 months at 20 °C - 25 °C), which demands extra care and attention during storage and transportation, raising the product›s cost (Mitter *et al.*, 2021). Product registration and patent application are examples of constraints. Lack of a clear legal and regulatory definition for "plant biofertilizer" or "plant biostimulant." is the reason behind the absence of worldwide coordinated and harmonious strategy. In maximum places of the world, the process of registering biofertilizers

Table 3: Increments in grain yields of crops by biofertilizers

Bio-fertilizers	Crops	Increment in grain yield (%)	References
Azotobacter	Cabbage	24.3	Verma et al. (1991)
	Garlic	14.8	Wange (1995)
	Onion	18	Joi and Shinde (1976)
Azospirillum	Cabbage	7	Jeevajyothi *et al*. (1993)
	Chilli	26.7	Paramaguru and Natrajan (1993)
	Knolkhol	14.9	Chatto *et al*. (1997)
	Onion	9.6	Thiiakavathy and Ramaswamy (1999)
	Okra	9	Subhiah (1991)
	Radish	9	Sundaravelu and Mutukrishna (1993)
	Sweet potato	8.5	Desmond and Walter (1990)
Rhizobium	chickpea	27.9	Gupta and Namdeo (1996)
	Cowpea	4.09	Mishra and Solanki (1996)
	Pea	13.38	Kanaujia et al. (1999)
PSM	Onion	9.6	Thiiakavathy and Ramaswamy (1999)
	Potato	30.50	Guar (1985)
	Pumpkin	51.0	Karuthamani *et al*. (1995)

(Source: Kashyap et al., 2017).

is confusing or troublesome, also lengthy, and complex (Basu et al., 2021).

Conclusion

Biofertilizer is a product that constitute microorganisms which colonize the rhizosphere and encourage development by increasing the availability of nutrients to the host plant. Bacteria, fungi, and blue green algae are commonly utilized as biofertilizers. These organisms are available in the plant's rhizosphere to increase their activity in the soil. They aid plants indirectly by boosting nitrogen fixation and nutrient availability in the soil. Crop production must expand into new frontiers while not depleting natural resources or degrading environmental quality. In conclusion by minimizing the usage of chemical fertilizers and enhancing plant nutrient use efficiency, biofertilizers are playing an increasingly important role in improving agricultural production in environment friendly manner. To support the development of organic agriculture, sustainable agriculture, green agriculture, and pollution-free agriculture, biologically based products are the most essential and they are the most advanced biotechnology. Biofertilizers restore the soil›s natural fertility and protect it from drought and soil diseases, and thereby stimulating plant growth.

Conflicts of interest

The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript.

Author contributions

Elaboration and execution, Development of methodology, Conception and design; Editing of articles and supervision of the study have involved all authors.

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