Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 57 Issue: 06:2024
DOI: 10.5281/zenodo.11665961

ROLE OF BIOFERTILIZERS IN PLANT GROWTH PROMOTING, NUTRIENT SOLUBILIZATION AND SALINITY TOLERANCE: A REVIEW

HALIMAH O. AL KHALLAF *
Department of Biological Sciences, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia.
Department of Biological Sciences, Faculty of Science, University of Jeddah, Jeddah, Saudi Arabia.
*Corresponding Author Email: hoalkhallaf@gmail.com, ORCID ID: https://orcid.org/0009-0000-5413-2664

HAMEED A. ALSAMADANY
Department of Biological Sciences, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia.

HASSAN M. RASHAD
Department of Biological Sciences, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia.

Abstract

Biofertilizers (BF) are an eco-friendly additive that decreases reliance on chemical fertilisers, alleviates their adverse impacts, and aids in reducing expenses and agricultural requirements. They are bioactive microbe formulations that enhance plant growth and development by enhancing nutrient uptake. In addition, they enhance soil productivity through the process of nitrogen fixation, wherein they convert atmospheric nitrogen into a form that can be utilized by plants. They also facilitate the dissolution of phosphorus in the soil and enhance the accessibility of potassium, so increasing its availability to plants. This application shows great potential in the realm of sustainable crop production. The purpose of this review is to provide a clear understanding of the key issues concerning biofertilizers, including their many types, uses, and the benefits they offer when applied. Additionally, it will discuss the primary methods of administering biofertilizers to plants and their function in enhancing plant resistance to salinity stress.

Keywords: Biofertilizers, PGPR, Nitrogen Fixation, Nutrient Solubilization, Salinity Stress.

INTRODUCTION

Biofertilizers

The anticipated doubling in food demand due to population growth necessitates increased irrigation to enhance agricultural yields and ensure stability. This approach, however, may exacerbate environmental challenges like soil salinization, particularly in arid areas, thereby hindering agricultural output (1,2). Additionally, reliance on chemical fertilizers and pesticides in traditional farming methods presents risks such as eutrophication(3,4). Consequently, the pursuit of environmentally sustainable practices becomes essential to counter these detrimental effects. There is a growing shift towards the sustainable cultivation of nutrient-dense foods to promote biosafety (5). In this context, biofertilizers serve as organic alternatives that enhance soil biodiversity, bolster nutrient availability, and facilitate sustainable agricultural practices without adverse environmental consequences (6–10). Moreover, the ability of plants to withstand abiotic stresses, such as salt, is improved. Therefore, the utilization of advantageous microorganisms as biofertilizers is essential, considering their substantial contribution to enhancing food safety and fostering sustainable agriculture. An essential eco-friendly approach in agriculture entails utilizing biofertilizers that employ plant growth-promoting rhizobacteria

(PGPR). PGPR refers to a diverse range of microorganisms found in the rhizosphere that promote plant growth through one or more unique pathways (11). In addition, both endo- and ectomycorrhizal fungi, as well as cyanobacteria and other beneficial microbes, play a crucial role. The combined presence of these organisms leads to better absorption of nutrients, improved growth of plants, and higher ability to withstand both living and non-living challenges (5).

Biofertilizers (BF) are comprised of living microbes such as bacteria, fungi, and algae, either alone or in combinations, as highlighted by (12). These formulations enhance nutrient availability to plants, offering a greener and more cost-effective alternative to synthetic fertilizers, thus promoting sustainable farming practices and improving soil health (13). Essentially, BF contain microorganisms that transform nutrients from non-bioavailable to bioavailable forms via natural processes, potentially reducing or eliminating the need for chemical fertilizers (12,14). (15) and (16) elucidate on biofertilizers as microbial concoctions that harbor plant growth-promoting rhizobacteria (PGPR), which bolster plant growth through mechanisms like nitrogen fixation, nutrient solubilization, hormone production, and siderophore production. Additionally, (15) describe these agents as consisting of viable microorganisms, which, upon application to soil, seeds, or plant surfaces, colonize the rhizosphere or the plant interiors, thereby enhancing growth by boosting the availability of primary nutrients.

(17) Characterize biofertilizers as blends or formulations comprised of live or dormant microbes, tailored for prolonged preservation, straightforward management, and effective transportation of beneficial microorganisms from labs to agricultural fields. These biofertilizers are globally acknowledged as potent microbial agents that foster plant development by enhancing nutrient assimilation within the plant's rhizosphere. Commonly, they are identified by various terms such as bioformulations, microbial inoculants, microbial cultures, bioinoculants, and bacterial fertilizers or inoculants. It is essential to recognize that the act of administering biofertilizers to plants is termed inoculation (18,19). Furthermore, the utilization of biofertilizers is projected to alleviate salt stress, thereby reducing its detrimental impact on plant growth (20,21).

Types of biofertilizers depending on the source of the formulation

Biofertilizers are pivotal to the promotion of sustainable agriculture, enhancing soil fertility, boosting plant growth, and reducing dependence on synthetic fertilizers. They can be broadly categorized into three types (Table 1) based on their source of composition: bacterial, fungal, and algal biofertilizers.

Bacterial biofertilizers comprise nitrogen-fixing bacteria (NFB) like *Rhizobium*, *Azotobacter*, and *Azospirillum*, which facilitate the conversion of atmospheric nitrogen into a usable form for plants. Additionally, phosphate-solubilizing bacteria (PSB) such as *Bacillus* and *Pseudomonas* convert insoluble phosphate into forms accessible to plants. These bacteria play a vital role in increasing nutrient availability to crops and do so without the negative environmental effects often associated with chemical fertilizers (22). **Fungal biofertilizers** include mycorrhizal fungi, which form symbiotic associations with plant roots to boost water and nutrient absorption. Trichoderma, another significant fungal biofertilizer, is recognized for enhancing plant growth and controlling soil-borne diseases. **Algal biofertilizers** comprise macro algae, like seaweed extracts, which are abundant in growth-stimulating hormones, vitamins, and minerals. Additionally**,** microalgae such as chlorella and spirulina are utilized for their rich concentrations of essential nutrients, including potassium, phosphorus, and nitrogen (23). A thorough understanding of the various biofertilizers and their sources is crucial for leveraging their potential to sustainably improve crop yields and soil health. This knowledge aids in making informed decisions in agricultural practices, contributing to environmental preservation and increased agricultural productivity.

Types of biofertilizers depending on their function

BF include many microorganisms and vary according to their intended use. BF can be classified according to the nature of their behavior and effect or their functions the plant:

The role of BF in nitrogen fixation: PGPR are integral components of the plant microbiome, performing a variety of beneficial functions within the plant rhizosphere, such as nitrogen (N_2) fixation (24,25). This biological transformation involves the conversion of atmospheric nitrogen into ammonia, a reaction facilitated by the bacterial enzyme nitrogenase. The following equation illustrates the process of biological nitrogen fixation (BNF):

$$N_2 + 8H^+ + 8e- + 16\ ATP \xrightarrow{\text{Nitrogenase}} 2NH_3 + H_2 + 16ADP + 16\ Pi$$

While the primary product of this reaction is ammonia (NH_3), it rapidly converts to ammonium (NH_4^+), with the predominant forms available to plants being NH_4^+ and NO_3^- (26). This transformation occurs alongside the hydrolysis of 16 ATP molecules and results in the production of hydrogen gas. Biological nitrogen fixers enzymatically convert the ammonia produced by nitrogenase into glutamate using glutamine synthetase. It is important to note that the enzymes activating nitrogenase are highly susceptible to oxygen damage. Consequently, many bacteria cease enzyme production in aerobic environments (27). Numerous nitrogen-fixing organisms thrive solely under anaerobic conditions, employ respiration to decrease oxygen concentrations, or associate with proteins like leghemoglobin, which carries oxygen. This protein bears a resemblance to blood hemoglobin and plays a crucial role in sustaining the low oxygen levels essential for effective nitrogen fixation. Leghemoglobin's primary functions include facilitating oxygen supply to nitrogen-fixing bacteria and shielding nitrogenase from oxygen-induced deactivation (28). Annually, approximately 50-465 kilograms of nitrogen per hectare are fixed through these interactions. Recent data indicate that over 90% of the global soil nitrogen is restored via biological fixation processes. In contrast, a minor portion, between 0.5% and 5%, is fixed using the Haber-Bosch Method (HBM), which synthesizes ammonia by combining atmospheric nitrogen with hydrogen derived from natural gases, under elevated pressure and temperature, in the presence of ferric oxide.

Nitrogen fixation by microbes occurs in two ways: (1) symbiotic fixation and (2) non-symbiotic fixation**: (1) symbiotic fixation**: occurs by bacteria that carry out BNF and increase the N supply to crops in the soil, they are an important component of nitrogen-fixing biofertilizers. In addition to some fungi that contribute to this type of fixation. Mycorrhiza means (fungal roots); in which the mycorrhizal fungi form a symbiotic relationship with the roots of the plant (facilitating the supply of phosphorus to the plant , as the presence of phosphorus is transferred) (29). There are two main types of them: (a) - Ectomycorrhiza: in this type, the fungus does not penetrate the cell wall of the plant roots. Type (b) - Endomycorrhiza: They penetrate the cell walls of the plant root cells. We can therefore define symbiotic biofertilizers as products of microorganisms that live together with the roots of the plant; and provide the plant with some nutrients while obtaining their nutritional needs especially the carbon source from the plant (mutualism relationship).

The genus Rhizobium, a prominent example of nitrogen-fixing microbes, establishes symbiotic relationships with the roots of legumes like peas, soybeans, and clover. These bacteria adhere to the roots and form nodules that assimilate atmospheric nitrogen and convert it into ammonia, crucial for the plant's growth. Despite being aerobic, Rhizobium effectively engages in nitrogen fixation. Extensive studies demonstrate that legumes inoculated with Rhizobium fix significantly more nitrogen compared to uninoculate ones (30–33). Similarly, the genus Frankia, belonging to the actinomycetes and further categorized into various groups, also engages in a symbiotic relationship with non-leguminous plants. Frankia induces the formation of nitrogen-fixing nodules on the roots of plants such as alders (*Alnus spp*.) and Casuarina trees, exemplifying another type of symbiotic nitrogen-fixing microbe (34).

(2) Non-symbiotic fixation: Independently living microorganisms that fix atmospheric nitrogen are called free-living diazotrophs. These microorganisms can be divided into two categories: First, bacteria and second; cyanobacteria (blue-green algae). **Bacteria** are divided into the following types according to the (carbon, nitrogen, oxygen, and the need for reducing groups): **(a)** Aerobic bacteria: e.g. *Azotobacter*, *Gluconaceotobacter* and *Burkholderia* (35,36) **(b)** Facultative anaerobic bacteria: e.g. *Bacillus*, **(c)** Anaerobic bacteria: e.g. *Clostridium*, **(d)** Photosynthetic bacteria: e.g. *Rhodomicrobium*. **Cyanobacteria**: Both heterocystous and non- heterocystous species of cyanobacteria fix atmospheric nitrogen, for example. *Anabaena*, *Anabaenopsis*, *Nostoc* etc. (37). Heterocysts, also known as heterocytes, are very effective nitrogen-fixing cells produced by some filamentous cyanobacteria, including *Nostoc punctiforme*, *Cylindrospermum stagnale*, and *Anabaena sphaerica*, when nitrogen is deficient (14,38).

The process of BNF, both symbiotic and non-symbiotic, is influenced by several factors, namely: **(1) - Factors** influencing **symbiotic nitrogen fixation** include (a) soil factors such as good aeration, sensitivity to high heat, moisture and salinity and pH ;the process requires a neutral pH. (b) The soils mineral nitrogen content (NH_3^+, NO_3). (c) The availability of certain elements such as Ca, K, Mn and PO_4. (d) biotic factors: e.g., the difference between bacterial strains and a sufficient number of bacteria. In addition, host plant specificity, nodule formation and genetic compatibility: The genetic compatibility between the host plant and the rhizobia strain (39). **(2)- Factors influencing non-symbiotic nitrogen fixation** include (a.) the mineral nitrogen content of the soil. (b.) the availability of certain elements (Ca, Mo, Fe and Co). (c.) the availability of energy sources: e.g., carbohydrate compounds. (d.) pH of soil: non-symbiotic N_2 fixation does not take place in acidic conditions. (e.) Soil moisture: Non-symbiotic N_2 fixation requires sufficient moisture (40).

Research indicates that the development of biofertilizers incorporating nitrogen-fixing bacteria such as Rhizobium and Azotobacter has produced favorable outcomes (41). Commonly available nitrogen biofertilizers in the market include Rhizobium, along with other bacteria like Azotobacter and Azospirillum, and are frequently applied to legumes (41,42). These strains of nitrogen-fixing biofertilizers, including Rhizobium and Azotobacter, are known to enhance plant growth and overall health, and they improve plant resistance to salinity stress.

A. **BF Role in solubilization of nutrients:** The PGPR also play an important role in solubilization of nutrients (43,44).

1. **Phosphorus solubilization (P):** is an essential process that is increasingly influenced by global warming, which accelerates soil salinization and calcification, thus reducing phosphorus availability in arid and semi-arid regions globally (45). In soil, phosphate ions (H_2PO_4, HPO_4, and PO_4) exist in two primary forms: they either adhere to clay particles or form complexes with cations such as calcium phosphate and magnesium phosphate in alkaline soils, or iron phosphate and aluminum phosphate in acidic soils, rendering them inaccessible to plants (46,47). Phosphate-solubilizing bacteria (PSB), like *Pseudomonas* and *Bacillus*, offer a more sustainable alternative to mineral phosphorus fertilizers. These bacteria release compounds including phenolic substances, protons, and both organic and mineral acids, which acidify the soil and liberate phosphorus from $Ca_3(PO_4)_2$ in alkaline environments (48–50). Organic acids further increase phosphorus bioavailability by chelating cations such as Ca^{2+}, Al^{3+}, and Fe^{3+}(51). Additionally, by secreting growth-promoting substances like indole acetic acid (IAA), gibberellins, and cytokinins, phosphate-solubilizing bacteria enhance nitrogen fixation, phosphorus availability, and plant growth(52). Other mechanisms, including the activity of alkaline phosphatases, protonation by H^+ ions, anion exchange, chelation, and siderophore production, also improve soil and plant phosphorus nutrition(53–56). Furthermore, inoculating crops with PSB has been shown to increase crop yields and enhance phosphorus nutrition in cereals such as rice and maize (57–59). PSB enable plants to access and utilize phosphorus effectively, even in salinized soils, ensuring adequate phosphorus for critical biological functions.
2. **Solubilization of sulfur (S):** Mineral sulfur added as a fertilizer to alkaline soils to reduce their alkalinity and increase the level of sulfates SO_4 that plants need. Mineral sulfur is a powder that is insoluble in water, and chemolithotrophs oxidize mineral sulfur in well-aerated soils into sulphuric acid (Fig.1). The most important of these microbes

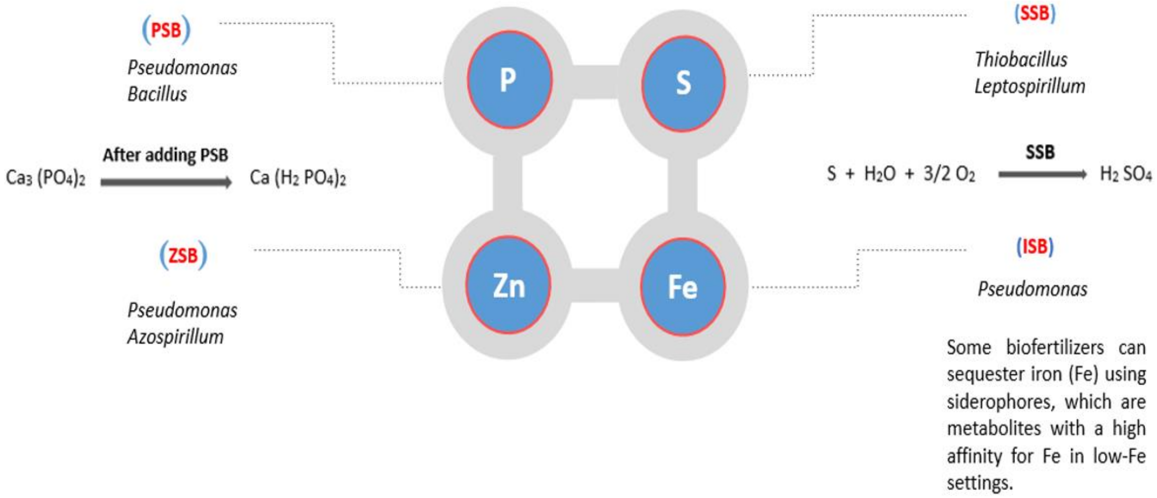
(Sulfur-Solubilizing Bacteria (SSB)) are *Thiobacillus*, *Leptospirillum*, *Sulfobacillus and Acidianus* (37).

3. **Zinc solubilization (Zn)**: is crucial for plant productivity, especially given the widespread zinc deficiency in soils globally. This deficiency is primarily due to nutrient depletion from continuous crop harvesting (60). While chemical zinc fertilizers are commonly applied at about 5 kg per hectare to address this issue, they are costly and often not readily available in forms that plants can absorb (61). Recent research highlights the effectiveness of zinc-solubilizing biofertilizers (ZSB) in enhancing plant development and yield by increasing zinc uptake (62,63). For instance, a study by (64) demonstrated that biofertilizers containing Pseudomonas, Azospirillum, Azotobacter, and Rhizobium significantly boosted zinc absorption in wheat plants. Additionally, a study on soybeans found that 134 bacilli strains from the rhizosphere notably enhanced zinc levels in the plants compared to those that were not inoculated (65). Recent findings also show that various ZSB strains isolated from the rhizospheres of wheat and sugarcane, including *Pantoea dispersa*, *Pseudomonas fragi*, *Pantoea agglomerans*, *Rhizobium* sp., and *Enterobacter cloacae*, have been effective in increasing zinc content and promoting growth in potted wheat plants (62). Moreover, a greenhouse experiment by (66) testing several rhizospheric ZSBs revealed that treated soil and plants exhibited higher zinc concentrations than untreated controls.

4. **Solubilization of iron (Fe):** Iron-solubilizing bacteria (ISB) utilize specific mechanisms to capture iron (Fe) in environments where it is scarce. These biofertilizers produce siderophores, metabolites that bind strongly to iron, facilitating its uptake in iron-deficient settings (67). The Fe^{3+} complexes of microbial siderophores are produced in the microbial membrane, where they are then reduced to Fe^{2+} and released into the cell via an input process. Plants have access to the Fe^{2+} of bacterial siderophores and take it up directly the Fe-siderophore complexes or through ligand exchange during this process (68). An example of how rhizobacterial inoculants in BF can improve Fe nutrition is the development of siderophores (69). Siderophilic bacteria have been shown to play an important role in both preventing disease and promoting plant growth.

B. **BF Role in facilitating or extracting potassium (K) from clay minerals**: Plants require potassium in significant amounts as it is a vital element for their nutrition. A significant portion of the potassium is tightly bound to the mineral component of the soil, making it unavailable for exchange. Recent research has revealed the presence of certain microorganisms, including *Pseudomonas*, *Bacillus*, *Penicillium*, and *Aspergillus*. It has the ability to analyse the presence of aluminium silicate in clay minerals, with potassium being a distinguishing characteristic of these minerals. *Bacillus circulans* has the ability to extract silicon and potassium from silicate clay minerals like biotite and orthoclase. These microbes thrive in specific culture media, where they are cultivated, harvested, and then introduced into the soil. Research has indicated that certain bacteria have the ability to break down minerals containing potassium and transform it into a soluble form that plants can absorb. *Acidothiobacillus ferrooxidans, Paenibacillus* spp.*, Bacillus licheniformis, Burkholderia cenocepacia,* *Klebsiella variicola*, *Enterobacter cloacae,* and *Bacillus cereus* have the ability to dissolve K minerals like biotite, feldspar, illite, muscovite, and orthoclase through the release of organic acids (70).

C. **BF Role in improving phytochemical composition and disease resistance**: PGPR are essential for producing key substances that promote plant development(71). These bacteria also bolster plant defenses against various pathogens (72–74). Notable among these are *Azotobacter*, *Azospirillum*, *Mycorrhiza*, and other Phosphate-Solubilizing Bacteria (PSB). A symbiotic relationship exists between legumes and Rhizobium bacteria, which leads to the synthesis and emission of several phytohormones such as IAA, cytokinins, lumichrome, rhizobitoxine, gibberellins, jasmonate, ethylene, brassinosteroids, and growth-promoting enzymes (75,76). Indoleacetic acid, for instance, encourages the growth of longer roots and a greater number of root hairs (77). Research has shown that bacteria including *Rhizobium*, *Glomus* spp., *Azotobacter* spp., *Azospirillum* spp., and *Pseudomonas* are instrumental in reducing plant diseases (78,79). The use of biofertilizers has been linked to improved plant growth in environments with certain agricultural pests and pathogens, highlighting their capacity to foster stress resistance by triggering induced systemic resistance (ISR) (80). ISR involves a plant’s enhanced defensive capabilities when exposed to pests and pathogens, activating multiple physical and chemical defenses. Studies confirm that the presence of beneficial microbes in the rhizosphere can activate and enhance the plant's innate defense systems (81–83). Additionally, biofertilizers are pivotal in alleviating salinity stress by producing compounds that support root growth, improve nutrient uptake, and overall bolster plant resilience to saline environments.



Some biofertilizers can sequester iron (Fe) using siderophores, which are metabolites with a high affinity for Fe in low-Fe settings.

Figure 1: Microorganisms used as biofertilizers aid in the solubilization of certain macro and micronutrients. Bacteria that solubilize phosphorus, sulphur, zinc, and iron are referred to as PSB, SSB, ZSB, and ISB, respectively.

Table 1: Some types of BF according to their source (produced from bacteria, fungi or algae) and their role in promoting plant growth

Types of BF	Inoculants used	Treated Plant	BF Roles	Ref.
Bacteria	*Pseudomonas Azotobacter Azospirillum*	*Helianthus annus*	To improve growth	(84)
Bacteria	*Bacillus sp Pseudomonas sp Azospirillum* spp	*Triticum aestivum*	N-fixing & P-solubilizing	(85)
Algae	*Laurencia obtusa*, *Corallina elongata* and *Jania rubens*	*Zea mays* L.	To increase in P and N content, and enhancement of plant growth	(86)
Bacteria	*Pseudomonas*, *Azospirillum Azotobacter* & *Bacillus*	*Capsicum annuum*	To improve growth & yield	(87)
Bacteria	*Azospirillum*	*Lactuca sativa*	Tolerance salinity stress	(88)
Algae	Seaweed *Ascophyllum nodosum*	*Solanum melongena*	Salinity tolerance and Increased K content	(89)
Bacteria	*Pseudomonas* spp. LYT-1	*Triticum aestivum*	To improve the productivity	(90)
Bacteria	*Azospirillum*	*Triticum aestivum*	Biocontrol and Tolerance salinity stress	(91)
Bacteria	*Rhizobium*, *Azospirillum* & *Pseudomonas*	*Triticum aestivum*	Zn-solubilizing	(64)
Fungi	*Trichoderma sp* & consortia of BF	*Oryza sativa*	To increase productivity , diseases resistance & soil fertility	(15)
Algae	(green algae) *Ulva compressa* and Enteromorpha intestinalis (brown algae) *Sargassum muticum and Cystoseira amentacea*	*Vigna unguiculata L.*	To improve growth and Tolerance salinity stress	(92)
Bacteria	*Sinorhizobium meliloti, Bacillus flexus* & *Bacillus megaterium*	*Zea mays* L.	P-solubilizing	(43)
Bacteria	*Pseudomonas fragi, Pantoea dispersa, Pantoea agglomerans*, *Enterobacter cloacae* & *Rhizobium sp*.	*Triticum aestivum*	Zn-solubilizing	(62)
Bacteria	*Mesorhizobium sp., Paenibacillus sp. & Arthrobacter sp.*	*Lolium perenne*	K- solubilizing (extracting)	(56)
Bacteria	*Azospirillum lipoferum* & *Azotobacter chroococcum*	*Dodonaea viscosa* L.	Tolerance salinity stress	(19)
Bacteria	PGPR	*Triticum aestivum*	Tolerance salinity stress	(93)
Bacteria	*Bacillus cereus*	*Oryza sativa*	Zn-solubilizing	(63)
Bacteria	*Serratia plymuthica*	*Vicia faba* L.	P-solubilizing	(44)
Bacteria	Bioform “*Azotobacter, Azospirillum and Pseudomonas”* and	*Triticum aestivum*	To improve growth and biotic stress resistance	(80)

	Probio96 (*Bacillus subtilis* UTB96)			
Bacteria	*Bacillus cereus*	*Solanum tuberosum*	K- solubilizing (extracting)	(70)
Fungi	*Aspergillus niger*	*Lolium multiflorum*	S-solubilizing	(94)
Fungi	Arbuscular Mycorrhizal *Glomus intraradices*	*Colocasia esculenta* L.	Increase productivity and mitigation salinity stress	(95)
Bacteria	*Enterobacter AS19*	Pepper, Maize & *Gynura divaricata*	Fe-solubilizing Promote the germination and growth	(67)
Bacteria	*Bacillus mojavensis* I4	*Triticum aestivum*	Tolerance salinity stress	(96)

Importance and possible applications

BF are of great importance and are therefore: **Firstly**, one way to lessen the financial and ecological burden of farming is to use less chemical fertilisers, as most of the nutrients plants need are already present. Utilizing BF can enhance crop yields by around 25% while decreasing the need for inorganic nitrogen and phosphorus fertilisers by approximately 25-50% and 25%, respectively (97). In the same context and more generally using these BF to inoculate crops and farms, can significantly reduce the amount of commercial fertilizer used while still providing crops with the required amounts of N and nutrients (16). **Secondly**, the positive effect on the developing plant, which leads to the following: (a)-acceleration of seed germination, (b)-improvement of the growth and performance of the root system, contributing to increased absorption, increased aeration rate, and increased stress resistance. Also (c) - improving the growth of the vegetative system, (d) - improving plant productivity: biofertilizers help the plant to come into production earlier, improve quality in quantity and quality, and help to increase crop yield by 10-25% (12), (e) - protecting the plant from soil-borne pathogens: by increasing its immunity to injury or by increasing its ability to tolerate injury when it occurs (98). **Third**ly, they maintain the fertility of the soil in the long term by adding them to the soil in large quantities, which leads to a change in the microbial balance in the soil in favor of beneficial microbes, activates the biological processes in the soil and improves the natural properties of the soil. Thus, BF maintain a soil ecosystem rich in all kinds of micro and macronutrients, by fixing nitrogen, solubilizing or mineralizing phosphate and potassium, biodegrading organic material in the soil, releasing compounds that control plant growth and producing antibiotics (99).

Techniques for applying biofertilizers to plants:

BF are applied using different methods (on seeds, plant surfaces or soil). Each method has advantages and disadvantages (Fig.2), but several factors must be considered during application (12,100), including: Environmental conditions, Type of crop, Prosperities of the inoculant , Technical background and Farmers' constraints.

Seeds inoculation: is the most commonly used method for all types of inoculants. In seed treatment, beneficial microorganisms are transferred directly into the root system of the plant and BF can be sprayed on the seed before sowing. This technique promotes the development of a symbiotic relationship in young plants. It can be applied by seed treatment using BF with the help of a sticky material such as acacia gum (19) jiggery solution, or other sugary liquid (101). For example, 200 g of biofertilizer can be suspended in 300–400 ml of water and carefully mixed with 10 kg of seeds.

Plant inoculation (seedling root watering): with this method, BF can be mixed into the irrigation systems and supply the roots with nutrients; this guarantees effective nutrient up take. This method is used for transplanted plants. A planting substrate is prepared and filled with water. The roots of the seedlings are immersed in this water for eight to ten hours in the presence of the recommended biofertilizers and then transplanted (12).

Inoculating the Soil: The use of BF in the soil can be accomplished in two ways: either by using it as a top dressing during the growing season or by incorporating it into the soil prior to planting. According to (67), this method enhances the quality of the soil and increases the amount of nutrients that are accessible to the plants. As an illustration, 200 kilogrammes of compost is combined with four kilogrammes of each of the best biofertilizers, and the mixture is then permitted to sit overnight. It is necessary to incorporate this mixture into the soil before planting or sowing an item.

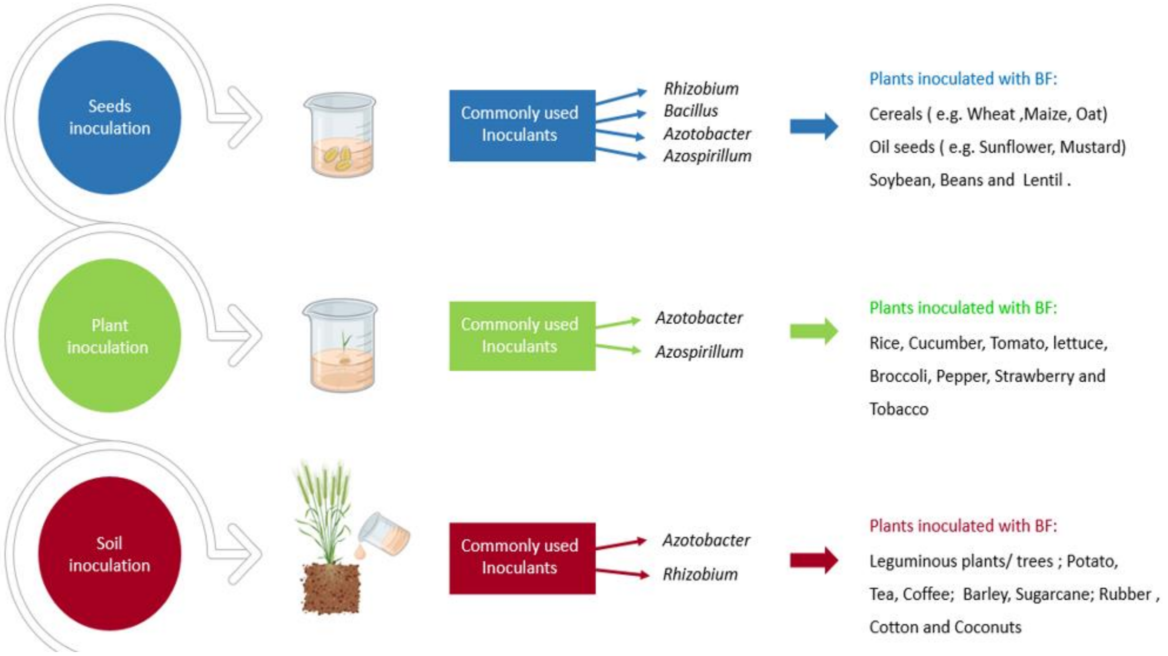


Figure 2: Methods of treating plants with biofertilizers (BF) and the main types of inoculants used in each case.

Role of biofertilizers in the tolerance of salinity stress

Salinity stress

Salinity, stemming from natural origins (primary salinity) and anthropogenic activities (secondary salinity), is increasingly deteriorating. Forecasts suggest that by 2050, salinity will affect half of the world's agricultural lands (102). This situation results from an overabundance of soluble salts, mainly sodium chloride (NaCl), in soil and water environments, severely restricting the growth and viability of many crops. Plant growth is curtailed by salinity through three principal mechanisms: (a) osmotic stress, involving the buildup of phytotoxic ions, (b) ionic stress, occurring within the cytosol, and (c) oxidative stress, triggered by reactive oxygen species (ROS).

These salinity-induced stressors impede water uptake, cause ion and hormonal disruptions, enhance ROS production, and reduce photosynthetic efficiency, collectively diminishing plant growth and overall productivity (2,103). Moreover, the detrimental impacts of salinity also include soil erosion, ion toxicity, nutrient shortages, and oxidative damage, all contributing to a decline in agricultural output and economic benefits (93).

Some of the roles of biofertilizers in salinity tolerance

1. Improvement of morphological properties

Research has demonstrated that plant tolerance to abiotic stress factors, such as salinity, improves with inoculation (104,105). Specific rhizobacterial species, notably *Azospirillum*, *Pseudomonas*, and *Azotobacter*, significantly enhance seedling germination and growth, as reported by (84). Furthermore, (19) observed that the application of biofertilizers, particularly with *Azotobacter chroococcum* and a combination of *Azotobacter chroococcum* and *Azospirillum lipoferum*, effectively bolstered the resistance of *Dodonaea viscosa* to salt stress. Biofertilizer treatments produced several beneficial effects on plant morphology, including increases in stem dry weight, regenerative development, seed output, germination rates, and overall vegetative growth. These positive outcomes are likely attributable to the productive symbiotic relationships formed between rhizobacteria and plant roots.

These associations not only shield plants from the adverse effects of salt stress but also mitigate the broader impacts of salinity on plant development. Additionally, the benefits are linked to the enhanced absorption of growth-promoting elements and nutrients facilitated by bacterial inoculation. This interaction aids plant growth and development by maintaining a robust root connection, which allows for better nutrient uptake and environmental stress tolerance (106).

Research indicates that rhizobacteria, including *Azotobacter*, contribute to increased plant height and regeneration by synthesizing phytohormones and supporting plant nutrition, producing antibiotics, and protecting against root infections (88,107,108). Studies on various cereal varieties have also shown that inoculation with *Azospirillum* bacteria positively affects plant characteristics such as bush height, root length, leaf size, and the volume and dry matter content of plants (11,91). The maximum vigour index and percentage germination of 99% of pepper seeds were recorded by (87) in a combined inoculation of four different bacteria, namely *Pseudomonas*, *Azospirillum Azotobacter* and *Bacillus*.

2. Improvement of biochemical properties

According to (19), the use of BF treatment improves plant tolerance to salinity stress by minimizing the impacts of osmotic stress and lowering the levels of ionic toxicity. In addition to this, it has a beneficial effect on the plant's capacity to absorb water as well as its efficiency in water utilization. It is possible that the promotion of root growth and elongation that occurs as a result of PGPR treatment is responsible for the improvement in water use efficiency.

This is because the treatment enables roots to extend deeper into the soil. This more extensive root system allows the plant to more efficiently take in water and nutrients, which is beneficial to the plant's overall health. Root-associated bacteria mitigate the negative effects of salinity by producing the enzyme ACC deaminase, which reduces plant ethylene levels, a response highlighted in studies by (109).

This reduction is a key mechanism that enhances plant salinity tolerance and mitigates its detrimental impacts. (105) also identified additional factors contributing to salinity tolerance, including the enhancement of hormonal balance and root system development, which further elevate the resistance levels of inoculated plants.(110) found that applying biofertilizer at a rate of 10 liters per hectare increased chlorophyll content in *Amaranthus tricolor* L. under salinity stress, suggesting that biofertilizers are more effective when they contain a diverse microbial consortium.

These microbes possess capabilities such as nitrogen fixation, phosphate solubilization, production of plant growth regulators, and decomposition of organic matter. Nitrogen, being a fundamental component of proteins and chlorophyll molecules, significantly influences chlorophyll synthesis and chloroplast development, playing a critical role in forming green pigments in leaves.

Moreover, enhanced nitrogen levels contribute to increased chlorophyll production and photochemical efficiency of leaves. This enhancement also boosts the activity of antioxidant enzymes and improves the permeability of cell membranes, thereby preserving cell structure and function (111,112).

Challenges in the use of biofertilizers in plant production

Every technology and application, for all its advantages can also have some disadvantages and BF technology is rather positive in the current period. However, some negative aspects are related to the difficulty of producing inoculants, preserving them and ensuring their longevity (113).

There is also a lack of talented workers researchers to manufacture and handle the subsequent requirements. Moreover, the continuous support for industrialization and research in this field is still lower than expected.

Acknowledgements

All of the authors would like to express their gratitude to King Abdulaziz University for their generous support.

References

1) Bänziger M, Araus J-L. Recent Advances in Breeding Maize for Drought and Salinity Stress Tolerance. In: Jenks MA, Hasegawa PM, Jain SM, editors. Advances in Molecular Breeding Toward Drought and Salt Tolerant Crops [Internet]. Dordrecht: Springer Netherlands; 2007. p. 587–601. Available from: https://doi.org/10.1007/978-1-4020-5578-2_23

2) Hussain S, Shaukat M, Ashraf M, Zhu C, Jin Q, Zhang J. Salinity Stress in Arid and Semi-Arid Climates: Effects and Management in Field Crops. Clim Chang Agric. 2019;

3) Santos VB, Araújo ASF, Leite LFC, Nunes LAPL, Melo WJ. Soil microbial biomass and organic matter fractions during transition from conventional to organic farming systems. Geoderma [Internet]. 2012;170:227–31. Available from: https://www.sciencedirect.com/science/article/pii/S0016706111003259

4) Youssef MMA, Eissa MFM. Biofertilizers and their role in management of plant parasitic nematodes. A review. J Biotechnol Pharm Res. 2014;5(1):1–6.

5) Bhardwaj D, Wahid Ansari M, Kumar Sahoo R, Tuteja N. Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity [Internet]. Vol. 13. 2014. Available from: http://www.microbialcellfactories.com/content/13/1/66

6) Araújo ASF de, Santos VB, Monteiro RTR. Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piauí state, Brazil. Eur J Soil Biol. 2008;44(2):225–30.

7) Mahmud AA, Upadhyay SK, Srivastava AK, Bhojiya AA. Biofertilizers: A Nexus between soil fertility and crop productivity under abiotic stress. Curr Res Environ Sustain [Internet]. 2021;3:100063. Available from: https://doi.org/10.1016/j.crsust.2021.100063

8) Megali L, Glauser G, Rasmann S. Fertilization with beneficial microorganisms decreases tomato defenses against insect pests. Agron Sustain Dev. 2014;34:649–56.

9) Raja N. Biopesticides and biofertilizers: ecofriendly sources for sustainable agriculture. J Biofertil Biopestici 4: e112. 2013.

10) Sahoo RK, Ansari MW, Dangar TK, Mohanty S, Tuteja N. Phenotypic and molecular characterisation of efficient nitrogen-fixing Azotobacter strains from rice fields for crop improvement. Protoplasma [Internet]. 2014 May 5;251(3):511–23. Available from: https://doi.org/10.1007/s00709-013-0547-2

11) Mia MAB, Shamsuddin ZH, Wahab Z, Marziah M. Effect of plant growth promoting rhizobacterial (PGPR) inoculation on growth and nitrogen incorporation of tissue-cultured Musa plantlets under nitrogen-free hydroponics condition. Aust J Crop Sci. 2010;4(2):85–90.

12) Kumar R, Kumawat N, Sahu YK. Role of biofertilizers in agriculture. Pop kheti. 2017;5(4):63–6.

13) Bisen K, Keswani C, Mishra S, Saxena A, Rakshit A, Singh HB. Unrealized potential of seed biopriming for versatile agriculture. Nutr use Effic from basics to Adv. 2015;193–206.

14) Vessey JK. Plant growth promoting rhizobacteria as biofertilizers. Plant Soil [Internet]. 2003;255:571–86. Available from: https://doi.org/10.1023/A:1026037216893%0A%0A

15) Simarmata T, Turmuktini T, Fitriatin BN, Setiawati MR. Application of bioameliorant and biofertilizers to increase the soil health and rice productivity. HAYATI J Biosci. 2016;23(4):181–4.

16) Aloo BN, Tripathi V, Makumba BA, Mbega ER. Plant growth-promoting rhizobacterial biofertilizers for crop production: The past, present, and future. Front Plant Sci. 2022;13:1002448.

17) Sahu PK, Brahmaprakash GP. Formulations of biofertilizers–approaches and advances. Microb Inoculants Sustain Agric Product Vol 2 Funct Appl. 2016;179–98.

18) Malusá E, Sas-Paszt L, Ciesielska J. Technologies for beneficial microorganisms inocula used as biofertilizers. Sci World J. 2012;2012.

19) Yousefi S, Kartoolinejad D, Bahmani M, Naghdi R. Effect of Azospirillum lipoferum and Azotobacter chroococcum on germination and early growth of hopbush shrub (Dodonaea viscosa L.) under salinity stress. J Sustain For [Internet]. 2017;36(2):107–20. Available from: http://dx.doi.org/10.1080/10549811.2016.1256220

20) Kumar R, Swapnil P, Meena M, Selpair S, Yadav BG. Plant Growth-Promoting Rhizobacteria (PGPR): Approaches to Alleviate Abiotic Stresses for Enhancement of Growth and Development of Medicinal Plants. Sustain. 2022;14(23).

21) Mokabel S, Olama Z, Ali S, El-Dakak R. The Role of Plant Growth Promoting Rhizosphere Microbiome as Alternative Biofertilizer in Boosting Solanum melongena L. Adaptation to Salinity Stress. Plants. 2022;11(5).

22) Basu A, Prasad P, Das SN, Kalam S, Sayyed RZ, Reddy MS, et al. Plant Growth Promoting Rhizobacteria (PGPR) as Green Bioinoculants : Recent Developments , Constraints , and Prospects. Sustainability. 2021;1–20.

23) Miranda AM, Hernandez-tenorio F, Villalta F, Vargas GJ, Alex AS. Advances in the Development of Biofertilizers and Biostimulants from Microalgae. Biology (Basel). 2024;1–19.

24) Bahulikar RA, Torres-Jerez I, Worley E, Craven K, Udvardi MK. Diversity of nitrogen-fixing bacteria associated with switchgrass in the native tallgrass prairie of Northern Oklahoma. Appl Environ Microbiol. 2014;80(18):5636–43.

25) Hara S, Morikawa T, Wasai S, Kasahara Y, Koshiba T, Yamazaki K, et al. Identification of nitrogen-fixing Bradyrhizobium associated with roots of field-grown sorghum by metagenome and proteome analyses. Front Microbiol. 2019;10:407.

26) Worsfold P, Townshend A, Poole CF, Miró M. Encyclopedia of analytical science. Elsevier; 2019.

27) Postgate JR. Nitrogen fixation. Cambridge University Press; 1998.

28) Sudhakar P, Latha P, Reddy P V. Phenotyping crop plants for physiological and biochemical traits. Academic Press; 2016.

29) Bardi L, Malusà E. Drought and nutritional stresses in plant: alleviating role of rhizospheric microorganisms. Abiotic Stress New Res. 2012;1–57.

30) Gedamu SA, Tsegaye EA, Beyene TF. Effect of rhizobial inoculants on yield and yield components of faba bean (Vicia fabae L.) on vertisol of Wereillu District, South Wollo, Ethiopia. CABI Agric Biosci. 2021;2(1):1–10.

31) Ketema P, Tefera T. Effectiveness of Rhizobium strains on faba bean (Vicia fabae L.) at Gumer district, highland area of Southern Ethiopia. Ukr J Ecol. 2022;12(1):13–8.

32) Koskey G, Mburu SW, Njeru EM, Kimiti JM, Ombori O, Maingi JM. Potential of native rhizobia in enhancing nitrogen fixation and yields of climbing beans (Phaseolus vulgaris L.) in contrasting environments of Eastern Kenya. Front Plant Sci. 2017;8:443.

33) Sanyal D, Osorno JM, Chatterjee A. Influence of Rhizobium inoculation on dry bean yield and symbiotic nitrogen fixation potential. J Plant Nutr. 2020;43(6):798–810.

34) Benson DR, Silvester WB. Biology of Frankia strains, actinomycete symbionts of actinorhizal plants. Microbiol Rev. 1993;57(2):293–319.

35) Hungria M, Franchini JC, Campo RJ, Crispino CC, Moraes JZ, Sibaldelli RNR, et al. Nitrogen nutrition of soybean in Brazil: contributions of biological N2 fixation and N fertilizer to grain yield. Can J Plant Sci. 2006;86(4):927–39.

36) Melchiorre M, De Luca MJ, Gonzalez Anta G, Suarez P, Lopez C, Lascano R, et al. Evaluation of bradyrhizobia strains isolated from field-grown soybean plants in Argentina as improved inoculants. Biol Fertil Soils. 2011;47(1):81–9.

37) Bagyaraj DJ. Microbial biotechnology for sustainable agriculture, horticulture & forestry. New India Publishing Agency; 2011.

38) Bhattacharyya PN, Jha DK. Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. World J Microbiol Biotechnol [Internet]. 2012;28(4):1327–50. Available from: https://doi.org/10.1007/s11274-011-0979-9

39) Laranjo M, Alexandre A, Oliveira S. Legume growth-promoting rhizobia: An overview on the Mesorhizobium genus. Microbiol Res [Internet]. 2014;169(1):2–17. Available from: http://dx.doi.org/10.1016/j.micres.2013.09.012

40) Bekele M, Yilma G. Nitrogen Fixation Using Symbiotic and Non-Symbiotic Microbes: A Review Article. Biochem Mol Biol. 2021;6(4):92.

41) Adeleke RA, Raimi AR, Roopnarain A, Mokubedi SM. Status and prospects of bacterial inoculants for sustainable management of agroecosystems. Biofertilizers Sustain Agric Environ. 2019;137–72.

42) Vassilev N, Vassileva M, Lopez A, Martos V, Reyes A, Maksimovic I, et al. Unexploited potential of some biotechnological techniques for biofertilizer production and formulation. Appl Microbiol Biotechnol. 2015;99:4983–96.

43) Ibarra-Galeana JA, Castro-Martínez C, Fierro-Coronado RA, Armenta-Bojórquez AD, Maldonado-Mendoza IE. Characterization of phosphate-solubilizing bacteria exhibiting the potential for growth promotion and phosphorus nutrition improvement in maize (Zea mays L.) in calcareous soils of Sinaloa, Mexico. Ann Microbiol. 2017;67:801–11.

44) Borgi MA, Saidi I, Moula A, Rhimi S, Rhimi M. The attractive Serratia plymuthica BMA1 strain with high rock phosphate-solubilizing activity and its effect on the growth and phosphorus uptake by Vicia faba L. plants. Geomicrobiol J. 2020;37(5):437–45.

45) Adnan M, Fahad S, Zamin M, Shah S, Mian IA, Danish S, et al. Coupling phosphate-solubilizing bacteria with phosphorus supplements improve maize phosphorus acquisition and growth under lime induced salinity stress. Plants. 2020;9(7):900.

46) Halajnia A, Haghnia GH, Fotovat A, Khorasani R. Phosphorus fractions in calcareous soils amended with P fertilizer and cattle manure. Geoderma. 2009;150(1–2):209–13.

47) Yadav H, Fatima R, Sharma A, Mathur S. Enhancement of applicability of rock phosphate in alkaline soils by organic compost. Appl Soil Ecol. 2017;113:80–5.

48) Chen J, Sharifi R, Khan MSS, Islam F, Bhat JA, Kui L, et al. Wheat Microbiome: Structure, Dynamics, and Role in Improving Performance Under Stress Environments. Front Microbiol. 2022;12(January):1–15.

49) Jones DL. Organic acids in the rhizosphere–a critical review. Plant Soil. 1998;205:25–44.

50) Ryan PR, Delhaize E, Jones DL. Function and mechanism of organic anion exudation from plant roots. Annu Rev Plant Biol. 2001;52(1):527–60.

51) Kucey RMN. Effect of Penicillium bilaji on the solubility and uptake of P and micronutrients from soil by wheat. Can J Soil Sci. 1988;68(2):261–70.

DOI: 10.5281/zenodo.11665961

52) Kucey RMN, Janzen HH, Leggett ME. Microbially mediated increases in plant-available phosphorus. Adv Agron. 1989;42:199–228.

53) Chaiharn M, Lumyong S. Screening and optimization of indole-3-acetic acid production and phosphate solubilization from rhizobacteria aimed at improving plant growth. Curr Microbiol. 2011;62:173–81.

54) Pathan SI, Větrovský T, Giagnoni L, Datta R, Baldrian P, Nannipieri P, et al. Microbial expression profiles in the rhizosphere of two maize lines differing in N use efficiency. Plant Soil. 2018;433:401–13.

55) Tiwari VN, Lehri LK, Pathak AN. Effect of inoculating crops with phospho-microbes. Exp Agric. 1989;25(1):47–50.

56) Xiao Y, Wang X, Chen W, Huang Q. Isolation and identification of three potassium-solubilizing bacteria from rape rhizospheric soil and their effects on ryegrass. Geomicrobiol J. 2017;34(10):873–80.

57) Afzal A, Ashraf M, Asad SA, Farooq M. Effect of phosphate solubilizing microorganisms on phosphorus uptake, yield and yield traits of wheat (Triticum aestivum L.) in rainfed area. Int J Agric Biol. 2005;7(2):207–9.

58) Krishnaraj PU, Dahale S. Mineral phosphate solubilization: concepts and prospects in sustainable agriculture. In: Proc Indian Natl Sci Acad. 2014. p. 389–405.

59) Pal SS. Interactions of an acid tolerant strain of phosphate solubilizing bacteria with a few acid tolerant crops. Plant Soil. 1998;198:169–77.

60) Cakmak I, McLaughlin MJ, White P. Zinc for better crop production and human health. Plant Soil. 2017;411:1–4.

61) Montalvo D, Degryse F, Da Silva RC, Baird R, McLaughlin MJ. Agronomic effectiveness of zinc sources as micronutrient fertilizer. Adv Agron. 2016;139:215–67.

62) Kamran S, Shahid I, Baig DN, Rizwan M, Malik KA, Mehnaz S. Contribution of zinc solubilizing bacteria in growth promotion and zinc content of wheat. Front Microbiol. 2017;8:2593.

63) Perumal MD. Enhanced Zinc Nutrient and Enzyme Activity of Rice Crop by Zinc Solubilizing Bacteria with Zn sources in Zn Deficient Rice Soil. Madras Agric J. 2019;106(march (1-3)):1.

64) Naz I, Ahmad H, Khokhar SN, Khan K, Shah AH. Impact of zinc solubilizing bacteria on zinc contents of wheat. Am Euras J Agric Environ Sci. 2016;16:449–54.

65) Sharma SKMP, Ramesh A, Joshi OP. Characterization of zinc-solubilizing Bacillus isolates and their potential to influence zinc assimilation in soybean seeds. 2011;

66) Dinesh R, Srinivasan V, Hamza S, Sarathambal C, Gowda SJA, Ganeshamurthy AN, et al. Isolation and characterization of potential Zn solubilizing bacteria from soil and its effects on soil Zn release rates, soil available Zn and plant Zn content. Geoderma. 2018;321:173–86.

67) Wang Y, Zhang G, Huang Y, Guo M, Song J, Zhang T, et al. A potential biofertilizer—Siderophilic bacteria isolated from the rhizosphere of Paris polyphylla var. yunnanensis. Front Microbiol. 2022;13:870413.

68) Yehuda Z, Shenker M, Romheld V, Marschner H, Hadar Y, Chen Y. The role of ligand exchange in the uptake of iron from microbial siderophores by gramineous plants. Plant Physiol. 1996;112(3):1273–80.

69) Aloo BN, Makumba BA, Mbega ER. The potential of Bacilli rhizobacteria for sustainable crop production and environmental sustainability. Microbiol Res. 2019;219:26–39.

70) Ali AM, Awad MYM, Hegab SA, Gawad AMA El, Eissa MA. Effect of potassium solubilizing bacteria (Bacillus cereus) on growth and yield of potato. J Plant Nutr. 2021;44(3):411–20.

71) Rizvi A, Ahmed B, Khan MS, El-Beltagi HS, Umar S, Lee J. Bioprospecting plant growth promoting rhizobacteria for enhancing the biological properties and phytochemical composition of medicinally important crops. Molecules. 2022;27(4):1407.

72) Agisha VN, Kumar A, Eapen SJ, Sheoran N, Suseelabhai R. Broad-spectrum antimicrobial activity of volatile organic compounds from endophytic Pseudomonas putida BP25 against diverse plant pathogens. Biocontrol Sci Technol. 2019;29(11):1069–89.

73) Jayakumar V, Ramesh Sundar A, Viswanathan R. Biocontrol of Colletotrichum falcatum with volatile metabolites produced by endophytic bacteria and profiling VOCs by headspace SPME coupled with GC–MS. Sugar Tech. 2021;23:94–107.

74) Rizvi A, Zaidi A, Khan MS, Saif S, Ahmed B, Shahid M. Growth improvement and management of vegetable diseases by plant growth-promoting rhizobacteria. Microb Strateg Veg Prod. 2017;99–123.

75) Jaiswal SK, Mohammed M, Ibny FYI, Dakora FD. Rhizobia as a source of plant growth-promoting molecules: Potential applications and possible operational mechanisms. Front Sustain Food Syst. 2021;4:619676.

76) Mohite B. Isolation and characterization of indole acetic acid (IAA) producing bacteria from rhizospheric soil and its effect on plant growth. J soil Sci plant Nutr. 2013;13(3):638–49.

77) Datta C, Basu PS. Indole acetic acid production by a Rhizobium species from root nodules of a leguminous shrub, Cajanus cajan. Microbiol Res. 2000;155(2):123–7.

78) Avis TJ, Gravel V, Antoun H, Tweddell RJ. Multifaceted beneficial effects of rhizosphere microorganisms on plant health and productivity. Soil Biol Biochem. 2008;40(7):1733–40.

79) Noumavo PA, Kochoni E, Didagbé YO, Adjanohoun A, Allagbé M, Sikirou R, et al. Effect of different plant growth promoting rhizobacteria on maize seed germination and seedling development. Am J Plant Sci. 2013;4(5):1013.

80) Pourya M, Shakarami J, Mardani-Talaee M, Sadeghi A, Serrão JE. Induced resistance in wheat Triticum aestivum L. by chemical- and bio- fertilizers against English aphid Sitobion avenae (Fabricius) (Hemiptera: Aphididae) in greenhouse. Int J Trop Insect Sci. 2020;40(4):1043–52.

81) Borriss R. Bacteria in Agrobiology: Plant Growth Responses. Bacteria in Agrobiology: Plant Growth Responses. 2011.

82) Naeem M, Aslam Z, Khaliq A, Ahmed JN, Nawaz A, Hussain M. Plant growth promoting rhizobacteria reduce aphid population and enhance the productivity of bread wheat. Brazilian J Microbiol [Internet]. 2018;49:9–14. Available from: https://doi.org/10.1016/j.bjm.2017.10.005

83) War AR, Paulraj MG, Ahmad T, Buhroo AA, Hussain B, Ignacimuthu S, et al. Mechanisms of plant defense against insect herbivores. Plant Signal Behav. 2012;7(10).

84) Kamran S, Shazia A, Shahida H. Growth responses of Helianthus annus to plant growth promoting Rhizobacteria used as a biofertilizers. Int J Agric Res. 2010;5(11):1048–56.

85) Saber Z, Pirdashti H, Esmaeili M, Abbasian A, Heidarzadeh A. Response of wheat growth parameters to co-inoculation of plant growth promoting rhizobacteria (PGPR) and different levels of inorganic nitrogen and phosphorus. World Appl Sci J. 2012;16(2):213–9.

86) Safinaz AF, Ragaa AH. Effect of some red marine algae as biofertilizers on growth of maize (Zea mayz L.) plants. Int food Res J. 2013;20(4):1629.

87) Kanchana D, Jayanthi M, Usharani G, Saranraj P, Sujitha D. Interaction effect of combined inoculation of PGPR on growth and yield parameters of chilli var k1 (Capsicum annuum L.). Int J Microbiol Res. 2014;5(3):144–51.

88) Fasciglione G, Casanovas EM, Quillehauquy V, Yommi AK, Goñi MG, Roura SI, et al. Azospirillum inoculation effects on growth, product quality and storage life of lettuce plants grown under salt stress. Sci Hortic (Amsterdam) [Internet]. 2015;195(November 2015):154–62. Available from: http://dx.doi.org/10.1016/j.scienta.2015.09.015

89) Hegazi AM, El-Shraiy AM, Ghoname AA. Alleviation of Salt Stress Adverse Effect and Enhancing Phenolic Anti-oxidant Content of Eggplant by Seaweed Extract. Gesunde Pflanz. 2015;67(1):21–31.

90) Hussain M, Asgher Z, Tahir M, Ijaz M, Shahid M, Ali H, et al. Bacteria in combination with fertilizers improve growth, productivity and net returns of wheat (Triticum aestivum L.). Pakistan J Agric Sci. 2016;53(3):633–45.

91) Mazhar R, Ilyas N, Saeed M, Bibi F, Batool N. Biocontrol and Salinity Tolerance Potential of Azospirillum lipoferum and its Inoculation Effect in Wheat Crop. Int J Agric Biol. 2016;18(3).

92) AlAbdallah NM, Basalah MO, Y SSR. T he promotiv e effect of a lgal bi ofertiliz ers on gro wth an d so me metaboli c activ ities of Vign a unguic ulata L . un d er salt stress conditions. Egypt J Exp Biol. 2017;13(2):187–95.

93) Marakana T, Sharma M, Sangani K. Isolation and characterization of halotolerant bacteria and it's effects on wheat plant as PGPR. Pharma Innov J [Internet]. 2018;7(7):102–10. Available from: https://www.thepharmajournal.com/archives/?year=2018&vol=7&issue=7&ArticleId=2235

94) Klaic R, Guimarães GGF, Giroto AS, Bernardi ACC, Zangirolami TC, Ribeiro C, et al. Synergy of Aspergillus niger and components in biofertilizer composites increases the availability of nutrients to plants. Curr Microbiol. 2021;78:1529–42.

95) Baltazar-bernal O, Spinoso-castillo JL, Á EM-. Arbuscular Mycorrhizal Fungi Induce Tolerance to Salinity Stress in Taro Plantlets (Colocasia esculenta L . Schott) during Acclimatization. Plants (Basel). 2022;

96) Ghazala I, Chiab N, Saidi MN, Gargouri-Bouzid R. The Plant Growth-Promoting Bacteria Strain Bacillus mojavensis I4 Enhanced Salt Stress Tolerance in Durum Wheat. Curr Microbiol [Internet]. 2023;80(5):178. Available from: http://0o102l2jd.y.https.link.springer.com.kau.proxy.deepknowledge.io/article/10.1007/s00284-023-03288-y#citeas

97) Khan S, Chattopadhyay N. Effect of inorganic and biofertilizers on chilli. J Crop Weed. 2009;5:191–6.

98) Fasusi OA, Cruz C, Babalola OO. Agricultural sustainability: microbial biofertilizers in rhizosphere management. Agriculture. 2021;11(2):163.

99) Sinha RK, Valani D, Chauhan K, Agarwal S. Embarking on a second green revolution for sustainable agriculture by vermiculture biotechnology using earthworms: reviving the dreams of Sir Charles Darwin. J Agric Biotechnol Sustain Dev. 2010;2(7):113.

100) Mahmood A, Turgay OC, Farooq M, Hayat R. Seed biopriming with plant growth promoting rhizobacteria: A review. FEMS Microbiol Ecol. 2016;92(8):1–14.

101) Amjad M, Akhtar J, Rashid MS. Evaluating the effectiveness of biofertilizer on salt tolerance of cotton (Gossypium hirsutum L.). Arch Agron Soil Sci [Internet]. 2015;61(8):1165–77. Available from: http://dx.doi.org/10.1080/03650340.2014.990006

102) Butcher K, Wick A, DeSutter T, Chatterjee A, Harmon J. Soil Salinity: A Threat to Global Food Security. Agron J. 2016 Oct 6;108:2189–200.

103) Lal R. Soil management in the developing countries. Soil Sci. 2000;165(1):57–72.

104) Ashraf M, Hasnain S, Berge O, Mahmood T. Inoculating wheat seedlings with exopolysaccharide-producing bacteria restricts sodium uptake and stimulates plant growth under salt stress. Biol Fertil Soils. 2004;40(3):157–62.

105) Bashan Y, De-Bashan LE. How the plant growth-promoting bacterium Azospirillum promotes plant growth—a critical assessment. Adv Agron. 2010;108:77–136.

106) Abbas-Zadeh P, Saleh-Rastin N, Asadi-Rahmani H, Khavazi K, Soltani A, Shoary-Nejati AR, et al. Plant growth-promoting activities of fluorescent pseudomonads, isolated from the Iranian soils. Acta Physiol Plant. 2010;32(2):281–8.

107) Awasthi P, Karki H, Vibhuti V, Bargali K, Bargali SS. Germination and Seedling Growth of Pulse Crop (Vigna Spp.) as Affected by Soil Salt Stress. Curr Agric Res J. 2016;4(2):159–70.

108) Vrbničanin S, Božić D, Sarić M, Pavlović D, Raičević V. Effect of plant growth promoting rhizobacteria on Ambrosia rtemisiifolia L. seed germination. Pestic i fitomedicina. 2011;26(2):141–6.

109) Grichko VP, Glick BR. Amelioration of flooding stress by ACC deaminase-containingplant growth-promoting bacteria. Plant Physiol Biochem. 2001;39(1):11–7.

110) Siswanti DU, Umah N. Effect of Biofertilizer and Salinity on Growth and Chlorophyll Content of Amaranthus tricolor L. IOP Conf Ser Earth Environ Sci. 2021;662(1).

111) Hassanpouraghdam MB, Tabatabaie SJ, Nazemiyeh H, Vojodi L, Aazami MA. Volatile oil constituents of alecost [Tanacetum balsamita L. ssp. balsamitoides (Schultz-Bip.)] growing wild in North-West of Iran. Herba Pol. 2009;55(1):53–9.

112) Mehrabani LV, Hassanpouraghdam MB, Shamsi-Khotab T. The effects of common and nano-zinc foliar application on the alleviation of salinity stress in Rosmarinus officinalis L. ACTA Sci Pol hortorum cultus. 2018;17(6):65–73.

113) Safari M, Motamedi E, Kari Dolatabad H, Modarres Sanavy SAM. Nano-carriers effects on the viability and efficiency of Pseudomonas strains as phosphate solubilizing bacteria. Heliyon [Internet]. 2020;6(10):e05076. Available from: https://doi.org/10.1016/j.heliyon.2020.e05076